Technological Research and Innovation 2023

MINISTRY OF DEFENCE

SECRETARIAT GENERAL OF DEFENCE
AND NATIONAL ARMAMENTS DIRECTORATE

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PRESENTATION

INTRODUCTION BY THE SECRETARY GENERAL OF DEFENCE/NAD

Also in 2023, in line with tradition, I am pleased to introduce the Report on the State of the Art of Technological Research of the Secretariat General of Defence and National Armaments Directorate.
As known, the technical-administrative area includes two components: the Secretariat General of Defence – with technical-administrative, legal and regulatory competences – and the National Armaments Directorate. The latter operates in the technical-industrial sector with the following aims:

- Procuring weapon systems and equipment for the Armed Forces, complying with the requirements established by the Defence technical-operational area, based on the investment resources allocated;
- Enhancing the capabilities of the Italian defence industry, also by means of international cooperation and agreements;
- Ensuring a technological advantage for our military instrument through continuous research and innovation activities.

Those two components perform different but complementary tasks, both pursuing the same purpose – to provide our Armed Forces with all the necessary capabilities for an advanced and effective military instrument, so that they can substantially contribute to our country's growth, projection and importance on an international level.
The recent changes in the global scenario have highlighted the necessity of constant technological updating in order to protect national interests in every sector. Therefore, it is paramount to maintain and increase strategic autonomy through focused scientific and technological research, so as to contribute to reaching the strategic goals clearly stated by the Ministry of Defence, in close synergy with the technical-operational area.
This requires proactive action in the field of innovation, to stay competitive and maintain a technological advantage on potential opponents.
Indeed, in this highly competitive global context, being completely dependent on foreign technologies would mean taking the risk of being unprepared to face any crisis, and – even worse – submitting the capacity to defend national interests to the will of those who possess the technological know-how.
Hence the need to preserve and strengthen strategic autonomy in scientific and technological research, fostering cooperation with other countries, in such a way that Italy may hold the role of a capable and proactive partner rather than a mere user.
In this scenario, efforts must be focused on the following crucial objectives:

- Strengthening the synergy with universities, research centres and industry, implementing innovation tools and hubs that may work as idea incubators and accelerators, and creating a coherent flow from first conception to final investment;
- Enhancing small and medium enterprises and start-ups as significant contributors to the development of innovative thinking, facilitating their participation in the projects of the National Military Research Plan (PNRM) as well as in those financed by the European Commission and within the Atlantic Alliance;
- Increasing the national capacity to influence international forums on innovation, pursuing alignment between the goals established within the EU and NATO and the priorities set at national level.

It is crucial to be able to play a primary role in the international forums because the military

PRESENTATION

technology sector is a massive influence amplifier on the global geopolitical scene, as well as contributing to providing fully interoperable systems, not only in a joint environment but also at multinational level.

Furthermore, it will be paramount to increasingly converge technological research projects on the processes of capability development of the military instrument and defence industrial policy, focusing our attention and resources on the areas where we are aware that we have a potential gap in terms of technological development speed, i.e. cybernetics, space, and artificial intelligence.

In this respect, I deem it important to underline that the speed of technological evolution may provide innovative solutions that are so radical and hardly predictable as to impose a new vision of our modus operandi (i.e. the so-called Emerging and Disruptive technologies).

Let's remember the revolution in military affairs that happened between the first and the second World Wars, when technological research and the strong industrial boost led to the introduction and enhancement of new technologies and systems, so disruptive as to outdate the techniques, tactics, procedures and armaments used until then.

Therefore, while research needs to support capability efforts, we must also be open to define our own capability gaps by thoroughly analysing the opportunities provided by emerging technologies.

Hence the importance of increasing synergies among all components (technical-administrative and technical-operational areas, industry, universities, military and civilian research centres), new working methods for quickly sharing requirements, proposals and opportunities in order to identify the best solutions.

In other words, I believe that the world of planning and defence industry should directly support on-field operators with resilience and quick adaptability, often being able to anticipate operational events through a constant, in-depth strategic and scenario analysis.

Lieutenant General
Luciano Portolano

PREFACE

By the Director of the 5th Departmen Technological Innovation

In the variable European strategic and geopolitical scenario, the socio-economic and technological challenges of the last few years – mainly related to the COVID-19 pandemic, the recent military tensions in the East of the continent, and the vast arc of crisis in the neighbouring Middle-East countries – have stressed the utter importance of an effective common European foreign and security policy as well as of aggregating actions for the sector of Defence. The latter should be aimed at strengthening knowledge and technical-scientific know-how – with particular reference to enabling technologies for the modernization or future development of Defence systems – and enhancing the operational capabilities of the Armed Forces as well as the academic-industrial base.

Therefore, in Europe and especially for the EU, technological research is a pivotal element for integrating technological assets and different national competences, in order to have a constantly updated military instrument and meet the right national and EU ambition levels, in line with the NATO Euro-Atlantic defence and policy directions.

This requires investment in research and innovation, with organizational and procedural tools and resources that are adequate for the above-mentioned ambition levels. It is also important to ensure the protection of outstanding national technologies, in order to maintain an appropriate and necessary technological superiority in the strategically relevant sectors for the country's defence and security system. Such an approach is always seeking the best balance between industrial integration processes, aimed at increasing competitivity especially at international level, and protection issues. All the above, in line with the general directions of the highest political and military authorities, informs the main guidelines for the activities of research and technological innovation (RT) carried out by the Secretariat General of Defence/National Armaments Directorate (NAD) through its 5th Department, within the scope of its technical-administrative functions of high guidance, direction and control.

The research activities of the Defence Administration – constituting the so-called "military research" – are identified, promoted and launched in both a domestic and an international environment. The former includes the National Military Research Plan (PNRM), the RT projects carried out at the Defence Test Centres,[1] and Framework Agreements with Italian Universities and Research Centres, in line with the country's broader technical-scientific policy.[2] The environment of international cooperation includes RT programmes developed within a European framework, mainly pertaining to the EU, EDA (European Defence Agency) and NATO, as well as in a extra-European context, through bi- and multi-lateral agreements.

1 With a view to coordinating, harmonizing and enhancing the specific characteristics of Defence Technical bodies.

2 Which is in turn reinforced and supported by the measures and objectives set in the National Recovery and Resilience Plan (PNRR).

Technological and industrial cooperation within the EU and with Allied countries is an increasingly crucial factor for national strategic autonomy, i.e. the possibility to act "alone when necessary, with partners when possible" through the complementary action of the EU and NATO. Such cooperation is mainly aimed at the identification and potential acquisition of common capabilities, especially critical ones, including, but not limited to, space and aerospace technologies, cyber technologies, artificial intelligence (AI), autonomous systems, biotechnologies/smart materials for soldier empowerment and CBRN protection, etc. In the current, increasingly complex geopolitical context, all issues and policies concerning technological development will continue to be consistently informed on the basis of the STRATEGIC COMPASS and the EMERGING AND DISRUPTIVE TECHNOLOGIES ROADMAP, two parallel initiatives of the EU and NATO respectively, both aimed at identifying the future challenges that are going to be faced by Europe and the Alliance, with particular reference to technological confrontations.

More specifically, the STRATEGIC COMPASS is a guide concerning security and defence that identifies tools, time frames and threats, measures the progress towards a specific ambition level, promotes and fosters investments in research and innovation in order to jointly develop new technologies and supporting processes. EMERGING AND DISRUPTIVE TECHNOLOGIES (the so-called EDTs)[3] are mainly those technologies that have a potentially disruptive impact on competitive advantage, and consequently on the economic fabric and geopolitical positioning. The Alliance has started a specific roadmap to enhance this kind of technologies, with relevant policies and a different implementation plan for each one of them. In this regard, an action plan has also been set at European level – with Italy's contribution alongside the other Member States' – to identify the most promising technological trends, both on a strictly capability/operational military level and in terms of dual-use civilian technologies also employable by the Defence. Special focus is put on the existing industrial capabilities at EU level – so that they can be adequately ready for the development and integration of such technologies – as well as on the results of monitoring processes and prediction of possible future scientific-technological developments (Technology Watch and Foresight) implemented within the EDA (European Defence Agency) with the contribution of all Member States. The results of Technology Watch and Foresight are the technical foundation for the RT and capability planning tools used within the EDA, such as the OVERARCHING STRATEGIC RESEARCH AGENDA (OSRA) and the CAPABILITY DEVELOPMENT PLAN (CDP). Moreover, the Secretariat provides contributions and actions aimed at developing strategies for the implementation of EDTs in the field of Defence, starting from artificial intelligence (AI), a "general purpose"4 technological innovation that is considered to be a paramount game changer, whose development can lead to deep changes and transformations in the military instrument.

4 Meaning a technical innovation that does not introduce new functions, but whose implementation and use – also in combination with other technologies – can revolutionize the tools and methods used so far. In this case, the AI is a source of progress that increases human intellectual and cognitive capabilities and helps in performing very tiring, complex and/or routine tasks, although it may also pose potential threats or criticalities for society.

At the same time, within the EU context, the Secretariat General of Defence/NDA

3 Within the NATO, they currently are: Data and advanced analytics, Artificial Intelligence, Autonomy, Quantum technologies, Space technologies, Hypersonics, Biotechnology, Human enhancement, Novel materials (& manufacturing), 5G (& microelectronics).

is increasingly contributing to the technical processing and harmonization of the contents of annual Calls concerning research and development within the EUROPEAN DEFENCE FUND (EDF) managed by the European Commission. In particular, the activities of the 5th Department of the Secretariat have been focused on the field of RT. The descendant research projects, ranging from Defence Medical Support/CBRN/Biotech and Human Factors to Simulation and Training (including disruptive technologies), are strategically connected and complementary to those launched in other contexts, especially at national level, in a wide-ranging multi-annual transnational perspective. This is aimed at fostering synergies and modernization drives between different actors in the RT sector – firstly national and then European, public and private – potentially interested or involved in the aforementioned EDF Calls, as well as their technological competitivity in a highly variable and competitive global market. The significant participation and success of Italian research actors in the EDF Calls launched so far, which has been appreciated at national and European levels, fosters positive expectations for our national economic system and especially for the development of the relevant production chains.

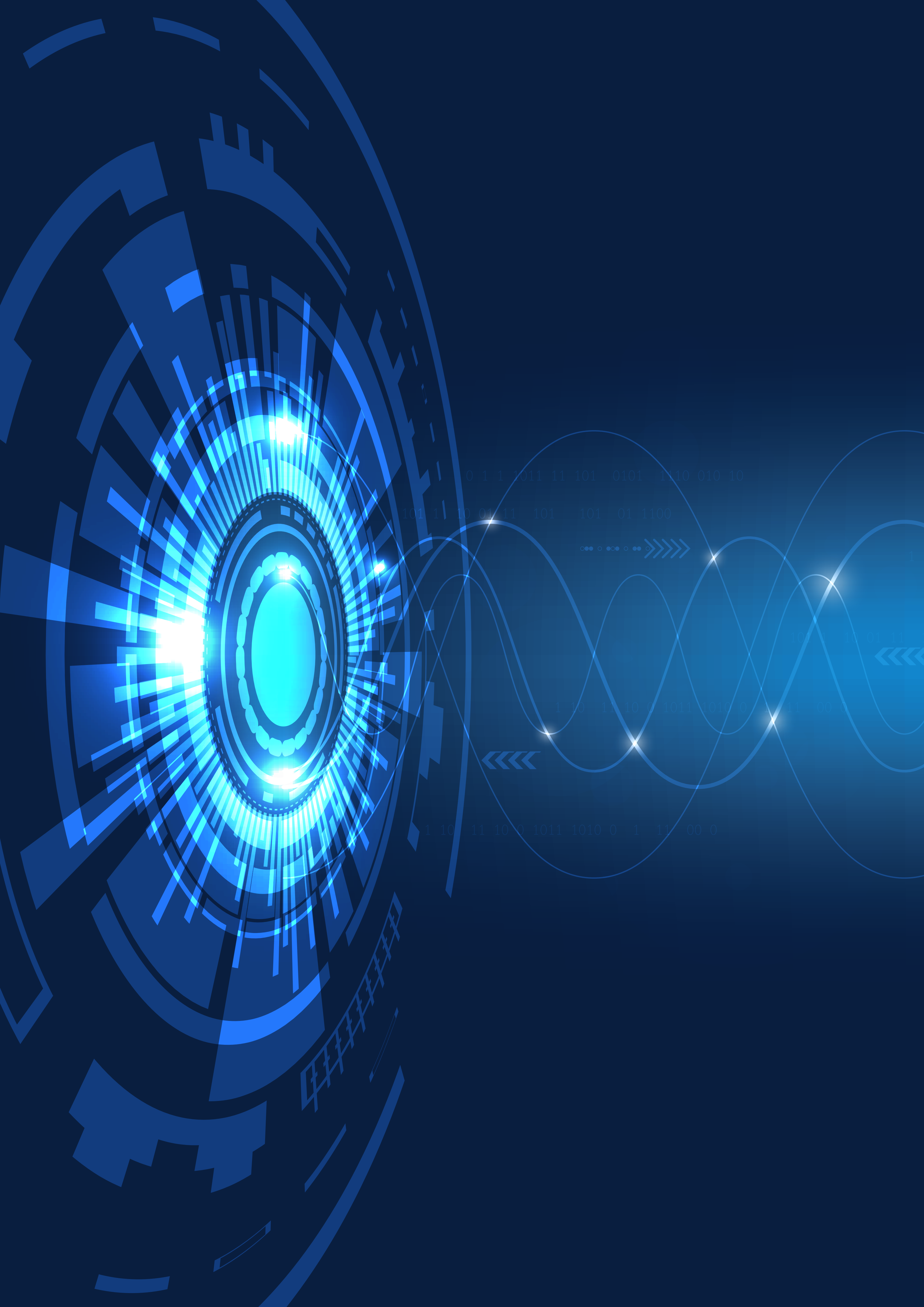
Parallel to all this, the Secretariat General of Defence/NAD attaches great importance to the military research activities carried out at domestic level in order to fill specific technology gaps, mainly through the aforementioned PNRM, prioritizing the sectors of paramount interest jointly identified with the Defence General Staff, including, but not limited to, C2 and Multi-Domain situation awareness, space technologies, cyber sector, autonomous systems, AI solutions, countering emerging threats, underwater sector, urban warfare, sustainability, security, and energy resilience.

In line with the above, the Secretariat gives significant attention to energy and environment issues, mainly through the participation of its 5th Department in the CONSULTATION FORUM FOR SUSTAINABLE ENERGY IN THE DEFENCE AND SECURITY SECTOR (CF SEDSS). This initiative of the European Commission – currently in its third phase – is aimed at acquiring and sharing information, knowledge and best practices on improving energy management, increasing energy efficiency in buildings, using renewable energy sources in the Defence and Security sector, and enhancing the resilience of critical energy infrastructures.

As regards the methodological, organizational and management aspects of innovation, with a view to maintaining the technological advantage of the Atlantic Alliance, the Italian Secretariat General of Defence/NAD has been fully and continuously involved in the NATO initiative DEFENCE INNOVATION ACCELERATOR FOR THE NORTH ATLANTIC (DIANA), a civilian-military acceleration programme with dedicated mechanisms and financial resources supplied by the Member States, focused on the study/development and testing – also with similar methods to USA-inspired challenges – of new, cutting-edge emerging technologies with a potentially strong impact on the defence and security sector. In this regard, the Secretariat designates the Italian national representative to the DIANA Board of Directors. The Secretariat is equally interested in following the developments of the NATO INNOVATION FUND, a voluntary participation venture capital fund aimed at supporting Allied countries' startups with a strong dual-use connotation and a concrete potential for technological application in the field of defence and security. Similarly to the NATO DIANA initiative, the EDA has also established a HUB FOR EU DEFENCE INNOVATION (HEDI), promoted through its network of Capability Technology areas/groups (the so-called "CapTechs"), which includes all Member States with their Defence representatives and experts, both from the Government and from other environments (university, industry, RT/test

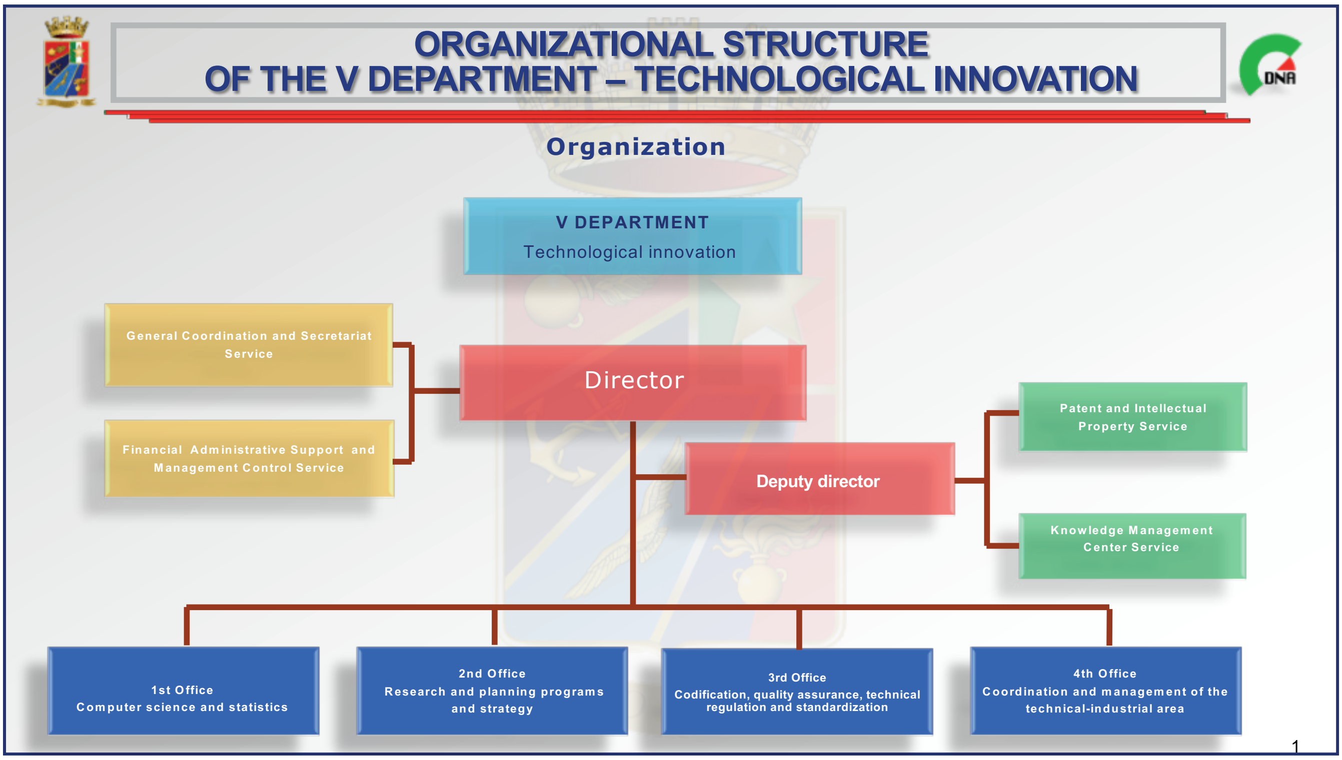
centres, etc.). In this way, the Secretariat General of Defence/NAD can also monitor their respective progress.
All the above clearly demonstrates how the technological research activities directed and coordinated by the Secretariat, both at national level and through international cooperation – continuously seeking a fruitful balance between the requirements of the national military instrument and those emerging from the international context, looking at possible future technological sectors of strategic interest – significantly strengthen and enhance the fundamental role of the Secretariat General of Defence/NAD as an essential reference point in the defence and security sector for research and innovation in all scientific-technological domains, as well as a promoter of our country's technological and industrial capabilities on the international scene.

Director General
Luisa Riccardi



ORGANIZATION OVERVIEW

ORGANIZATIONAL STRUCTURE

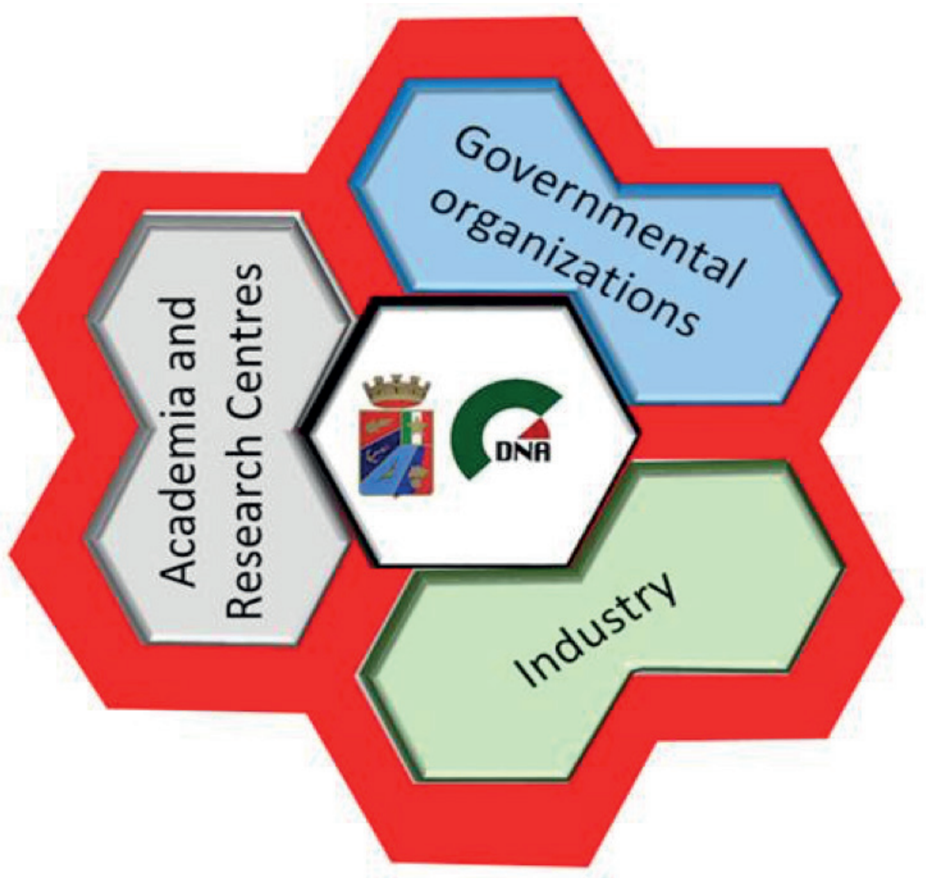


ORGANIZATIONAL STRUCTURE

THE "NETWORK" FOR TECHNOLOGICAL RESEARCH

THE EXTERNAL ORGANIZATION

The effectiveness of the innovation and technological research strategy implemented by the General Secretariat/DNA is based on the creation and constant updating of a network of external relations with highly specialized and heterogeneous elements and organizations which pursue different objectives, but competing in a synergistic manner with the achievement of Defense guidelines in the field of innovation and research. : The network of relationships maintained by the Secretary is divided into 3 clusters of organizational elements:



THE INTERNAL ORGANIZATION

No less important, but on the contrary a fundamental tool for identifying objectives, the management and exploitation of knowledge is the internal organization of the Defense relating to research technology which can also be summarized according to three cornerstones:

- the Defense General Staff and those of the Armed Forces, oriented towards identifying the objectives and exploit the results;
- the Technical Directorates of the General Secretariat and the General Directorate of the Commissariat and

General Services, essential for technical competence and project management;

- the FF.AA. Test Centers, an ideal test bed for the valorization and validation of demonstrators technological, the final objective of the research programmes.

STRATEGIC OBJECTIVES

According to the Guiding Act of the Minister of Defence, the modernization of the military instrument requires supporting and harmonizing technological research, which should be aimed at achieving the capability development goals of the Armed Forces by synergistically involving all Defence bodies that deal with research, trials and testing in both a developmental and an operational environment.

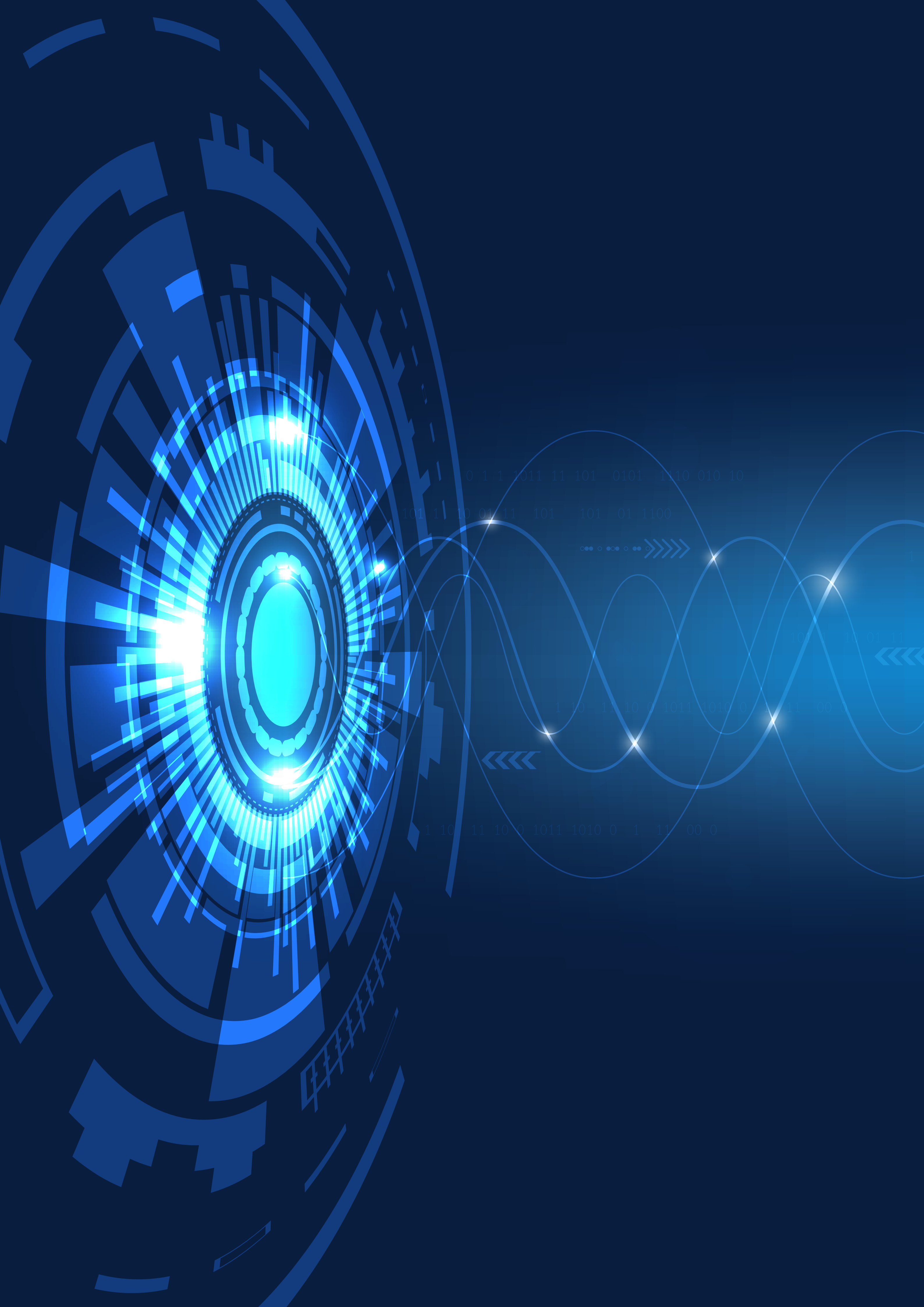
The strategic objectives of Defence scientific and technological research programmes cover different intervention areas, with a view to identifying and protecting strategically important technologies in order to ensure national technological sovereignty and support national projects or projects of national interest within the EU cooperation programmes. This is done in collaboration with the defence industry so as to maintain and develop the specific technological know-how of this sector, also cooperating with national and international industrial partners and seeking synergies with research centres and universities.

In order to reach those objectives, the Secretariat General of Defence and National Armaments Directorate – through its 5th Department "Technological Innovation" – uses a strategy based on both capability-pull and technology-push approaches. This strategy entails coordination and cooperation among different organizations such as ministries, research centres, industrial companies and scientific bodies, with a view to creating a network of synergistic connections for technological research in cooperation with governmental, scientific and industrial organizations.

The consequent Defence technological research activities range through different contexts, including the National Military Research Plan (PNRM), technological research and development projects carried out at Defence test centres, Framework Agreements with universities and research institutes, and international programmes at EU, NATO and bilateral levels.

In full coherence with the Defence capability requirements, the priority sectors for military technological research include:

- Soldier capability protection and enhancement: developing technologies to improve individual capabilities and soldiers' protection.
- Emerging and disruptive technologies, such as quantum technology, Big Data, 5G/IoT, especially when associated with the enhancement of ISR (Intelligence, Surveillance, and Reconnaissance) in land, air, sea, space and cyber environments.
- Autonomous systems, artificial intelligence, navigation safety and protection, development of advanced sensors and optical communication: focus on the use of advanced technologies for autonomous systems, artificial intelligence, navigation safety, development of sensors and optical communications.
- Satellite capabilities: enhancement of platforms' performance, payloads and sensors to improve the quality and effectiveness of space services and ensure the protection of in-orbit assets, including satellite communication systems, Earth observation, positioning, navigation and space monitoring (Space Situational Awareness - SSA).



NATIONAL RESEARCH

INTRODUCTION

In the context of the national research programs conducted by the General Secretariat of Defense and National Armaments Directorate during 2022, the results of some projects are presented below as they are considered exemplary of the technical-scientific activities, currently underway or completed, of technological relevance for the Defense and security sector:

- Submarine UnderWater Invisibility through MetaMaterials **(SUWIMM)**
- Programmable and modular sensors for passive acoustic monitoring **(DAMPS)**
- Innovative propulsion system solutions **(SPARTA)**
- Naval mobile firing range **(AVNT)**
- Firmware analysis ptototypical platform **(SAFE)**
- Healt projects for radiation protection **(iDETEC e Healt Shell)**
- (Phase change metamaterial for secure satellite telecommunications) **(METEORE)**
- (Advanced Radio Access for Military Solution **(ARAMIS)**
- Bulletproof vest **(PBI-G12-EVO)**
- Analsys and acquisition in broadband RF localization **(ZSpectrum)**
- HERP Electromagnetic Protection System **(HEPROSYS)**
- Immersive training and remote maintenance 4.0 for military aeronautics **(AIR4MAM)**
- High efficiency and high power laser sources using microstructured ceramic materials as active media **(CeMILAP2)**
- Remotely piloted aircraft system **(HERO)**
- Sensors developed by mapping and detection techniques for IED detection **(MILDAR)**
- Artificial intelligence for drone swarms **(NAIS)**
- Network quantum cryptography **(QUCRYPTNET)**
- Modular exoskeleton for lower and upper limbs) **(EMArlS)**
- 6-channel SCANning EW receiver based on integrated photonics **(esa-SCAN)**

SUWIMM

The potential of meta-materials is to go further the characteristics of physics materials, enabling otherwise not reachable vibro-acoustic properties. The project 'SUWIMM - Submarine UnderWater Invisibility through MetaMaterials' aims to develop a prototype of a submarine outer cladding (called meta-material) capable of guiding the incident acoustic signal around the shape of the hull in order to make it invisible to active sonar pulses, both monostatic and multistatic.
Through the phase 1 of the project, the characteristics of the meta-material were identified, its performance was simulated and an initial 2D scale prototype was built and tested in water: encouraging results were achieved. During the phase 2, a 3D meta-material was defined, covering a mock-up of a simplified scale submarine, extending the engineered solution of phase 1 with the actual geometry of the submarine to the 3D case. Finally, in phase 3, the 3D meta-cloak prototype will be tested in an underwater environment.
The results already obtained in the early stages of the project encourage to continue the study. However, it is known that, in addition to the reduction in target strength produced by the use of this technology, the implications of the meta-cloak on the submarine's hull will have to be evaluated during a later stage. Nevertheless, meta-materials are a full candidate for the designation of 'disruptive' technology. Just think to the reverberations that would occur in the world of Anti-Submarine Warfare as soon as this technology becomes ready.

INTRODUCTION

The growing technological evolution in the underwater world, combined with the strategic importance of the infrastructures that lie there, lead to an increase in the importance of a unique warfare asset of its kind: the submarine. Due to the fast changing global framework, the submarine must respond adequately, now more than ever, to the constant technological innovations in the field in which it operates, increasing its stealth capabilities. However, up to a few years ago, the localization of a submarine target was symmetrical, relying mainly on a one-to-one ship-submarine challenge: the ship (or airborne platform), equipped with monostatic active sonar, could only locate the submarine if it was within sonar range. In this context, the submarine was in a strong position, playing on the Range Advantage Factor that limited the risk of detection, making of secondary interest, considerations regarding the absorption of acoustic energy emitted by active sonars. With the advent of multistatic sonars, the submarines' advantage factors have been drastically reduced: the ability of ships to detect and locate them increases considerably, limiting the submarine's ability to operate covertly. Furthermore, even the simple absorption of the incident acoustic energy on the submarine becomes not enough to avoid detection of modern multi-static sonars, as even huge reductions of the expected signal arriving at the receiver are considered anomalies to be investigated.
As a result, the expected requirement of modern submarines becomes now the acoustic transparency at sea, which is exactly what the PNRM (National Military Research Plan) SUWIMM is aiming for.

TECHNICAL BACKGROUND

The technological solution identified by the Milan University (scientific partner of the project) is to cover the submarine with a meta-material capable of make what is inside it perfectly invisible to an acoustic pressure wave, creating what the scientific community calls an acoustic cloak [1]. This implies that the cloak is able to simultaneously eliminate the reflections of the incident wave (backward scattering) and the acoustic shadow (forward scattering) born on the opposite side of the hidden object within the cloak itself.

The project starts from the state-of-the-art in meta-material technology in which the scientific community evaluates two different approaches to the invisibility acoustic problem: the first is based on inertial cloak [2] [3] and the second is based on pentamode materials [4]. Both are at the state of art of demonstrators of the physical principle and are far from interesting implementations for possible real-world applications, where there are constraints with regard to the thickness of the cloak and the wavelengths involved, which can be several times smaller than the characteristic size of the target to be stealth.

SUWIMM's ambition is to fill this gap by studying the solution based on pentamode materials, which appears to be the most promising, because it avoids the problem of infinite mass that would occur with the inertial cloak approach. Nevertheless, the total mass of the cloak, in the case of perfect pentamode cloak, is the same mass of the fluid region that would occupy the total volume of the submarine plus cloak. This would make buoyancy impossible and, therefore, even adopting this solution, strategies have been developed to reduce the total weight of the cloak and, as a counterpart, a reduction in performance has been accepted [5].

METHODOLOGY

Figure 1 shows the transformation required to get an object acoustically stealth. Designing an invisibility cloak that works as illustrated is, in few word, an inverse design problem: the desired material behavior is known, but it must be look for the physical properties of the material that match these specifications (inhomogeneity, anisotropy and impedance matching). Basically, it must be studied a meta-material that is capable of deflecting the acoustic rays: in the radial direction, the rays must undergo a contraction with respect to the original region without the submarine and must now travel in shorter trajectories. On the contrary, in the circumferential direction, the rays, which originally had to travel straight trajectories, must now travel longer trajectories at the same time and, as a result, an extension of space will be required. It can therefore be deduced that the material of which the cloak is composed must possess a higher propagation velocity than in sea water in the circumferential direction, and a lower propagation velocity in the radial direction [6].

Image made by the University of Milan

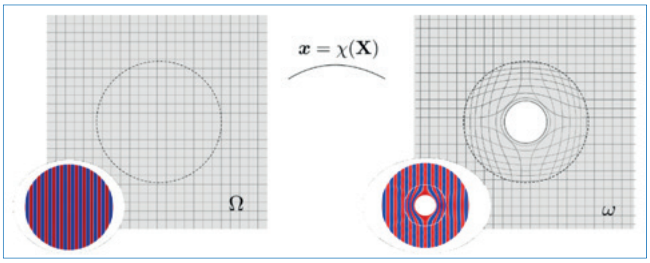


Figure 1: acoustic transformation to be realized

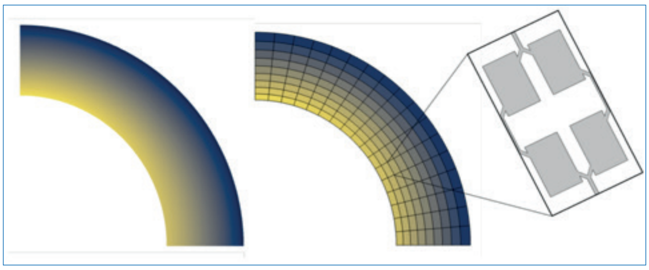


Figure 2: study of the elementary cells of the meta-cloak

During the phase 1, it was simulated not only the performance of the 2D meta-shell (elliptic section) by designing the elementary cells (Figure 2), but were carried out also tests in a pool measuring the actual performance of the 2D meta-shell produced, comparing the target strength (a quantity expressing the amount of energy diffused in all directions by the object immersed in water) of the submarine section in the 'no shell', 'shell' and 'reduced diameter' submarine cases (Figure 3). The results were extremely encouraging: the cloak reduced the energy spread by the submarine section, making it practically smaller, making a conventional submarine acoustically like an Underwater Unmanned Vehicle (Figure 4).

In Phase 2, the ambition of the project grows by studying a scaled 3D case, both in terms of engineering design (Figure 5) and physical realization. In phase 3, the acoustic properties of the 3D meta-cloak prototype will be tested again inside water.

Photos taken by the University of Milan

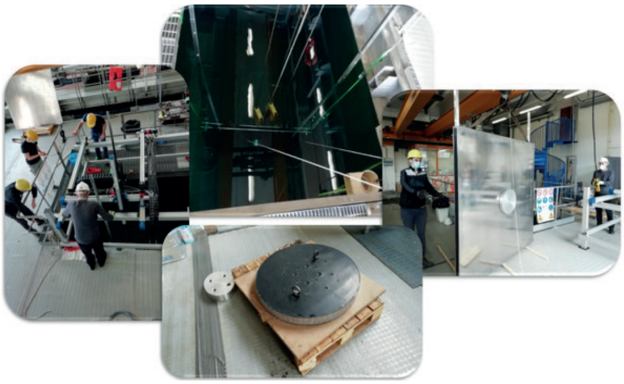


Figure 3: Target Strength measurement test of the 2D meta-cloak prototype in a pool

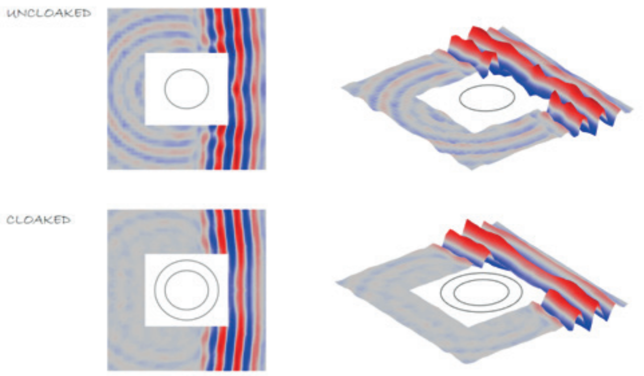


Figure 4: real data comparison of backscattering and forward scattering (section with and without meta-cloak)

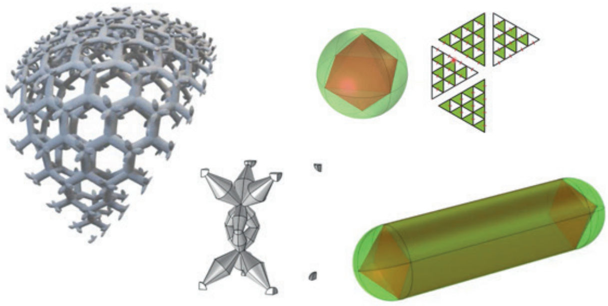


Figure 5: 3D shell engineering phase

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The results already got from the project show that the path taken is promising and encourages to continue the study to verify the actual effectiveness of the 3D model as well. However, as the project will be completed, it will be known the actual reduction in target strength produced by the use of this technology. The application of such a solution will bring a new disruptive concept to the submarine and it will be necessary taking into account, at an early stage of the project's development, the implications on the platform and on combat system associated with the adoption of the meta-cloak.

The effects of this cutting-edge technology, on the entire military shipbuilding industry, could be disruptive. Just think that, nowadays, there are no known shipyards in the world that are capable of producing underwater meta-cloak, and consequently, being the leader in this field would not only be a source of prestige for national centers of excellence and research, but also an important new 'building block' in support of the 'National Underwater Pole', which was created with the aim of enhancing, implementing and promoting Italy's potential and competitiveness in the underwater world. The SUWIMM project and its potential, therefore, bear witness to the fact, from the interest in what happens underwater, that arises the most significant impulses in the field of research. Those new emerging industrial technologies continue to make Italy one of the most developed nations in the world in the underwater sector.

CONCLUSIONS

In the near future, the use of meta-materials for purposes related to target strength reduction may play a key role in determining a nation's supremacy in a field, the underwater world, with its strategic infrastructure, that grows its importance every day. This technology, which is intended not only for applications related to acoustic cloaking, but also, for example, for focusing the pressure waves to generate next-generation acoustic projectors, is of such value that it deserves the appellation 'disruptive'. Just think of what the future of the ASW could be if one nation succeeds in making the first acoustically invisible submarine. In one shot, it would fall all the studies, tactics, and investments made to realize bi-multistatic underwater systems aimed precisely to maximize the detection and tracking capabilities of acoustic energy emissions produced by adversary submarines. The world of ASW hunting would then have to be re-evaluated and fully rethought.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

2D	*bi-dimensional*
3D	*tri-dimensional*
ASW	*AntiSubmarine Warfare*
PNRM	*National Military Research Plan*
SUWIMM	*Submarine UnderWater Invisibility through MetaMaterials*

KEYWORDS

Submarines, Underwater, SSK, Meta-Materials, Acoustic Cloak, Target Strength, pentamode materials

PROJECT INFORMATION

Numero scheda PNRM:	a2018.096
Amministrazione appaltante:	Direzione degli Armamenti Navali - NAVARM
Ente responsabile del progetto:	NAVARM – 3^Divisione.
Città, Regione:	Roma
Titolo e nome del responsabile del progetto:	CV (GM-GN) Christian PERRONE
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The Distributed Autonomous Mobile Passive System project aims to design, modify and evaluate the use of programmable and modular sensors for passive acoustic monitoring (also intended as a receiver component of a multi-static system), and evaluate the coordination of resources and of capabilities among multiple autonomous vehicles to achieve the set goals. Given the potentially high amount of information to be synchronized and evaluated to allow rapid decisions at a centralized level, the project will have to develop automatic analysis logics in the specific peripheral platform, increasing its modularity, enhancing its operational versatility, optimizing its lifecycle costs. Furthermore, other project objectives are to study underwater communication protocols on a secure network, to study data exchange between multiple units in shallow and confined water environments, with high environmental noise, and, overall guarantee the robustness, safety, adaptability, and interoperability characteristics of the systems network. Starting from the already existing autonomous underwater navigation capability, distributed detection systems will be developed, with the abilitye to operate in multiple application scenarios, based on local processing and data fusion with an adaptive, secure,and undetectable underwater communication infrastructure.

INTRODUCTION

The DAMPS project (Distributed Autonomous Mobile Passive Sonar system) was born with the aim of studying and realizing a distributed sonar implemented through an adaptive geometry volumetric system that operates the fusion of data from heterogeneous sensors for passive acoustic monitoring (PAM) that can be managed by an autonomous underwater vehicle (AUV) team. The system provides that each AUV, locally and autonomously, is able to process the signal of its PAM by estimating the directions of arrival (DoA) of the useful signal.

The designed system of systems will employ the usage of six vehicles equipped with PAM sensors and two additional vehicles employed as mobile gateways. The vehicles involved will transmit the results of local processing to each other: a consensus algorithm will be automatically executed thanks to the team's communication infrastructure and, if a target is identified, consent will be given to bring it back to command and control (which will be a manned station positioned on board the mothership or on shore, an indifferent aspect for the modular architecture of the system). The consensus algorithm is performed in DAMPS with an underwater communication network whose signals will be low power and secure

TECHNICAL BACKGROUND

Underwater acoustic source localization is used in many underwater applications such as tracking marine mammals, search & rescue operations, off-shore exploration tactical surveillance, oceanographic data collection and pollution monitoring. Underwater localization of a noise source is a challenging task due to technological and environmental constraints. Acoustic sensors inevitably face unpredictable and frequency-dependent attenuation, time-varying multipath effects, large Doppler and delay spreads, and limited bandwidth. For source localization , existing underwater acoustic systems rely on PAM (Passive Acoustic Monitoring) sensors which can provide the source bearing, but not the range. Combining bearing estimations coming from multiple sensors placed in different locations makes it possible to estimate the position of the acoustic source.

Multi-robot systems are usually employed in these is kind of tasks ,especially as the technological maturity level of Autonomous Underwater Vehicles (AUVs) is improving more and more in the last years, with outstanding national capabilities in network robotic systems. DAMPS addresses the development of a multi-robot system for the position tracking of a noise source in an underwater environment. It has been proposed as a passive, distributed and reconfigurable sonar system, composed by a team of AUVs and distributed detection systems based on local processing of the data coming from PAM sensors and data fusion among the vehicles through a safe underwater communication infrastructure.

METHODOLOGY

The DAMPS system is composed of a team of AUVs that collaborate in order to localize a target in underwater environment. The system works in the following way: each AUV composing the team locally processes the signal coming from its PAM sensor, detects a potential target and shares the locally-processed information through the communication system with the other members of the team, initializing an algorithm that allows to fuse the data. This combination of local decision-making and autonomous cooperation in the data fusion terminates with the transmission of the estimated target position to a remote station, where a human operator can integrate such information and reconfigure the system or other potential assets.

The system architecture (Figura 1) components are:

- AUVs architecture;
- Communication system;
- Command & Control system (C&C in the following);
- Navigation, guidance and mission management system;
- Sonar system.

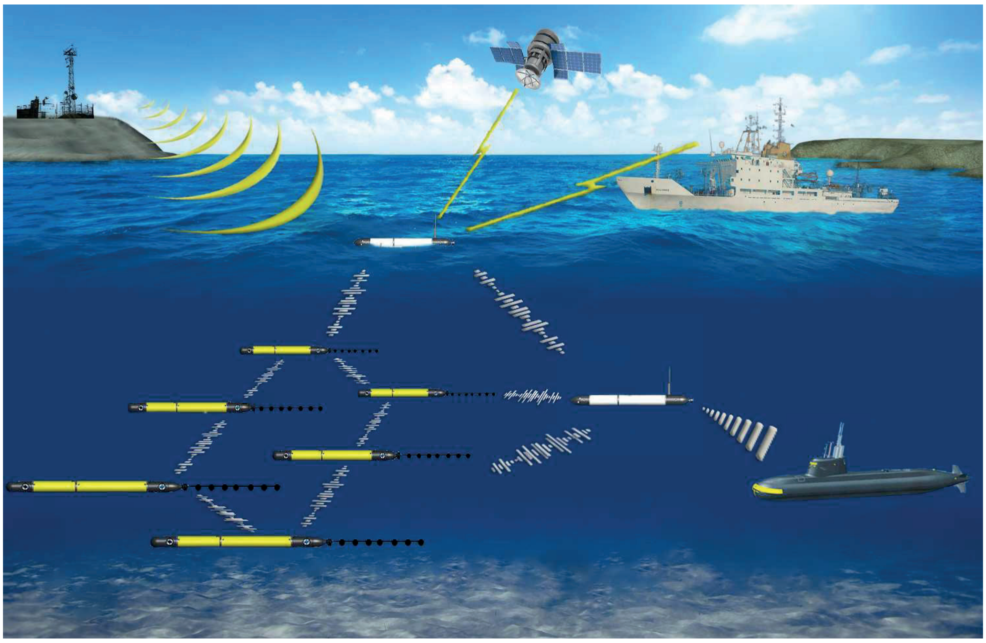

Figure 1 - DAMPS system architecture

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

Possible application scenarios in which the DAMPS system will be validated include ASW (Anti-Submarine Warfare) operations and passive monitoring of marine mammals.

Given that the characteristics of the generic scenarios in terms of ranges and frequencies are wide, all the technical choices will be better specified depending on the PAM sensors, the communication and the localization systems and on the relative influence among each other in terms of performances. Regarding the specific application scenarios (Figura 2), it is possible to identify:

- Hold at risk (a);
- Sea shield (b);
- Mammals monitoring (c).

The system has been designed to be flexible and easily extendible.

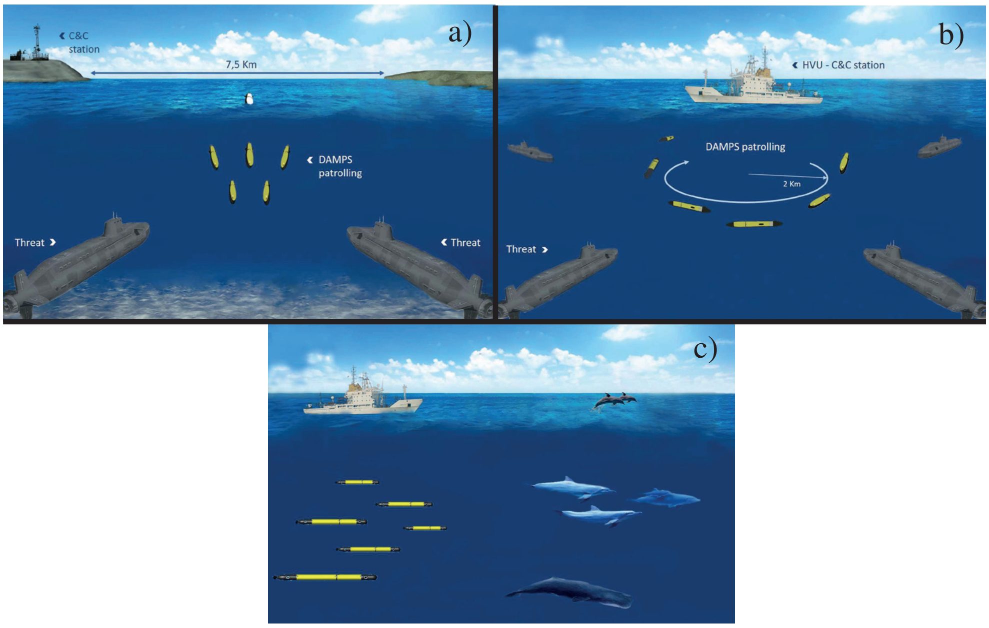

Figure 2 – Specific application scenarios: Hold at risk (a), Sea shield (b), Mammals monitoring (c).

CONCLUSIONS

The DAMPS project addresses the development of a multi-robot system for the position tracking of noise sources in an underwater environment. The robots composing the team collaborate in order to fuse the local information coming from the analysis of a Passive Acoustic Monitoring sensor, with the final aim of estimating the position of the acoustic source. The multi-robot team is thus a distributed, modular and reconfigurable sonar system that can be controlled remotely from a Control & Command center. The system has been designed and tested by means of simulations and real-time emulations, including tests in field for some separate components. Future works forecasted in the next phases will concern the implementation of all the submodules, and the integration and validation of the entire system in a realistic scenario at sea.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

PAM	Passive Acoustic Monitoring
AUV	Autonomous Underwater Vehicles
DoA	Direction of Arrival
FF.AA	Armed forces
SGD	Secretariat General of Defence

KEYWORDS

underwater acoustic source localization, acoustic communication, multi-robot control

PROJECT INFORMATION

PNRM number:	a2018.165
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DOI: 10.1109/MetroSea52177.2021.9611595
https://doi.org/10.1109/MetroSea52177.2021.9611595

The entry in service of the last generation Sonar systems has made obsolete the targets traditionally used for the training of AntiSubmarine Warfare (ASW) personnel. Moreover, targets to evaluate the behaviour at sea of torpedoes with high anti-countermeasure performances are not available. Currently, only real targets or large autonomous vehicles can be used to train the ASW personnel with consequent strong logistic limitations. The purpose of the study is to evaluate innovative solutions of propulsion systems, attitude control and acoustic signal management to realise Sonar and torpedo targets able to execute long duration missions with limited logistic constraints. The best suited technologies to be adapted to small vehicles have been selected for an integrated propulsion and attitude control system and for the analysis of the acoustic signal. Bench tests and sea trials have evidenced the capability of the target to execute long duration missions at the cruise speed of submarines and to generate the acoustic echo and signature of a real submarine.

INTRODUCTION

New generation Sonars require targets for training equipped with lower frequency and higher Source Level acoustic systems with respect to the available targets; these new targets must also execute longer missions on larger distances. Only real targets or large autonomus vehicles are currently able to assure these capabilities. The availability of small targets, without specifc constraints of deplyment and recovery could allow the platforms equipped with new generation Sonars to execute autonomously the training activities. Curently available small vehicles cannot be used as targets because of the low navigation speed, the low operational autonomy and the complexity to integrate acoustic systems with high sensitivity in the frequency bandwidths typical of the Sonars and torpedo Acoustic Heads. The study has been mainly focused into two directions, the propulsion system and the acoustic echo and signature generation. The selection of the technologies to be developed has been executed taking also into account the minimisation of the logistic constraints for the operation of the target.

TECHNICAL BACKGROUND

Underwater autonomous vehicles can be divided into two families, vehicles for monitoring at low speed, whose attitude control is based on thrusters and vehicles devoted to specific applications at high speed, whose attitude control is based on rudders. A Sonar target must be able to navigate at low speeds, lower than 4 knots, and high speed, up to at least 15 knots. In order to minimise at the same time the dimensions and the logistic constraints, an innovative solution has been identified integrating the attitude control with the propulsion system, makimng use of four motors installed in the vehicle afterbody, as shown in Figura 1.

To achieve the objective of maintaining limited dimensions and minimizing maintenance needs, an Innovative solution has been identified which involves integrating the ride control with the propulsion system, using four engines arranged in the rear area of the vehicle, as illustrated in Figure 1.

The attitude control on the horizontal and vertical planes is achieved by regulating the thrust difference of the four engines, which also regulate the navigation speed. In this configuration

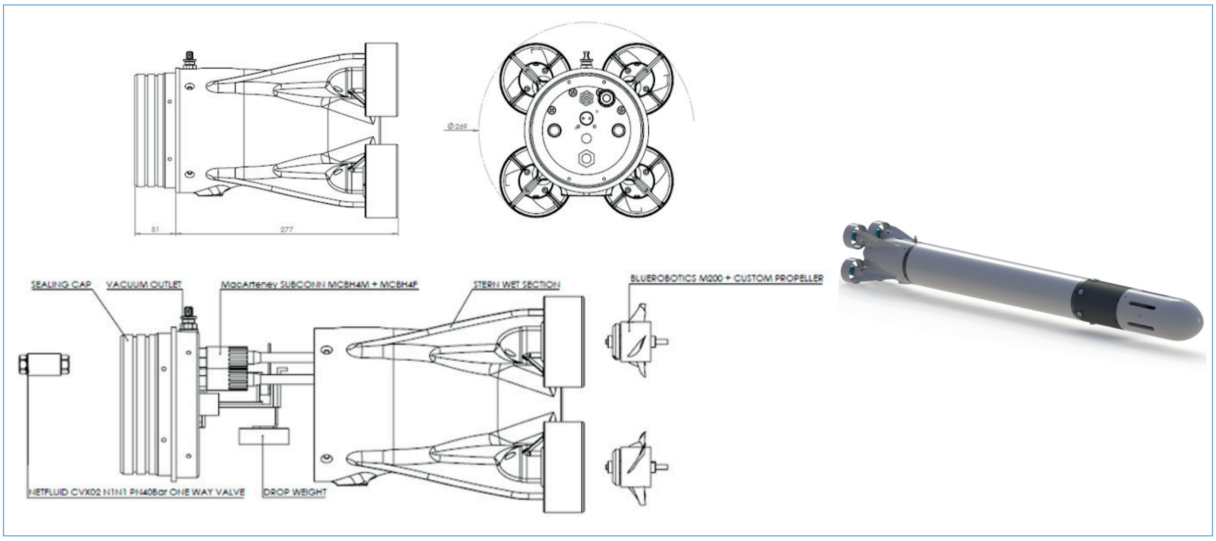

Figure 1

all moving components are external and easily accessible without the need to dismantle the vehicle The small vehicles can be supplied only by means of relatively low voltage power supplies, which presents two critical issues. On one side the supply currents are relatively high inducing relatively high electrical noise and on the other side large acoustic Source Level require the integration of large dimensions transformers. These criticalities have been reduced using separate transducers for reception and transmission, selecting a transmission transducer not requiring tuning filters and realising a single large bandwidth receiving chain with high signal dynamic. In this way, the desired signal can be selected with accuracy.

METHODOLOGY

The idoneity of the selected solutions has been demonstrated through numeric simulations and tests on single components. The evaluation of the system behaviour has been evaluated through final sea trials of a prototype.

The capability of the propulsion system to push the vehicle at the desired speed has been demonstrated through tests in a pool. The vehicle has been bound with a cord on which a dynamometer was mounted to measure the push, as represented in Figura 2.

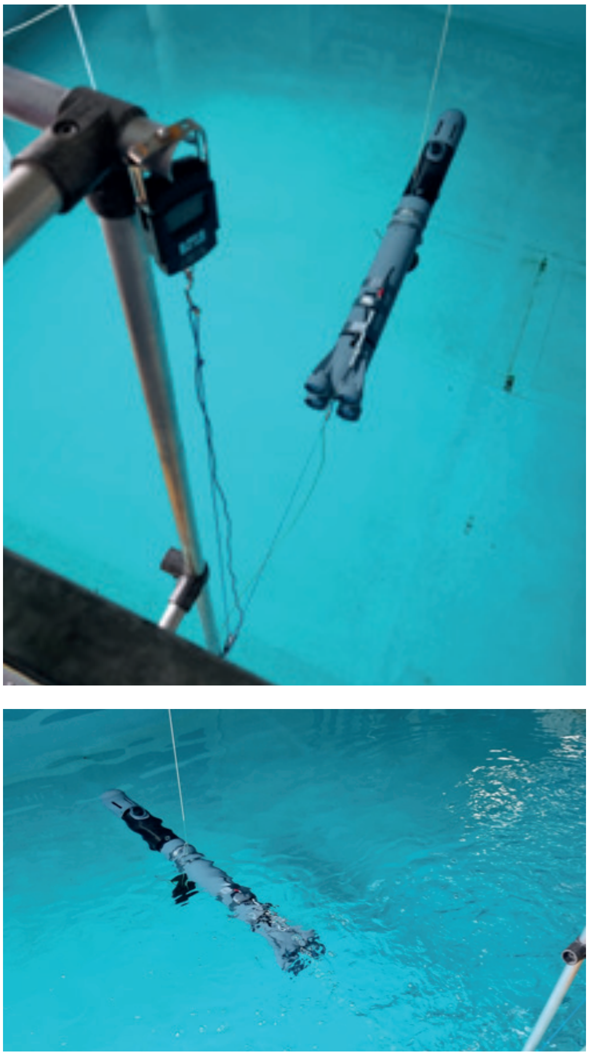

Figure 2

% Thruster	Corrente assorbita (A)	Spinta generata (Kgf)
10	1	0,5
20	2	1,3
30	5,9	3
40	11,5	4,9
50	19	6,8
60	28	9
70	36	10,9
80	48	12,4

Tabella 1

The propulsion system is able to generate a 130 N (13 kgf) push, as reported in Tabella 1.
This push corresponds to 10 knots navigation speed. The propulsion system is supplied by a battery specifically designed to deliver 1425 Wh at 50 A. The design of the battery has also included the study of a battery charger able to minimise the charge time allowing repetitive operations with short stop periods. The complete charge can be achieved in less than one hour without disassembling the vehicle, as represented in Figura 3.
The attitude control is realised by means of two separate PID regulators on the horizontal and vertical planes. The outputs of the two regulators are transformed in the push of the four motors, in accordance with the scheme in Figura 4
The proportional, integral and derivative gains of the two PID regulators have been set up by means of numeric simulations and verified during the sea trials.

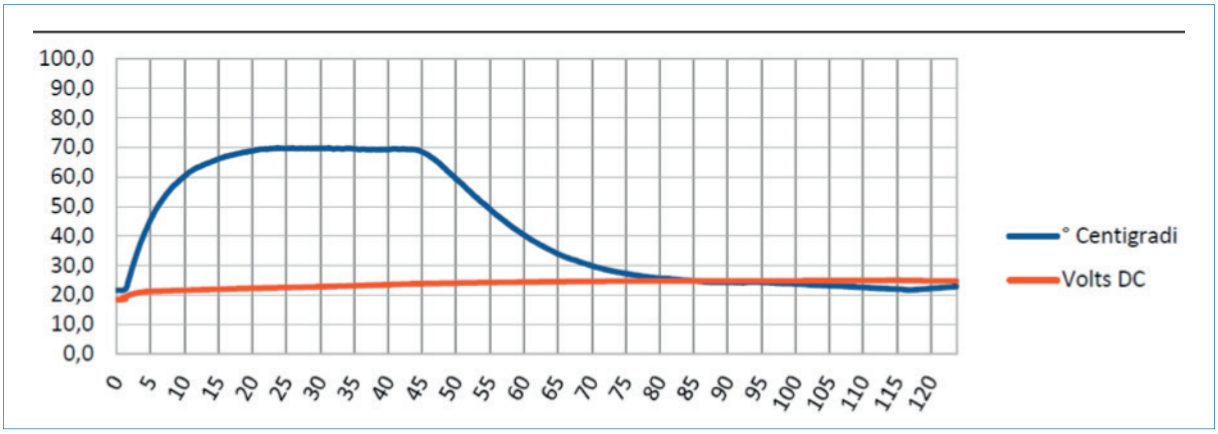

Figure 3

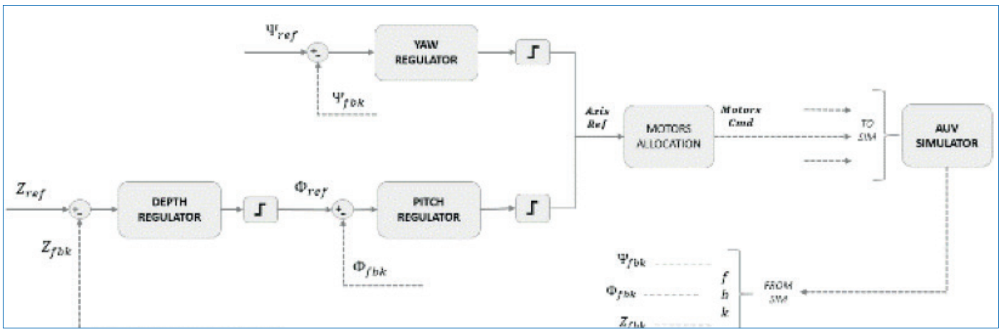

Figure 4

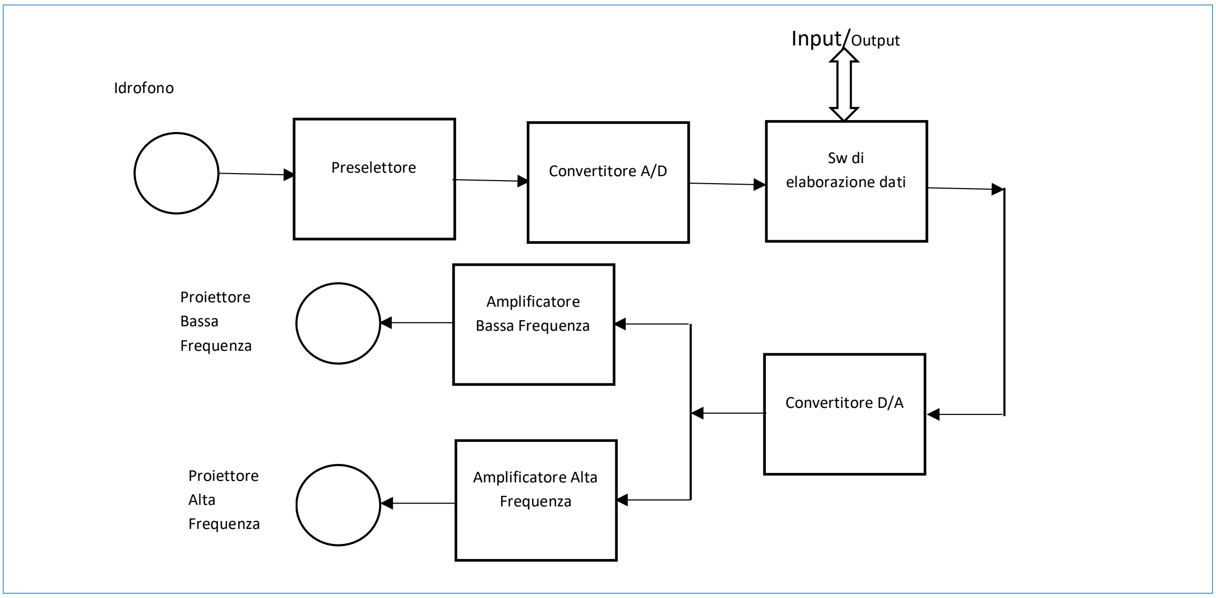

Figure 5

The acoustic module has to receive the Sonar emission from a minimum distance assumed equal to 1000 m up to a 80 km maximum distance. The receiver must then have more than 160 dB signal span. This span has been distributed in a 25 to 85 dB variable gain reception amplifier and a 18 bit analogue to digital coverter, for a 200 dB total span. The bandwidth of the receiver is between 10 Hz and 120 kHz. The input electrical noise has been measured at bench lower than 0,38 nV / √Hz and then lower than the environmental nois at sea state 0. The processing electronics recognises the Sonar and torpedo emissions and drives the signal generator, with single highlight for the Sonar emission and for the torpedo with a number of highlights coherent with the type of target to be simulated. The scheme of the acoustic section is in Figura 5.

Pitch and heading control

During the tests at sea, without a real Sonar, the scho repeater capability has been verified in presence of a sinusoidal 1kHz acoustic signal emitted by a projectot in fixed position and verifying the answer of the transmitter during the run.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

Some of the techologies selected for the Sonar target have interest in other fields. Il bersaglio Sonar è realizzato sviluppando alcune tecnologie di interesse in campi diversi. The capability of the vehicle to navigate at low speed to execute monitoring operations and at high speed to perform a quick transfer between different areas of interest can be adapted to other applications not only for underwater survey for defence and security, but also for oil&gas applications. The attitude and direction control through regulation of the push of more motors, already applied in surface vehicles, can be extended to all underwater vehicle applications. The development of these technologies is included in the product strategies of Graal Tech to expand the oil&gas applications.

The receiver of the acoustic system of the target is coceived as a large bandwidth and large span standard amplifier that can be applied in several multisensor applicarions, like volumetric array and towed or fixed array, that are in the objectives of TECNAV Systens.

CONCLUSIONS

The study has developed the main component of a small Sonar target, compatible with the needs for the training of ASW personnel of the new generation Sonar. The vehicle can generate an echo coherent with the characteristics of the Sonar and execute the cynematic trajectories proper to a real submarine. The prototype propulsion system has to be upgraded to reach higher speeds. It shall be equipped with an additional transmitter to generate the echo for the torpedo acoustic heads. In this way it will operate in secnarios representing also the antisubmarine reaction. In any case, the basic technologies of the attitude control and of the acoustic reception have already shown in the prototype the required capability during the tests at bency and at sea.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

ASW	Anti-Submarine Warfare
$Nv / \sqrt{Hz}$	Unità di misura della densità spettrale di rumore elettronico
PID	Proportional Integral Derivative regulator (Regolatore Proporzionale, Integrale e Derivativo)

KEYWORDS

Target, Sonar, Training, Attitude Control, Battery, Underwater Vehicles.

PROJECT INFORMATION

PNRM number:	a2019.014
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Currently the naval shooting campaigns for which it is necessary to evaluate the points of fall into the sea are carried out in the coastal area but are subject to time restrictions, particularly during the summer period, and to environmental problems deriving from the emission of heavy metals in proximity of the shooting stations and the dispersion of projectiles in the adjacent sea areas.

The present project envisages a solution that can be installed on naval units and used on the high seas for the detection and measurement of the points that fired shells fall into the sea for evaluation of shooting performance. In essence, it is a question of bringing the fall point measurement system used in a coastal polygon to the open sea in order to have unlimited ranges and lower environmental impact.

INTRODUCTION

The scope of the project is the development of a technological demonstrator capable of detecting the fall points of projectiles fired by Naval Units during exercises, checks and calibrations on the high seas.

The demonstrator consists of three local data collection and processing stations equipped with autonomous calculation capabilities and a centralized operating console (to be developed in phase 2 of the project) capable of managing and controlling the entire polygon.

Each monitoring station is equipped with a local operating console, a gyrostabilized optronic turret integrating an optical sensor operating in the visible spectral bands, a GPS receiver and a radio transceiver for interconnection with the other stations (Figure 1).

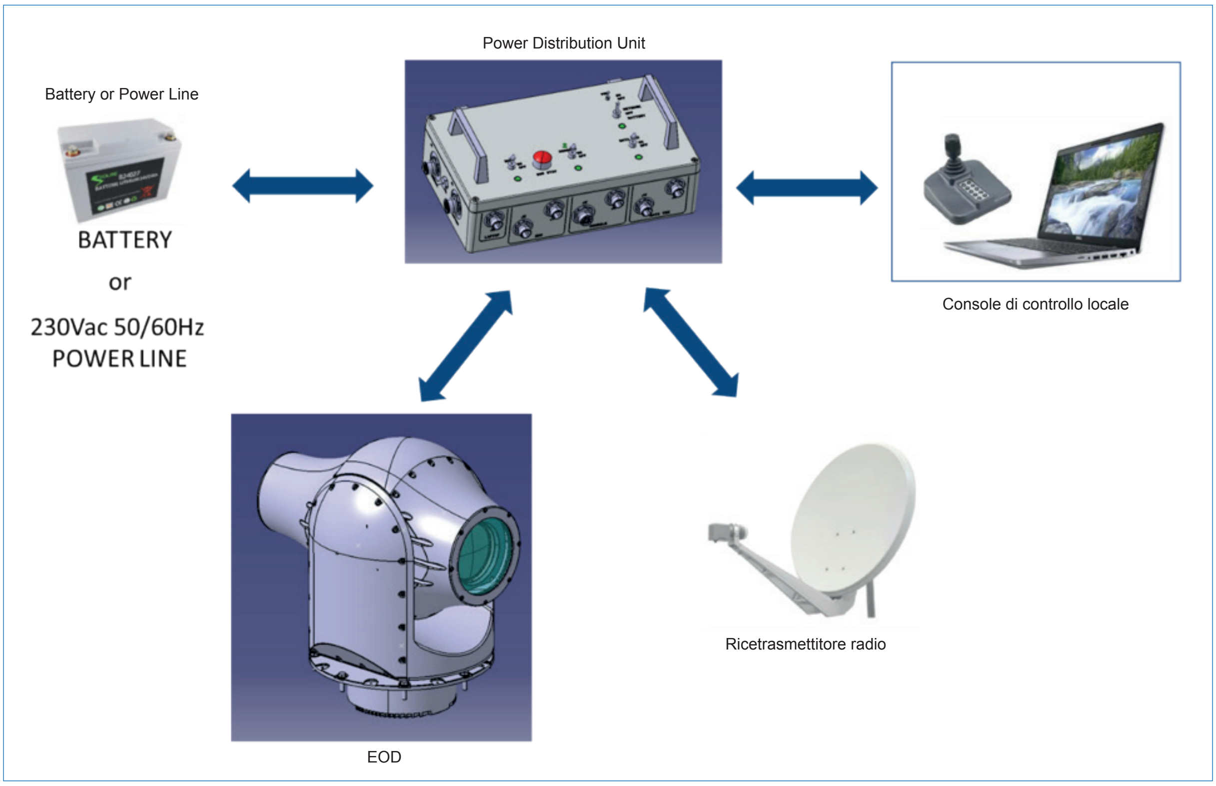

Figure 1 - Local Station – Layout

Each station can detect the fall points of the shots fired at a target (real or theoretical) and communicate them (in terms of difference of pixels with respect to its line of sight) to the centralized console which calculates the real geographical point of fall of the projectile, also using the additional data of all the turrets that have detected the event, including their geographical position, their attitude, the angles of azimuth and elevation and the detection time.

TECHNICAL BACKGROUND

From the study of the Italian scenario in terms of management of military shooting ranges, critical issues emerged mainly concerning the periodic reclamation of the ranges, the time limit for exercises and the costs of management and planning of ballistic activities.

Limited to the Balipedio Cottrau shooting range in La Spezia, among the various existing problems the following emerged:

- Firing area falls entirely within the Gulf of La Spezia and is affected by heavy boating and merchant traffic.
- Ammunition, security needs prevent the use of real war equipment
- Environmental impact, the introduction of projectiles into the Gulf of La Spezia could in the future lead to limitations on shooting activities.

In this context, the solution was born of moving the monitoring stations to the open sea as systems to be installed on board the MMI naval units.

To carry out this task, the system is composed of three local observation stations that can be installed on naval units as well as, to be implemented in phase 2 of the project, a centralized console, and a radio transceiver system (Figure 2).

An image processing algorithm installed on board the turrets identify the projectile falling overboard and communicates the deviations with respect to the LOS of the detection turret of the phenomenon detected to the centralized console (Figure 3).

Subsequently, the calculations of the geographical point of fall will be carried out having available the data of all the turrets that have detected the event, including the geographical position data of the turrets, their attitude and their LOS (Figure 4).

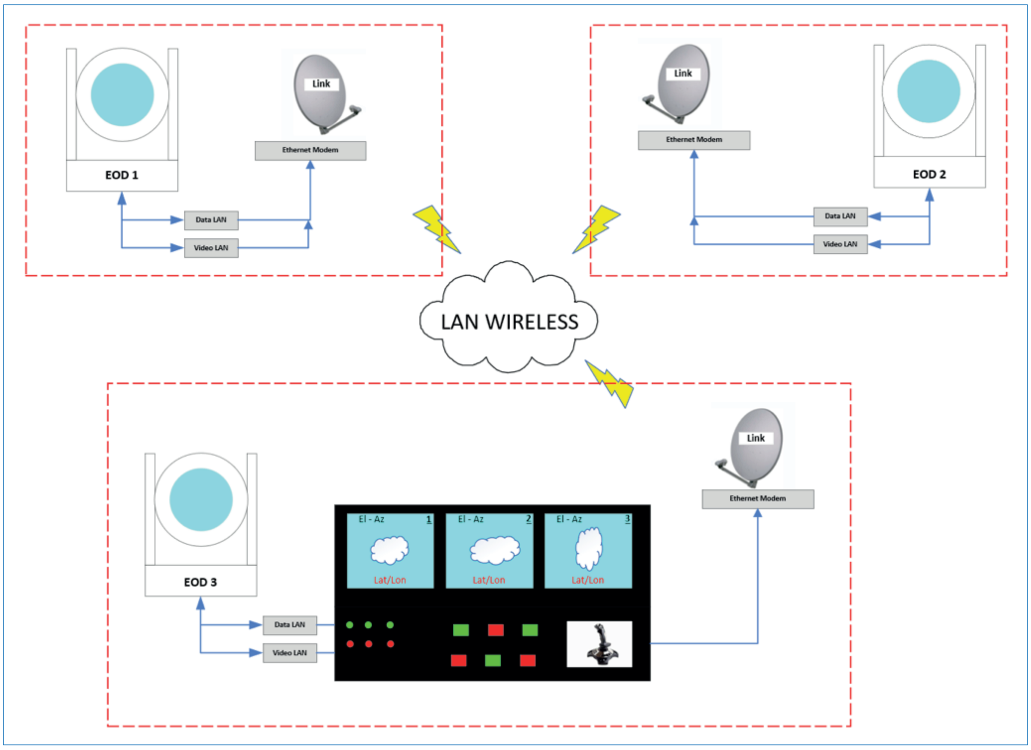

Figure 2
System Architecture

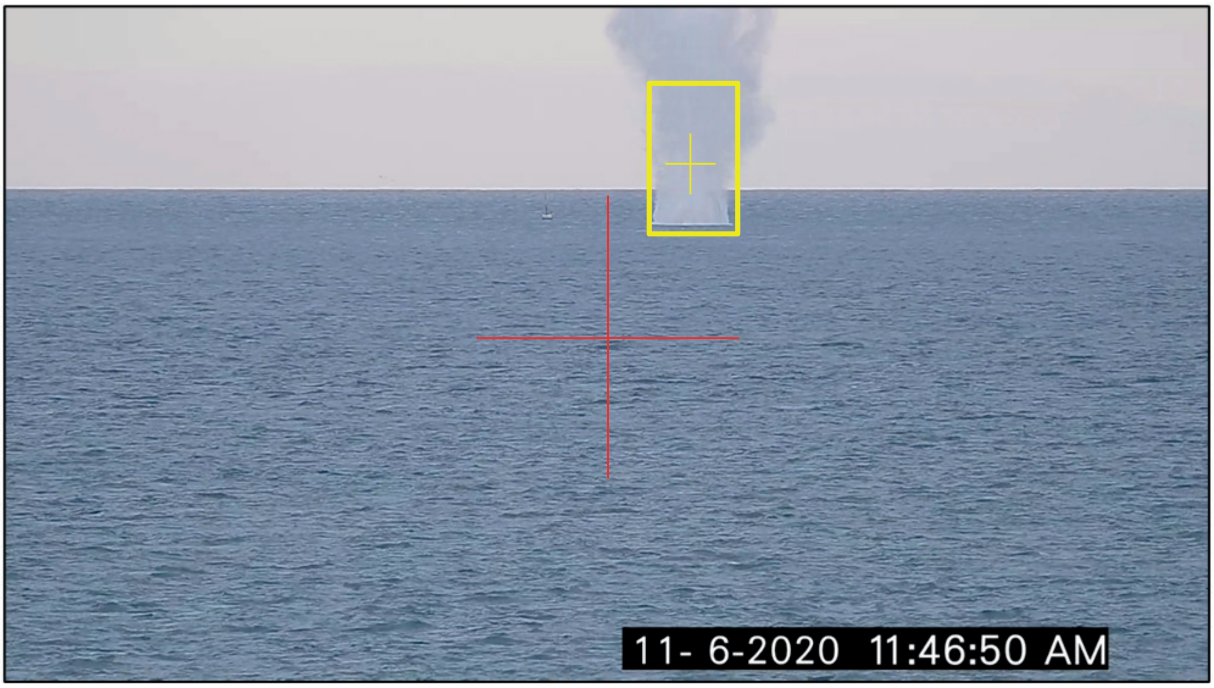

Figure 3 - Event detection – The point of the projectile falling into the sea can be identified through an automatic detection algorithm or by manual positioning of the yellow crosshair on the point of fall by an operator. Once the point of fall has been identified, the differences in terms of pixels between the point of fall (yellow crosshair) and the line of sight of the sensor (red crosshair) are known.

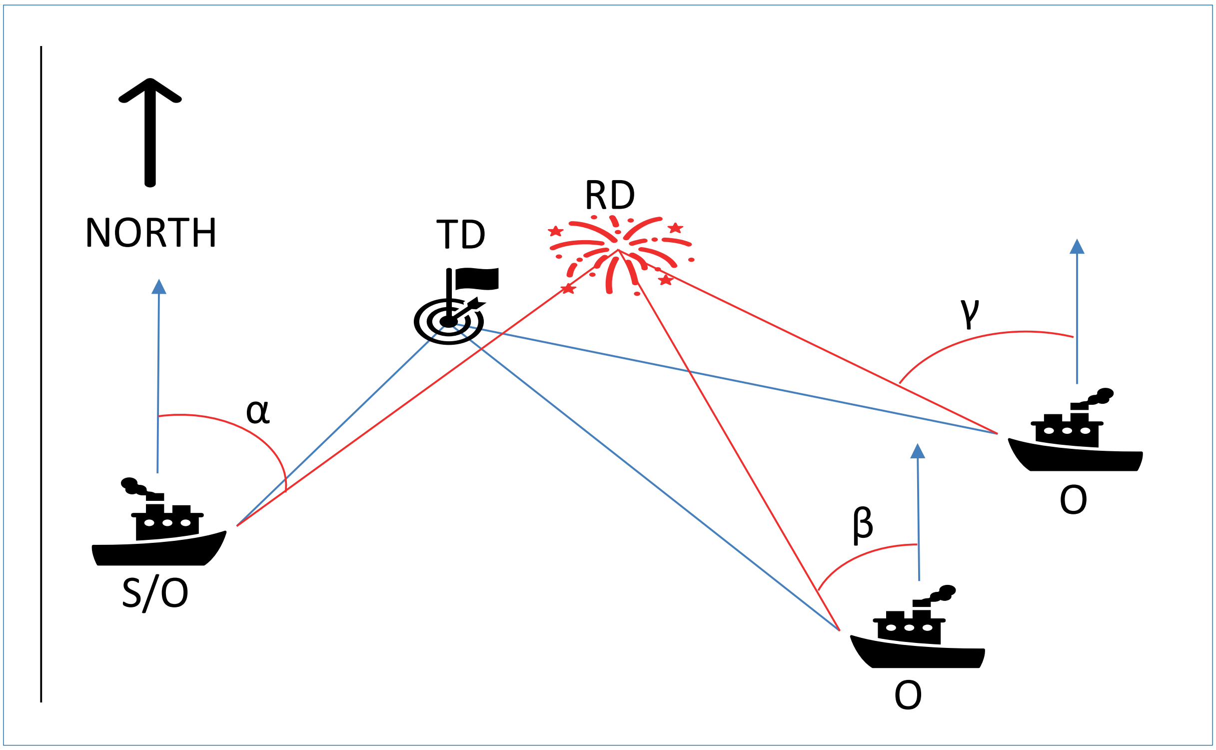

Figura 4 - Operation – The figure shows a possible operative scenario in which two optronic turrets are installed aboard Naval Units (O) and one optronic turret is aboard the vessel performing firing tests (S/O). The target (theoretical point of fall) is indicated with TD and the actual point of fall is indicated with RD..

METHODOLOGY

The turret is equipped with position and inertial speed sensors, sliding contacts (slipring) and servomotors which allow the orientation of the DLTV camera in elevation and azimuth keeping the Line Of Sight (LOS) stable on the target even in the presence of external disturbances.

To guarantee the required precision and positioning accuracy, the turret is equipped with direct drive motors, absolute optical encoders and an IMU-GPS module for the correct geo-referencing of the system and the appropriate calculation of coordinates in stray planes.

The vision sensor is a DLTV camera operating in the visible spectrum which complies operational needs by allowing the observation of targets with a minimum size of one meter at a distance of 20 km (Figure 5).

To verify the optical performances of the selected camera, a test campaign was conducted by testing the camera on different targets at different distances and from different observation points: Punta Corvo, Punta Castagna and Balipedio (Figure 6 and Figure 7).

The local control console is the main interface unit between the operator and the EOD system; it consists of a laptop on which the system control and HMI program is installed and a desktop IP unit for EOD movement control and camera control.

The software architecture of the system consists of two main subsystems:

- control system (embedded) which manages the turret control, i.e. controls the actuators and acquires the EOD sensors in order to perform the operations requested by the operator through the User Interface (UI) subsystem.
- user interface (PC SW) which creates the user's graphical interface allowing data acquisition (video, deviation, ...) from the local station.

The two subsystems communicate through an Ethernet LAN link.

Figure 5 - Main operative scenarioe

Figure 6 - Observation of the column of water raised by the 127 mm caliber projectile falling into the sea [distance = 6,500 m] from Punta Castagna

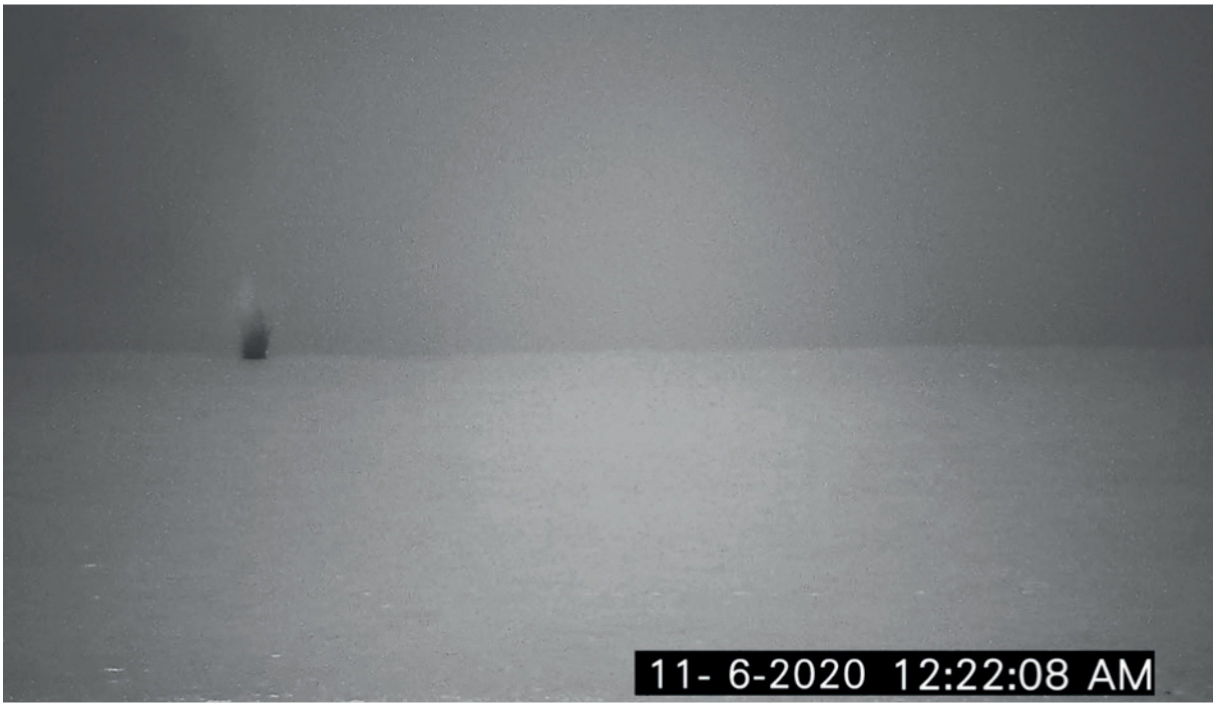

Figure 7 - Observation of the water column raised by the 76 mm caliber projectile falling into the sea [distance > 10,000 m] from Punta Castagna

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The system was designed to be used in different operating scenarios:

A. A ship carrying out the firing tests (or a weapon positioned on land) and the detection turrets installed in fixed land positions typically in the test scenario of the Gulf of La Spezia.

B. A firing ship carrying one optronic turret and a target dragging ship carrying a second turret (Figure 8).

C. A gun ship carrying one optronic turret, a target dragging ship carrying another turret, and a third ship carrying a final optronic turret.

In addition to the scenarios described above, more generally, the solution can be used for observing the point of fall of the projectile from fixed or mobile locations or by their combination.

Furthermore, the individual local stations, if installed on board MMI naval units, can be used not only for range activities during firing tests, but also as on-board equipment for long-range surveillance, control and monitoring activities, thanks to the large-scale diurnal sensor zoom capabilities and resolution installed in electro-optical turrets.

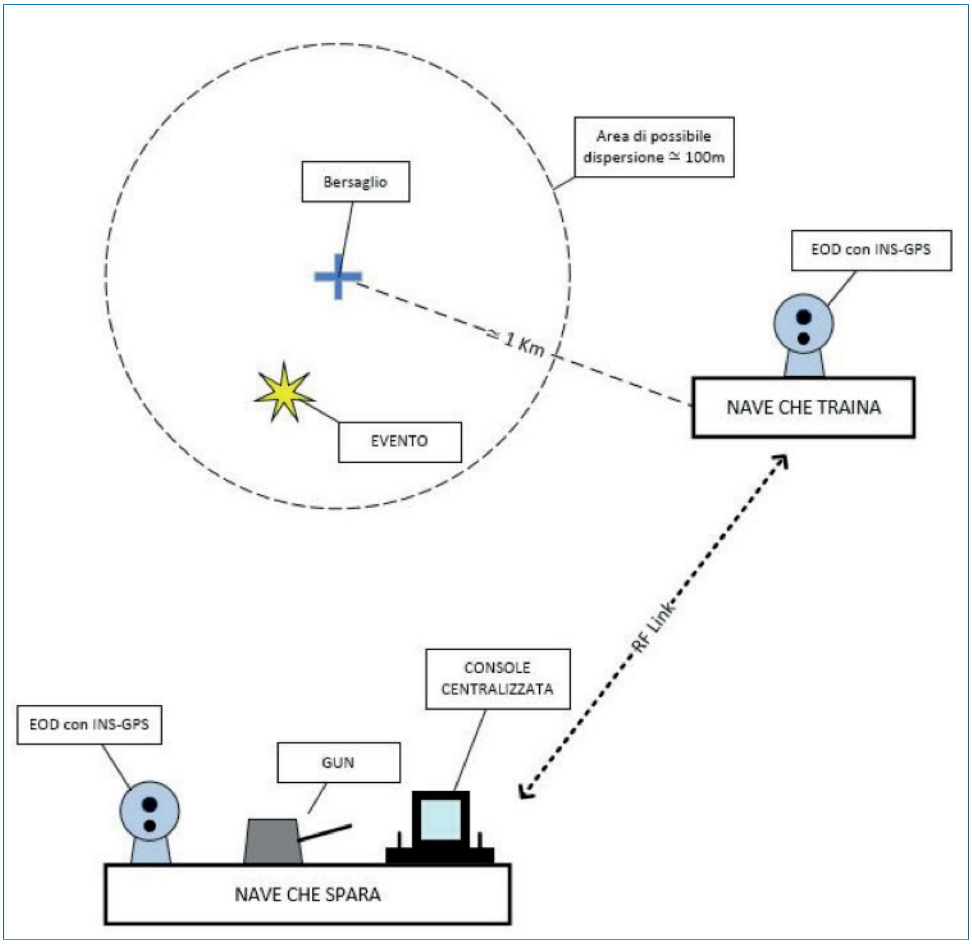

Figure 8 - Operative scenario with optronic turret and central console aboard the firing ship (S/O) and second optronic turret aboard the target towing ship (T/O)

CONCLUSIONS

The design and development of the local monitoring stations has highlighted an excellent level of technological maturity achieved by the demonstrator developed with COTS elements, already oriented towards producibility, competitive market value, quality of the final product and its testability.

For the moment, the test campaigns to verify the optical performance of the day vision sensor have demonstrated the excellent performance of the selected DLTV camera, and the tests on the gyrostabilized turrets have confirmed the expected technical characteristics in terms of precision and accuracy in the evaluation of the point of projectile falling into the sea.

The next phases of the project include the design and development of the Centralized Operator Console and Communication and Geolocation Subsystems and the preparatory study for the installation of the system both on land and on board the Naval Units, as well as carrying out some shooting campaigns and data collection to test the effectiveness of the technology demonstrator.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

COTS	Commercial-off-the-shelf
DLTV	Day-Light Television
EOD	Electro Optic Device
GPS	Global Positioning System
HMI	Human Machine Interface
IP	Internet Protocol
LOS	Line of Sight
MMI	Marina Militare Italiana (Italian Navy)
PC	Personal Computer
SW	Software
UI	User Interface

KEYWORDS

Projectile, electro-optical turret, DLTV, optronic, gyrostabilized.

PROJECT INFORMATION

PNRM number:	A2018.002
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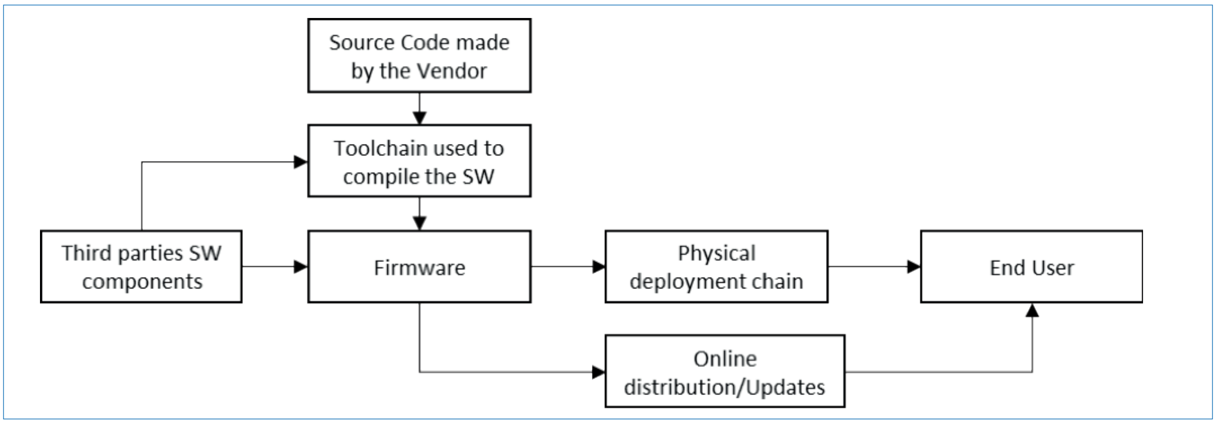
The PNRM SAFE Project developed a prototype platform to analyse firmware by applying self-attentive recurrent neural networks (self-attentive RNNs) capable of recognising the similarity between binary files and between assembly language functions. The research activity generated a set of technical project documentation, which summarises the state of the art in the use of neural networks applied to the analysis of binary files, helping to increase the security level of hardware and software supply chains. The realised prototype can identify malicious code in firmware executables and the version of the libraries used for its compilation. This tool is designed in favour of an in-depth control ICT equipment configuration. It aims to support cybersecurity analysts in the life cycle management of IT and OT solutions in critical systems.

INTRODUCTION

The SAFE project aims to implement an automatic capability to verify the integrity and security of firmware used on automotive, naval or terrestrial platforms, regardless of source code availability. Updating firmware is a critical element in the life-cycle management processes of IT and OT equipment. The timely control of the software configuration of weapon and support systems is an essential part of the various controls required to ensure the cyber security of installations. The extensive use of COTS systems in weapon systems makes supply chain security a critical element in developing systems.

In the Picture 1 is reported the supply chain of distribution of the firmware:



Picture 1 - Firmware supply chain Firmware

The use of third-party hardware and software libraries and components complicates the checks required to ensure that the product deployed operationally is fully compliant with the safety standards required by the end user.

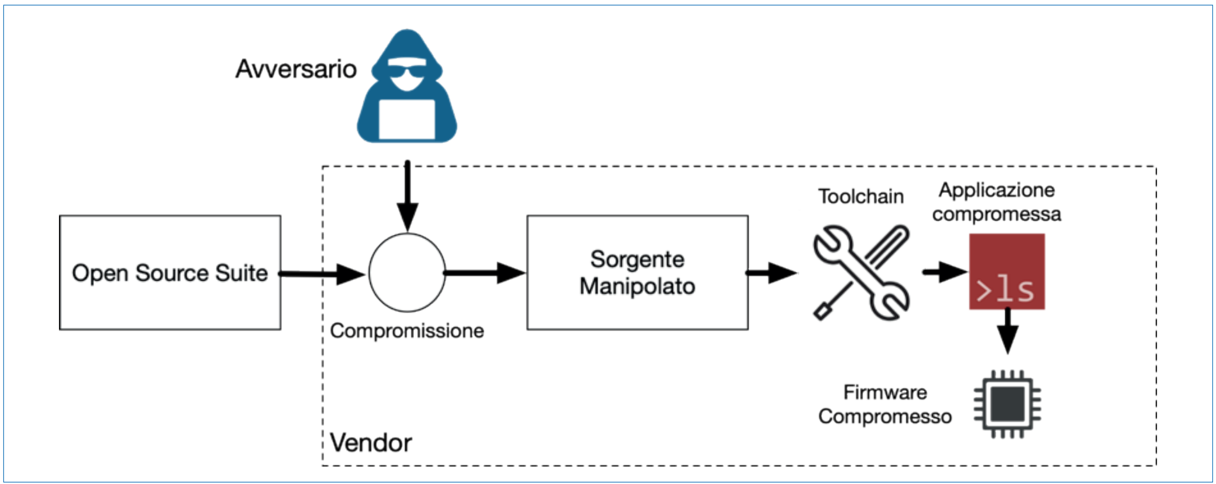
TECHNICAL BACKGROUND

The scenario analysed in this project assumes that a target could be compromised through techniques encoded as Supply Chain Compromise-T1195(MITRE ATT&CK, 2020)). Since end-users cannot easily access the source code of the firmware, generally owned by the manufacturers, the only means available for a deep inspection of the executables is the reverse engineering approach. Due to the cost and the high skill required for the task, it appears reasonable to explore alternative strategies to a manual reverse engineering approach. Reverse engineering activities are complex and particularly costly and, therefore, difficult to apply

extensively to all the available organisation assets. SAFE use Artificial Intelligence to support security verification activities, aiming to drastically simplify the tests performed on the equipment, both in production and during software upgrades.
The objectives of the project can be summarised in two main macro-objectives:

a. Verifying the integrity of firmware installed on a system in service, using automatic function similarity analysis; this activity makes it possible to check whether two different firmware versions originate from the same source code when this one is not available, for example, to identify whether there are different sources for the two firmware versions.

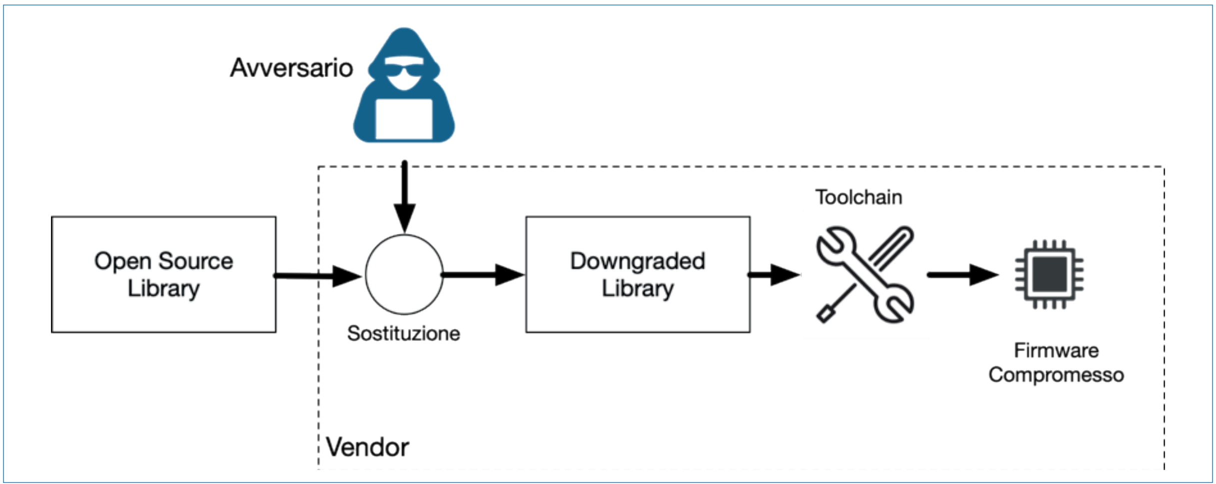
In the Picture 2 is reported the main tasks related to a compromise with insertion of malicious code:



Picture 2 - Compromise with insertion of malicious code (e.g. backdoors)

b. When you have two firmware that do not derive from the same code, for example, two successive versions of the same firmware, figure out which functionalities are in common and which are added into the new firmware (i.e. check for new functionalities if the source code is not available).

In the Picture 3 is reported the main tasks related to a vulnerability exploiting by applying a library downgrade:



Picture 3 - Vulnerability introduction applying a library downgrade.

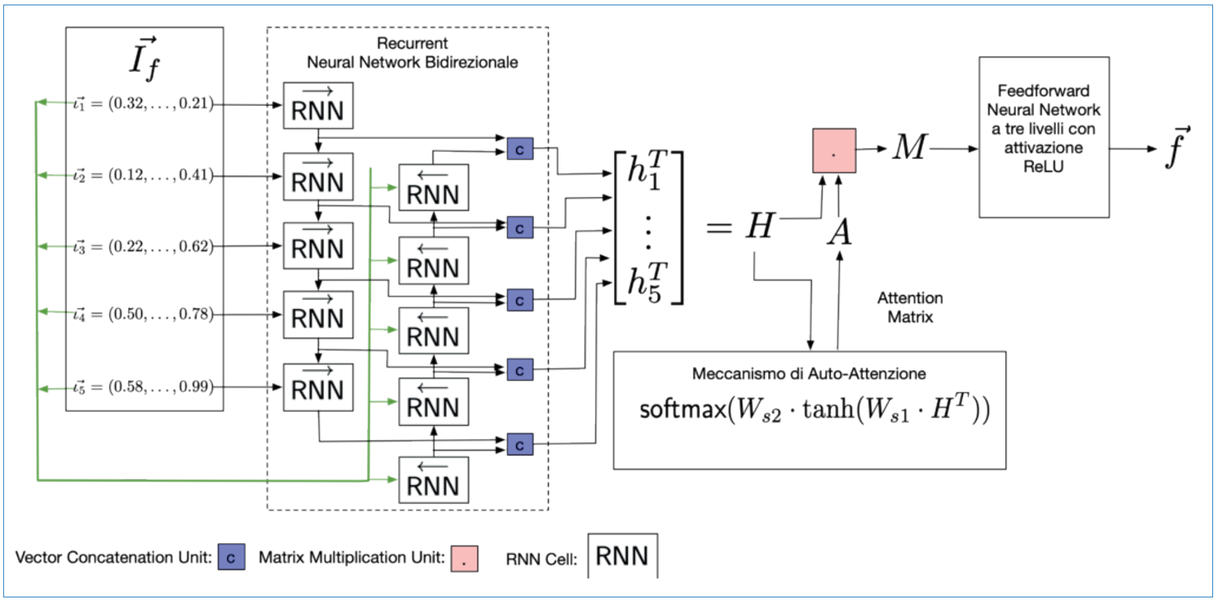
METHODOLOGY

The techniques used in this project are based on using neural networks to create 'semantic representations' of the code. These representations are numerical vectors that capture the semantic specificities of the objects analysed by the network. In the case of source or binary codes, these vectors, also known as embeddings, are close in space if the codes are similar and far apart if the codes are dissimilar. In the specific case of the project, neural networks that are self-attentive, from the English Self-Attentive, were analysed. Specifically, the proposed solution creates embeddings using a recurrent neural network (RNN).

In the following Picture 4 is represented the Safe architecture:

In this case, a sample is represented with a sequence $[X_1, X_2, \ldots, X_N]$ of elements, where each element is, in turn, represented by a feature vector. These samples naturally emerge in various fields, such as classifications of texts or sentences (a sentence is a sequence of words), audio/video (sequences of frames) and software (sequences of instructions). Usually, these sequences have different lengths: think of sentences composed of different numbers of words.

Recurrent Neural Networks are based on reusing the neural architecture for each element in the sequence (this technique is called weight sharing). The same network is applied to all the sequence elements starting from the first element. At each step, the network calculates both an output vector and a hidden state; the latter being given as input in the next step together with the next element of the sequence. From an intuitive point of view, the sequence network calculates a kind of summary in the hidden state of the sequence elements it has already seen and then uses this hidden state to define its behaviour in the next step.



Picture 4 - SAFE Architecture

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

SAFE appears as a fundamental tool for supply chain security, aimed at drastically reducing the costs of security checks by limiting the recourse to reverse engineering activities to only those few cases where an actual compromise of systems occurs.

By its very nature, the SAFE project is dual use, extensively applicable to all applications based on the reference architectures (X64, ARM 32/64bit and MIPS 32/64bit). The technology is, eventually, directly applicable to many of the devices used in critical infrastructures and IoT systems, including consumer products. The development of similar solutions for other architectures not currently included in the reference scenario of the funded project cannot be ruled out for future development.

CONCLUSIONS

The SAFE project promises to provide cybersecurity analysts with new practical tools for verifying the integrity of IT, OT and IoT systems, even in the face of rapidly evolving hardware and software technology, by enabling more efficient management of security checks during software updates frequently proposed by COTS system manufacturers.

Thus, Artificial intelligence technologies can help make firmware supply chains more secure by introducing new systematic tests to perform autonomously on controlled equipment. This tool could give rise to a class of products capable of making the systematic analysis of binary applications, particularly firmware, accessible on a large scale, maybe conducted by personnel not necessarily (over)qualified for reverse engineering activities. Reverse Engineering activities, which are generally highly demanding in terms of time resources and operator skill, may still become necessary in case of ascertained system compromise: in this case, SAFE can also help the qualified analyst speed up the identification process of the compromised functions.

Lastly, SAFE represents an excellent example of how artificial intelligence systems applied to the analysis of complex problems can support analysts in their work, enhancing their capabilities on scales that individual teams of experts cannot manage.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

IoT	Internet of Things
IT	Information Technologies
OT	Operational Technologies.
RNN	Redundant Neural Networks
COTS	Commercial off the shelf

KEYWORDS

Cyber Secyrity, IOT, OT, Firmware, RNN, SAFE, Reverse Engineering, Supply chain.

PROJECT INFORMATION

PNRM number:	a2019.195
Organization:	Direzione Armamenti Navali
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Electronic material

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iDETECT e Health Shell

iDETECT e Health Shell

The project involves the development of two technological solutions to protect military personnel from ionizing X and Gamma radiation during field operations. The first solution, called HEALTH SHELL, consists of a light, thin, and low-cost protective layer that can be easily integrated into personnel equipment or vehicles without significant weight, bulk, or energy consumption. HEALTH SHELL is designed to increase the likelihood of survival of personnel in contaminated areas and protect equipment from potential damage.

The second solution involves the prototyping of a real-time detection system for ionizing Gamma radiation in the operational area. The system consists of miniaturized sensors and mobile devices such as smartphones, which send data to an operational center in real-time. The software is designed to allow data transmission between team components in the field and the operational center. Ionizing radiation detectors are based on the technology of organic semiconductor crystals and are capable of measuring radiation detected by sensors precisely, accurately, and in a timely manner, as demonstrated by realistic field tests. In conclusion, these two technological projects represent an important step forward in protecting the health and safety of military personnel and equipment employed in potentially radiological risk areas.

INTRODUCTION

The projects are designed to provide military personnel with innovative equipment to protect against potential exposure to ionizing X and Gamma radiation in operational scenarios that can cause various types of harm, including increased risk of carcinogenesis, damage to the cardiovascular system, and acute syndromes. Currently, radiation protection available is generally characterized by high weight and thickness, limiting the dynamism of vehicles, the handling of portable devices, and wearability. The HEALTH SHELL project has identified silicone rubbers as one of the most suitable materials for producing lightweight and flexible screens capable of protecting military personnel and equipment. Among the shielding compounds tested, Barium has been particularly effective due to its high reflective power to ionizing radiation.

The iDetect project focuses on real-time detection of ionizing radiation, providing soldiers with timely information on exposure levels. The system is easily integrable into soldier equipment or vehicles such as mini UAVs or vehicles. The developed solution helps to mitigate the difficulties associated with effective countermeasures and identifying the source of emissions, effectively managing the stress resulting from exposure to ionizing radiation. In addition to military applications, the iDetect system can also be used in industrial environments at risk of radiation exposure, in the remediation of illegal dumps, or for monitoring sensitive sites such as ports and airports exposed to possible acts of terrorism. Ultimately, these two technological projects represent an important contribution to the safety and protection of military personnel and equipment used in situations potentially at risk of exposure to ionizing radiation.

TECHNICAL BACKGROUND

Ionizing radiation represents a source of danger for living organisms and artifacts, with direct effects on the operational capability of military units. Exposure to radiation can cause various

iDETECT e Health Shell

health problems, which can also manifest years after exposure. Furthermore, the same artifacts, if exposed to radiation, can suffer different damages depending on the materials they are made of. Currently, lead is the most commonly used protective material, but it presents various issues related to density, toxicity, and opacity. Health Shell is an innovative technological solution, a silanol-based rubber enriched with barium, which guarantees effective protection from ionizing radiation (Figure 1).

i-Detect is part of the doctrine model based on Network Centric Warfare (NCW), which involves connecting all operational forces to the network to share information and increase Information Superiority. In this context, it is one of the solutions that the "Soldato futuro" project, provided in the NEC Force program, could adopt to have an automatic, real-time detection capability of ionizing radiation, which may be present in the environment or released following industrial accidents or intentional acts (Figure 2).

These innovative technological solutions represent an important step forward in the protection of military personnel and in the management of risks deriving from ionizing radiation in complex and challenging operational contexts.

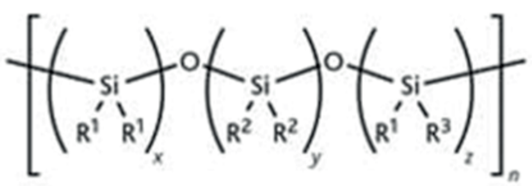

Figura 1 - Tipi di gomma utilizzati. VMQ: Vinyl-Methyl-Polysiloxane e PVMQ: Phenyl-Vinyl-Methyl-Polisiloxane.

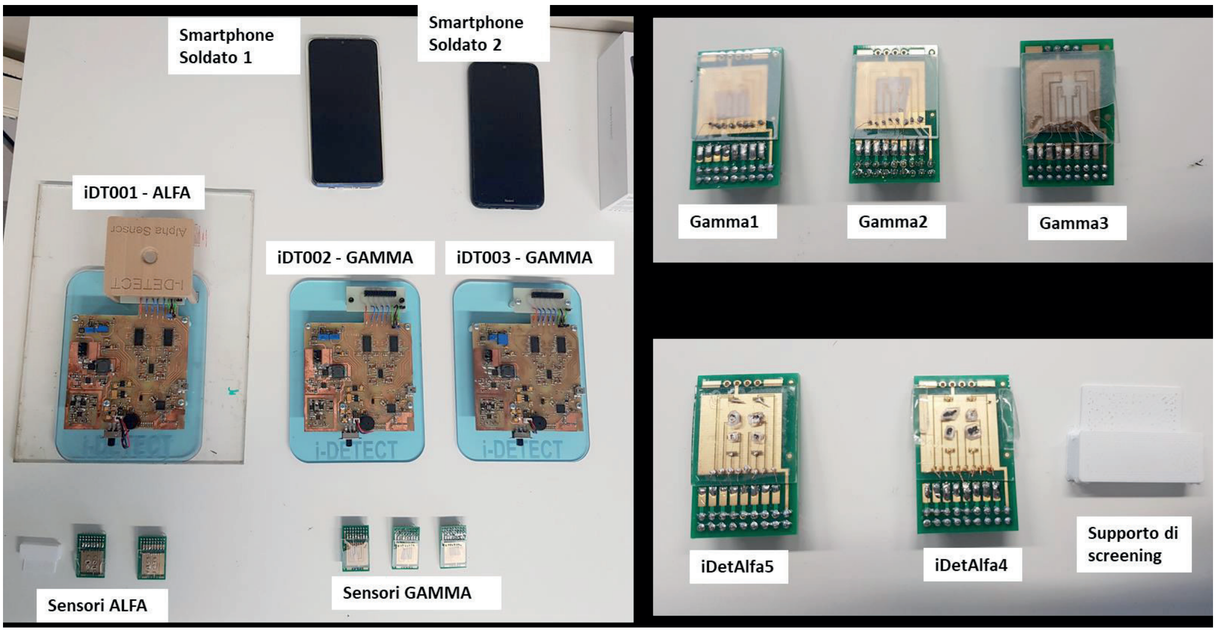

Figura 2 - Dall'alto a sn. al basso a dx: smartphone (Soldato 1 e Soldato 2); 3 elettroniche di lettura dedicate (iDT001, iDT002, iDT003) e 5 sensori (2 per alfa e 2 per gamma). Dettaglio dei sensori iDetect: 3 sensori gamma a perovskite (Gamma1, Gamma2 e Gamma3); 2 sensori alfa (iDetAlfa4 e iDetAlfa5) più il supporto di screening per le particelle alfa per la lettura differenziale.

METHODOLOGY

The process of creating Health Shell layers consists of the following phases: Mixing, Vulcanization, Post Curing, and Stabilization, graphically represented in Figure 2. At the end of the production process, raw sheets with excellent X-ray and Gamma radiation protection properties are produced, while maintaining the elasticity, flexibility, and lightweight characteristics of silicone rubber (Figure 3).

To verify the absorbing properties of the materials produced in the laboratory, a test environment specifically developed to carry out necessary checks, record measurements and ensure maximum test safety was used. The Test environment is divided into a protected area where radiation emissions are performed for dynamic tests and a controlled area, where monitoring stations for activities in the bunker and personnel equipped with dosimeters are allocated.

The shielding effect of the project was tested on silanolic sheets with different levels of Barium enrichment:

- "VMQ60Sh-WHITE" 1.8 mm thick, not optimized for X-ray absorption (reference);
- "VMQ75Sh-GREY" 2.2 mm thick, with a 50% Barium mixture of the identified solution;
- "VMQ75Sh-LIGHTGREY" 2.4 mm thick with a 100% Barium mixture of the identified solution.

Table 1 shows the radiation absorption values measured during the validation tests, while Figure 4 shows the attenuation values for ionizing radiation detected during the technical developments achieved during the project. The results show a significant shielding capacity of the created layer and a consequent reduction in ionizing radiation

iDetect, on the other hand, is a system for detecting and quantifying ionizing radiation that allows automatic communication of data to the chain of command and various levels of conduct and planning. The system can be used for both military and civilian purposes in contexts where exposure to ionizing radiation is possible, such as in the nuclear

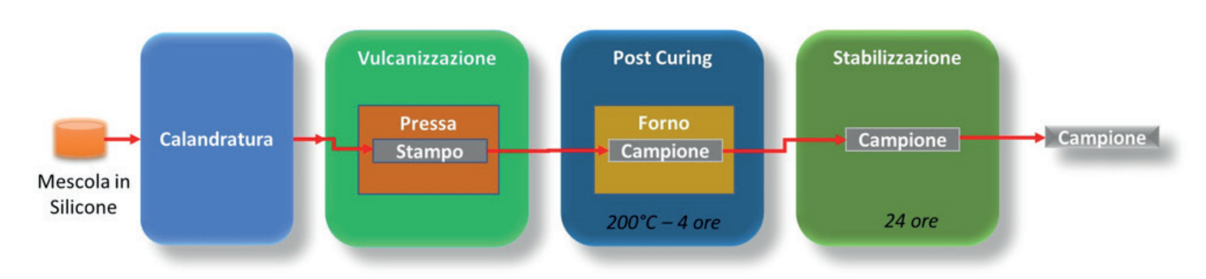

Figura 3 - Processo di realizzazione campioni "x-ray".

Energia XR (kVp) I = 500uA	Attenuazione XR (%)		
	VMQ60Sh(1.8mm)	VMQ75SH (2.2mm) Grey	VMQ75SH (2.4 mm) Light grey
40	81.5 ± 3	99.63 ± 0.01	99.55 ± 0.03
60	76.5 ± 0.1	99.23 ± 0.02	99.83 ± 0.01
80	73.6 ± 0.1	98.77 ± 0.02	99.63 ± 0.01
100	70.0 ± 1.0	97.89 ± 0.05	99.07 ± 0.02
120	66.5 ± 1.1	96.58 ± 0.13	98.39 ± 0.04
140	63.3 ± 0.9	95.67 ± 0.01	97.77 ± 0.02
150	61.1 ± 0.4	94.95 ± 0.05	97.26 ± 0.03

Tabella 1 - Calcolo dell'assorbimento dei campioni per differenti energie dell'emettitore.

industry. The laboratory-created sensors are of two types, one based on 4-hydroxycyanobenzene, for detecting X-ray and gamma radiation with energies ranging from 30 to 660 keV, while the second, based on thin films of MAPI, detects X-ray radiation with energies from 17 keV to 150 keV for thicknesses up to 1 micron. Both sensors are stable, are reproducible, have a linear response, and operate with low power consumption. The detectors are connected to a sensor control system that collects sensor readings, and a management system that receives and processes incoming data. The system was validated by exposing the sensors to various gamma photon and alpha particle sources, and demonstrated excellent detection capabilities (Figure 5).

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The HEALTH SHELL and iDETECT technologies represent innovative responses to the need for detecting and protecting against the effects of ionizing radiation. HEALTH SHELL provides effective radiation protection for military personnel and equipment, as well as in risk sectors such as aerospace and construction. Furthermore, it

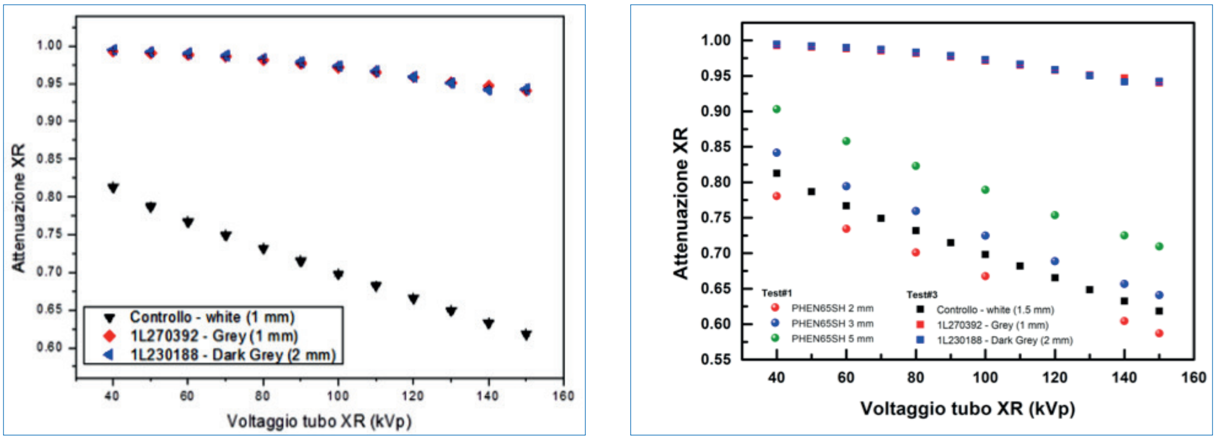

Figura 4 - Sn: Attenuazione dei raggi X a corrente costante (500 μA) al variare della tensione di accelerazione del tubo (40 – 150 kVp). L'attenuazione è riportata in percentuale, normalizzata ad 1. Dx: Confronto del potere di attenuazione XR tra le mescole testate

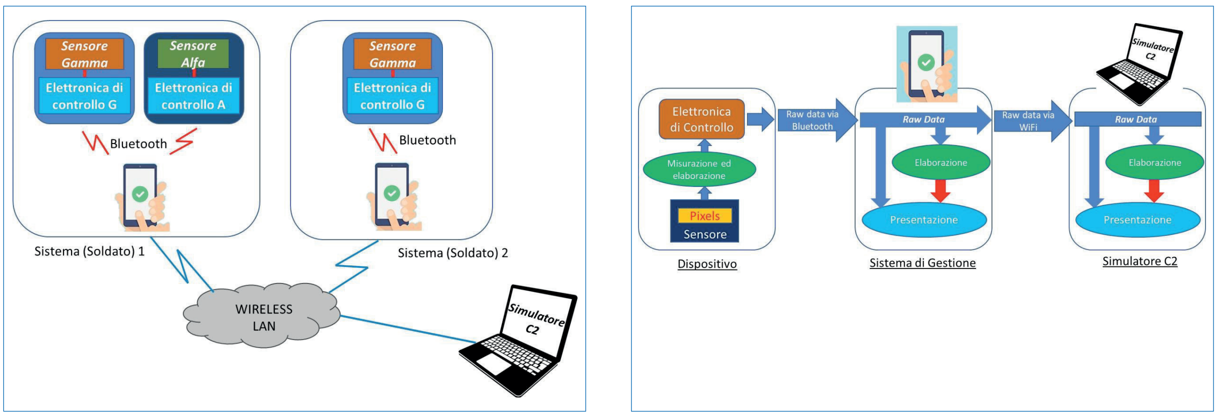

Figura 5 - Schema logico della dislocazione degli elementi del sistema sul campo (sn) e schema concettuale delle comunicazioni (dx).

has great potential for dual applications, such as detecting illegal landfills containing radioactive waste and at checkpoints in ports and airports.
On the other hand, iDETECT is a system for detecting ionizing radiation that can be integrated into the "Soldato Futuro" project and used to protect military personnel in hostile environments. iDETECT is also used in civilian applications for monitoring areas at risk of ionizing radiation. Furthermore, it has strong potential for the nuclear energy industry, where radioactive pollution and nuclear accidents require a detection and monitoring solution.
Both technologies have strong commercial implications in many military and civilian applications, including high-risk industrial sectors, such as foundry metalworking, medical radiology, and construction. In summary, HEALTH SHELL and iDETECT are advanced solutions capable of addressing the risks associated with ionizing radiation, with significant impacts on the protection of people and property, in a wide range of military and civilian applications.

CONCLUSIONS

Two solutions have been developed for protection from ionizing radiation. HEALTH SHELL shields buildings and vehicles, reduces negative effects on personnel and materials, finds applications in military and civilian contexts, and presents commercial opportunities. iDetect is a system for detecting ionizing radiation that provides real-time data and automatic communication to the chain of command, suitable for military and civilian use in risk contexts such as the nuclear industry, and also as a complement to UAV equipment. Both solutions offer increased protection for people and materials exposed to ionizing radiation, while also providing commercial application opportunities.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

eV	Electronvolt
Ci	Curie
Bq	Becquerel
VMQ	Vinyl-Methyl-Polysiloxane
PVMQ	Phenyl-Vinyl-Methyl-Polisiloxane
XR	X-Rays

KEYWORDS

Ionizing radiation detection system, sensor, Gamma rays, X-rays, radiation protection.

PROJECT INFORMATION

PNRM number:	a2018.018 and a2020.007
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Project lead:	Ing. Stefano SINIBALDI
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METEORE

Security in military telecommunications, especially satellite telecommunications, is certainly one of the strategic sectors of technological development. The PNRM METEORE project "Phase-change metamaterials for secure satellite telecomunications" (A2019.234, start: 25 August 2021) intends to contribute to this issue, placing itself within the potential interests of Defense in the development of actions and technologies for security in particular in the space sector.

METEORE has as its primary objectives the design, implementation and optimization of single-photon sources based on rare earths to be used in quantum cryptography for secure satellite or aerospace telecommunications in the near infrared or visible spectral range. For this purpose, quantum emitters (Er or Eu for example) coupled to actively reconfigurable metamaterials based on VO_2 will be used, exploiting their properties as phase-change material. This will also allow the development of *smart radiators* based on VO_2 for the active thermal management of satellite devices.

The METEORE Consortium is formed by the Research Unit of the University of Padua (UniPD) coordinated by Prof. Giovanni Mattei (Dept. of Physics and Astronomy, Principal Investigator of the Project), by the Research Unit of the University of Rome "La Sapienza" (UniRM), coordinated by Prof. Concita Sibilia (Department of Basic and Applied Sciences for Engineering), and by the Research Unit of the University of Palermo (UniPA), coordinated by Prof. Roberto Macaluso (Department of Engineering).

INTRODUCTION

Telecommunications and in particular satellite telecommunications (military and civilian) require ever greater security standards [1,2]. Quantum cryptography, based on fundamental laws of physics, has recently established itself as a new frontier for achieving levels of security not achievable with standard cryptography. For example, for Quantum Key Distribution (QKD), quantum cryptography requires the exchange of single photons in which the information is encoded for example in its polarization state. Recently the possibility of QKD has been demonstrated between satellite and ground with transmission at 850 nm. [3]

The generation of single photons for satellite-to-satellite and satellite-to-ground telecommunications requires the development of new, increasingly efficient sources that are ideally capable of producing single photons *on-demand* in different spectral regions. Moreover, while fiber or empty space transmission are more immune to photon loss and decoherence [1], to have an effective transmission through the atmosphere of coherent single photons some frequency windows are particularly suitable such as the Near-Infrared NIR (0.75 - 1.4 μm), the Short-Wavelength Infrared SWIR (1.4 - 3.0 μm) or the Long-Wavelength Infrared LWIR (8.0 - 14.0 μm).

Another typical problem of non-classical light generation and single photons is the stabilization and/or thermal insulation of the opto-electronic components used. In general, in fact, the sources currently used work at cryogenic temperatures of a few Kelvins. In satellites this problem is particularly urgent because of the high thermal difference between the phase in which the satellite is under solar illumination (which requires components that shield the radiation by removing excess heat) and the phase in which the satellite is in the Earth's shadow cone. [4] Thermal insulation could be ensured both at the circuit and at the entire satellite level.

The METEORE project therefore has as its primary objectives the design, implementation and optimization of single photon sources based on rare earths to be used in quantum cryptography for secure satellite or aerospace telecommunications in the near infrared or visible spectral range. For this purpose, quantum emitters (Er or Eu for example) coupled to actively reconfigurable metamaterials based on VO_2 will be used¬, exploiting their properties as phase change material. This will also allow the development of *smart radiators* based on VO_2 for the active thermal management of satellite devices.

STATE OF THE ART OF THE PROPOSED TECHNOLOGY

Single-photon sources are the basis of many quantum technologies and in particular for secure satellite telecommunications. The ideal source should provide a single photon, on-demand and with a defined state of polarization. [5]

The main sources are based on two main methods: nonlinear frequency conversion or spontaneous emission of individual emitters. The first is currently the technological reference, but suffers from the increasing probability of generating multiple photons as brightness increases,[6] losing its effectiveness. Therefore, single-emitter sources – single ions, color centers (such as N-V centers in diamond) or quantum dots – are becoming more investigated, as they are similar to a 2-level system intrinsically capable of emitting single photons regardless of brightness. [7] Many of these emitters work only at cryogenic temperatures and although this is less critical in space, it still requires a temperature stabilization effort in orbiting satellites. Photon-sources based on rare earth ions in oxides offer spectrally very sharp atomic transitions (usable even at non-cryogenic temperatures) and long coherence times. [8] The very long lifetimes of the radiative excited state (about 10 ms for Er at 1.5 μm) lead to very low emission efficiencies. A promising avenue is the coupling with nanostructured cavities, e.g. Si, which has led to an increase in emission efficiency of 2-3 orders of magnitude for Er to 1.5 μm, i.e. in the typical telecommunications range. [9] The design of more efficient optical resonators and the ability to externally reconfigure them with controlled variations of the Local Density of States LDOS around the emitter would allow for even higher performance. The satellites are subject to external temperature changes of -150 to + 150 ° C, but internally regulated between -10 and 50 °C. Current dynamic thermal control systems use open and closed mechanical shutters to regulate radiation. [10] A simple Al radiator keeps the internal temperature in the allowed range but only for low thermal loads (2-8 W/m^2). For higher thermal loads (150 W/m2) they require coatings with high emissivity. Current Smart Radiators use thin-film coatings on Kapton and Teflon FEP thermal blankets or Al thermal radiators [11], but significant weight, cost and integration advantages can be achieved with phase-change materials such as WO_3 or VO_2 thin films. [12]

TECHNICAL AND INNOVATIVE ASPECTS OF THE PROPOSED TECHNOLOGY

The technological solution proposed in METEORE is based on the use of solid-state phase-change materials (PCMs) such as vanadium dioxide (VO_2) coupled with quantum emitters (rare earth ions such as Er3+ or Eu3+).

VO_2 shows a reversible semiconductor-to-metal transition (SMT) from Monoclinic M1 to Rutile phases at a temperature of about 68°C that can be modified by appropriate doping (with W, Ge, …) and/or surface nanostructuring, as shown in Fig. 1 [15].

It is possible to dynamically change the optical properties of VO_2 (such as reflectivity, particularly in the IR infrared spectrum) but also the electrical and thermal conductivity, making it compatible with the stringent requirements of the space environment.

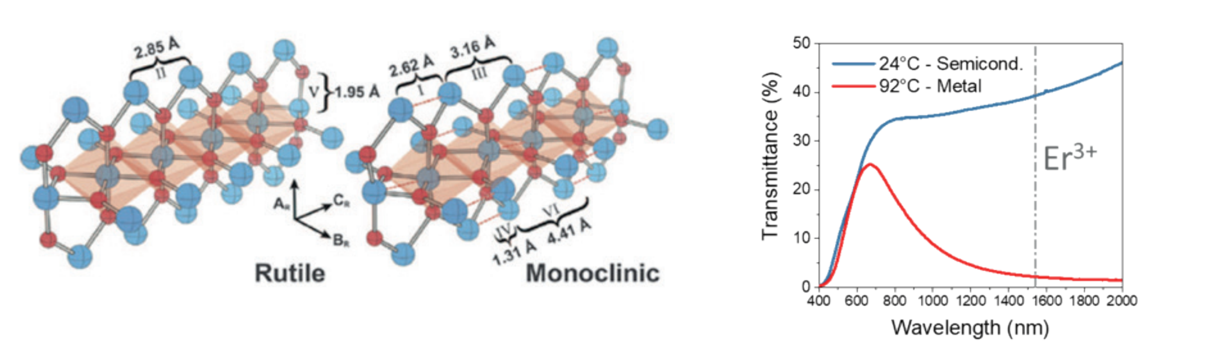

Fig. 1 - Left: The two crystallographic structures of VO2: rutile (high temperature, metallic), monoclinic (room temperature, semiconductor). Right: optical transmittance in the two phases relative to the ion Er3+, the emitter chosen in METEORE. [15]

The use of rare earth ions in dielectrics as single-photon sources is related to the nature of radiative transitions involving 4f states that, being shielded from the outermost electrons, make them very similar to ideal two-level quantum systems. However, transitions between 4f states have a low emission efficiency. The basic idea of the project is to increase the emission efficiency of single rare earth ions (Er at 1.5 μm and Eu at 0.6 μm) by coupling to photonic nanostructures with engineered LDOS. Recently our group demonstrated an almost order-of-magnitude increase at room T in the emission efficiency of Er ions in SiO2 coupled to plasmonic nanohole arrays with extraordinary optical transmission at 1.5 μm. [13] Working at cryogenic temperatures can further increase performance. [9] The most innovative aspect of the project is the use of optical resonators with reconfigurable metamaterials based on VO_2, which allow an active control on the emission of rare earth with two mechanisms: engineering of optical states and their modification exploiting the ultrafast transition induced by ps or fs pulsed laser pumping. Our group has recently shown with electrodynamic simulations how simple nanostructures in which Er ions in SiO_2 are coupled to a nanolayer of VO_2 and to ordered arrays of Au nanoantennas increase by an order of magnitude the emission efficiency and directionality upon the SMT transition to metal. [14] The innovative idea of the project is twofold: to design and implement even more effective optical resonators tested on emitter systems and then to push the study towards the single emitter located where the optical cavity offers the greatest increase in quantum efficiency. The project will demonstrate the possibility of obtaining single photon emission from a source that is less sensitive to temperature than the sources currently studied. The further degree of innovation is in thermal control made with reconfigurable metamaterials containing VO_2. By appropriately designing nanostructured metasurfaces of VO_2, a significant improvement in IR emission is obtained. The project will demonstrate how smart radiators based on nanostructured metasurfaces of VO_2 open a new avenue for energy-saving and cost-effective passive thermal control systems for spacecrafts.

METHODOLOGY

The Project is divided into 3 Phases (each lasting one year) as described below.

Phase 1 – Design and development of metamaterials (TRL 1-2)

In this (just concluded) phase, metamaterial properties (spectral absorption and reflectivity) and control of emitter LDOS (radiative lifetime reduction, Purcell effect and directivity) were performed for the design of reconfigurable nanostructured optical resonators. Thin films of VO_2 were then produced to be used as nanostructured optical resonators and for active temperature control. The SMT transition of metamaterials and the emission properties of coupled emitters were investigated and the thermal dissipation properties of metamaterials were also studied.

Phase 2 – Metamaterial optimization (TRL 2-3)

In this phase thin films of VO_2 with different dopants (W, Co or Ti, Ge) will be produced for the control of SMT temperature and the optical properties. We will then proceed to the design and synthesis of advanced metamaterials (e.g., materials with hyperbolic optical dispersion) based on VO_2 for the control of quantum emission efficiency and, in particular, to the detection of single photon emission with thermal or optical control of VO_2-based nanosystems. .

Phase 3 – Development of a demonstrator (TRL 3-4)

In the final phase, the study of the thermal stability and of the optimization of the purity of the single photon emission will be completed. This is also done through the development of technologies to integrate optical ps or fs pumping to optically induce phase transition in VO_2. Possible alternative solutions for SMT transition control with electrical potentials will be evaluated. Eventually, the metamaterials will be integrated into a laboratory demonstrator emitting single photons on-demand with external thermal shielding.

RESULTS

At the moment the results obtained by METEORE concern Phase 1 ("Design and Development of Metamaterials"). Two main objectives were achieved: (i) the demonstration of the control of the quantum emission efficiency of Er^{3+} at 1.5 microns through coupling with VO_2; (ii) the demonstration of the control of the emissivity in the IR of nanostructured thin films of VO_2.

Phase change metamaterial coupling with the emitter

The demonstration of the active control of the emission of Er^{3+} ions in SiO_2 was obtained as shown in Fig. 2 for a 135 nm thick VO2 film obtained by PVD deposition technique and near-field coupled to a 20 nm layer of Er in SiO2 (emitting at room temperature at 1540 nm) at a distance of 16 nm from the interface. In particular, Fig. 2d shows how with the layer of VO2 the lifetime of the emission is accelerated by a factor of 10 with respect to the reference τ_{ref} = 10.8 ms) in excellent agreement with the increase of the Purcell factor and the density of the optical states. This increase in quantum emission efficiency linked to the decrease in lifetime, can be actively controlled by varying the temperature of VO_2. In fact, as shown in Fig. 2d, a further acceleration of the reversible emission is measured during the phase change of VO_2 (τ_{M1} = 1.33 ms and τ_R = 0.65 ms, for the monoclinic and rutile phases, respectively), as expected from the simulation results.

The demonstration of the active and continuous control of the emitter as a function of temperature is further shown in Fig. 3. In particular, it is seen (Fig. 3a) that the emission lifetime follows the same hysteresis cycle around the temperature expected for the SMT transition (68°C) followed by both crystal structure and optical transmittance (Fig. 3b), all related to the variation of the relative fraction of the monoclinic phase (M1, semiconductor, low temperature) to the rutile phase (R, metal, high temperature) as shown in Fig. 3c.

Control of the Infrared emission

The control of the VO_2 infrared emissivity is demonstrated in Fig. 4 for samples with different thickness obtained by Pulsed Laser Deposition PLD on sapphire at 550°C as a function of the number of laser pulses (reported in Fig. 4a). As it can be seen, the different nanostructuring linked to the different thickness produces a different variation of

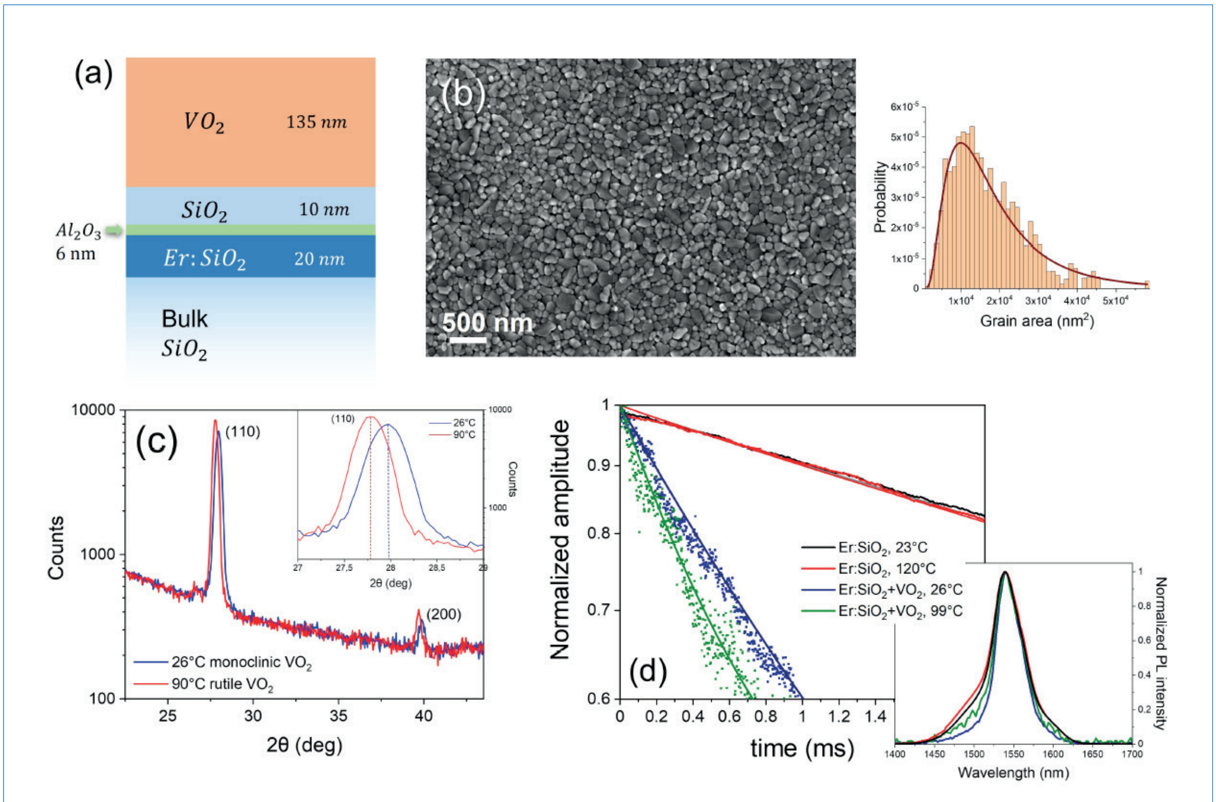

Fig. 2 - a) diagram of the structure of the sample. (b) SEM image in planar view of the surface of layer VO_2; The panel on the right shows the particle size distribution and the corresponding lognormal fit (red curve). c) GIXRD spectra of the VO_2 thin filmobtained at room temperature (26 °C) and high temperature (90 °C); the insert shows the shift of the peak of VO_2 (110) as a consequence of its phase transition from monoclinic to rutile. (d) normalised time decay curves of the Er^{3+} emission at 1540 nm (logarithmic scale) measured at low and high temperature by the $Er:SiO_2$ layer without and with the VO_2 thin film on top; Solid lines are fit to experimental data. The insert shows the Er^{3+} PL spectra at room temperature measured in the range 1400-1700 nm.

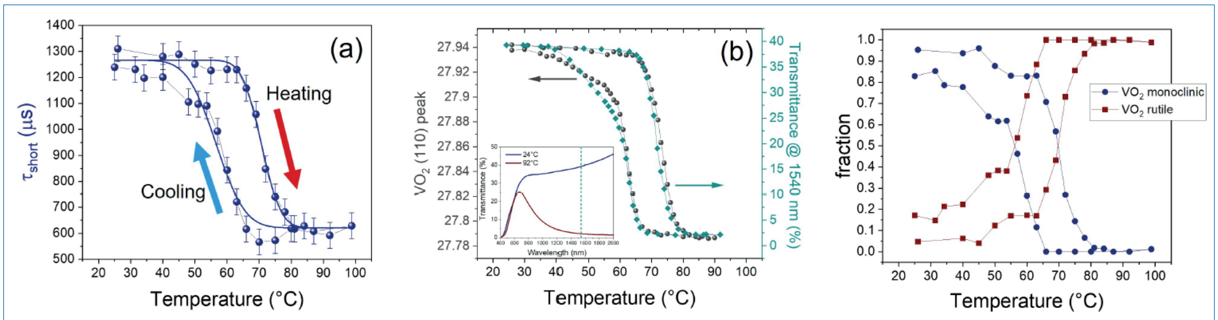

Fig. 3 - a) Evolution, as a function of temperature, of the lifetime of the emissions of the Er^{3+} ion. Solid lines are fit to experimental data. (b) Cycles of thermal hysteresis of the VO_2 (110) GIXRD peak (gray dots, left scale) and sample transmittance at 1540 nm (dark cyan dots, right scale). The insert shows the transmittance curves in the range 400-2000 nm, measured at low (24 °C) and high (92 °C) temperature; The dashed line indicates the wavelength of 1540 nm. (c) Er^{3+} ion fractions coupled with VO_2 in the monoclinic phase (fM, blue dots) or rutile phase (fR, red squares), as a function of the sample temperature.

the emissivity properties in the Long-Wavelength Infrared LWIR range (8 - 14 µm).

In particular, the emissivity exhibits cycles of hysteresis as a function of temperature that have amplitude that scale with the sample thickness, as shown in Fig. 5. Moreover, depending on the thickness of the film, the LWIR emissivity shows a sharp decrease above the SMT transition of VO2 compared to the data at room temperature.

CONCLUSIONS

Security in military telecommunications, especially satellite telecommunications, is certainly one of the strategic sectors of technological development. METEORE Project intends to contribute to this issue, placing itself within the potential interests of the Defense in the development of actions and technologies for security also in the space sector. Moreover, the results obtainable by METEORE on

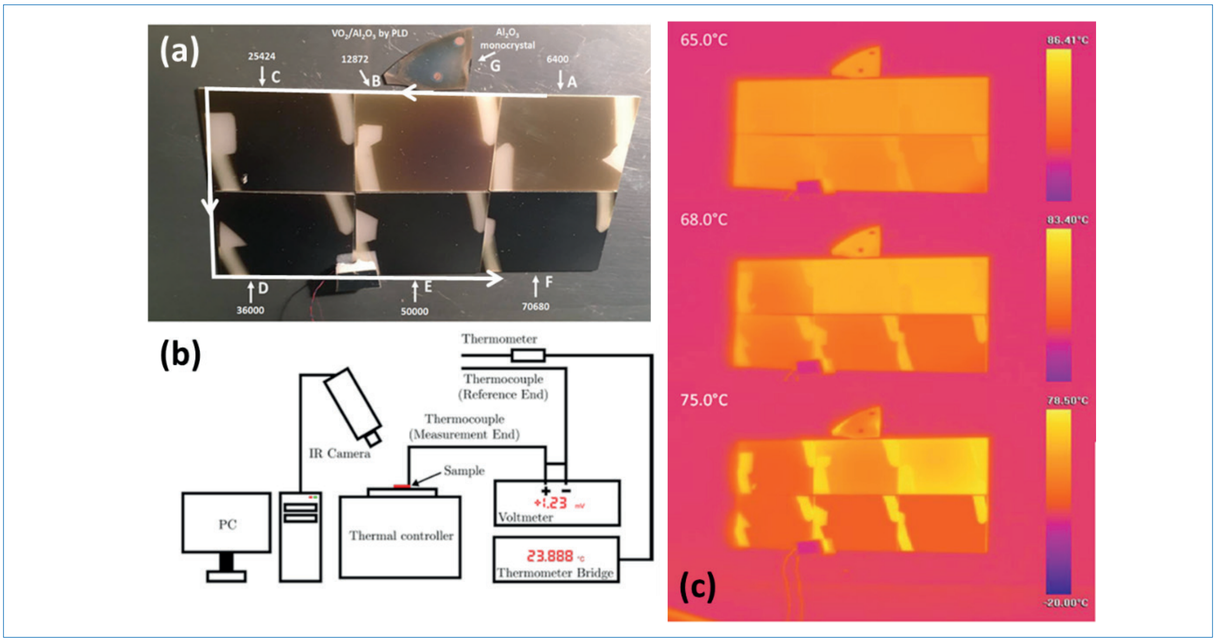

Fig. 4 - (a) photos of VO2 films produced by PLD as a function of the number of laser pulses at T=550°C; (b) diagram of the infrared thermography setup used to obtain thermographic images; (c) Thermographic image of samples A,B,C,D,E and F below and above the transition temperature (65, 68 and 75 °C) during the heating cycle. The samples shall be placed on an aluminium plate according to the same arrangement in (a). On the left the apparent temperature measured by the thermocouple. On the right the color map of the apparent temperature.

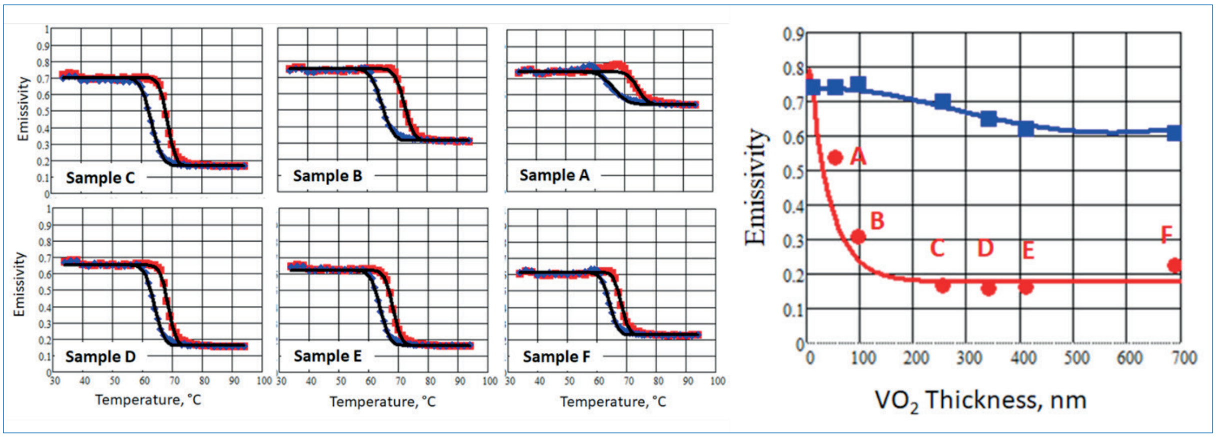

Fig. 5 - **left**: Emissivity as a function of real temperature for VO2 thin films for the samples A, B, C, D, E and F deposited on a 0.5 mm sapphire substrate by PLD at 550 °C. Emissivity is calculated by IR thermography in the LWIR range (8 - 14 µm). Red (blue) colors refer to the heating (cooling) cycle. The continuous black lines represent the fit. Right: emissivity integrated in the LWIR spectrum as a function of the thickness of the VO2 films for the monoclinic (blue) and rutile (red) phases.

the active control of thermal dissipation certainly have value even beyond the satellite systems: in fact, they can be transferred and expanded to contribute, for example, to the reduction of thermal budget problems in all those aerospace or terrestrial systems that need to work in conditions of strong thermal variations.

The development of single-photon sources and the management of thermal dissipation problems are also valuable in the civil field: the development of efficient single-photon sources in the infrared can in fact find immediate application also in technologies of interest in civil fiber telecommunications. For example, the optical fibers currently in use based on silica have a band with minimal propagation losses right in the window around 1.5 μm in which Er is already widely used. In addition, the metamaterials developed to manage thermal dissipation can immediately be transferred to the civil architectural-residential technology of smart windows, in which indoor thermal isolation can be self-limited and/or smartly adjusted with phase-change materials, contributing to a greener management, with reduced environmental impact.

As described in the methodologies section, the average TRL level of METEORE is more shifted towards basic technological development. However, the proposed methodologies are based on technologies that are easily scalable at industrial level. In addition, the objective of Phase 3 of the project is to develop a demonstrator (TRL 4) that can be produced under transferable conditions at the production level.

ACRONYMS, SYMBOLS AND ABBREVIATIONS

GIXRD	Grazing-Incidence X-Ray Diffraction
IR	Infrarosso
LDOS	Local Density of States
LWIR	Long-Wavelength Infrared
M1	Fase Monoclina della VO_2
NIR	Near-Infrared
PCM	Phase Change Materials
PLD	Pulsed Laser Deposition
QKD	Quantum Key Distribution
R	Fase Rutilo della VO_2
SMT	Semiconductor-to-Metal transition
SWIR	Short-Wavelength Infrared
TRL	Technology Readiness Level

KEYWORD

Phase change material, single photon sources, thermal control.

RECAPITI AMMINISTRATIVI DEL PROGETTO

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The project ARAMIS (Advanced Radio Access for Military Solution) assigned by the Minister of Defence (Teledife) to Italspazio in the field of PNRM (Piano Nazionale Ricerca Militare) is addressed to the finalization of a communication payload with a geostationary satellite (Athena-Fidus), inter-satellite link (ISL) and researching for interference radar payload.
It is possible thanks to the use of little satellite systems with a rapid launch strategy that can increase the capacity of the mission and complete the existing strategies resources, from a low-cost point of view.
After an initial analysis of the operational requirements, mission analyses were carried out, which allowed us to emit the requirements of the systems of each payload. As follow, was defined the specific realization of eachcomponent, and then there was the electrical and mechanical design (RF), which happened through well-known tools of planning and simulation that the company has itself, to the realization of the single components.
Between the innovative elements it is important to mention the development of the two-communication payload:

- The communication with the geostationary satellite was made through the development of an antenna in the Ka band as a deployable type of 60 cm, that is able of being located within only 1.5U CubeSat, through the chain project of up conversion and down conversion, which allows the sharing of the data modem with the ISL payload.
- The Intersatellite (ISL) communication was made through the development of a type of antenna called "bull's eye", which allows to optimize the space necessary for its positioning in and through the chain project of up-conversion and down-conversion that allows to share the use of the data modem with the communication in Ka band.

The project, development, simulation, and realization of the antenna for communication payload in the Ka band represents a significant technical and technological challenge for the company that has followed with constructive choices, to realize a deployable antenna to be contained in 1,5U CubeSat.
The "bull's eye" antenna responds to the communication requirement between satellites (ISL) and also it was able to save space inside of the CubeSat as follow in Figure 1.
The ground radar signal reception payload was designed and developed using an RF/microonde front-end that can translate, on an instantaneous 1GHz band, the spectrum from 2 to 18 GHz typically of the observation of reception radar. Associated with the

Figure 1 - Bullseye antenna

front-end it was developed a digital unity made of an A/D converter with a chip that belongs to a new generation of MpSoc having an FPGA Zynq Ultrascale highly performing and two ARM Cortex dual processor and quad-core. The company believes that the association of the RF front-end components and digital unity represents an important innovation in the development of the CubeSat as to permit to have operational flexibility that will allow it to operate in signals that have a wide range of frequency, with an instantaneous band of analysis through 1 GHz.

INTRODUCTION

As a market demand where the needing for low-cost systems and the possibility of rapid implementations is becoming more and more evident, there are already some answers to this type of question in the satellite sector, even if they are systems more inclined to strategic use, with generally not low costs, both for their creation, deployment and for their use. The ARAMIS Project belongs to this research framework, with the objective of studying, developing, implementing, and verify of some spatial technologies for the CubeSat and the realization of a little IOV/IOD mission of a Low-Cost satellite system based on some CubeSat that represents a little constellation in Low-Earth Orbit at 530 km from the Earth.

The project in its military and civil applications field aims to the creation of a CubeSat constellation for the interference research signal that can be a flexible response in both militaries, with a specific reference to the tactical needs of the Army, and for monitoring and mapping natural phenomena and also for commercial application, in the telecommunication and satellite imagine fields.

The mission analysis has demonstrated the possibility of realizing this system through three or four CubeSat 12U platforms, deployed in medium inclination orbits, ideal for the covering of regions at mid-latitudes, or sun-synchronous if global coverage is required. The sub-systems of the requirements for the maintenance of this information have been the object of a wide mission analysis that has also covered the verification of some systems inside of the laboratory, using some mock-ups (Figure 2 and 3).

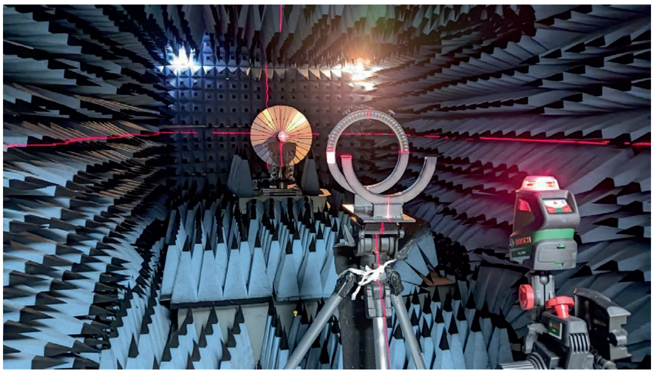

Figure 2 - Antenna test in an anechoic chamber

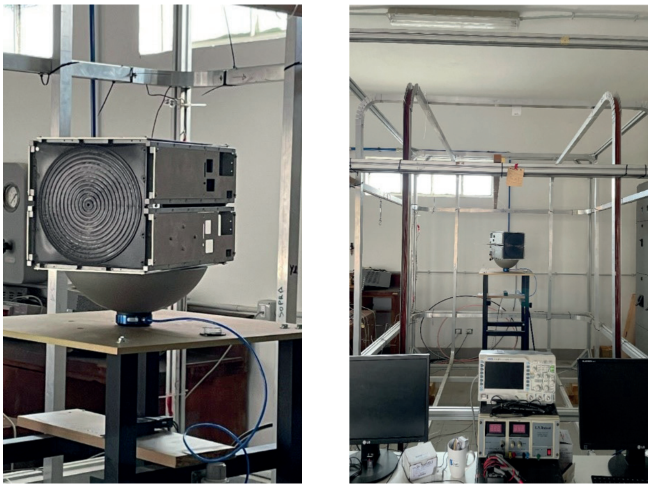

Figure 3 - Attitude test of satellite in Helmholtz chamber

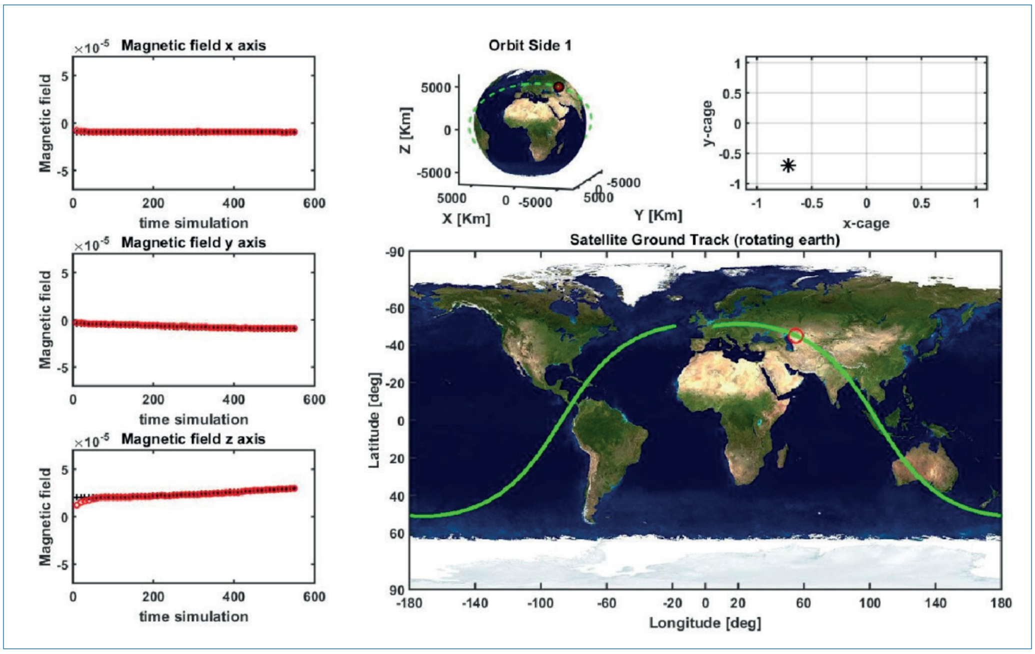

Figure 4
satellite trajectory

TECHNICAL BACKGROUND

There were identified several issues concerning the development of a satellite receiver capable of collecting ground radar emissions and the integration of the different sections of radio communications with the Geostationary satellite and between the satellites in formation (Figure 4). The major difficulties were related to the necessary miniaturization of the solutions of the various segments constituting the various payloads that integrate into the CubeSat dimension the various functional units and maintain the affability and strength required for the satellite life cycle in an adequate time for the missions to develop.

In order to establish the communication between Leo satellite and the Geostationary satellite have been taken in consideration solutions related to the use of high-gain antennas to reduce the power of the amplifiers which would also involve the massive use of energy resources and make the communication link budget feasible. The company has identified this needing and it was able to conjugate high gain with limited space of the CubeSat, developing a sophisticated and complex deployable antenna, as shown in Figure 5.

Concerning the necessity to guarantee the

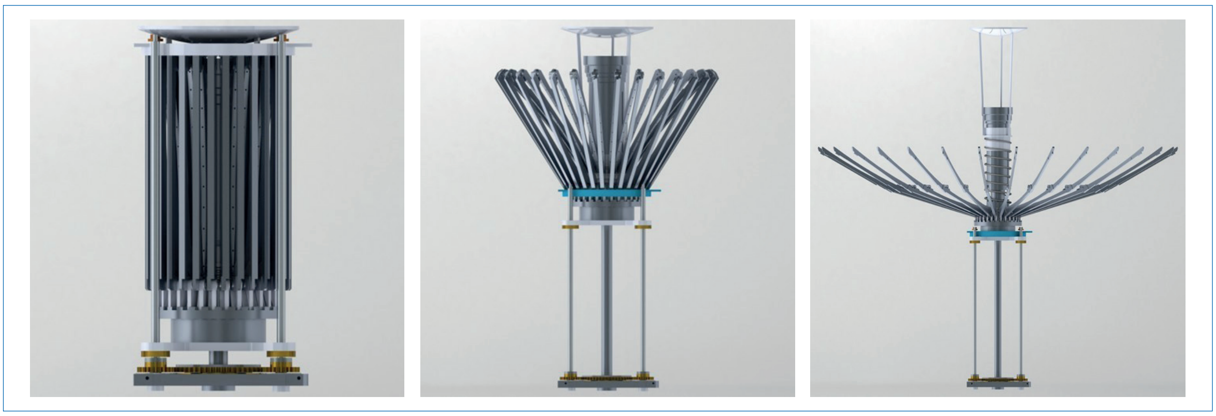

Figure 5 - Deployable Antenna Ka

communication between ISL satellites formation, it was considered the possibility to project and realize low volumetric impact antennas inside the CubeSat themselves, proposing a "bull's eye" antenna type.
The problems related to the development of the Receiving radar signals payload were related to the necessity of realizing a receiver that has simultaneously a high grade of miniaturization for the integration inside of a CubeSat and also the capacity of monitoring a wide band of frequency (2-18 GHz) with an instantaneous 1 GHz. This objective was achieved using a system with "double conversion superheterodyne" technology connected to an A/D converter with a sampling rate at 3 GSpS that is linked to a MpSoc structure, integrating at the same time the new generation of FPGA, the dual ARM processor, and the right quad-core to acquire the data with high speed from the A/D converter and to achieve a first elaboration on the gained data. The final processor collects the manipulated data and stores them in the Mass Unit and makes them available for transmission to the ground.

METHODOLOGY

As follow the scientific and technological details about the research and development of the technology.

COMMUNICATION LEO-GEO PAYLOAD

The double reflection antenna is optimized forthe Ka frequency, in the bands Rz: 20.7 – 21.2 GHz and Tx 30.7 – 31 GHz. The Cassegrain reflectors, the Gregorian reflectors, and the "splash plate" configuration have been identified as possible candidates for the realization of the antenna.
Two main constraints are derived from the need for mechanical drives. In the first place, the relationship F/D (where F is the focal length and D is the diameter of the reflector) results as determined by the necessity of reducing to the minimum the curvature of the ribs so that they fit between the sub-reflector/horn distribution mechanism and the walls of the CubeSat.
For a reflector of 58 cm, it is determined a relationship F/D of a minimum of 0,44. In the second place, the highness of the sub-reflector is directly influenced by the size of the sub-reflector and by the number of necessary mechanisms for its placement.
To constrain the deployment project of the sub-reflector only to the feed, this must be located at most 24 cm above the vertex. Among the possible resolutions, it was chosen a Cassegrain configuration to satisfy the deployment constraints. The focal length is set to the required minimum of 0,44 (F/D relation) at 25,72 cm to minimize the diameter of the sub-reflector to reduce the

Figure 6 - Deployable Ka Antenna

blocking effect. The maximum possible directivity D max (D /z) ² of the antenna of 580 cm is: 45,21 dBi at the 30,75 GHz frequency (Figure 6).

The following figures 7 and 8 represent the blocking scheme of the Up-conversion and Down conversion of the payload in the Ka band:

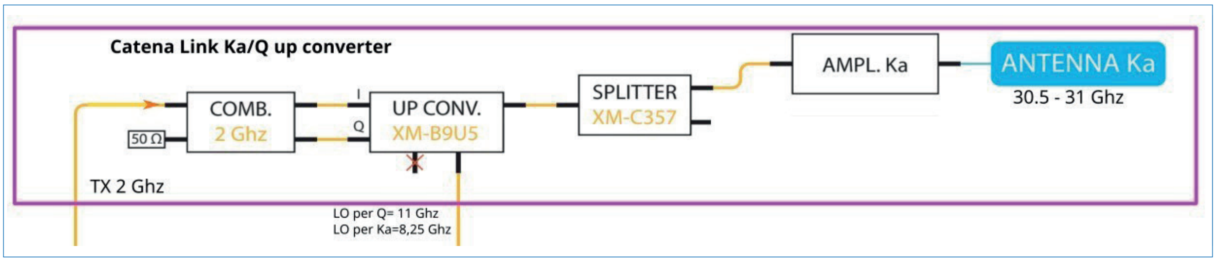

Figure 7 - Transmission line Communication LEO-GEO payload

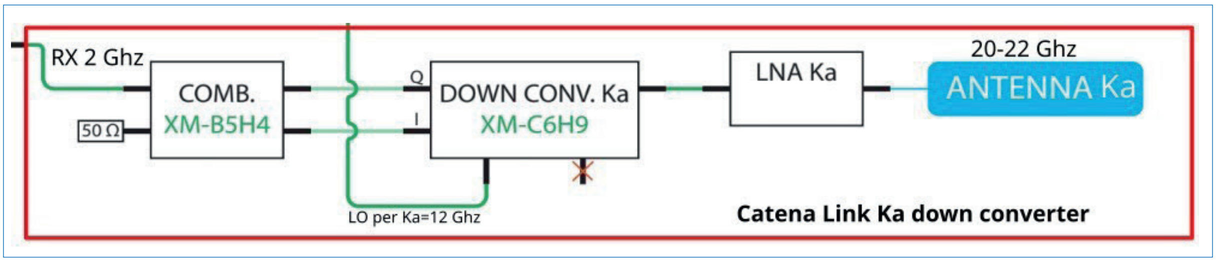

Figure 8 - Receiving line Communication LEO-GEO payload

COMMUNICATION LEO-LEO PAYLOAD

The antenna is made of a metallic plate with a small central opening that is surrounded by a periodic structure, with a "square wave" periodicity. The operational range is [41.800, 42.200] GHz which is excited by a circular guide section through a circular slot. The minimum thickness of the antenna is limited by the depth of the corrugations. The periodic corrugated structure begins at an offset distance and the currents are unaffected by reactive fields emerging from the radiating slot. Furthermore, a small offset is present at the periphery of the antenna dish to reduce the level of the side lobes. This improvement may be related to

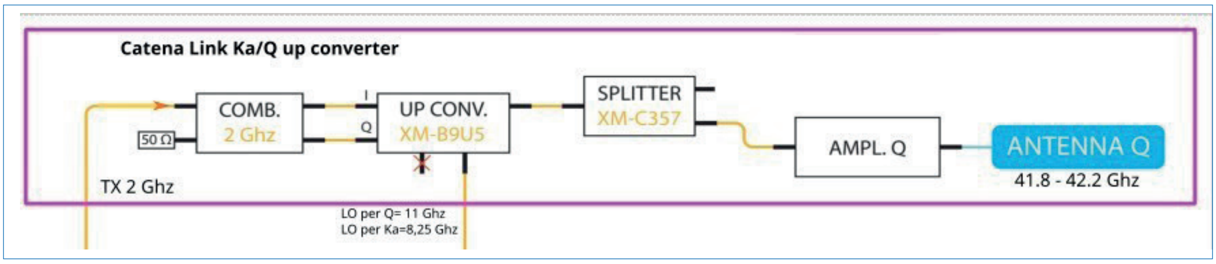

Figure 9 - Transmission line of Communication LEO-LEO payload

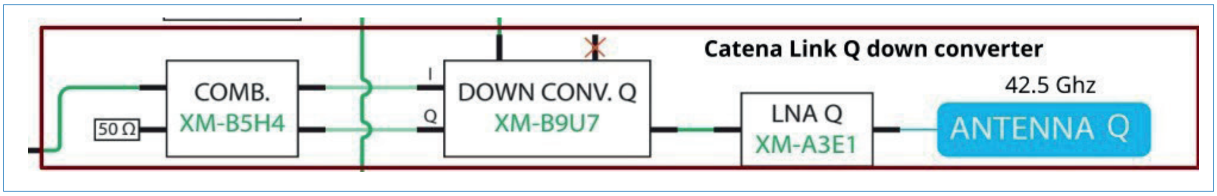

Figure 10 - Transmission of the line of Communication LEO-LEO payload

an optimization of the termination concerning the propagation of the RF signal. Broadside radiation occurs when the period of the corrugated structure is close to the wavelength; in this condition, with appropriate sizing of the corrugations, the periodic structure radiates a narrow beam by excitation of the spatial harmonic an appropriate sizing of corrugations, the periodic structure radiates a narrow beam by excitation of the spatial harmonic n= -1 (or Floquet mode). The symmetry of the structures has allowed the use of electric and magnetic planes of symmetry, obtaining the advantage of being able to work on 1/4 of it. The minimum length of the mesh elements (tetrahedra) is about 0.37 mm.

The antenna structure shows a diameter of 193.190 mm with a corrugation of 12.

Furthermore, the up and down converter conversion chains were also realized as seen in figures 9 and 10 to guarantee data communications between the satellites:

PAYLOAD FOR RECEIVING RADAR SIGNALS

The double conversion superheterodyne Microwave receiver design is characterized by the first conversion at a frequency higher than the maximum receivable frequency. It was chosen to have a first conversion IF at 29 GHz being able to have the technology of suitable microwave GaAs components, mixers, and amplifiers, to be able to manage this frequency. Figure 11 shows the miniaturized example of the double conversion receiver and Figure 12 illustrates the block diagram of the double conversion heterodyne receiver.

The second conversion brings the signal to 1 GHz in a base band that it will send to the A/D converter for the digital conversion and the following elaboration of the digital unit.

The architecture choice of the double conversion is determined by the necessity to minimize both the number and the spurious level in the band made by the mixer and to eliminate the impact of the imagined frequency that may enter in the band of the IF filter.

As it was said, this result was obtained by doing a first up-conversion of the received signal 2-18 GHz at a higher frequency, in this case, 29 GHz with BW of 1 GHz. An adequate filter guarantees the elimination of the spurious made by the proceeding of the mixer multiplication.

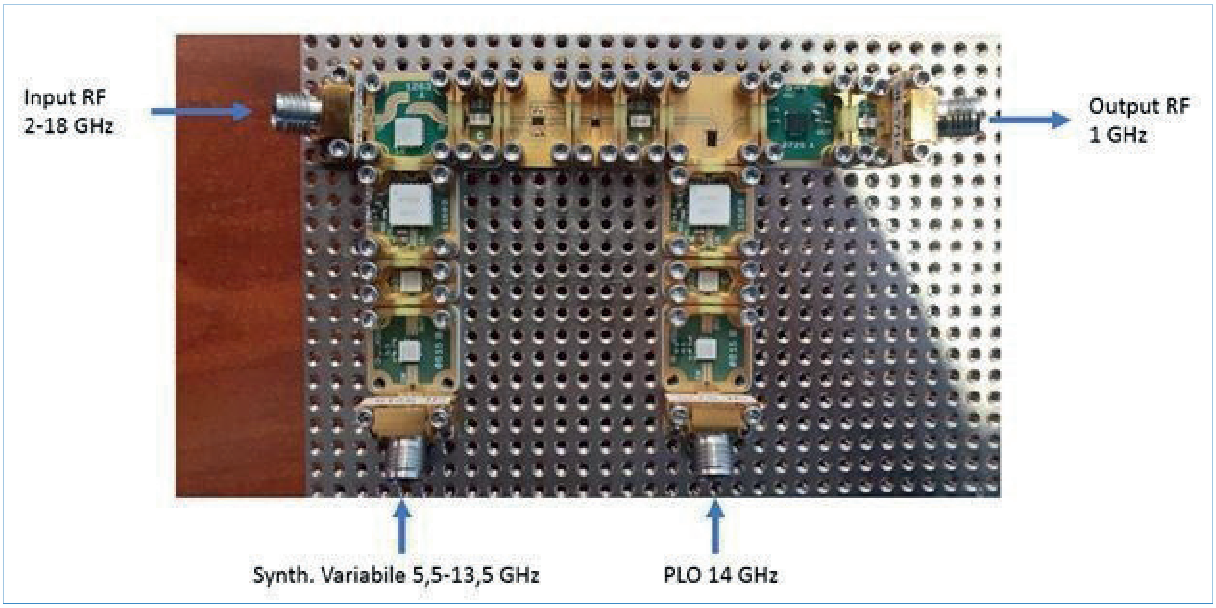

Figure 11 - Miniaturized receive payload heterodyne receiver layout

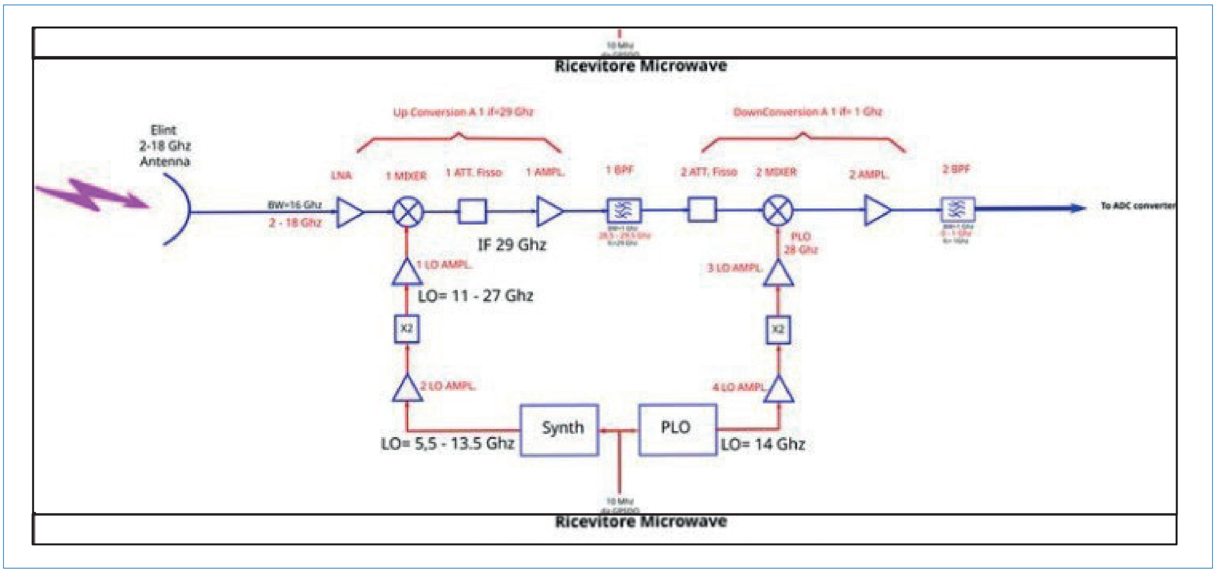

Figure 12 -Block scheme double conversion Microwave receiving

The figure above shows the schematic of the executive project of the analogic conversion section of the receiver.

To carry out this conversion, two lines of equal “Local Oscillators” have been designed having in sequence an amplifier, a multiplier x2, and another amplifier. The multiplicator x2 allows using a Synth for the first-up conversion in a range of frequency 5,5 GHz÷13,5 GHz and a PLO in a fixed frequency of 14 GHz.

The simulation of the systems shows a spurious free dynamic range (SFDR) and a linear dynamic range (LDR) of 40.2 dB and 52.6 dB respectively, a total noise figure (NF) of less than 3.2 dB, and a flat conversion gain of about 28 dB (Figure 13,14 and 15).

The section of conversion brings the radio signal that comes from the antenna 2-18 GHz in the signal base band of 1 GHz, to subsequently be converted into digital samples by the A/D converters present in the digital unit.

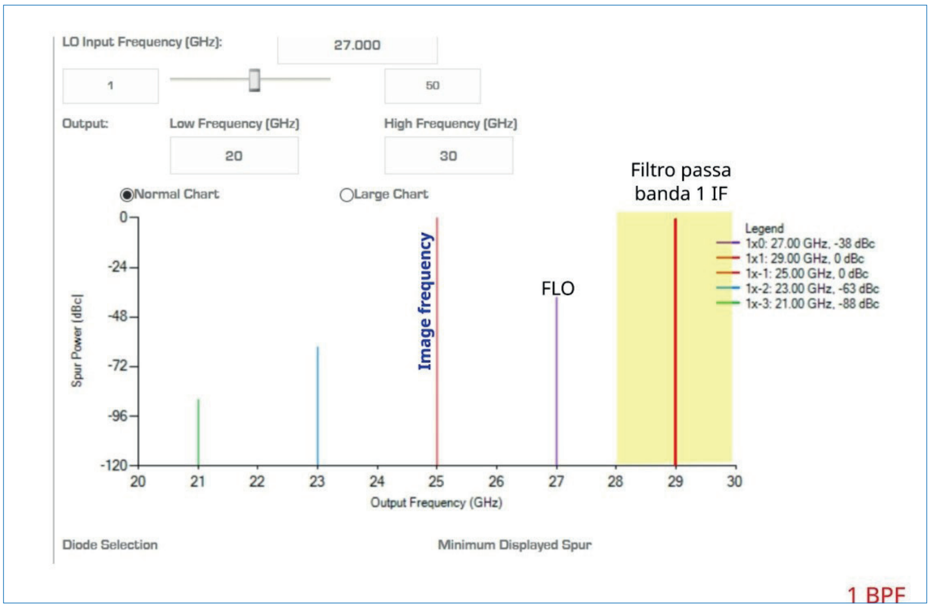

Figure 13 - Product simulation IMD first conversion

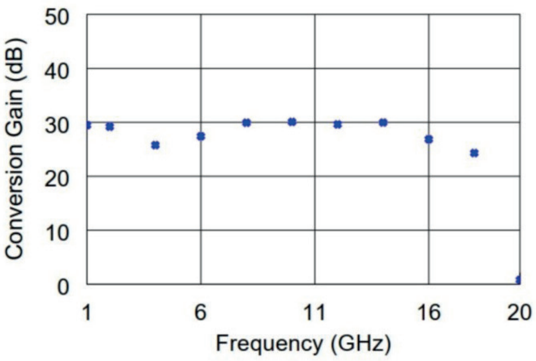

Figure 14 - Simulation Receiver gain vs frequency

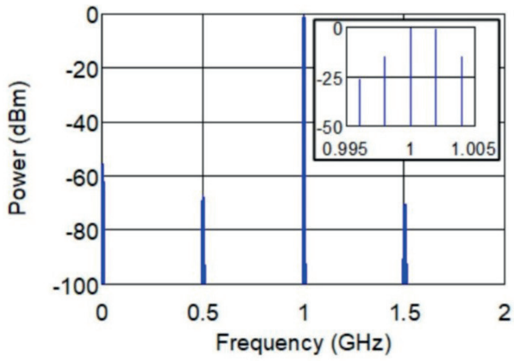

Figure 15 - Simulation products IMD second conversion

It is important to remember that the sampling frequency of the digital unit is 3 GSPS, which would therefore allow the sampling of signals up to about 1.5 GHz theoretical bandwidth.

The digital unit receives the signal in the 1 GHz band from the receiving downconverter. The digital unit has integrated the RF interface board containing the A/D converter (model A/D 9208 or equivalent); this converter together with the two DDC generates the samples to allow the algorithms present on the FPGA&Processing unit to operate correctly.

The ADC module exchanges data with the FPGA module on the FMC+ interface connector. The FPGA&Processing module is based on the FPGA chip of Xilinx of the Xilinx Zynq UltraScale+ MPSoc. This high-scale integration solution allows you to have all the necessary functions on a single board, reducing the necessary space, thanks to the new technologies based on SoC chips (MPSoC: Multiple Processor System on Chip), Xilinx's new generation UltrascaleRFSoC(MPSoC: Multiple

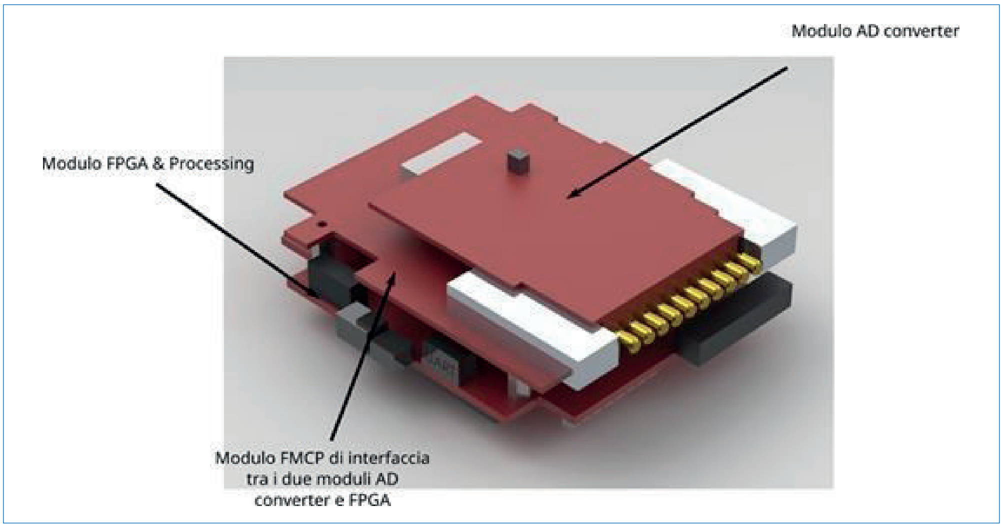

Figura 16 - Rendering 3D unit digital of the receiving payload

Processor System on Chip), RESocUltrascale of a new generation of the Xilinx. The dimensions of the digital unit it is contained in about 100 x 100 mm (Figure 16).

Figure 17 shows the overall diagram of the payload receiver:

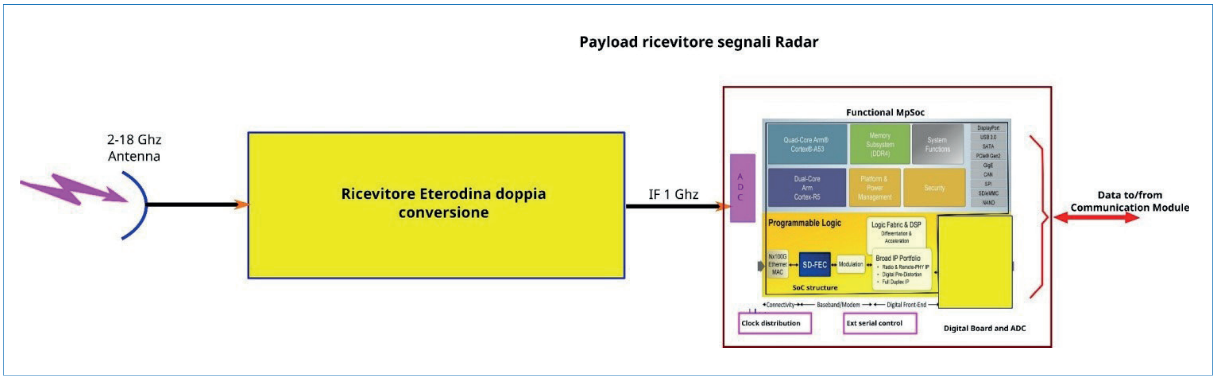

Figura 17 - Overall block diagram/theme of the radar signal reception payload

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The ARAMIS Project will allow the monitoring of wide areas of military interest through a constellation of LEO satellites of CubeSat (to 12U) proposed by onboard sensors and also provides for relaunching the data, through ISL connections, both towards the CubeSats of the future constellation in Q band and towards the ground via a UHF antenna too. These data could be widespread through the receiving stations by the CubeSat satellite proposed. The proposed service is oriented to the smallsat platform for the receiving activities for the radar signal.

The typology and the correlated functionality of the proposed system were referred to as military applications and civil applications. The using of this typology of the system in the civil field and go through the scientific sphere and commercial too; in this application, the field relates to the observation of the Earth as the monitoring, and mapping of natural phenomena such as deforestation, pollution, desertification, seismic risk, etc. And the application is commercial field as telecommunication, and satellite imaging (agriculture, fishing, aqueducts and water management, electricity networks, etc). In this specific case, the capabilities of the "Radar Signal Detection" payload embarked on the satellites of the future ARAMIS constellation can be a valid contribution to the research and localization of RF emissions interfering with civil and scientific activities in Italy, but also in other countries with which bi-or multilateral collaboration programs are in place (or to be implemented in the future).

CONCLUSIONS

During the design, development, implementation, and testing of the Engineering Models of the various payloads, Italspazio has confirmed the design choices made to create the various items of the system, having clear that the final objective would have been to proceed in phase 3 of the project to create the CubeSat satellites ready for launch. To achieve the set objective, the parts that can be confirmed in the development and implementation of the ready-to-fly system have been identified and the parts that will have to be improved precisely in the face of the work and tests carried out also having new technologies available for the miniaturization of the various functions.

In particular, the choices relating to the radar signal reception payload are confirmed, which during the tests offered the performance that was the objective of the project, for the heterodyne microwave receiver part, and the digital unit part. The choices relating to the satellite attitude control

methods and the communication methods for the data and telemetry links are also confirmed.
At the same time, the points that will have to be the object of design improvement during the next phase have been identified, such as the power/efficiency of the final power amplifiers of the LEO-LEO and LEO-GEO communications payloads and the improvement of the absorptions of the various components to which the new cooling techniques/technologies suitable for the size of the CubeSat and finally the optimization of the distribution of the local oscillators necessary for the various modules will have to be associated.

ACRONYMS, SYMBOLS AND ABBREVIATIONS

A/D	Analog to Digital Converter)
ARAMIS	Advanced Radio Access for Military Solution
ARM	Advanced RISC Machine
DDC	Digital Down Converter
F/D	F è lunghezza focale e D è il diametro del riflettore
FMC+	Fixed-mobile convergence
FPGA	Field Programmable Gate Array
GEO	Geosynchronous equatorial orbit
IMD	IntermodulationDistortion
IOV/IOD	In-Orbit Demonstration and Validation
ISL	Inter Satellite Link
LDR	Linear dynamic range
LEO	Low-Earth Orbit
MpSoc	Multiple Processor System on Chip
NF	Noise figure
PNRM	Piano Nazionale Ricerca Militare
RF	Radiofrequenza
SFDR	Spurious free dynamic range
UHF	Ultra-high frequencies
BW	Bandwidth

KEYWORD

Satellite electromagnetic spectrum monitoring.

PROJECT INFORMATION

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PBI-G12-EVO

PBI-G12-EVO

The PNRM PBI-G12-EVO offers an upgrade to the PBI-G12 family of bulletproof jackets. The project is divided into several topics from which prototypes of TRL 6 have been developed, each bringing innovations in different operational aspects, such as: overall improvement of comfort; enhanced modularity of the system; evolution of ballistic protections in terms of weight reduction and the extension of protection to new types of threats; availability of information to support logistics management. Thanks to the prototypes, the project has experimentally quantified the efficiency of the proposed innovations..

INTRODUCTION

Key elements in soldier protection and mobility are certainly among the most representative ballistic protection and agility of movement during the transportation of equipment required for the mission.

The ever-increasing demand for mobility in theatres of employment has often been associated with the demand for a reduction in the size and weight of the vest. Such reduction is from always in contrast with the elevated level of protection that the MoD guarantees to the own staff. The result of this contrast is between Armour Carrier type vests, opaquer and also equipped with protection from splinters for the entire chest, and Plate Carrier type vests, slenderer and more equipped with only the rigid antero-plates for the protection of vital organs.

In addition, the need to maintain the lifetime logistic support of vests requires effective information entry into the periodic verification phase of the vests. The project proposes sensory systems capable of monitoring the entire operational life of ballistic protections.

Employment of Armed Forces for heterogeneous tasks ranging from missions in theatres of operations abroad to urban security, requires adaptation to threats, including experimentation on actual ballistic threats in the field, potential future ballistic threats and unconventional threats such as blades, spikes and needles.

The PNRM PBI-G12-EVO then addressed all the above aspects, allowing a weight reduction at the same protected area. In addition, the project brings an increase in system ergonomics, through appropriate accessories to support mobility, an optimization of adjustment and a device for the improvement of thermal comfort.

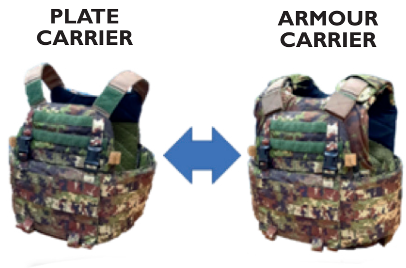
PROBLEM IDENTIFIED - TECHNOLOGICAL SOLUTIONS - METHODOLOGY

Since the aim of the project is to stand out, therefore the technological solutions, methodologies of development and testing of each of the prototypes are shown

Modular and Continuous Control System

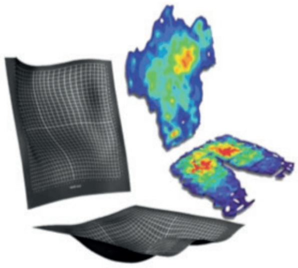
In order to increase the level of modularity of the vest has been realised a system of coupling and quick release that allows you to add to the vest in the configuration, Plate Carrier, IIIA level flexible protection elements that wrap the entire surface of the upper trunk to obtain an Armour Carrier type vest.

A system of buckles and ribbons has also been developed, which together with the emergency release system allows an adjustment of the fitting to the jacket, in particular of the vest straps already worn.



G12-Porter

It's a lumbar support system that can be attached to the vest that allows you to transfer the load of the vest and its accessories on the pelvis, rather than on the shoulders. To prove the effectiveness of this system, an innovative wearable measuring system has been developed in collaboration with the University of Pisa.



Mech Legs interface

It's a system that allows you to interface the G12-Porter system with the Mech Legs system. The Mech Legs system is a passive lower limb exoskeleton developed by MechLab, part of the PBI Consortium, within another PNRM. This system allows you to transfer the load of the jacket and its accessories directly to the ground instead of the shoulders, improving the transportability of the overall system.

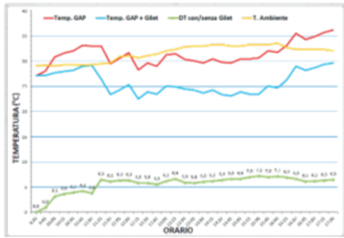
Sensors protections

It's a set of sensors for thermo mechanical shock and humidity, built into the ballistic plates and flexible protections. Such sensors are capable of recording data for more than 5 years without the need for any maintenance. The recorded data can be consulted through the use of an Android APP.

The recorded data relate to mechanical or thermal shocks that go beyond the normal conditions of use of the plates or water infiltration in the flexible protections. Measured events are potential elements that could reduce the efficiency of protection. These sensors can therefore be used effectively in the course of efficiency control activities.

Refreshing Vest

It is a lightweight vest wearable under the vest, which demonstrate that through the immersion in water, it allows you to feel cool dry, measured in a delta of 4-7 C against the ambient temperature, for the duration of 8 hours. This garment exploits the principle of thermal evaporation and with a very low logistical impact can be used numerous times obtaining an improvement in operating comfort.



Advanced protections

The theme of evolution has been addressed both from the point of view of an extension of the park of possible ballistic threats and from the point of view of weight.

From the point of view of ballistic threats, several protection plates have been developed and tested, both in stand-alone and ICW configuration, meeting different levels of protection ranging from level III and III+ to level IV+ which considers tungsten core armour-piercing projectiles.

From the point of view of weight have been tested flexible protections level IIIA and anti-splinter that, using in innovative configurations materials already reliably proven over the past years, it allows to save a few hundred grams per square meter. Ballistic plate geometries have also been tested, with a lower amount of ballistic material to be used, allowing further weight reduction. Overall, the set of potential weight reductions was applied to a PBI-G12-IT Vest, already in service demonstrating a weight reduction of 10%.

Anti-Blade Protection

Ballistic protections have been developed to integrate the anti-blade protection taking the K1 VPAM level as reference. An additional protection kit has also been developed that can be applied to vests that are already in service to obtain protection from the blade.

Computational Model of Ballistic Protection

In collaboration with the University of Cassino, a computational model of the current PBI-G12-IT vest plate has been developed. This model demonstrated a completely equivalent behaviour between ballistic simulation and results of ballistic tests at the shooting range (military facility). In this sense the model could be used in the future to predict the behaviour of evolved plates.

Potential uses and application impacts of technology

Some of the prototypes developed and built during the project have already had effective and practical application in the development of the PBI-G12-EVO jacket recently used for service. Among these innovative elements introduced in service, the adoption of the licensed system of transformation from Plate Carrier to Armour Carrier and the fleet extension of tested ballistic threats stands out. Other elements, which include the interface with the Mech Legs exoskeleton, the refreshing vest, the anti-blade kit and the sensor's plates, are potentially useful and can be the subject of experimentation and subsequent industrial engineering.

CONCLUSION

The PNRM PBI-G12-EVO addressed the evolution of the vest with a systemic and holistic approach, developing a set of evolutions that increase the effectiveness and comfort of the bulletproof vest, also providing new management methodologies that improve logistics management for the entire "life cycle". The PBI-G12-EVO vest and its accessories provide the soldier with adequate, modern, effective ballistic protection that ensures adequate mobility in highly kinetic activities. The ballistic protection considered is consistent with the field operations. The increase in the level of modularity allows to correspond, with a single product, operational needs that address the use of Armour Carrier type vests or Plate Carrier type.

ACRONYMS

PNRM	(National Military Research Plan)
TRL	(Technological Readiness Level)
ICW	(In Conjunction With)
MoD	(Ministry of Defence)
A.D.	Amministrazione Difesa

KEYWORD

Composite materials, ceramics, mobility , weight reduction ,heat exchange, ergonomics.

PBI-G12-EVO

ADMINISTRATIVE DATA OF THE PROJECT

PNRM card number:	a2018.161
Contracting Authority:	Land Armaments Directorate
Project Manager:	Consorzio PBI
City, Region:	Rome, Lazio
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zSpectrum

The project "zSpectrum" aims to investigate the feasibility of a distributed measurement system for wideband spectrum sensing and RF (radio frequency) emitters localization by means of Compressed Sensing (CS).
During the initial steps of the research program, several simulations were performed for assessing the performance of the adopted CS scheme, in terms of signal reconstruction quality and position accuracy. Then, off-the-shelf components were selected for implementing the demonstration system, consisting of four RF sensing nodes, and a command-and-control center.
An experimental campaign was conducted at the Land Armaments Territorial Technical Office of Nettuno where four transmitters working at several carrier frequencies were sensed and localized with a position error in the order of 1 m for Compression Ratios up to 10.
The obtained results demonstrated that the bandwidth limits of the systems available on the market and proposed in scientific literature due to the bottleneck of the wireless link are overcome thanks to the use of CS, which allows reducing of ten times the amount of data. The technological advancements offered by the project open the possibility to implement passive tracking systems for anti-drone and reactive jamming applications. .

INTRODUCTION

RF spectrum monitoring represents an activity of primary importance both in civil and military applications. The proliferation of wideband RF technologies and the growing demand for wireless services have led to a more and more complex electromagnetic environment. To guarantee the correct functioning of the various radio communication networks, RF spectrum monitoring becomes a very important activity. This activity is of primary importance also for guaranteeing the security of sites and infrastructures, such as airports, power plants, embassies, and so on. In this case, it is required to sense, intercept, and localize the RF emitters, with the aim of recognizing them and taking immediate counteractions. With the increase of wireless transmitters working in the GHz frequency range, especially in urban environments, the coverage of traditional RF spectrum monitoring equipment is no longer effective. Thus, distributed systems have been proposed. However, the constraints in the transmission bandwidth of the sensing nodes could limit the sampling rate and therefore the analysis bandwidth. Therefore, although the frontend of the equipment can observe a wide band, often its use is prevented by the availability of enough data rate for transmitting the acquired samples to the command-and-control center.

TECHNICAL BACKGROUND

Recently, Compressed Sensing (CS) has been proposed for reducing the data rate of Internet of Things systems for signals having a sparse representation in a specific domain, that is they can be represented by a vector of few significant elements after a mathematical transformation. Signals acquired to monitor a wide band satisfy this requirement, where the considered transformation is the Fourier transform, as RF signal are often concentrated in a narrow band while most part of the observed band is empty in a specific time.
Exploiting this concept, the aim of the project was to implement a distributed measurement system based on CS, allowing to monitor a wide RF bandwidth and simultaneously localize several

emitters working at different carrier frequencies.
One of the most used CS techniques and the simplest to be implemented in hardware for data acquisition is the Non-Uniform Sampling (NUS). A NUS-based acquisition system consists of an ADC where the samples are acquired at randomly selected sampling times taken from a uniform grid. Compared with the common uniform sampling, a reduced set of samples is acquired, thus saving storage requirements and the bandwidth for the transmission to the command-and-control center.
However, the compressed signal is not understandable as it is noise-like, and the signal recovery represents a computationally intensive task to be accomplished in the command-and-control center.
The project proposal aims at implementing a prototype of a passive sensing and localization system based on distributed wideband nodes using NUS. The system consists of four or more nodes sensing the RF spectrum simultaneously and sending the compressed data to a command-and-control center. In the command-and-control center, the signal recovery is implemented, and the sensed spectrum is shown. Moreover, for the selected carrier frequencies, the positions of the emitters are estimated.

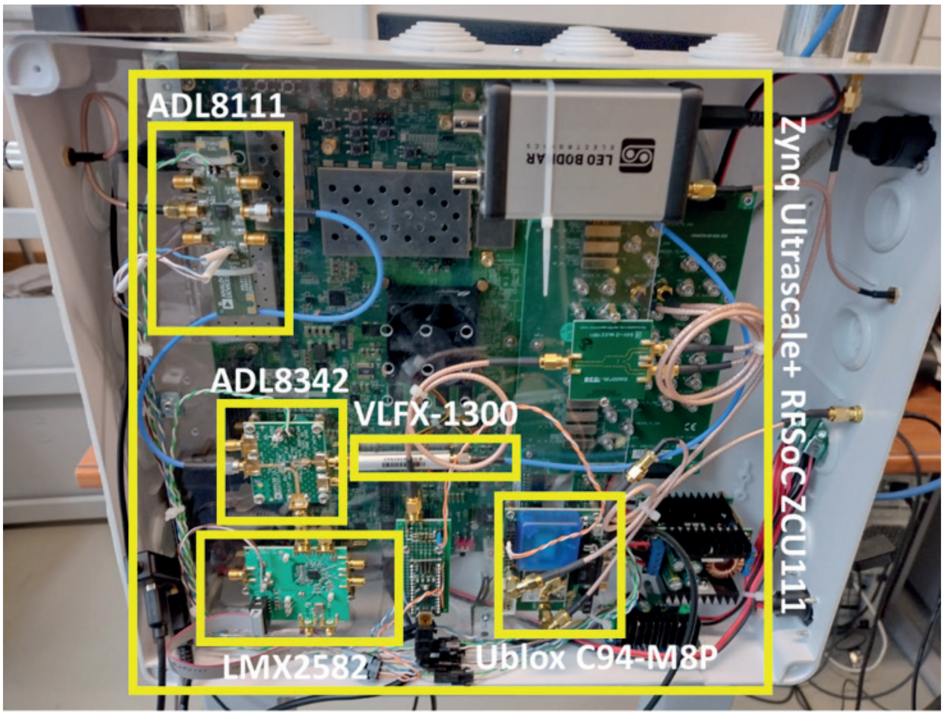

Figure 1 - photo of the node prototype.

METHODOLOGY

A picture of the developed node is reported in Fig. 1. After a frequency down-conversion, the ADC embedded in the RF System-on-Chip (RFSoC) acquires both the signal coming from the OmniLOG antenna and a synchronization signal coming from the GNSS receiver, such that a record of samples is stored when a rising edge of the synchronization signal is found. The GNSS synchronization allows all the nodes to acquire simultaneously and to evaluate the Time Difference of Arrival (TDoA). In the programmable logic of the RFSoC, the acquired samples are down converted and filtered such to fit in the specified frequency range. Then,

the samples are compressed by applying NUS in the CPU embedded in the RFSoC and sent toward the command-and-control center.
In command-and-control center, consisting of a Server, the signals are recovered from the compressed data and then the emitter positions are obtained from the TDoA measurements.
The entire system has been tested at the Land Armaments Territorial Technical Office of Nettuno. The system was configured by placing four nodes as depicted in Figure 2, while the emitters were placed in the positions labeled Tx 1, Tx 2, Tx 3, and Tx 4. The emitter was configured to transmit an On-Off Keying (OOK)-modulated signal at the bit rate of 5 Mbit/s, according to a randomly generated data sequence. In Figure 3, an example of the RF spectrums and the demodulated signals acquired by the nodes are reported. In Figure 4, the estimated position for Tx 1, Tx 2, and Tx 3 are depicted considering a Compression Ratio, CR (that is the ratio between the acquired samples and the compressed ones), of 8. A maximum position error of 1,16 m for Tx 1 was obtained against a value of 1,01 m without compression.

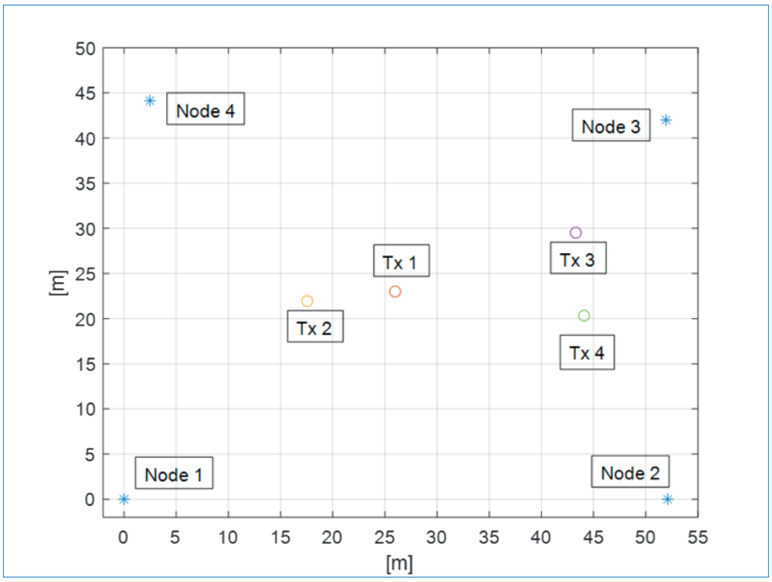

Figure 2 - configuration setup of the system during the experimental campaign.

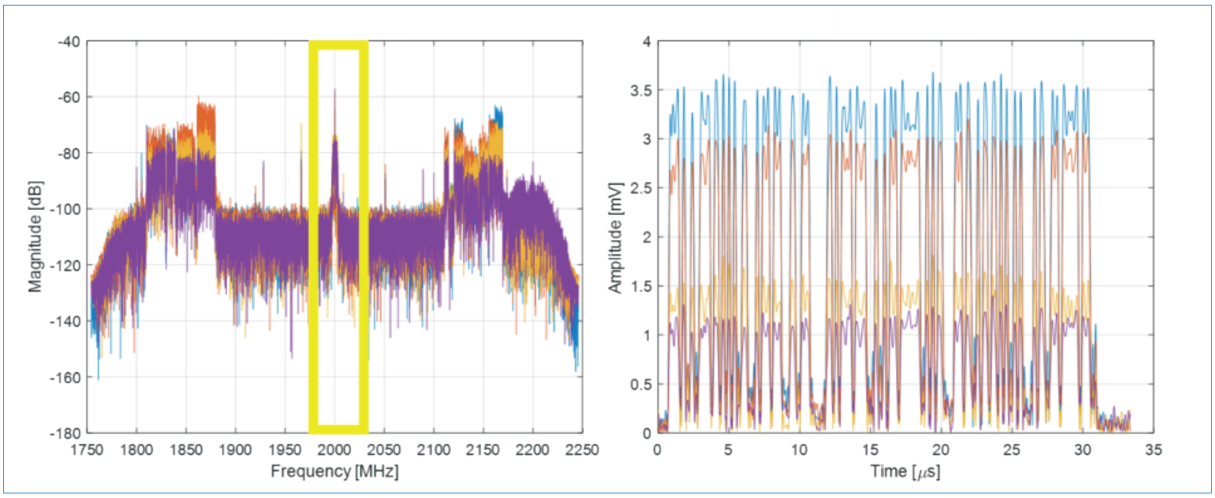

Figure 3 - RF spectrums and demodulated signals acquired by the four nodes. Highlighted in yellow the signal transmitted by the emitters in Tx 1 at 2 GHz.

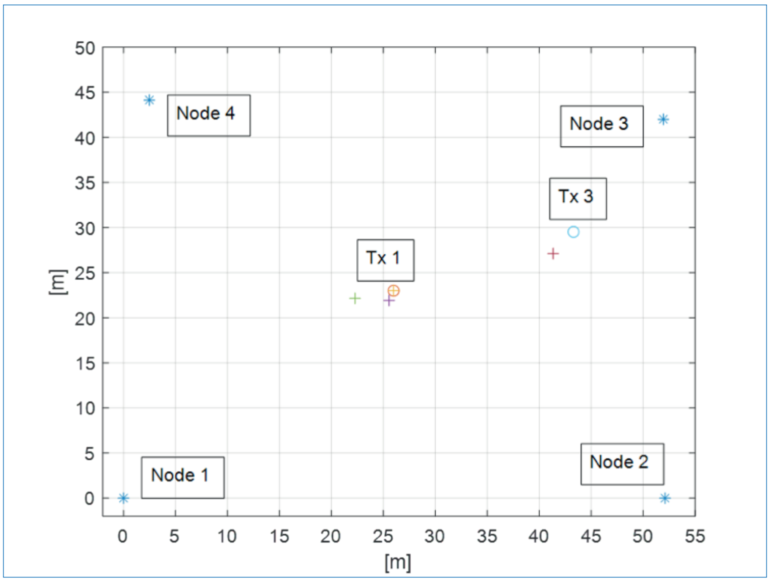

Figure 4 - results obtained from an experimental test with two RF emitters in Tx 1 and Tx 3: + estimated positions with CR = 8 and o reference positions.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The proposed system has been intended for guaranteeing the security of critical sites and infrastructures by monitoring and tracking RF emitters in a passive way. However, its use can be extended to several specific applications.

For example, beyond their civilian uses, UAVs have been used as devices for penetrating restricted areas. The proposed technology can be adopted as part of an anti-drone system for identifying and tracking UAV operations.

Furthermore, a node can be embedded in an unmanned aerial or ground autonomous vehicle to protect and monitor borders or access gates of regions or restricted areas.

Another interesting application is for search and rescue operations. In case of emergency scenarios, due to the aftermath of a natural or human disaster, the communication infrastructure may be totally or partially damaged. The proposed system can be integrated into a swarm of UAVs for identifying persons in distress or trapped under rubble.

Reactive jamming is an efficient technique where a jamming signal at a specific bandwidth is transmitted only when an emitter is detected. A node of the proposed system can be used for analyzing a high RF bandwidth in real time, thus providing prompt feedback for jamming.

CONCLUSIONS

The project zSpectrum was concluded in 2022. As result, a demonstrator of the system was developed, and its performance was assessed with an experimental campaign performed at the Land Armaments Territorial Technical Office of Nettuno. The obtained results demonstrated that the system could monitor a maximum bandwidth of 800 MHz within a frequency range of [600 MHz, 3.4 GHz] at a minimum refresh rate of 100 ms. Furthermore, with a CR up to 10, the obtained position error is in the order of 1 m.

Further work can be focused on increasing the bandwidth of analysis, using the other ADCs embedded on the RFSOC board, and reducing the refresh rate by implementing the compression on the FPGA instead of the CPU. Since the obtained position accuracy is mainly affected by the time precision of the adopted GNSS receiver (i.e., exhibiting a standard deviation of 10 ns), it can be improved by considering a GNSS having a better precision. Moreover, the node prototype could be optimized from the energy consumption point of view with the aim of reducing the battery size.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

RF	Radio Frequency
CS	Compressive Sampling
CR	Compression Ratio
NUS	Non-Uniform Sampling
ADC	Analog-to-Digital Converter
GNSS	Global Positioning System
RFSOC	Radio Frequency System-on-Chip
CPU	Central Processing Unit
TDOA	Time Difference of Arrival
OOK	On-Off Keying
UAV	Unmanned Aerial Vehicle
FPGA	Field Programmable Gate Array

KEYWORDS

Wideband Spectrum Sensing, RF localization, Compressed Sampling, Distributed measurement system, TDOA measurement.

PROJECT INFORMATION

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HEPROSYS

The general aim of the research project "HEPROSYS - HERP Electromagnetic Protection System" is to define and develop possible devices to mitigate the exposure in electromagnetic fields of an operator on board military vehicles.
Thanks to the synergistic collaboration between LARIMART S.p.A., SAPIENZA UNIVERSITA' DI ROMA and CE.POLI.SPE. (multipurpose testing centre). PHASE 1 of the research project is focused on the understanding and characterization of the electromagnetic scenario present on a VBM 8x8 "Freccia".
The investigation has identified values of on-board SAR (Specific Absorption Rate) and Electric Field. At the same time, possible hardware solutions have been proposed and implemented to reduce electromagnetic exposure and related risks for on-board operators.
In summary, PHASE 1 led to the detailed definition of the problems related to exposure in electromagnetic fields by personnel on military vehicular platforms. The activities also included the development of solutions that could contribute to the mitigation of exposure. The collaboration between industry (LARIMART S.p.A.), the academic structure (Sapienza) and the Armed Force (CE.POLI.SPE.) has led to the publication of a scientific paper entitled "Numerical Evaluation of Human Body Near Field Exposure to a Vehicular Antenna for Military Applications".

INTRODUCTION

Electromagnetic waves interact with organic matter, but the harmfulness of this interaction to humans is not well known and is currently being investigated. There are a number of studies and regulations on this, but they are often not recent publications that do not consider current technological developments.
Indeed, this evolution has been much faster than it has been possible to study and understand the short- and long-term effects of human exposure to electromagnetic fields. Assuming, however, that it is appropriate to limit exposure to electromagnetic fields, particularly for fields of considerable importance, namely high-power electromagnetic fields, it is therefore necessary to investigate the aspects concerning the possible danger of human exposure to electromagnetic fields in the operating contexts on board the vehicle and to determine and/or identify the threshold values or those values for which human exposure can be considered safe. In particular, in HEPROSYS PNRM, during PHASE 1, possible solutions to contain the harmful effects and protect the health of the crew who may be operating in very "polluted" electro-magnetic contexts have been analysed and defined.
Studies have revealed the concrete opportunity to use innovative and wearable screening solutions, able to reduce exposure to electromagnetic fields and with which you will have the opportunity to protect the health of the operator from short and long-term effects.

TECHNICAL BACKGROUND

The study of Phase 1 defined the level of exposure to an operator when wearing a protective helmet (Helmet CI-9/89 EVO already supplied by the Armed Forces) and where such an operator is placed in the proximity of electromagnetic sources on board vehicular platforms. The exposure was evaluated on the measurement campaigns carried out by the Armed Force, both on the basis of theoretical studies and numerical simulations. In particular:

- the exposure level found in the different electromagnetic scenarios has been evaluated;

- the exposure level has been quantified with accurate dosimetric simulations;
- suitable devices for the protection of personnel and for the mitigation of exposure levels have been identified;
- TRL4 level demonstrators have been designed and manufactured.

The results that emerged from the numerical simulations, performed in the HF band, demonstrates that the helmet is not sensitive to perturbations in the distributions of Electric Field and SAR when the operator is wearing it. In particular, the simulated values of Electric Field and SAR are always far below the limits required by regulations. However, the effect of the integration of shielding material into the helmet has been evaluated and a demonstrator has been created as required by the PNRM. Numerical simulations

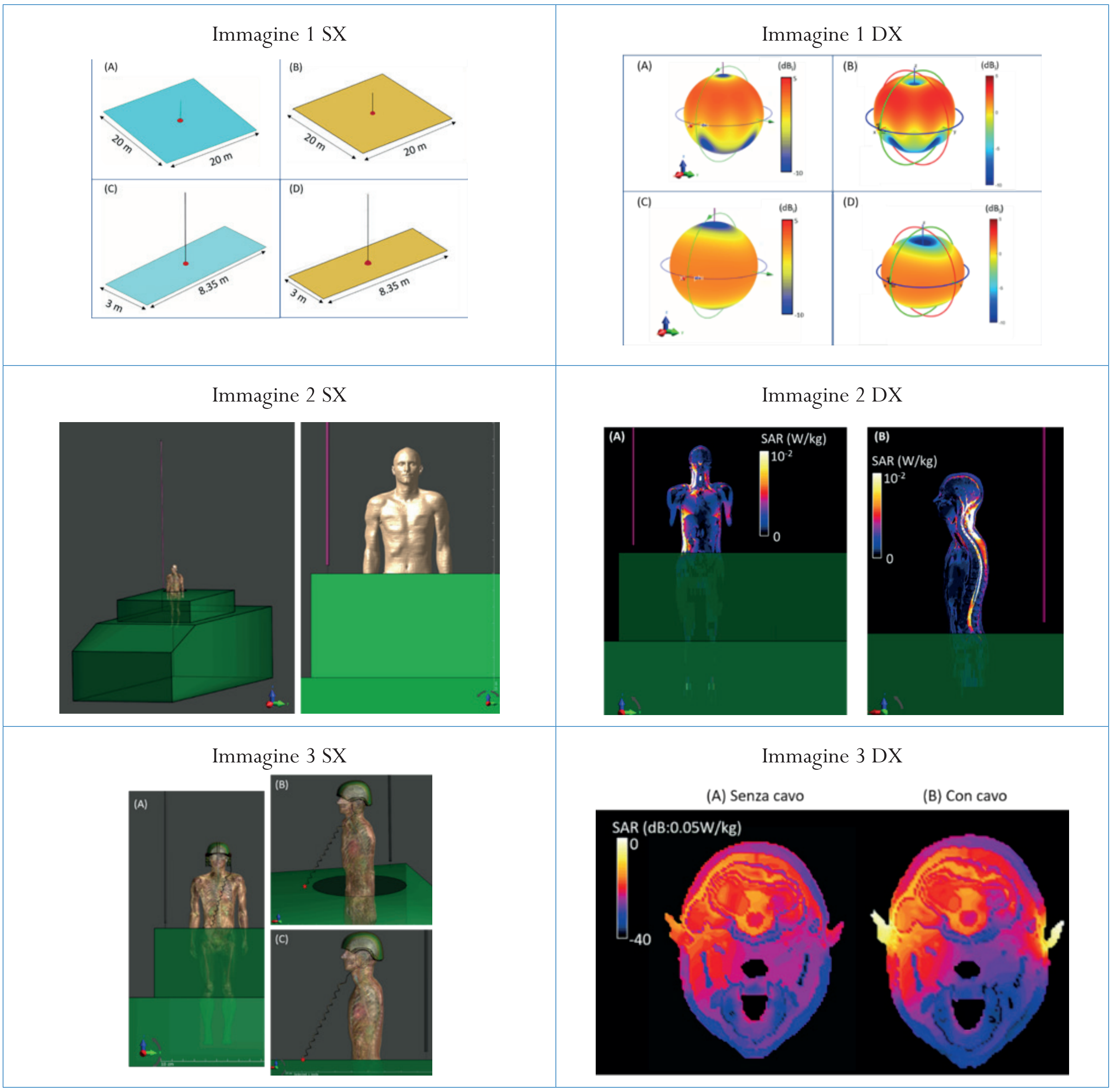

Figure 1 - Image 1 SX: Antenna model verification by Sim4Life (FDTD) comparison and Antenna toolbox, Matlab (mom); Image 1 DX: Three-dimensional radiation diagram (Directivity); Image 2 SX: Computational model of the vehicle with monopole and virtual model of man inserted inside the hatch; Image 2 DX: Distribution of the electric field inducted in the virtual model Duke; Image 3 SX: Model of vehicle and man inserted inside the hatch, with the addition of the protective helmet and the connection cable to the intercom system; Image 3 DX: SAR map on the XY plane through the nape

confirmed the shielding effect of the input material. Finally, the possibility of connecting the helmet and its intercom audio headphone via optical fibre has been evaluated and developed, eliminating any coupling effect of the connecting cable with respect to the electromagnetic scenario. In addition, for the last case a demonstrator was designed and built.

METHODOLOGY

The methodology applied during PHFASE 1, concerned in the first instance the study of the electromagnetic reference scenario in the HF band in order to identify possible exposure conditions that could be dangerous for the operator. It then identified and analysed the setup of the electromagnetic sources of a vehicle "VBM 8x8 Arrow" reference to understand the possible distribution of the electromagnetic field in the vicinity of the "operator in the trapdoor". The theoretical study was supported by an intensive set of dosimetric simulations to evaluate SAR and Electric Field. We proceeded step by step, starting from a simplified model (only transmitting antenna) to a more realistic operating scenario (a vehicle plus human model) as shown in Figure 1.
Once the reference scenario was identified, after having found in detail the value of the SAR and the distribution of the Electric Field, it was passed to the design phase and then to the realization of laboratory demonstrators aimed at protecting the operator from exposure to electromagnetic fields. In particular, two demonstrators have been realized:

1. Screened Helmet: we started from the current architecture of the Helmet 9/89 EVO (hereafter helmet) supplied by the Armed Force and, after careful study and selection of screening material in the bands of interest, the demonstrator shown in Figure 2 has been achieved. The helmet architecture has been numerically simulated to validate the aspects of further lowering of the SAR. It has been shown that the shielding solution allows further lowering of exposure levels to the electromagnetic field thus ensuring significant protection to the operator.

Figure 2 - Laboratory Demonstrator of Screened Helmet

2. Optical Audio Link: an optical connection of the helmet to the UIS-379/D intercom system has been developed. To eliminate any possible coupling between the typical electromagnetic field of the reference scenario and the connecting cable that can be located, in particular operating conditions (for example man out of hatch Figure 3), in the vicinity of electromagnetic sources.

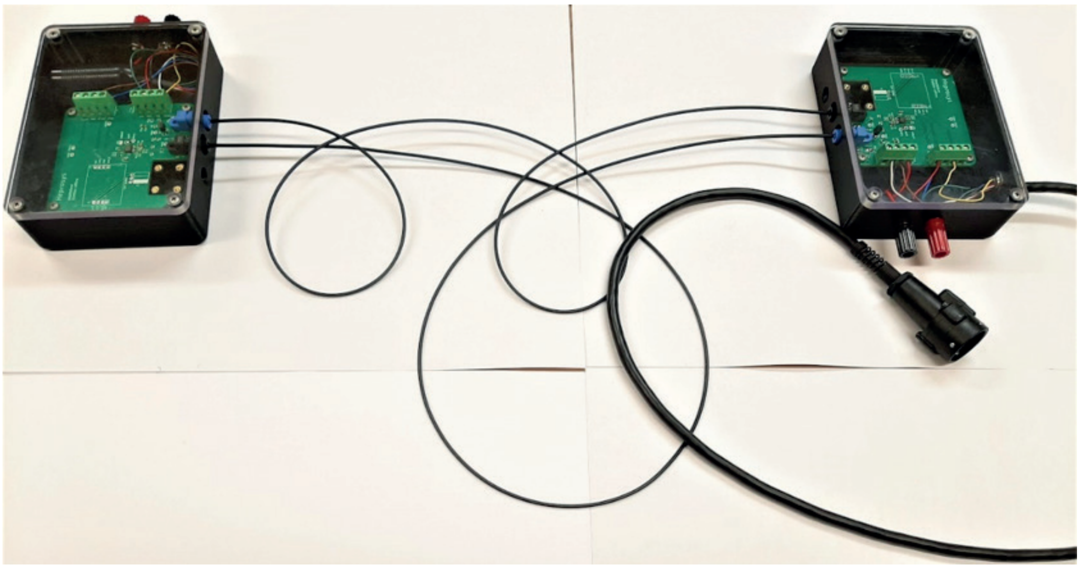

Figure 3 - Demonstrator of the optical link between the helmet and intercom system

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATIONS

The current market analysis in the military sector of products/accessories/devices related to protection from exposure to electromagnetic fields of the soldier on a vehicle operating in high intensity scenarios, shows a growing trend in demand, wich that does not find adequate response . The technological implications of the PNRM are therefore related to the possibility of having a solution (after the necessary subsequent engineering and industrialization of the pre-prototype system available at the end of Phase 2), which is potentially able to guarantee an attractive competitive position in relation to the big players in the sector and to find broad space both in the reference market and, in the perspective of duality, in the civil/professional market. The research program HEPROSYS is included in the corporate strategy of Larimart S.p.A, along with of solutions identified with respect to the civil market, which are progressively sensitive to the issues of electromagnetic pollution in everyday life.

CONCLUSIONS

The enormous evolution of communications which has characterised the last thirty years in the civilian market has contributed to an equivalent development in the military field. Communications development supported the ongoing shared concept that information supremacy is one of the most important keys to conflict resolution. The availability and diffusion of large amounts of data has led to the proliferation of radio processing and communication systems at all levels.

All this has contributed to the creation of a cybernetic space in which a huge amount of data is continuously spread and processed, thus creating an environment heavily imbued with radio waves that generate the real phenomenon of electromagnetic pollution.

The HEPROSYS PNRM aims to reproduce and analyse the electromagnetic scenario within a digitalized military vehicle in specific operational scenarios, in order to develop effective technological solutions to mitigate the exposure of the operators on board.

ACRONYMS, SYMBOLS AND ABBREVIATIONS

A.D.	Amministrazione Difesa
HERP	Hazards of Electromagnetic radiation to personnel
SIC	Sistema individuale per il combattimento
NEC	Network Enabled Capabilities
VBM	Veicolo blindato medio

KEYWORD

HERP, protection, Soldier, radio frequency , EMI, EMC, vetronics, CIS

PROJECT INFORMATION

PNRM Number:	a.2018.171
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The need to improve the efficiency of aircraft maintenance personnel training and field maintenance support activities, while ensuring a high level of quality, is perceived in both the military and commercial aircraft sectors. The data recently collected by the 10th RMV of Galatina show an extension of the period necessary for the training of the technical personnel due to the difficulty of reconciling the classroom phases with the practical phases on the aircraft. With regard to maintenance and logistics support, the need is therefore to make maintenance processes more efficient by reducing intervention times, minimizing the movement of expert resources and automatically and securely recording information relating to interventions.
The proposed technological solution involves the use of innovative technologies in continuous evolution: Virtual, augmented and immersive reality, Analytics and Blockchain (see conclusions). and is structured as follows: PRACTICAL MAINTENANCE TRAINING (Fig. 1). The solution represents a substantial evolution of today's Virtual Maintenance Trainers (desktop-based) as, starting from the same data (technical publications, CAD models, etc.) and from the same functional simulation of the aircraft, it introduces immersive virtual reality technologies (eg. HTC Vive viewer, graphics engine) and haptic devices (e.g. gloves), generating an effective and easy-to-use completely virtual and immersive training environment with which the user interacts in a realistic and natural way. Thanks to this solution, which is part of the practical training phase, the student, virtually inserted in the maintenance environment (hangar), is guided in the step-by-step execution of the maintenance procedures, possibly with the support, even remote, of an instructor sharing the same virtual environment. All the activities performed by the student are tracked and evaluated automatically by the system with the possibility of modifying the evaluation by the instructor.

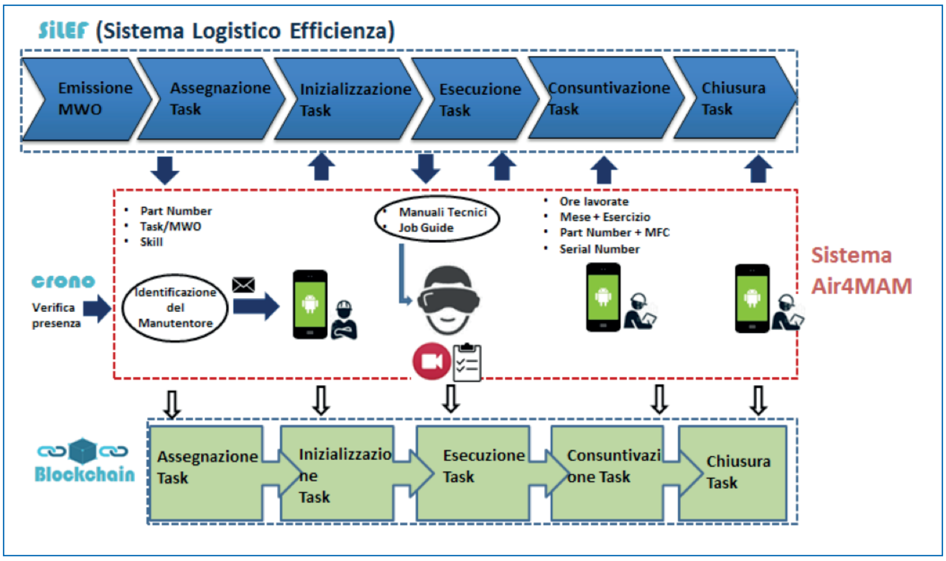

Figure 1

REMOTE MAINTENANCE (Fig. 2). In the face of a maintenance intervention, on the basis of diversified information, the system proposes the most suitable management model, which can provide for remote support from a more expert technician and/or the intervention of a outside firm. Technicians can be alerted through mobile devices. The technician working on the aircraft uses an augmented reality viewer (e.g. Hololens) to obtain contextual information (e.g. scheduled maintenance cycle, suggestions on causes of failure, component details, spare parts availability, video recordings, etc.).

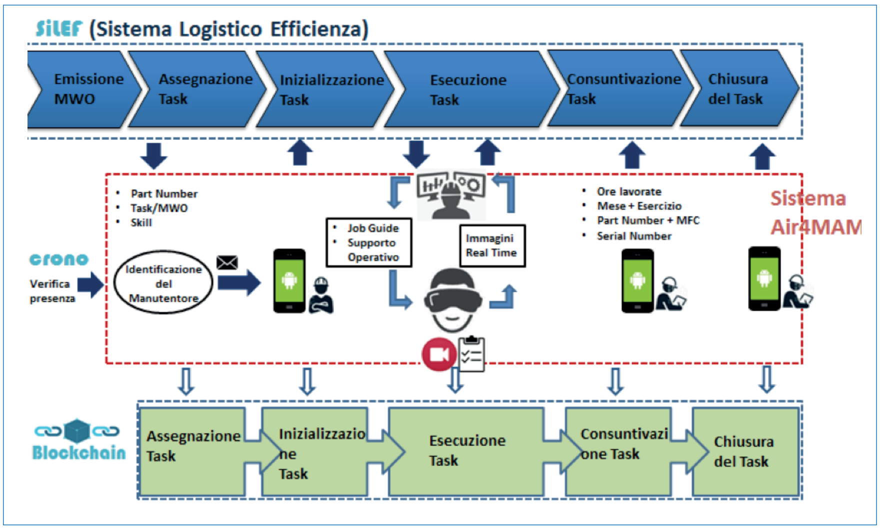

Figure 2

INTRODUCTION

The reference scenario identified for this project is configured to improve the management and efficiency of maintenance personnel training and aircraft maintenance support activities, developing innovative solutions for the processes of 1) maintenance personnel training through experimentation with suitable tools of simulation and immersive virtual reality 2) support for remote maintenance with augmented reality technologies, analytics, blockchain for organizational efficiency, execution and final accounting of interventions.

PROBLEM IDENTIFIED AND TECHNOLOGICAL SOLUTIONS

Considering what has been described above, new training systems have been developed: 1) which are able to reduce training costs and the time necessary for maintenance students to reach an adequate level of practical training in terms of the breadth of concepts as well as of greater ease in acquiring skills on a complex system such as a military aircraft, reserving the real aircraft only for a subset of tasks for which contact with the aircraft is essential 2) support for the maintenance of aircraft and TLC equipment, which allow a) select the most appropriate intervention management model (peripheral/centralized/distributed) based on Analytics (ML, predictive analyses) on qualifications/experience/availability/location of maintainers, type of intervention/equipment, specialist supplier assistance b) guarantee the operator immediate and detailed information on the activities to be carried out and on the components (diagrams, etc) c) allow expert maintenance technicians to remotely assist the operator in carrying out the intervention and troubleshooting. These new systems can also be applied in different contexts, such as training institutes, to allow the updating of their laboratories by replacing, even partially, the physical components of aircraft or equipment.

METHODOLIGY

The project intends to develop an integrated solution which, through the adoption of advanced IT technologies, makes it possible to streamline maintenance training and remote support processes for operational maintenance in the field: 1) The maintenance staff training process will be supported through the identification and testing of the most suitable simulation and immersive virtual reality tools (appropriately identified and tested) responding to the needs of aeronautical maintenance training, with attention to the aspects of ergonomics and man-machine interface that can significantly affect its effectiveness . Solutions based on Blockchain technology will also be introduced for the authentication of training events and on Analytics technology for evaluating the outcome of training activities with a view to optimizing subsequent training moments. 2) The remote maintenance support process for aircraft and equipment will be supported by technologies (blockchain, augmented virtual reality, analytics - Artificial Intelligence and Machine Learning) which will allow the efficiency of the phases of organization of maintenance interventions (planned or in case of failure), remote execution of interventions and final accounting of the activities carried out at the end of the intervention. An appropriate integration of the processes is foreseen and the consequent experimentation of the solutions implemented on the M346 aircraft product line, as well as (for the remote maintenance process only) on an equipment jointly selected with AM. The project provides for an important involvement of the Air Force personnel, as end users, able to define the needs for improving the effectiveness of maintenance training and remote maintenance support.

POTENTIAL USES, APPLICATION IMPLICATIONS OF THE TECHNOLOGY

The digital technology market in Italy is dominated by many international players compared to a few large national ones; a strengthening of companies is expected that will be able to combine vertical skills with analysis, cloud and mobile solutions including IoT evolution and with specializations by sectors: Business to Customer Business to Government, Business to Business, Industry 4.0, smart manufacturing. In this context, Leonardo believes it has to position itself as a national player of reference for the Defense, Public Administration and Industry markets. Augmented and virtual reality technologies are spreading in products such as mobile phones and tablets, enabling the customer to be offered "increasingly multi-media experiences". This market will certainly act as a driving force for the rapid evolution of the technology of interest to the project, being estimated by P&S Market Research, a development rate of 58.1% between now and 2023. With appropriate use of the technologies referred above, the project envisages obtaining a prototype of training and in-service support system for aeronautical maintenance with solutions able to overcome the difficulties in the faithful and natural reproduction of maintenance actions by the student and to provide subsequent maintenance support by remote thus optimizing costs considerably. This system could also be easily offered on the market in support of "aircraft" systems. In the future, the results of the project could make it possible to evaluate the expansion of the training offer of the International Flight Training Academy, adding training on aeronautical maintenance to the current portfolio, using systems developed following the experimentation described in this project proposal.

CONCLUSIONS

All the technologies used in the project are born and developed in the civilian market and begin to spread also in the military one. In particular, the technologies analyzed are already existing but of aeronautical/industrial interest and are:

- Blockchain: already theorized since the 90s, has been concretely applied since 2008 in the financial field, with the virtual currency Bitcoin for the immutable sharing of economic transactions, currently being tested for the secure management of data.
- Analytics: it has circulated for decades in the civil market, although its importance has only recently been understood, effectively starting a process optimization process guided by the extraction of valuable information intrinsically present in the available data (data driven optimization) .
- Augmented, virtual and immersive reality systems: they are originally developed for civil applications, such as entertainment, since the 90s of the last century. They undergo a remarkable maturation from the end of the first decade of the 2000s mainly thanks to the gaming companies. In the last 10 years, development has extended to different sectors such as automotive, manufacturing, medical, museum, training, etc. Inspired by the automotive sector, Airbus has developed systems for customizing the cabin for some classes of aircraft.

SIGLE, ACRONIMI, SIMBOLI ED ABBREVIAZIONI

RMV	Reparto Manutenzione Volo
CPU	Central Processing Unit
COTS	Commercial off-the-shelf
IFTA	International Flight Training Academy
TLC	Telecomunicazioni
HTC	High Tecnology Computer

KEYWORDS

Augmented and immersive virtual reality, blockchain, analytics, A/C Maintenance, Training, Ergonomics.

PROJECT INFORMATION

PNRM number:	a2018.013
Organization appaltante:	Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO)
Responsible Entity	Raggruppamento Temporaneo di Imprese costituito dalla LEONARDO S.p.A. in qualità di mandataria, dall' Università del Salento Dipartimento di Ingegneria dell'Innovazione (UNI SALENTO), dalla M3S S.r.l. e dalla WIDE-VERSE S.r.l.s.
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CeMILAP2

The CeMiLAP2 project proposes the development of innovative technologies to obtain high-efficiency and high-power laser sources using newly developed microstructured ceramic materials as active media, capable of reducing the effects that limit laser emission at high power densities.
The laser sources currently on the market use active media consisting of single crystals, which, especially in high-power lasers, are subject to thermal stresses, generate distortions of the emitted laser beam and reduce the emission efficiency.
The project proposes the development of innovative active media formed by newly conceived microstructured ceramic materials, wich are less subject to thermal effects, for the improvement of the performance of solid-state laser sources. By varying the composition and doping within the active medium in a controlled way, it is in fact possible to limit the thermal and thermo-mechanical effects, increasing the levels of maximum power and efficiency .
The objective of the project is to develop advanced manufacturing techniques for the production of YAG/Yb:YAG-based and co-doped microstructured ceramics, with controlled distribution of the composition over at least two spatial dimensions (2-D structuring). At the end of the project, the prototypes will be validated in an ad hoc high power laser demonstrator.

INTRODUZIONE

In recent years, military applications of high-power laser systems have undergone a major development, with a significant increase in TRL resulting in the creation of numerous demonstrators in the area of so-called Directed Energy Weapons (DEW), for applications such as the destruction of small boats missiles, artillery shells and drones. These new applications also complement more established ones, i.e., laser guidance systems for missiles or bombs from aircraft; 3-D sensing for vehicle detection and identification, etc. High-power lasers also have many applications in the fields of industry, medicine and scientific research, i.e. in nuclear fusion research for energy production
However, these applications use single crystals as active media for laser sources, which have limitation due both to the thermal loads generated in the active medium (which limit the output power), and to the difficulties in manufacturing large components for high power laser applications.
Therefore, innovative laser materials are needed to overcome these technological limitations inherent in single crystals, enabling the development of laser sources that are more efficient, compact, and have optimized emission characteristics for the various applications of high-power systems. Microstructured laser ceramics are among the most promising candidates.

TECHNICAL BACKGROUND

Microstructured laser ceramics are promising candidates to overcome the technological limitations of single crystals.
Internationally, transparent YAG ($Y_3Al_5O_{12}$)-based ceramics have achieved quality levels similar to single crystals. Ceramic materials uniformly doped with Yb (e.g. Yb:YAG) have been shown to be very effective for the fabrication of solid-state laser systems pumped by semiconductor lasers and with near-infrared emission (λ=1030 nm). The ceramic process can produce gain media of

sizes that cannot be achieved by conventional single-crystal production technology. Composites containing areas uniformly doped with different ions are also produced and commercialized.

Despite its strategic importance, the technology is predominantly American and Japanese: Konoshima Chemicals (Japan) is the only commercial supplier of transparent ceramics for laser applications. Furthermore, this technology still has limitations related to the flexibility of the process, which only allows the creation of composite structures with simple architectures.

The technological solution proposed in CeMiLAP2 bridges this technological gap with the non-European competition through an innovative two-dimensional (2-D) microstructuring technology of YAG-based ceramics. By varying the composition and/or dopant within the material in a controlled manner, it is indeed possible to manage and limit the thermal and thermo-mechanical effects that limit the maximum power and efficiency levels achievable.

By controlling the distribution of the Yb dopant (which absorbs the pump radiation and emits the laser radiation), it is possible to control the thermal load distribution within the active material and to limit its undesirable effects on the emission power, with the introduction of other dopants (i.e., Cr^{4+}) allows suppression of parasitic laser emission in undesirable directions (an effect known as Amplified Spontaneous Emission, ASE).

METHODOLOGY

The CeMiLAP2 project activities are carried out in collaboration with the Institute of Science, Sustainability and Technology for the Development of Ceramic Materials (CNR ISSMC, formerly ISTEC) and the National Institute of Optics (CNR INO). The project is organized in three phases of 12 months each. The activities carried out in phase 1 can be summarized as follows.

a) Study and design of the laser system and definition of structures and compositions of the active medium by numerical simulations (laser emission and thermo mechanical stress).
b) Optimisation of the 1-D and 2-D structuring process of the YAG-Yb:YAG ceramic system, exploiting the results obtained in the PNRM CeMiLAP project. Production of small-size prototypes of YAG-Yb:YAG with simplified structuring (Figure 1).
c) Study and optimization of the fabrication process of Cr:YAG with uniform doping, preparatory to Phases 2 and 3.
d) Optical, spectroscopic characterization and preliminary laser emission testing of the fabricated components.

The activities that will be carried out in Phase 2 are:

e) Study and development of the process for structuring the dopant distribution in 3-D. Studies of dimensional scalability of components and dopant diffusion in materials.
f) Optical characterization and laser emission testing of the produced components.
g) Setup of the preparatory version of the laser demonstrator.
h) Verification of the design of the active medium structure and the laser system based on the experimental results.

The activities that will be carried out in Phase 3 are:

i) Production of the structured samples based on the final design.
j) Optical characterization and laser testing of produced components.

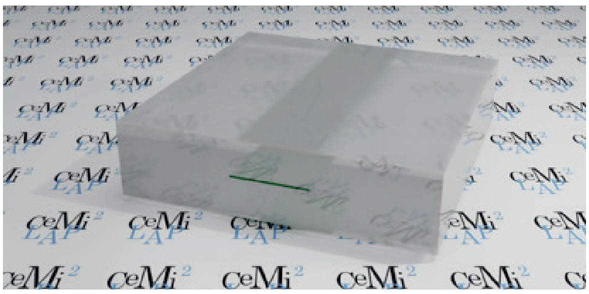

Figure 1 - Waveguide 0.5 mm wide, 7.4 mm long, 140 micron thick, consisting of undoped YAG and Yb:YAG

k) Setup of the laser demonstrator and characterization of the emission properties using the structured components.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The proposed technology will have spillover effects in the military as well as in the civilian sector. The results of the project can be exploited both in industries and for research purposes. Industrial applications of high-power lasers with continuous emission involve, for example, material processing such as cutting, welding, and surface heat treatments (e.g., quenching, annealing). Such applications require laser systems of high power (to achieve high processing speeds), high spatial quality of the beam (for reasons of precision in performing treatments), with energy efficiency, and last but not least, to be cost-effective and highly reliable over long operating periods. These requirements largely overlap with those for the realization of DEW systems. In fact, it is no coincidence that the DEW system demonstrators presented so far at the international level are based on the development and integration of solid-state laser systems initially developed for the industrial applications mentioned above. In scientific research, high-power lasers are of interest for fundamental studies of radiation-matter interaction, plasma physics, particle beam generation, or nuclear fusion with laser ignition

CONCLUSIONS

The aim of the CeMiLAP2 project is the development of innovative laser technologies for sources of high emission power, based on active media consisting of newly-conceptualized microstructured ceramic materials.

The activities of Phase 1 mentioned above resulted in the production of two types of samples:

Figure 2 - Sample of 0.5% Cr:YAG

- transparent Cr:YAG demonstrators with uniform doping, diameter up to 19 mm, thickness up to 3.0 mm (Figure 2).
- laser active elements with 2-D rectangular waveguide structure, in YAG/Yb-YAG, with transmittance up to 74.5% (expected theoretical value: 83.5%) with provided laser emission up to 14.4W peak in quasi- continuous mode (Figure 3).

The results obtained are in line with the project specifications as well as with the numerical simulations. The fabrication techniques used are

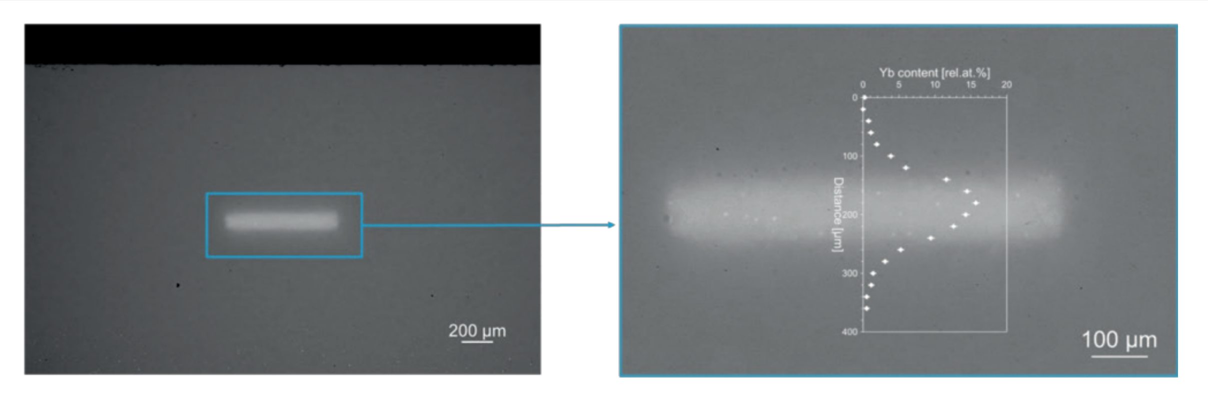

Figure 3 - Cross section perpendicular to the guiding zone made of Yb:YAG in undoped YAG; light gray strip corresponds to the Yb doped region. The rectangular section of the waveguide is clearly visible; width about 0.65 mm. No layered process-derived defects were observed.

suitable for the fabrication of optical components with a more complex structure, as well as for the power scaling envisaged in the subsequent phases of the project.
To achieve the final objective, it is necessary to continue with Phases 2 and 3, where the degree of complexity of the microstructuration of ceramics will be increased to overcome the intrinsic limits of single crystals and thus obtain the desired benefit for the development of high-efficiency and high-power laser sources.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

YAG	Yttrium Aluminium Garnet ($Y_3Al_5O_{12}$)
Yb:YAG	Yb-doped Yttrium Aluminium Garnet
Cr:YAG	Cr-doped Yttrium Aluminium Garnet

KEYWORDS

Transparent ceramics, doping, high-power laser, YAG, active medium, solid-state laser, ceramic processing.

PROJECT INFORMATION

PNRM number:	a.2018.059
Organization:	Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO),
Responsible entity:	CNR ISSMC (Consiglio nazionale delle Ricerche, Istituto di Scienze, Tecnologia e Sostenibilità per lo Sviluppo dei Materiali Ceramici)
Institute of Science, Technology and Sustainability for Ceramics	CNR ISSMC (Consiglio nazionale delle Ricerche, Istituto di Scienze, Tecnologia e Sostenibilità per lo Sviluppo dei Materiali Ceramici)
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HERO

The use of rotary wing remotely piloted aircraft systems (RPAS) will have a significant impact on the civil and military aeronautical sector, especially in those applications where vertical take-off and landing is essential. At the moment, one of the main obstacles for obtaining an aeronautical certification of rotary wing unmanned aircraft systems is the limited experience in operational scenarios of this type of aircraft. The PNRM HERO project has as its objective the integration and evaluation of a rotary wing SAPR technological demonstrator, designed and built by Leonardo S.p.A., in operational scenarios of potential interest for the national Armed Forces with particular reference to operations from naval units . As part of the project, the automatic take-off and landing system was developed, the SAPR was integrated on board naval units including landing operations and remotely controlled bridge operations, a simulator of complex operational scenarios and mission planning was developed , a Heavy-Fuel powered engine was integrated, an integration study of the SAPR with conventional piloted vehicles was carried out, and the integrity of the system from the EMC/EMI point of view was verified in the vicinity of emitting equipment with particular reference to naval units. Finally, a verification of the system in operating environments was carried out.

INTRODUCTION

Modern air and naval operations embrace a very broad spectrum of activities, which range from the more traditional ones (projection of military capabilities), to anti-piracy tasks, counter terrorist activities, controlling the legitimacy of maritime traffic, humanitarian relief initiatives or support to civilian population. Frequently, these operations evolve from one form to another, forcing the Naval Units (UN) deployed to change their operational posture and methods of intervention with great rapidity/fluidity. In order to deal with this diversified and changeable nature of the activities they are called upon to carry out, the Navies intend to employ aircraft such as APR (Remotely Piloted Aircraft) with the aim of increasing the effectiveness and sustainability of operations. This increase comes thanks to the possibility to expand the ISR capabilities of the assets deployed in the Operations Theatre, both in terms of the breadth of the explored areas and the persistence of the sensors, to reduce the risk exposure of the flight crews, increase the engagement precision of the Aeronaval Forces, prevent/contain the possibility of collateral damage and increase the cost-effectiveness of the aero-naval instrument within the Naval Squadron in relation to the moderate hourly costs of use of the assets in question.

TECHNICAL BACKGROUND

The use of remotely piloted aircraft systems is now consolidated not only in the military but also in the civil sector. Most of the RPAS operating in the world's armed forces are fixed-wing. The operational use of rotary-wing RPAS is instead currently limited to a few armed forces and a few models. In particular, the use of rotary wing RPAS is of interest to the Navies as these allow operations from naval units without the need to install take-off and landing devices on the ship deck (e.g. nets). The reason for theis limited operation of these systems is the peculiarity of the application from a technological point of view (for example the need to have an automatic take-off and landing system from the moving naval unit, including the safe anchoring to the deck of the ship), from an operational point of view (for example the use of heavy fuels) and from an environmental point of view (for example the saline environment). With the PNRM HERO project, the main technological capabilities were developed that allow these systems to be operated from naval units.

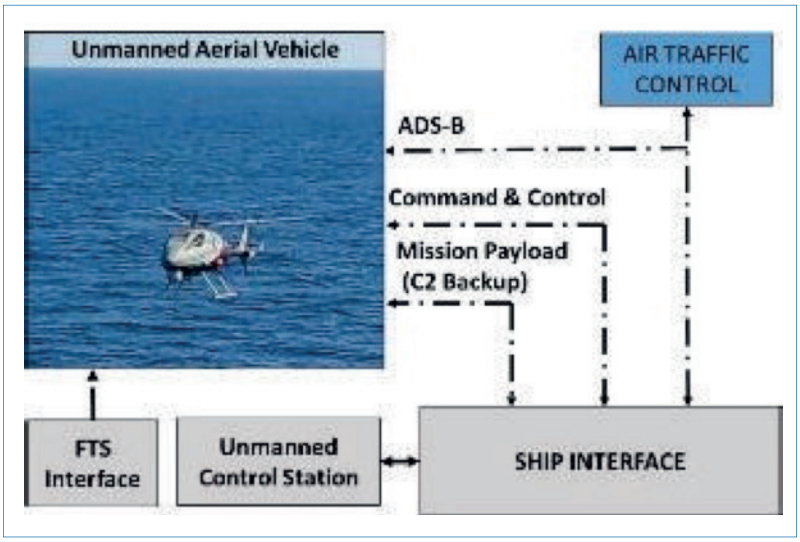
METHODOLOGY

The PNRM HERO project was carried out by Leonardo S.p.A.

In the context of the two phases of the project, the following activities were carried out :

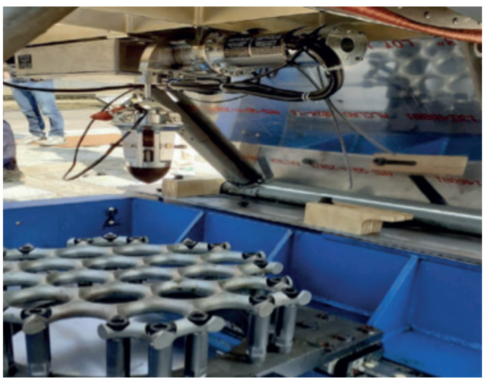
a) Realization of a remotely piloted rotary wing technology demonstrator used as a platform for the integration and validation of the systems and constructive solutions objectives of the research.
b) Search for constructive solutions dedicated to increasing the reliability of the demonstrator in operating environments, in the presence of contaminants (e.g. dust, rain, etc.) and/or corrosive environments (e.g. saline environment) with integration and testing of the solutions demonstrator optimized to isolate and/or protect the sensitive parts of the vehicle and guarantee its operation in such a context.
c) Search for optimized solutions in the EMC/EMI field to guarantee the operation of the demonstrator in highly emissive environments, with particular reference to the use by naval units.
d) Design, integration and bench and flight tests of a Heavy Fuel based power system;
e) Research of constructive solutions dedicated to the installation and operation of the demonstrator on naval units, including the development of an anchoring system to guarantee the blocking of the aircraft following landing or in the phases immediately preceding take-off and the development of a on-board antenna tracking system from mobile platform

f) Research, implementation and testing of a system for automatic take-off and landing from a moving vehicle.
g) Development of a simulator dedicated to complex operational scenarios
h) Study of integration systems with piloted vehicles.
i) Evaluation of the technological demonstrator and of the individual systems, developed within the project, in naval operational scenarios through a flight campaign dedicated to simulating ISR-type missions.



POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The project maturity status at the end of Phase 2 confirms a TRL level 7 - Demonstration of a system prototype in an operational environment. In fact, the operational capabilities of the technology demonstrator were demonstrated through a ground and flight test campaign in a maritime environment and in operational scenarios. This project has made it possible to develop and validate the main technological capabilities that allow the operation of rotary wing remotely piloted aircraft systems from naval units, paving the way for their widespread use.



CONCLUSIONS

The purpose of the PNRM HERO project is the integration and evaluation of a technological demonstrator of a rotary wing remotely piloted aircraft system in operational scenarios of potential interest for national Armed Forces with particular reference to operations from naval units. Within the two phases of the project, the automatic take-off and landing system has been developed, the SAPR has been integrated on board naval units including landing operations and remotely controlled bridge operations, a scenario simulator has been developed for operations and mission planning, a Heavy-Fuel powered engine was integrated, an integration study of the SAPR with conventional piloted means was carried out, and the integrity of the system from the EMC / EMI point of view was verified in the vicinity of broadcasting devices with particular reference to naval units. Finally, a verification of the system in operating environments was carried out. The closure of the project brought to light the opportunity to define some topics for possible developments of future technologies in the field of unmanned rotary wing systems and in particular:

- Hybrid propulsion (thermal/electric)
- Electric tail rotor
- Detect and avoid system
- Automatic landing system in emergency conditions (absence of GPS signal and/or datalink)
- Satellite Datalinks

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

APR	Remotely Piloted Aircraft
EMC	Electro-Magnetic Compatibility
	Electro-Magnetic Interference
ISR	Intelligence Surveillance Reconnaissance
SAPR	Remotely Piloted Aircraft System
UN	A Naval Unit

KEYWORDS

Aircraft, remote piloted, landing, take off, heavy fuel, ship landing

PROJECT INFORMATION

PNRM card number:	n. a2013.138
Contracting authority:	Directorate of Aeronautical Armaments and Airworthiness (ARMAEREO),
Project responsible:	Leonardo S.p.A., Divisione Elicotteri
City, Region:	Roma , Lazio Cascina Costa , Veneto
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MILDAR

The acronym IED, Improvised Explosive Device, has now become familiar in the lexicon of military operations especially those defined as "asymmetrical", i.e. fought between regular forces and guerrilla and/or terrorist forces. A potentially very effective solution is the one proposed with the MILDAR program through the integrated use of various sensors and the use of processing systems capable of merging and analyzing the information acquired for the identification of the IEDs. In the first phase of the project, the system analysis and modeling activities were carried out, defining its specifications and architecture, as well as creating initial laboratory prototypes, specifically for the LIDAR sensor, to allow for the evaluation of the initial hypothesis of mapping and detection capabilities of IEDs. In the subsequent phases of the project, progressively more advanced prototypes were created which allowed for in-flight testing of the integrated system solution on a specifically equipped flying laboratory to evaluate the capacity of the system itself.
The project, within the limits of the realised and tested prototypes which require further development for a serial and operational production, has delivered significative results in terms of sensors' performance and adopted "IED related" mapping and detection tecniques. It has been proposed a further Project's phase aimed to a serial production for a solution fit for airborne operational platform.

INTRODUCTION

IED ambush techniques have characterized conflicts since the Second World War; the IRA made extensive use of it in the Northern Ireland war, Hezbollah in the Lebanon war, and then the Iraq war; in Afghanistan, IED ambushes caused 35% of the deaths and 60% of the injuries of US forces. Knowing, countering and preventing attacks carried out with IEDs scattered in particular along the roads or in transit or rest areas has therefore become a priority for the troops operating in the various operational theaters. The solution proposed with the MILDAR project envisages the integrated use of various sensors operating in the infrared, visual and ultraviolet fields installed on manned flying platforms or UAVs (Unmanned Air Vehicles), capable of mapping the territory overflown and transmitting data surveyed at a ground station; what the sensors must detect are the IEDs themselves, if visible, or the characteristics of the ground and its evolution over time if buried.

In particular, the research activity of the MILDAR program was oriented towards the development of a LIDAR sensor capable of identifying objects on the ground, small up to 10cm and capable of analyzing the emissions of volatile substances from potential IEDs, using LIF techniques (Laser induced fluorescence).

TECHNICAL BACKGROUND

The aim of the MILDAR project is to provide effective support for the identification of potential IEDs in specific areas of interest, through the use of an articulated and integrated system, capable of processing and correlating data from multiple co-operating platforms, at different altitudes and on different levels of discrimination, through the use of appropriate complementary sensors. The synergistic use of these sensors and platforms is one of the main and innovative features of the MILDAR Project.
Three levels of use of the system with related aerial

platforms and sensors were therefore identified, as described in Figure 1:

- Level 1: high wing aircraft operating between 1000 ft and 5000 ft equipped with LIDAR sensor
- Level 2: UAV operating between 300 ft and 1000 ft equipped with electro-optical and infrared sensor
- Level 3: mini UAV operating up to 300 ft equipped with optical sensor

The main technology used in the program is the one called LIDAR which represents one of the innovative elements of the MILDAR system. In particular, two highly innovative specific techniques have been used in their combination: the laser-altimetric technique and the LIF spectrometric measurement technique. The first allows to generate a high resolution mapping of the terrain and to recognize measurable alterations of the environment such as: presence of landslides, residues from excavations, tyres traces and traces in general, dislocation of cars, containers, debris capable of hide an IED and/or hazardous chemicals.

The second technique, based on fluorescence, allows, through the generation of a superficial and limitedly sub-surface physical/chemical/biological profile, to detect chemical or biological traces potentially attributable to elements typically present within an IED. Often, in fact, the nature of the bombs causes losses of contents which can also be detected at a great distance by means of suitable laser sources.

Another essential element of the MILDAR system is the archiving and analysis system of the data acquired by the various sensors which, by video stream analysis algorithms and automation in the identification of potential threats, constitutes an effective support for the operators in charge of analyzing operational scenarios.

METHODOLOGY

The MILDAR project was carried out by the companies LEAT SpA, ISOCOMP srl and Alpi Aviation. The project was organized in three phases:

- the first phase focused on the definition of the specifications and the system architecture
- the second phase, divided into 2 sub-phases, concerned the creation of prototypes of

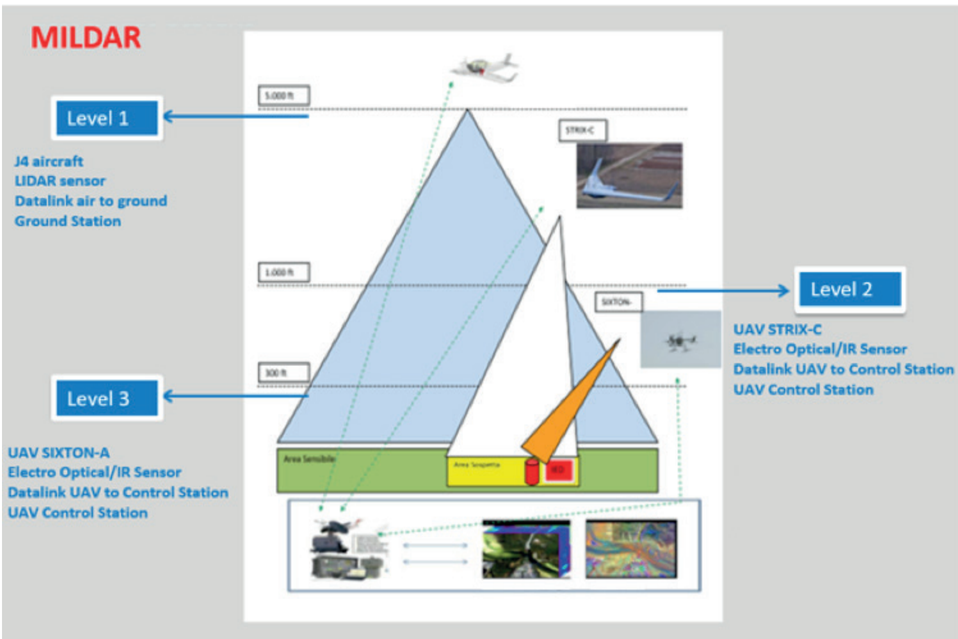

Figure 1 -MILDAR System of systems

increasing complexity which made it possible to validate and evaluate the initial hypotheses of the research activity; in particular, in phase 2A a laboratory prototype (Model A) of the LIDAR sensor was created which, operating on the ground, allowed to demonstrate the radar altimetric capability of the sensor and the ability to identify 10cm-sized objects from a distance of 3000ft.

- In phase 2B, on the basis of the results obtained in the previous phases, the Model B prototype of the system was developed which also included the electro-optical and infrared sensors and the setting up of a flying laboratory on which the sensor prototypes were installed .

In particular, the LIDAR sensor has been suitably engineered for use in flight: the layout and breakdown into subsystems are described in Figure 2 and Figure 3

Furthermore, the Processing station was developed, whose capabilities were made available both on the ground and, limited, in flight to support the early warning capabilities.

A flight test campaign was then conducted: the information acquired by the various sensors was centralized in the processing station, merged together to verify the change detection and object detection algorithms developed. This allowed to

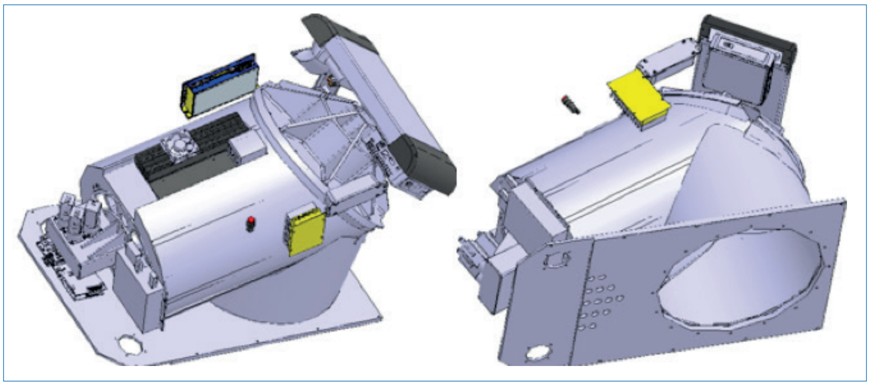

Figure 2 -LIDAR Sensor

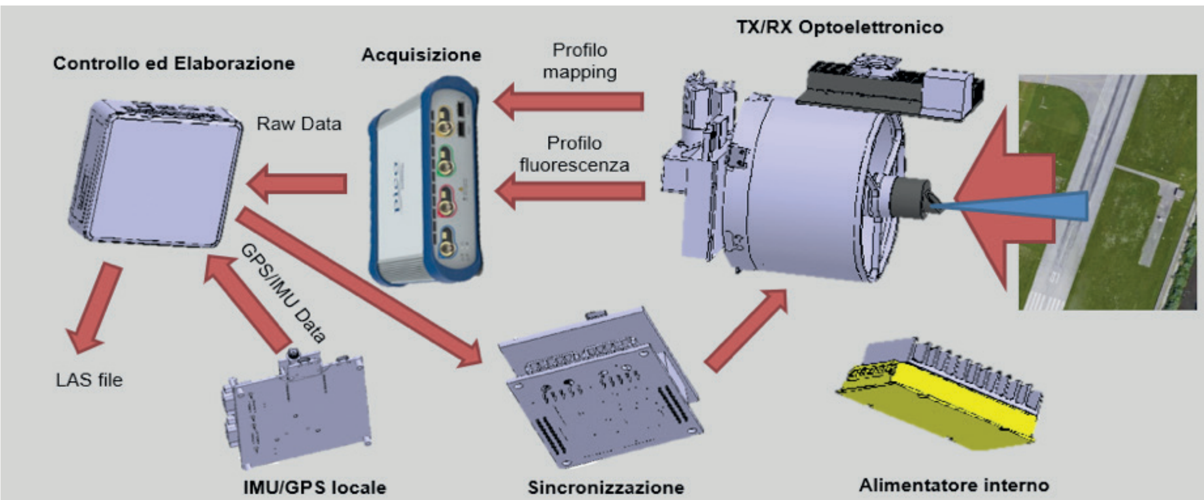

Figure 3 - LIDAR Subsystems

verify the ability of the individual sensors and of the system as a whole, to identify changes to the territory overflown and to identify objects on the ground with shapes compatible with those of a suitably populated database of "threats". As part of this test campaign, the ability of the LIDAR sensor to identify, through fluorescence analysis, the presence of emissions of volatile substances attributable to possible IEDs was also verified.

Figure 5 illustrates, for example, the processing sequence of successive images which highlights the identification of changes (change detection) between images acquired at successive times. Figure 6, on the other hand, highlights the ability of the processing station to support the operators in identifying objects (from appropriate reference libraries) and highlighting them in the acquired images (and video streams).

- The third phase concerned the engineering of the subsystem prototype and the verification of compliance with the environmental and EMI requirements for their use in flight.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The technological and application implications of the MILDAR system are numerous, both as regards the system as a whole and for the individual sensors. The study of the use and fusion of multi-sensors will have other fundamental impacts in the integrated and augmented visualization of the operational scenario, in the analysis of the line of fire and in the

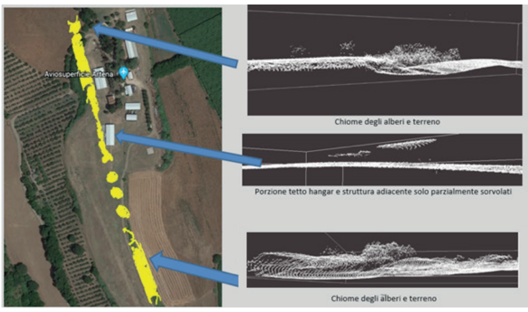

Figure 4 - LIDAR acquisition

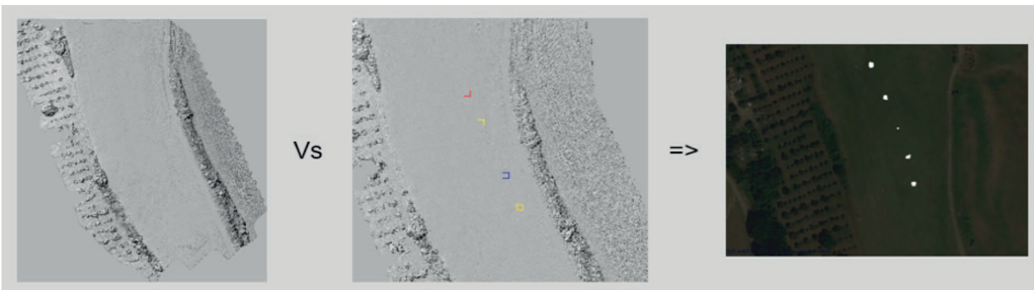

Figure 5 - Elaboration chain

Figurae 6 - Object Detection

planning of both military and Homeland Security actions in urban areas.
More generally, it is legitimate to assume that the number of autonomous or traditional vehicles/ aircraft that will make use of dedicated systems derived from the same basic MILDAR technology is going to increase with an exponential trend.
As regards to LIDAR technology, it is now universally recognized as one of the most effective Remote Sensing systems and the fundamental Stand Off IED Detection function, capable of providing precise and accurate information to Augmented Reality or Virtual Vision systems. In particular, the most interesting evolution is towards FLASH LIDAR systems, i.e. LIDAR systems capable of detecting an entire area with a single laser pulse, drastically reducing times and calculations, a requirement at the base of the next generation of UAS capable of reacting autonomously and in real time to the recognition of particular conditions. The study component of algorithms and IT management for image storage and analysis will have strong repercussions on the development of products also intended for Homeland Security and more generally for territorial control for any purpose.

CONCLUSIONS

The aim of the MILDAR project was the development of a "system of systems" for the analysis of the territory overflown in order to identify any IEDs, through the joint analysis of the information acquired by the sensors operating at different altitudes. In particular, the project led to the development of a LIDAR sensor with advanced capabilities for altimetric radar acquisition and for fluorescence analysis of the territory overflown. The need to jointly merge and analyze the heterogeneous data acquired by the various sensors has also led to the development of a ground station for data management and data analysis, in order to identify possible IEDs through change detection and object detection algorithms. The project has led, mainly for the LIDAR sensor, to the development of prototypes which, however advanced, require further engineering for their operational use. In fact, the test campaigns demonstrated the acquisition and discrimination capabilities of objects on the ground, even small ones (up to 10cm), by the LIDAR sensor operated up to an altitude of 3000ft. The performance of optical and infrared sensors, already selected for use in the armed forces, was appreciated. However, the prototype resulting from the PNMR does not currently have the size, weight and shape characteristics to be immediately used on several aerial platforms, or to be disassembled or installed and made operational in a short time in operational areas, without adequate infrastructures or specialistic personnel; a further project was therefore proposed for the refinement of the industrialization of this prototype which allows its use in a non-invasive and compatible way with the host air vehicle platform, for example with sensor integration in standard POD and interfaced with on-board systems.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

FT	Feet
IED	Improvised Explosive Device
LIDAR	Laser Imaging Detection and Ranging
LIF	Laser Induced Fluorescence
UAV	Unmanned Air Vehicle

KEYWORDS

IED, LIDAR, multi-sensor, scenario analysis, data fusion, object detection, change detection

PROJECT INFORMATION

PNRM number:	a2017.079
Organization:	Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO),
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NAIS

The NAIS project aims to study the application of new advanced computer vision algorithms based on "deep learning" for processing the data provided in real time by on-board sensors used on small UAVs. Four use cases are considered: target detection, classification and localization, road segmentation for autonomous navigation in "GNSS-denied" areas, human body segmentation and human action recognition. All algorithms were developed using state-of-the-art image processing methods based on neural networks. Acquisition campaigns were carried out to collect datasets characterizing typical operational scenarios, replicating the point of view of a multi-rotor UAV swarm. The performance of the algorithms shows high levels of accuracy and speed of inference. The results demonstrate the algorithms work when implemented on a commercial GPU-powered embedded device (NVIDIA Jetson Xavier) mounted on board a custom quad-rotor, opening the way to implement even on longer range UAVs high-level operational autonomy.

INTRODUCTION

Recent trends in the deployment of unmanned aerial vehicles (UAVs) in critical environments make it necessary to explore solutions based on drone swarms that exploit the growing availability of small systems with low-cost rotary and fixed-wing architectures. These new tools allow the planning and execution of new types of missions, being able to take advantage of a different configuration of tactical assets and the increase in data flow made available by the large number of sensors that can be deployed. However, in this new setting, each UAV equipped with a particular on-board sensor requires a dedicated operator to continuously monitor its activity. This limit the scalability of the system. At the same time, the new computer vision algorithms are available, thanks to innovations in the field of deep learning (DL). The performance of the image processing algorithms has overcome various limits imposed by the state of the art. With the NAIS project, new advanced algorithms based on "deep learning" have been studied for automatic processing of data provided in real time by on-board sensors used on small UAVs. Four use cases are considered: target detection, classification and location, road segmentation for autonomous navigation, human body segmentation, and human action recognition.

TECHNICAL BACKGROUND

Computer vision research has advanced at an unprecedented rate over the past decade, primarily due to the rise of deep learning technology and, in particular, convolutional neural networks (CNNs). Their performance in the context of image processing has made them the best technical solution available to be used also on swarms of drones. With the NAIS project, specific applications have been studied with the aim of demonstrating the operational advantage of these techniques. The effectiveness of the algorithms for the detection, classification and localization of a class of objects (person) has been demonstrated, using RGB images acquired by a drone flying with the camera oriented downwards. This scenario was chosen as representative of situations in which, for example, there is the need to detect a target and track it autonomously in contexts of search and rescue missions or monitoring of critical areas. The model for semantic segmentation has been applied in two different contexts. The first aims to distinguish road patterns in RGB images captured by a drone flying with the camera pointing downwards. This functionality can be used to implement autonomous navigation, particularly useful in areas without GNSS, for example to build a system capable of autonomously following a road for patrolling operations. The second application of semantic segmentation aimed to segment the human silhouette into 19 different body parts (such as head, hair, arms, legs, torso, feet) by processing RGB images acquired by a flying drone with the camera oriented at -40 degrees. The human action recognition model was trained to classify six different actions in RGB frame sequences captured by a drone flying with the camera pointing downwards. The classified actions were: stand still, walk, run, crouch, aim and throw. This feature can be used, for example, in crowded area monitoring applications to automatically identify threatening behaviour.

METHODOLOGY

One model was identified for each of the four use cases: YOLOv3 for object detection, classification and localization, DDRNet for the two segmentation scenarios (road segmentation and human body segmentation), and Two-stream ConvNet for recognition of human action. All algorithms have been customized to easily handle different types of inputs, supporting RGB and grayscale images in the visible spectrum, grayscale images in the infrared spectrum, and images captured by multispectral or hyperspectral cameras. These developments have also taken into account the specific hardware used for on-board applications and the need for near real-time inference. The four use cases considered in the NAIS project with the aim of demonstrating their application on board a multirotor drone posed a significant challenge. In fact, while a relevant number of image datasets for algorithm training are available for many applications, only some of them present the very particular aerial point of view, needed in our case. For this reason, a series of acquisition campaigns were conducted in the field with the aim of building the customized dataset necessary for the training of the algorithms. Figure 1 shows the custom payload for on-board implementation. Figure 2 shows samples used for object detection, segmentation, and action recognition, respectively. As a further research direction, we have also exploited the potential of Unreal Engine to create synthetic datasets with characteristics similar to those used for the four use cases considered and to virtually test the algorithms and their integration with navigation dynamics of the drone. Figure 3 shows the application of the object detection algorithm in a virtual scenario. Making correct use of these engines allows you to bypass the abelling phase, exploiting the knowledge of the composition of the virtual environment underlying the rendered scene, completely automating the generation of the dataset.

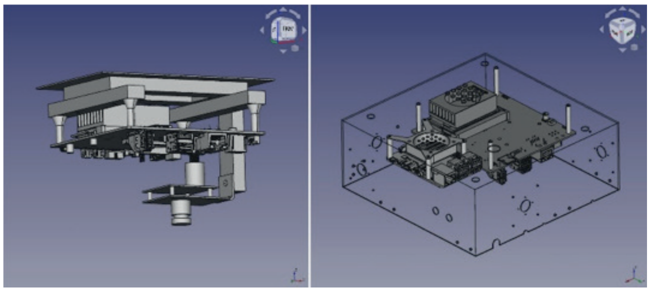

Figure 1 - Custom design of NVIDIA Jetson's support for deployment on-board of a multi-rotor drone

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

All algorithms have been implemented using state of the art deep learning frameworks (TensorFlow / Pytorch). To expedite hyper-parameter tuning and testing, algorithm training was done on a desktop computer powered by an NVIDIA RTX 3090 GPU. Implementation constraints drove development from the start, so the models were designed to be easily portable to GPU-based embedded devices. Trained algorithms have been implemented on the NVIDIA Jetson Xavier board, which is particularly suitable for integration on board UAVs, due to its

Figure 2 - Samples of the dataset used for the object detection, classification and localization scenario, road segmentation and human body segmentation scenarios, human action recognition scenario and annotation tool used for object detection and action recognition

Figure 3 - Applicazione dell'algoritmo di rilevamento degli oggetti in uno scenario virtuale generato con Unreal Engine

low weight and power consumption, as well as very flexible hardware and software interfaces. To maximize performance, low-precision arithmetic was used using the NVIDIA TensorRT tool. Figure 4 shows the final prototype assembled and ready to be used for tests with an opto-copter in quad-x configuration.

The technology adopted and the implementation choices were guided by the objective of creating a software library able to manage different types of input data and to provide outputs containing abstract and high-level information extracted from the frames.

CONCLUSIONS

The NAIS project demonstrated how it is possible to use deep learning-based artificial vision algorithms, developed, trained and implemented on an integrated NVIDIA Jetson Xavier aboard a small multi-rotor drone. All the models selected have been chosen to ensure broad applicability,

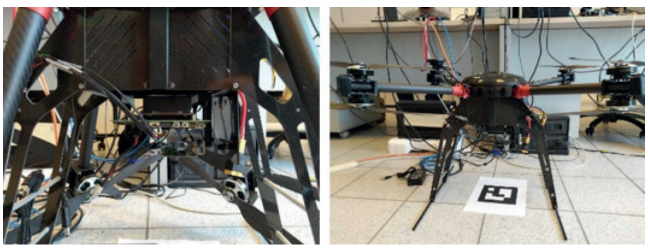

Figure 4: Intelligent Payload deployed on-board of a multi-rotor drone

favoring the simplest possible integration in terms of both input sources and downstream users, including third parties. The technology adopted and the implementation choices were guided by the objective of creating a software library able to manage different types of input data and to provide outputs containing abstract and high-level information extracted from the frames. The presented results demonstrate the successful application of state-of-the-art deep learning-based computer vision algorithms for processing data provided by near real-time sensors installed on board multirotor drones. The obtained performances showed that this approach can be very promising to pursue scalability in UAV applications with cooperating swarms and these functionalities can be directly applied in enabling fully autonomous systems.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

UAV	Unmanned Aerial Vehicle
GPU	Graphics Processing Unit
CNN	Convolutional Neural Networks
RGB	Red – Green- Blue standard video

KEYWORDS

Computer vision, object detection classification and localization, semantic segmentation, human action recognition, UAV.

PROJECT INFORMATION

PNRM number:	a2019.053
Organization:	Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO),
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QUCRYPTNET

Recent developments in quantum technologies, especially in Quantum Computing, constitute a Damocles' sword on modern cryptography: what seemed to be only a remote threat, since mid-2007 is a reality with D-Wave, which presented the first prototype of working quantum computer, and with today's developments from IBM, Google and Microsoft. If quantum computers threaten to bring down modern Cryptography, or at least that based on asymmetric algorithms, Quantum Cryptography, in its meaning of Quantum Key Distribution (QKD), proposes to save at least a part of it by offering a new way to generate and exchange secret keys to use. The objectives of the "QuCryptnet" project were aimed at the development of technologies capable of improving the performance of QKD devices. The study involved the design and engineering of the fundamental components, such as generation and detection devices of quantum states, a novel architecture to guarantee the extension of distances and the interconnection between networks, through Device Independent Quantum Key Distribution and quantum repeater, the use of optical fiber and free space channels with multidimensional quantum states and novel protocols.

INTRODUCTION

Quantum Key Distribution (QKD) is a protocol for generating and exchanging secret keys in absolute security between two legitimate users for cryptographic application, using elementary particles and exploiting the laws of Quantum Mechanics. QKD was proposed about 40 years ago and its foundations are Heisenberg's uncertainty principle and the no-cloning theorem. QKD offers a new way to solve the problem of secret key generation and distribution. Classical Cryptography solves this problem with the use of Asymmetric algorithms, which however are the most at risk of an attack by quantum computers (Shor's algorithm). However, if quantum computers threaten to bring down modern cryptography, or at least that based on asymmetric algorithms, QKD intends to save at least part of it by offering a new way of generating and exchanging secret keys to be used and, if integrated with classical systems with symmetric keys, could be used in current Military and Civil Cipher products, in the first instance in metropolitan areas, and subsequently, with the increase in the distances reachable by quantum channels, on a national and global scale. The technology certainly falls within the framework of the protection of Critical National Infrastructures (CNI).

TECHNICAL BACKGROUND

The current generation of cryptographic standards needs to be reviewed in the era of quantum computing. Quantum speed-up, while not making all cryptographic technologies obsolete, can have the effect of requiring larger key sizes, as is the case with AES. To overcome all the limitations of the CNI in terms of performance and resilience, four fundamental issues have been identified:

1 improvement of single photon or entangled state sources, able to operate at ambient temperature, with high efficiency and capable of guaranteeing the extension of existing protocols;
2) increase of the distribution distance of the cryptographic keys, solving the problem of "trusted" nodes in the so-called hop-by-hop distribution;
3) overcoming of the limits due to the non-ideal nature of real sources and detectors;

4) ensuring of the resilience of networks based on free space quantum channels with related quantum communication vectors.

To solve these problems, the following solutions have been proved within the project:

- single photon sources on materials such as diamond and silicon carbide (SiC) have been studied and implemented, and sources based on parametric down conversion phenomena in non-linear materials have been optimized;
- an extensive QKD network was designed with an architecture capable of avoiding "trusted" repeater nodes;
- a Device Independent QKD architecture has been developed, capable of overcoming the limits imposed by the non-ideal nature of sources and detectors;
- nanostructures capable of producing multidimensional quantum systems for optical communications in free space have been designed.

METHODOLOGY

The design of new quantum sources has followed three lines. The first line was based on the study of the Nitrogen Vacancy (NV) in diamond and in SIC. The NVs are an exceptional physical system similar to an atomic one, but positioned in an extremely stable and imperturbable structure, as the diamond. Among the various solid-state physical systems, its peculiarities lie in its extreme resistance, in the optical transparency on a band that goes from UV to infrared, and in the possibility of optically controlling the physical states of the electronic spin of a single color center through the Zeeman effect, in particular for its use as single photon source. Three different types of such emitters have been identified, and the emission of anti-bunched photons has been confirmed by Hanbury Brown-Twiss interferometry. Measurements showed no evidence of blinking over a time scale ranging from 100µs to several minutes and the emission remained stable for hours under continuous laser excitation. The second trend took the form of modeling a parametric source in ridge waveguide on a lithium niobate platform. An accurate modal analysis in pulsed pumping regime has been carried out, optimizing the profile of the pump beam and suitably sizing the guide according to the doping of the Lithium Niobate. Subsequently, two coupled fiber sources capable of emitting twin photons in a collinear configuration at the Telecom wave frequency were created. These sources have been used in an innovative quantum interferometer for controlling the coalescence of entangled states. The third approach was based on the development of a source integrated on an Indium Phosphide platform capable of generating single-photon entangled states (Fig. 1).

To solve the problem of extending distances, a hierarchical network was designed and built, capable of generating and distributing cryptographic keys

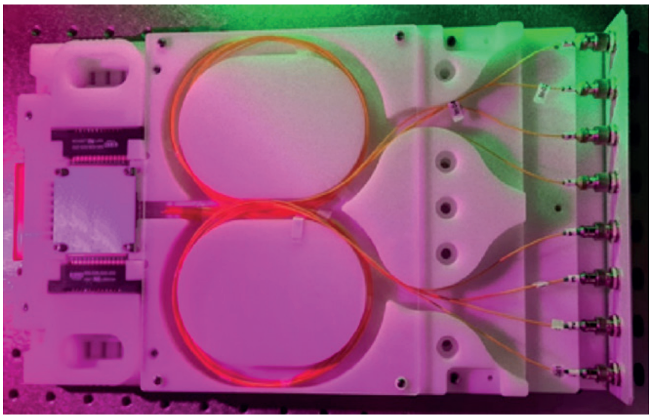

Figure 1 - Source of Single Photon Entangled States. The source was developed on an Indium Phosphide platform connected by optical fibers with four input ports and four output ports. The interferometric system can be connected externally to an attenuated laser generating a weak coherence state, or to a spontaneous parametric down conversion source realized on non-linear waveguides. The output ports can be coupled to a fiber optic network for quantum key distribution.

with all enabled users. The proposed architecture finds immediate use in the protection of National Critical Infrastructures (CNI) which are increasingly based on computerized communication structures: there is the need not only to protect the so-called Maximum Security Networks with encryption systems, but also to ensure their interoperability, maintaining a hierarchical structure. The Federation Agent concept has been implemented, i.e. the element that guarantees the connection between different networks, which behaves like a Quantum Repeater that allows secure communication between each enabled user of the first network and each enabled user of the second network (any-to-any configuration) over distances of hundreds of km (≈200Km) (Fig. 2). The technology of the new class of superconducting detectors capable of operating on the Telecom wavelength with high quantum efficiency (>70%) and higher band (1GHz) was also acquired.

The extension to free space channels has seen the introduction of multidimensional quantum systems using optical vortices. Optical vortices are phase singularities around which the phase wraps, creating a structure with helical wavefronts. In the project, metal matrix structures have been realized able to control the phase front of an input Gaussian beam. The functionality was demonstrated by generating different types of Laguerre-Gauss beams (Fig. 3). Actual cat-states (Schroedinger cat states) have been created, using the angular orbital momentum as degree of freedom, with experimental results in excellent agreement with the theoretical predictions. Nanometric structures have also been created for the generation and control of particular vortex states in polarization. The experiments confirmed the model predictions and opened the possibility of using innovative protocols.

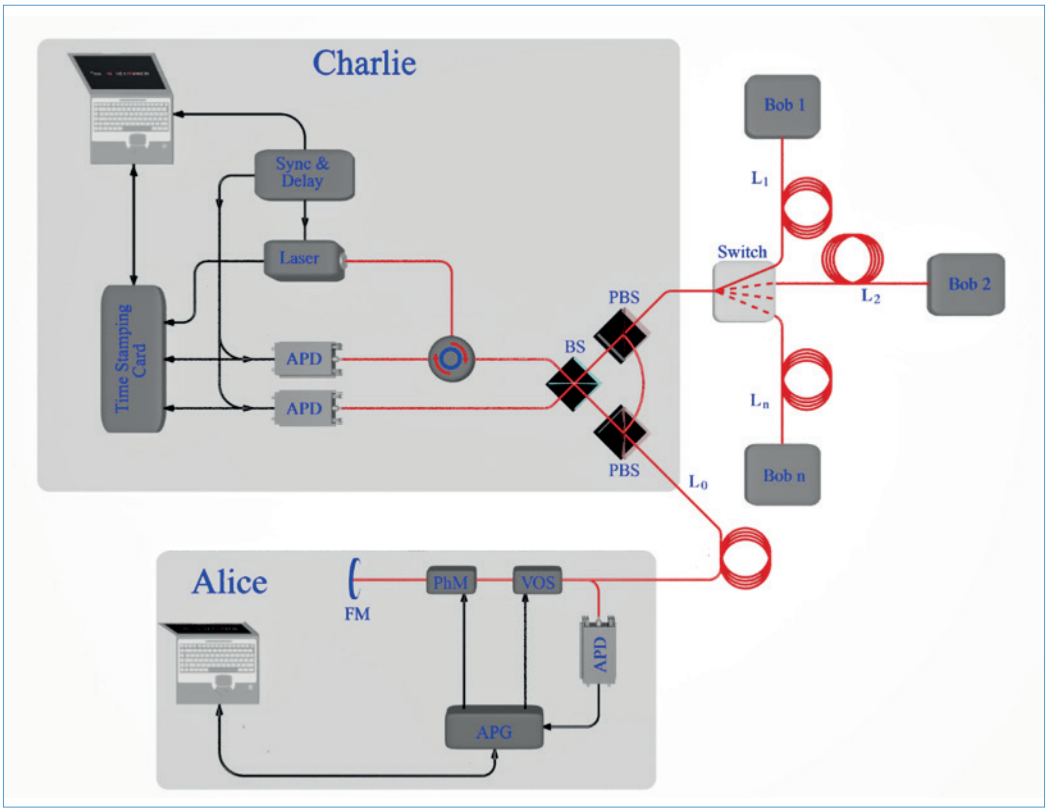

Figure 2 - Scheme of Device Independent QKD. The optical configuration that binds Charlie, Alice and Bob is equivalent to a Sagnac interferometer. Charlie (the server) has both the measuring devices (Single Photon Detector Module -SCPM-, Time Stamping Card), and the laser source, isolated by an optical circulator. Alice and Bob have the devices for controlling and monitoring the optical power of the attenuated coherent states sent by Charlie (Variable Optical Switch -VOS- and Avalache Photo Detector -APD-), and the devices for the phase coding necessary for the QKD (Phase Modulator - PhM-e Arbitrary Pulse Generator -APG-).

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The nature and typology of the technologies that make up the communication and information infrastructure have undergone considerable evolution. The number and nature of access devices to this infrastructure have multiplied and diversified to include fixed, wireless and mobile access terminals, and access via "permanent" connections is on the rise. As a result, the nature, volume and sensitivity of the information exchanged have increased substantially. With their increased connectivity, information systems and networks are now exposed to an increasing number of threats and a greater range of vulnerabilities, thus new security problems emerge. This has led to a higher awareness about the need to protect data from any violation, to guarantee its authenticity and to protect systems from attacks from the network. The use of the proposed technology allows to create a Quantum Safe Network based on the Quantum Key Distribution paradigm. The studied solutions make it possible to overcome the limitations of the previous QKD systems and allow to strengthen the security of communications and the protection of data in the existing Maximum Security Networks, both Military and Civil. The use of DI-QKD also allows the interoperability of Maximum Security Networks thanks to the Federation Agent, which is not a "trusted" node, but is configured as a quantum repetition system which is not able to have information on cryptographic keys.

CONCLUSIONS

In the "QuCryptnet" project all the current limitations, in terms of performance and resilience, affecting the QKD devices on the market so far have been addressed. The study of innovative sources, the development of an effective network architecture, the possibility of using both fiber communication and free-space connections, the use of single photon entanglement, constitute a step forward for the realization of QUANTUM SAFE NETWORK, capable of being robust against both quantum hacking and classical hacking. The developed technology

- is able to reach the optimal distances between adjacent nodes (in terms of cost functions and merit factors);
- is practical and economical: it can provide a low-cost service and can operate on existing and future optical networks;
- safeguards or mitigates the vulnerabilities of critical information infrastructure;
- can therefore meet the main security requirements of communication networks such as
  - availability;
  - data source authentication;
  - access control;
  - data confidentiality;
  - data integrity.

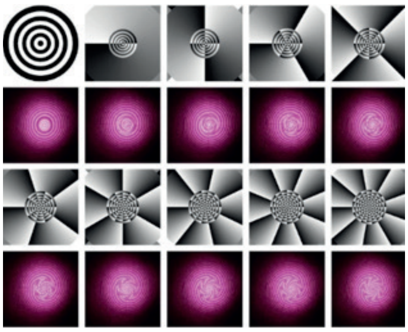

Figure 3: Example of multidimensional "quantum code" based on light vortex states generated by nanostructured devices. Each black and white image represents the phase structure which is converted by the nanostructured device into the corresponding optical beam (coloured image below). The phase structure is shown by an interferometric measurement.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

QKD	Quantum Key Distribution
CNI	Critical National Infrastructure
SiC	Silicon Carbide
UV	UltraViolet
DI-QKD	Device Independent - QKD

KEYWORDS

Quantum Cryptography, Quantum Key Distribution, Entanglement, Single Photon Source, Non-linear optics.

PROJECT INFORMATION

PNRM number:	a2010.143
Organization:	Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE)
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EMArIS

The EMArIS project is one of the actions put in place by the IT MoD to increase the ergonomics of a dismounted soldier, and his/her ability to perform tasks while carrying equipment.
EMARIS is a passive and modular exoskeletal structure able to reduce the impact that the prolonged transport of heavy equipment can have on the musculoskeletal structure of the soldier and at the same time to increase performance in terms of load capacity and mobility.
The developed exoskeletal structure is able to transfer a significant part of the load carried by the soldier to the ground, relieving the stress from the user's musculoskeletal system, while maintaining more than acceptable levels of comfort and mobility. The use of techno-polymers decreased the weight and reduced the system's production costs.
The adjustment system and the three tailoring sizes allow the structure to adapt to the majority of biometric models and to all percentiles of military personnel. The results obtained by the system put it in at the top tier of performance when compared to its international counterparts in terms of mobility, biometric adaptability, weights, simplicity cost-effectiveness of production and load capacity. It also meets all NATO requirements for exoskeletal development *(Integration of the Exoskeleton in the Battlefield).*

INTRODUCTION

When analysing the role of dismounted soldiers in the modern and future battlespace, one must always consider the balance between integrating equipments and critical technology on one side and, on the other side, the continuous evaluation of the load put on the soldier.
Dismounted soldiers need to be able to carry their equipment, and this can lead to an increased risk factor of injuries, both to the musculoskeletal system,and to the nervous system that controls the joints, and to an understandable reduction in the agility of the soldier, and to strong states of fatigue.

TECHNICAL BACKGROUND

The development of a light and comfortable exoskeletal structure would reduce the traditionally sustained weights (bulletproof vest, weapons, equipment etc.) on the shoulders of the soldier and would significantly reduce injuries and fatigue. However, accepting an adaptation to the exoskeletal structure also causes, a marginal limitation of freedom of movement and an effective increase in the overall weight of the soldier.
The same structure would also allow an increase in transport capabilities enhancing the ability to carry specific heavier equipment with the goal of maximizing the lethality of dismounted soldiers.

METHODOLOGY

The state-of-the-art analysis revealed a general immaturity of the sector and multiple approaches to solve the problem.
Each of these approaches has its own limitations when faced with military use: complexity and delicacy of the system, low efficiency, problems of adaptability in adjustment, inapplicable weights and dimensions and costs disproportionate to the benefits. The EMARIS solution proposes an adjustment system that allows to cover the entire military biometric range with 3 sizes, a choice of a material that is fast and economical to produce and a structure that is difficult to damage and easy to maintain.
The prototypes are also compliant with the NATO MMR (Minimum Military Requirements) defined

during the IEB (Integration of the Exoskeleton in the Battlefield) project.

An accurate kinematic and biometric study of human joints cross-referenced with anthropometric data present in ISO 7250-1: 2011 and with some reference models has enabled the design of an ergonomic and adaptable exoskeletal system Figure 1. The exoskeleton, as modular, is equipped with a coupling system for the upper modules, currently under development, that will allow interconnection and expand functionality.

The final prototypes were subjected both to a series of laboratory tests with a baropodometry platform Figure 2 capable of detecting the percentages of weight transferred to the ground by the exoskeleton without affecting the user's body, and to a series of operational tests evaluating comfort and freedom of movement that allow the soldier to carry out all his typical tasks Figure 3.

Figure 1 - Coverage of all percentiles of military personnel

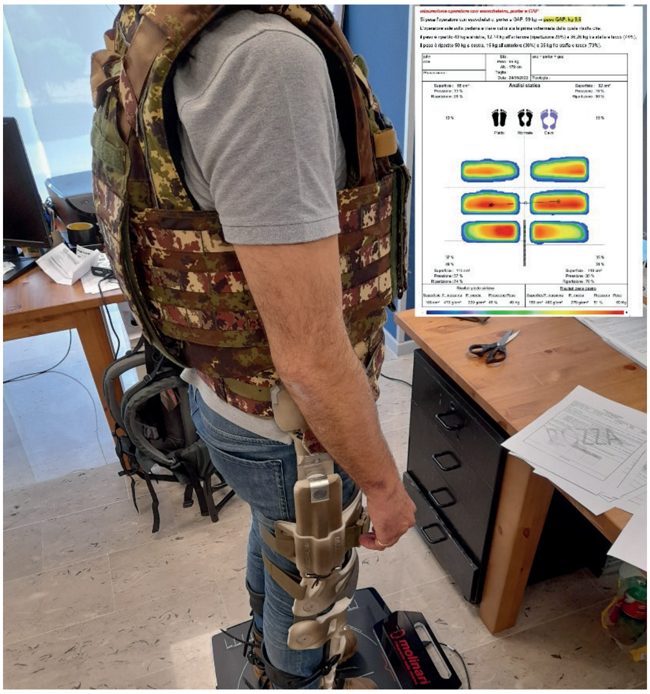

Figure 2 - Transfer test to the ground with baropodometric platform

Figure 3 - Exoskeleton in relevant environment

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

Mobility, survival and lethality have always been crucial when it comes to individual equipment assessment. In this perspective, the exoskeleton increases the performance of the soldier, in each of these three areas.

The project has the capability to perform not only in military applications but also in civil ones. The exoskeleton, in all its components, can help perform heavy duty activities in different areas of the civil environment, like support to first responders (i.e. civil protection, mountain rescue, firefighters) in carryng heavy equipment, and by allowing more agility and autonomy to respond to changing conditions of the intervention. The ability to lift and handle heavy loads could make exoskeletons ideal for reducing occupational risks. Warehouses, shipyards, and construction sites could use them for jobs that involve moving heavy objects. Moreover, the EMArIS exoskeleton would be an excellent technological basis for the development of powered and/or passive exoskeletons for rehabilitation.

CONCLUSIONS

At the current state of development, the Lower Limbs Exoskeleton has demonstrated the ability to transfer to the ground 70% of the load transported in the static phase.

The system can also be easily disassembled into single-material components and therefore easily recyclable.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AD	Defence Administration
EMArIS	Modular Exoskeleton for Lower and Upper Limbs
MMR	Minimum Military Requirements
NATO	North Atlantic Treaty Organization

KEYWORDS

Exoskeleton, equipment, cargo, armament, transport, weights, infantry, musculoskeletal system, health.

PROJECT INFORMATION

PNRM number:	a2019.012
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esaSCAN

The goal of the "6-channel scanning EW receiver based on integrated photonics" (esaSCAN) project is the study and development of a receiver demonstrator for EW (Electronic Warfare) applications. The receiver is of the superheterodyne type and the innovative element is in the frequency conversion which uses integrated photonic technology. The operating band goes from 0.5 to 40GHz and with 6 channels it is possible to implement the goniometry measure up to 6 antennas. All this while maintaining limited volume, weight and power consumption so that the receiver can also be installed on platforms such as drones.
In this way it is possible to keep the EW receivers up to date with the most modern threats.
The research develops on two themes: on the one hand, the introduction of integrated photonics which allows for containing dimensions and weight, on the other, enriching integrated optics with new RF signal processing functions to replace traditional microwave components with devices photonics.
Where it is necessary uses electronic components (e.g. sampling and processing), these will be specially designed to operate in symbiosis with the photonic part.
To date, two possible architectures have been identified, these differ in the generation of optical OLs and both will be implemented to evaluate which is the best.

INTRODUCTION

Electronic warfare (EW) receivers detect hostile radars and enemy communications, indicate their direction and identify their electromagnetic signature contributing to "situation awareness".
These receivers are expected, for the near future, to cover the 0.5-40GHz frequency range with high sensitivity (-80dBm), dynamic (40dB) and instantaneous bandwidth (>1 GHz). All this while maintaining the multiplicity of antennas and channels required by goniometry.
The esaSCAN project, using photonic technologies, allows the radical architectural innovation of a superheterodyne EW receiver, satisfying the requirements listed above. This approach, thanks to its applicability on unmanned platforms, allows pervasive control of the spectrum, and guarantees the spectral supremacy necessary for citizen safety. Among the military values, the reduction of dimensions, weights and heat dissipation should be underlined, improvements necessary for installation on high mobility platforms (drones). The technology also enables ultra-wide bandwidth coverage with reduced scan time for detecting next-generation and non-standard threats used to bypass current systems such as short-range remote-controlled drones for terrorist attacks on sensitive locations and threats of high-precision millimeter-band guided missiles.

TECHNICAL BACKGROUND

At an architectural level, the solutions proposed in esaSCAN are an alternative to direct sampling tunable receivers which sample the RF signal and process it digitally. In fact, the latter have limitations due to the analog-to-digital converters capable of acquiring signals up to 18 GHz against the 40 GHz and beyond which can be reached with esaSCAN. At a technological level, photonics applied to microwaves (microwave photonics) offers numerous advantages:

i) the reduction in size and weight of the cables for signal transfer, and consequent better installability;

ii) the possibility of remoting the sensors with respect to the receiver, by virtue of the very low attenuation of the optical fiber (up to 0.2 - 0.22 dB/km), overcoming the distance limitations present on naval systems;

iii) security against signal interception;

iv) improved robustness to received or induced electromagnetic interference (EMI).

v) immunity to natural phenomena indirectly induced by lightning.

Furthermore, the use of photonic integration technologies allows for a very large reduction in the size and weight of the receiver itself, obtaining bandwidth, stability, tuning speed and integration capabilities suitable for the implementation of future generation EW receivers, opening up their installation also on drones. The project presents the following innovative technological aspects:

i) the anti-aliasing optical filter is particularly challenging, and will be implemented thanks to the most recent techniques presented (also by the proponents) in the technical-scientific literature;

ii) the photonic integration of the entire reception system is challenging due to the total complexity of the project, which requires the interfacing of numerous functions and subsystems, the combination of which must in any case guarantee high performance.

METHODOLOGY

With regard to technologies, the use of integrated photonics is the most innovative component of this project.

The benefits of using photonics in the EW receiver have been evaluated in previous studies conducted by ELT and the CNIT [Ref. 4], [Ref. 5], [Ref. 6] and [Ref. 7]. The double RF-optical-IF conversion makes it possible to exploit the very wide frequency band of the photonic components to implement a scanning receiver that covers the entire 0.5-40 GHz range with almost constant performance.

The recent development of photonic integration technologies adds to the above advantages a considerable reduction in size and weight, which cannot otherwise be reduced with traditional radiofrequency technologies (Figure 1).

The development foresees the use of the main photonic integration technological platforms (SOI, SiN, InP, LNOI), each of which will be used for the most appropriate functionality, such as, for example, InP for modulation and amplification,

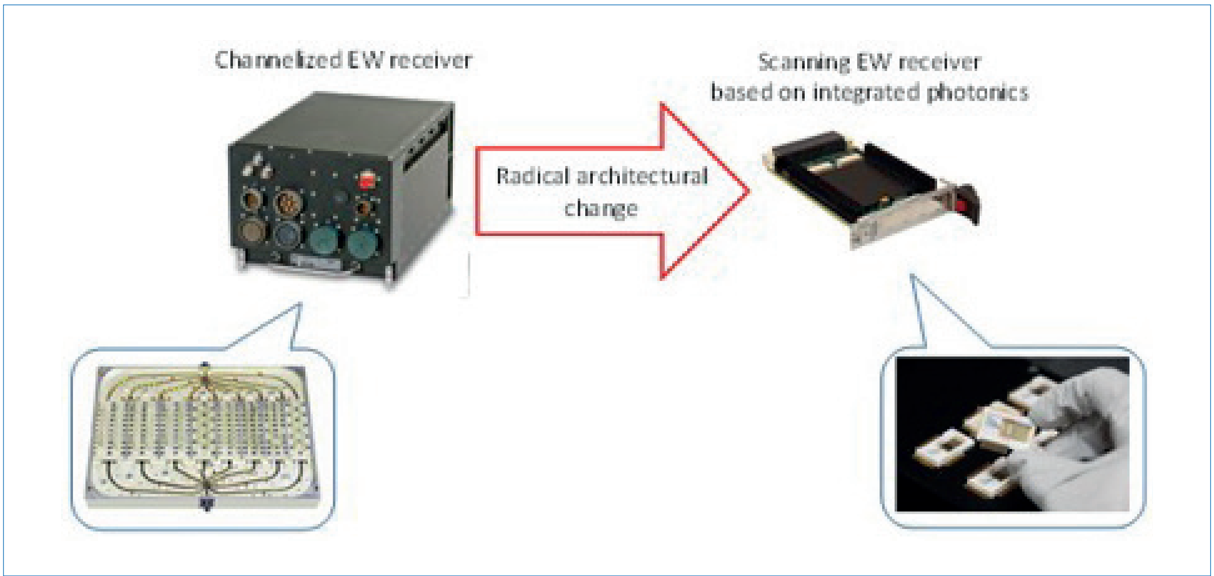

Figure 1 - Low SWaP solution needed for new platforms: Fighter 6th gen and UAV

SiN for filtering, etc.

As a result, in order to optimize the performance of the entire receiver, it is necessary to use more than one photonic integration technology platform.

Figure 2 shows one of the masks developed in phase 1 of the project [Ref. 2] and [Ref. 3] and which will be manufactured in the foundry and characterized in the current second phase. The first SiN chip is designed within a 32mm x 8mm area, while the InP chip is 8mm x 12mm in size. The most recent packaging techniques of the photonic subsystems have also been considered in the project. In particular, the alternative between packaging each monolithic photonic chip individually, and packaging a hybrid assembly in which multiple chips of different materials are assembled and boxed into a single more complex but more compact system deserves mention here.

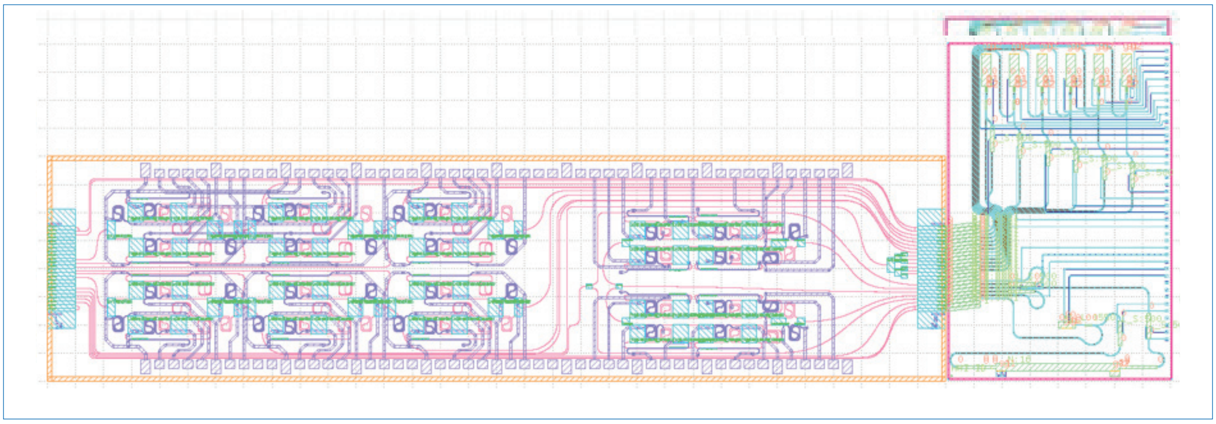

Figure 2 - Mask used for the fabrication of the two designed PICs

POTENTIAL TECHNOLOGY APPLICATION AND EXPLOITATION

Through the current project ELT has the possibility of producing new generation EW systems competitive on the market that can be applied both in the naval and avionic fields, and for both manned and unmanned platforms. Through the collaboration with the CNIT laboratory in Pisa, skills are being acquired on integrated microwave photonics technology (MicroWave Photonics, MWP) with the possibility of use for different applications both in the civil and military fields. On the other hand, the CNIT PNTLab will significantly increase its expertise in the field of integrated photonics for microwaves, strengthening its position of excellence in the international applied research scenario. The technological advance in the field of integrated photonics for microwaves can find application in the field of "cognitive radio" in next generation communications and in the medical field of biophotonics.

The project will therefore have important repercussions in increasing the skills of the proponents - and of the country system - in photonic technologies for microwaves. It is reasonable to expect that the project will also have very promising repercussions on the future products that Elettronica will be able to market. In fact, the solution implemented in esaSCAN can be applied both in the naval and avionic fields, and for both manned and unmanned platforms. The competitive advantage that will be achieved once the use of these technologies is industrialized and consolidated by Elettronica will allow the Company to maintain an undisputed leadership in the EW sector both in Europe and worldwide, and therefore to guarantee a level of growing sales and an expanding occupation, and consequently a possible economic and strategic advantage for the country.

CONCLUSIONS

The ongoing esaSCAN research program is of fundamental importance for ELT which, in order to remain competitive in the EW market, must continue to propose electronic warfare receivers increasingly compact and installable on sixth generation UAV and Fighter platforms. Furthermore, microwave photonics technologies will make it possible to integrate Ka-band coverage in a single receiver and therefore also counteract the new threats emerging in this frequency range. For the CNIT PNTLab, the research and development of integrated photonic technologies for microwave applications represents one of the main scientific and technological objectives. The development of esaSCAN therefore falls fully within its road map. Furthermore, the results obtained in esaSCAN will be able to generate new research in related application and technological fields, such as radars (both military and civil), wireless communications, biophotonics, etc.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

CNIT:	Consorzio Nazionale Interuniversitario per le Telecomunicazioni
ELT:	Elettronica S.p.A.
esaSCAN:	6-channel SCANning EW receiver based on integrated photonics
EW:	Electronic Warfare (Guerra Elettronica)
InP:	Indium Phosphide
LNOI:	Lithium Niobate On Insulator
MWP:	MicroWave Photonics
PNRM:	Piano Nazionale della Ricerca Militare
PNTLab:	Photonic Networks&Technologies Nat'l Lab
SiN:	Silicon Nitrate
SOI:	Silicon On Insulator
UAV:	Unmanned Aerial Vehicle
EMI:	Electro Magnetic Interferences

KEYWORDS

Integrated microwave photonics, RF spectrum sensing, coherent detection, Directional of Arrival, Electronic Warfaree

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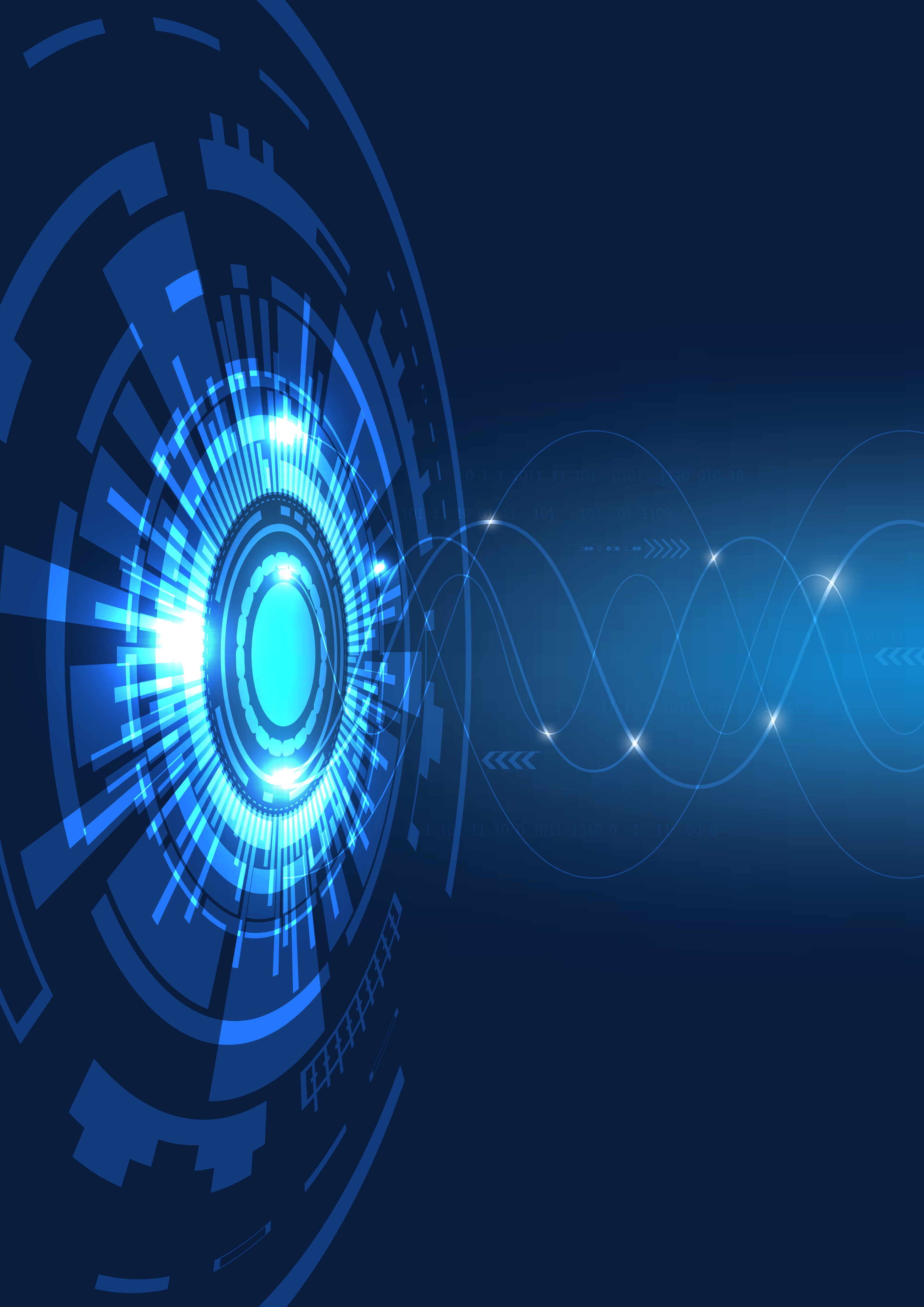

EUROPEAN RESEARCH

INTRODUCTION

In the context of European cooperation, Italy actively supports cooperative technological research projects within the European Defense Agency. Below are the results of some research projects considered exemplary of European cooperative technological research activities:

- Research project *"Advance Light Ballistic Protections"* **(ALBA)**.
- Research project *"European Detonation Code"* **(EDC)**.
- Research project *"Quantum Laser-based Multi-parametric Portable Sensor"* **(QLAMPS)**.

The ALBA Project was focused on study and development of level K6 (STANAG 4569) ballistic protection solutions to be applied to medium and light armoured vehicles. The following objectives were achieved: 1. Analysis of current state of light and medium armoured vehicles and their ballistic protections currently available on the market, corresponding to level K6. 2. Study of K6 threats interactions with armour materials and multi-layer armour solutions. Development of K6 threats numerical model to simulate the K6 threats interactions with the armour. 3. Development of K6 ballistic protection armour systems with good ballistic performance, favourable costs-performance ratio, reasonable weight ratio and manufacturing costs. This included the analysis of the benefits of using different advanced armour materials and their multi-layer combinations. 4. Ballistic tests of advanced armour materials and armour solutions. The development of the whole K6 armour system to be applied to medium armoured vehicles. Complex ballistic tests of the armour system using K6 threats to confirm it´s functionality and validity.
This project was managed and funded by Italy and Czech Republic in the frame of the Project n° B-1458-GEM1-GP of the European Defence Agency. The Industrial Consortium was composed by: Leonardo Electronics, Defence Systems Business Unit (IT), Vojenský výzkumný ústav, s.p.(CZ) and Bogges, spol. s r.o. (CZ).

INTRODUCTION

The study of terminal ballistics is a large and diverse field. It involves the physical penetration of a broad class of materials by a broad class of projectiles. Some of the projectiles have penetration mechanisms based on high velocities and overwhelming energies, and others on the ability to focus a maximum amount of energy on a very small pinpoint.

The traditional way to defeat armour piercing threats is through the use of monolithic metallic armour systems. These systems are quite well understood, and could easily be adapted to any of the new vehicles under development. The problem is that in order to defeat modern threats (long rods), which are becoming more and more lethal, a tremendous amount of the traditional armour is required. For level K6 (30mm APFSDS) threat, an advanced multi-component lightweight armour solution is required.

Two armour kit solutions were specifically studied and developed for:

- ALBA turret mock-up, having inside consortium the Original Equipment Manufacturer, the design has been inspired by existing solutions using the angles evolving from the solutions in-service with Aluminium Alloy base armour (24 ÷ 35 mm of AA5059-H136 grade);
- ALBA vehicle mock-up, the design has been inspired by the actual development trend for the medium class platforms with Steel base armour (25 ÷ 30 mm of 440 HBW Steel).

TECHNICAL BACKGROUND

The ballistic solutions developed in ALBA project are listed on Table 1, where they are compared in terms of weight with monolithic RHA. Defined the ballistic efficiency as the ratio between the necessary RHA areal weight to stop the threat and the areal weight of the considered ballistic solution, it is evident that the developed ballistic solutions are

very effective in terms of protections, but have a moderate ballistic efficiency.
As a matter of fact, during the program it was privileged the effectiveness and the level of confidence of the identified ballistic solutions. The result is that the contribution of the Base Armour and the spall liners to the protection is extremely low, as AoAs alone can stop the threats. The areal

	MAIN AREAS	30mm APFSDS-T NATO [°]	AREAL WEIGHT [kg/m^2]	RHA AREAL WEIGHT [kg/m^2]	BALLISTIC EFFICIENCY
SOLUTION 1	1T 3T 4T	46 50 56	547	678	1.24
SOLUTION 2	2T	67	327	369	1.17
SOLUTION 3	7T	NO	267	-	-
SOLUTION 4	6T	60	486	488	1.00
SOLUTION 5	5T	78	306	203	0.66

Table 1 - Final ALBA ballistic protection solutions.

weights obtained for the different configurations of ballistic protections sound good for heavy tracked vehicle but could be critical for the available payload of light and wheeled armoured vehicles. It is possible to save a relevant amount of weight optimizing the thickness of the layers of the AoAs in such a way that the Base Armour and internal spall liners actively contribute to stop the threat.
The weight of the total protection kit of a big turret in service using the actual results of ALBA project can be estimated in about 3.8 tons. The weight of the total protection kit for the same turret can be reduce of hundreds of kilograms, optimistically up to 3 tons, following a less conservative approach that considers of the contribution at the protection of the Base Armour and of the internal spall liners.
Methodology(8)

METHODOLOGY

The protection solutions were designed and optimized by the continuous interaction and tuning activity between the small-scale numerical simulations and the ballistic tests on representative engineered targets. The outputs of the numerical model were compared with the results of the ballistic tests of the MA, SWA and multi-hit of the armour systems (Figure 1).
The key parameter describing armour material capability to withstand the energy of the multi-hit is the material distortion area after projectile impact. Especially ceramic materials feature with the large area of the distortion after the projectile impact which markedly limits their capacity to withstand the multi-hit (Figure 2).
The final (global scale) numerical simulations of the demonstrator confirmed the validity and the accuracy of the numerical model developed (Figure 3). The investigations were based on an explicit-implicit approach in which the small-scale explicit results were used to reduce the simulation time of the global scale event, allowing full vehicle dynamic analyses to be performed on a timescale that is impossible with the conventional Finite Element Model.
The final Advanced Light Ballistic protections were built and installed on a real turret mock-up and vehicle representative panels. The final demonstrator tests were performed in Polička Proving Ground, according to AEP-55 Volume 1 and STANAG 4569.

The ballistic protections were able to withstand multiple shot impacts in the MAs and single shot impacts in SWAs. Totally of 32 shots were fired in the final demonstration test (Figure 4). The results of the ballistic tests confirmed the validity of the armour concept developed in the ALBA project.

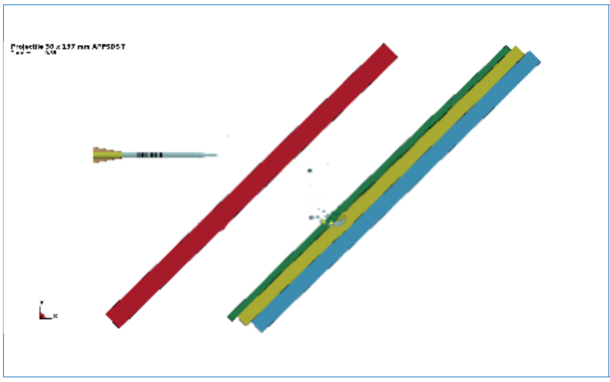

Figure 1 - Small-scale multi-hit MA impact simulation.

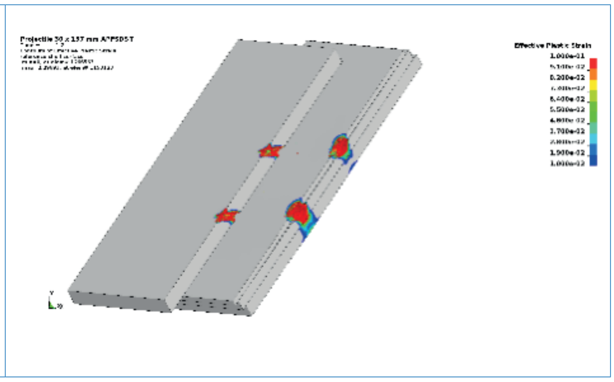

Figure 2 - Multi-hit AoA perforations and Base armour residual penetrations from simulation activity.

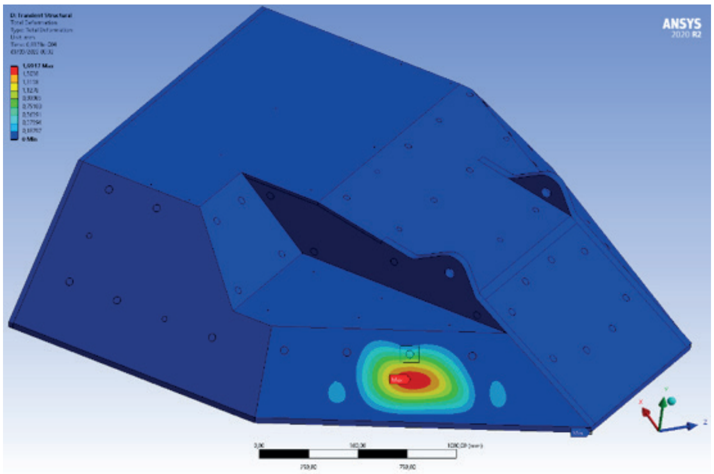

Figure 3 - Global scale simulation of the complete mock-up.

Figure 4 - ALBA demonstrator at the end of the ballistic test campaign.

PPOTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

Lightweighting is a cross-cutting competency across all modernization priorities of the Next Generation Combat Vehicle's objectives in close combat capabilities in manned, unmanned and optionally manned variants, and ability to fight and win against any foe.

The overarching principles and science of lightweighting will be paramount in ensuring that the vehicle:

- Is agile, expeditionary, more easily transportable, and lethal.
- Has overmatch capabilities to conduct operations that are decentralized, distributed, and integrated.
- Uses autonomous capabilities (full or autonomy-enabled), artificial intelligence and manned-unmanned teaming for decisive overmatch proficiency.
- Has smaller deployment, employment, and sustainment footprints.

CONCLUSIONS

ALBA project has demonstrated the capability to produce AoA solutions to be applied to medium armoured vehicles able to defeat both 30mm and FSP threats of Level K6 STANAG 4569. Even if the budget limitations of the project did not allow to assess the complete NATO qualification process of AEP-55 Volume 1 for ALBA Turret and Vehicle mock-up, the results were very satisfactory.

The developed solutions are cheap, steel-based, easily assembled and mounted on existing turret/ vehicles, and ready to use in the modern battlefield (start TRL 4 - final TRL 8). The developed numerical model allows to adapt/scale with high confidence levels the Advanced Light Ballistic protection solutions to other turret and vehicular platforms.

The proposed follow up of this project is to study "smart modules" that are effective "tricks" against long rod threats able to reduce and limit the weight of the total protection kit to be able to be installed mainly on light and wheeled armoured vehicles. The goal is to achieve a ballistic efficiency of 1.5.

Funzionario EDA (Giuseppe D'aquino), IT PAMG (Michele Tronci), CZ PAMG (Pavel Maňas) e Team del consorzio ALBA al termine della dimostrazione finale al poligono di Polička.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AEP	Allied Engineering Publication
AoA	Add-on Armour
APFSDS	Armour Piercing Fin Stabilised Discarding Sabot
FSP	Fragment Simulating Projectile
MA	Main Area
RHA	Rolled Homogenous Armour
STANAG	STAndardization Nato AGreement
SWA	Structural Weak Area
TRL	Technology Readiness Level

KEYWORDS

Ballistic protection, impact simulation, multi-layer solution, composites, multi-hit, long rod, lightweight armour

PROJECT INFORMATION

EDA Cat B number:	B-1458-GEM1-GP
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EUDETCODE

EUDETCODE

The detonation is a sequence of exothermic chemical reactions characterized by the rapid propagation and instantaneous increase in pressure and temperature. These reactions occur in the so-called detonation zone, which moves through the unreacted part of the explosive at the characteristic detonation velocity. Because of this process, the explosive is transformed into solid, liquid, or gaseous products at high temperature and pressure, and a shock wave is generated.
The EDA cat.B EUDETCODE project aims to develop a thermochemical code that allows the prediction of the detonation characteristics of explosives. The modular code will consist of three main blocks: a solver, capable of solving thermodynamic equations by minimizing the Helmotz's free energy, a collection of equations of state for reactants and products, and a database containing the coefficients of equations of state and thermodynamic constants. The code's performance in terms of detonation velocity, pressure, and expansion will be validated through experimental measurements of detonation velocity, pressure, and dynamic expansion of reaction products.
The ultimate goal of the project is to develop a state-of-the-art software tool capable of accurately predicting the chemical and physical characteristics of energetic materials during their detonation.

INTRODUCTION

The EUDETCODE project is focused on the development of a highly accurate computational code capable of predicting the performance of explosives and propellants. Such a code is currently unavailable in the European market, where obsolete versions of the CHEETAH code, developed by the Lawrence Livermore National Laboratory and classified as "US eyes only" in its latest versions, or other proprietary codes with low performance are used to design warheads, propellants, and ballistic systems.
Despite the fragmented expertise in numerical computation for predicting the performance of energetic materials in Europe, some member states, supported by national companies or research organizations, have developed their own detonation codes with partial response to the industry's needs. However, in Italy, the knowledge in this field is relatively immature, and the EUDETCODE project aims to establish a network of expertise among the armed forces, industry, and universities to mature this technology.
The short-term objective of the EUDETCODE project is to develop a beta version of the calculation code using new experimentally validated calculation models. In the long term, a computational platform will be created to support the European defense and industrial base in the field of energetic materials.

TECHNICAL BACKGROUND

The EUDETCODE project aims to develop a high-precision calculation code capable of predicting the performance of explosives and propellants. Currently, no such code is available on the European market, and outdated versions of the CHEETAH code, developed at the Lawrence Livermore National Laboratory and classified as "US eyes only" in its most recent versions, are used for designing warheads, propellants, and ballistic systems. Fragmented expertise in the field of numerical computation for predicting the performance of energetic materials exists in

Europe, and although some member states have developed their detonation codes, these codes only partially meet the needs of the industry. In Italy, knowledge in this area is underdeveloped, and the EUDETCODE project aims to establish a network of expertise among the Armed Forces, industry, and universities to mature this technology.
Current detonation codes are based on the Zeldovich-von Neumann-Döring (ZND) model and the Chapman-Jouguet (CJ) hypothesis, and assume chemical equilibrium in a steady state. Reactants and products are described by state functions and equations of state (EOS) that describe the behaviour of the chemical species involved in detonation at the high temperatures and pressures generated in the reaction zone. Most programs use the Becker-Kistiakowski-Wilson (BKW EOS) equation of state for gaseous reaction products; more advanced programs use a modified version of the BKW EOS, the Exp 6 EOS, or the Jacobs-Cowperthwaite-Zwisler EOS. The most advanced detonation code is CHEETAH 9.0, which can be used by European operators only under license from the US government. In Europe, other less-performing codes have been developed, but their results can be used as a reference and represent the state-of-the-art of thermochemical codes for detonation.
EUDETCODE will be able to handle various equations of state and allow the operator to select the most appropriate one to describe the detonation phenomenon under consideration. The software's ability, to easily switch between different equations, represents a significant improvement over all existing codes. In addition, it will be able to handle non-ideal explosives, using versatile and modern solvers based on precise, stable, and efficient numerical methods for optimization. EUDETCODE will be interfaced with a database containing input parameters for explosives and other substances involved in detonation. The main function of the code will be to determine the detonation velocity at the CJ point, i.e., the shock wave velocity. Moreover, the software will be able to predict the concentration of the products resulting from the chemical reaction and the thermodynamic variables in the isentropic expansion that occurs after the CJ point.

METODOLOGIA

This section describes the mathematical model underlying the EUDETCODE thermodynamic code. It will be implemented in C++ and used to predict the dynamics of stationary detonations. The research carried out so far can be divided into two areas: the development of the theory describing the problem and its numerical solution. To simulate the thermochemical behaviour of detonation products, it is necessary to define an equation of state (EOS); in this work, the Becker-Kistiakowsky-Wilson (BKW) EOS has been used, but in the future, the operator will be able to choose from a database of different EOS.

$$p = \frac{\rho RT}{W_{mix}} \cdot Z(\rho, T, x_{i,eq})$$

$$Z = 1 + \chi e^{\beta\chi} \qquad \chi = \frac{\rho\kappa\sum k_i x_{i,eq}}{W_{mix}(T+\theta)^{\alpha}}$$

The explosion state contains the expression of Helmholtz's free energy as a function of the chemical composition at fixed volume and temperature:

$$A = A^{id} + D_{p,A}$$

$$A^{id} = \sum_i n_i(\mu_i - RT) \qquad\qquad D_{p,A} = \frac{RT}{W_{mix}} \int_0^\rho \frac{Z-1}{\rho} d\rho$$

By minimizing the Helmholtz free energy, the equilibrium chemical composition can be obtained as a function of temperature, and the Hugoniot of the products can be defined:

$$H: \quad e\left(T, n_{eq}(T)\right) - e_0 - \frac{1}{2}(p(T) + p_0)(v_0 - v) = 0$$

$$e = e^{id} + D_{p,e}$$

$$e^{id} = A^{id} + TS^{id} \qquad\qquad e_{p,e} = \frac{RT^2}{W_{mix}} \int_0^\rho \frac{1}{\rho} \frac{\partial Z}{\partial T}\bigg|_\rho d\rho$$

The non-linear equation H is solved with respect to the temperature T for each specific volume, resulting in the construction of the Hugoniot curve in the pressure-volume plane.

The second module of the code is based on the Chapman-Jouguet theory. The shock wave velocity can be expressed as a function of the specific volume of the mixture by reversing the Rayleigh line relationship:

$$D(v) = \sqrt{\frac{p_H(v) - p_0}{\rho_0^2(v_0 - v)}}$$

Where the pressure behaviour as a function of specific volume is obtained by interpolating the previous results. A minimization method is used to find the value of D that makes the curves tangent (Figure 1). The code uses a combination of numerical techniques, including spline approximation, the interior point algorithm, and the Brent method, together with the ideal gas dynamics to model the behaviour of detonation waves, particularly their velocity and pressure profiles.

Finally, the last module, "isentropic expansion," describes the expansion of the products after the CJ point under the assumption of an isentropic transformation (Figure 2).

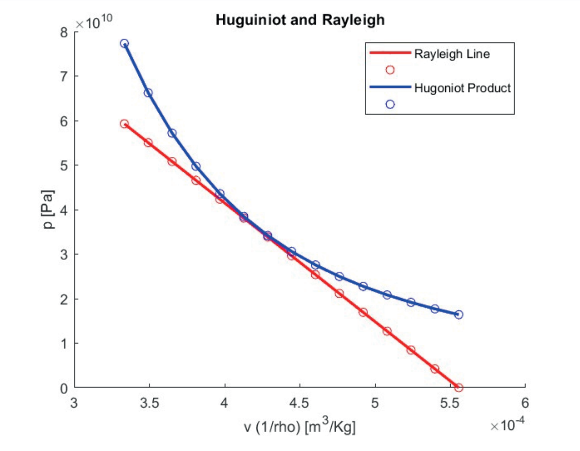

Figure 1 - Hugoniot curve of products (blue) and Rayleigh line (red) for RDX

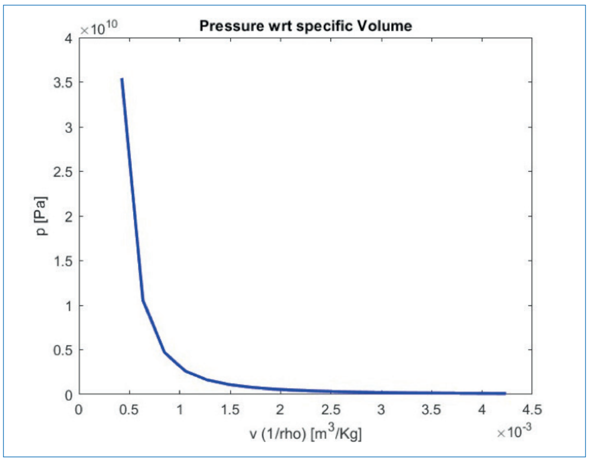

Figure 2 - Isentropic expansion trend of RDX products starting from the CJ point

RDX Density	Variable	Experimental Point	Our Code	Relative Error
$\rho_0 = 1000 \frac{Kg}{m^3}$	$D_{cj}\ [m/s]$	6128	6069	0,9%
	$T_{cj}\ [K]$	3600	3344	7,6%
	γ	2,48	2,62	5,7%
$\rho_0 = 1800 \frac{Kg}{m^3}$	$D_{cj}\ [m/s]$	8754	9105	4,0%
	$T_{cj}\ [K]$	2587	1827	7,1%
	γ	2,98	3,12	4,6%

Tabel 1 - Comparison between code and experimental results for RDX for various density values

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The defense sector is the primary beneficiary of the use of detonation codes: in fact, thanks to these tools, designers can simulate and predict the performance of warheads, missiles, thrusters, and launch systems. In particular, detonation codes are used in the design of high-energy explosives and propellants, allowing key parameters that influence explosive performance, such as velocity, pressure, and temperature reached in the detonation zone, to be determined with extreme accuracy. In general, the use of detonation codes also contributes to greater safety and reliability in the use of high-energy explosives and propellants, allowing new products that fully meet the needs of the defense sector to be designed and developed.

EUDETCODE will contribute to strengthening the industrial and technological base of European defense and improving European competence in the development of future missiles and munitions. In fact, a software tool will be developed to accurately predict the performance of energetic materials, and relevant experimental tests will be conducted to verify its accuracy. The ultimate goal is to provide a cutting-edge software tool that enables the European defense community to maintain its strategic autonomy

CONCLUSIONS

The modeling activity described in this article is part of the EUDETCODE project, aimed at developing a code capable of predicting the main characteristics of the detonation of energetic materials. Indeed, the use of such codes has become increasingly widespread in the research and development of high-energy explosives and propellants. These codes enable simulation and prediction of the performance of explosives and propellants, as well as the design of warheads, propulsion and launch systems, and lethality studies on energetic materials. However, the choice of the most suitable equation of state to describe the combustion/detonation phenomenon remains an open problem and continues to represent a challenge for researchers. Moreover, it is important that detonation codes are able to interface with other codes and solve time-dependent effects to ensure their longevity and long-term growth. In the future, research on these codes will focus on better describing the combustion/detonation phenomenon and implementing new features and capabilities that meet the needs of the scientific and defense community.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

A	Helmholtz's free energy
A^{id}	Helmholtz's free energy for ideal gases
BKW	Becker-Kistiakowsky-Wilson equation
CJ	Chapman-Jouguet point
D	Detonation Velocity
D_{cj}	CJ Detonation Velocity
$D_{p,A}$	Departure function of Helmholtz's free energy
$D_{p,e}$	Departure function of internal energy
e	Internal energy
e^{id}	Ideal internal energy
e_0	Internal energy of the explosive in standard conditions
EDA	European Defence Agency
EOS	Equation of state
EUDETCODE	European Detonation Code
FF.AA	Army Forces
n_i	Moles number of the i-th chemical species
p_H	Pressure for the Hugoniot's product
p_0	Reference pressure
P	Pressure
R	Universal gases constant
RDX	Cyclotrimethylenetrinitramine
S^{id}	Ideal Entropy of the system
T	Temperature
T_{cj}	CJ Temperature
US	United States of America
v_0	Reference specific volume of the explosive
W_{mix}	Molar mass of the mixture
Z	Compression Factor
ZND	Zeldovich-von Neumann-Döring model
α, β, θ, k	BKW Coefficient
k_i	Molare covolume of the i-th chemical species
μ_i	Chemical potential of the i-th chemical species
ρ	Density
ρ_0	Standard density of the explosive
X_i	Molar fraction of the i-th chemical species

KEYWORDS

EUDETCODE, detonazione, codice di detonazione, equazione di stato, letalità, esplosivi, materiali energeticii

PROJECT INFORMATION

PNRM number:	EDA cat. B.PRJ.RT.878
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Q-LAMPS

An early and effective hazard assessment plays a key role to prevent attacks. A full hazard assessment must simultaneously consider several threat factors, which include magnetic fields stemming from the presence of illicit materials and devices, ionizing radiation, chemical substances, and biological agents. These factors can cause humans, vehicles or buildings direct damage, can warn of significant risks as chemical or nuclear weapons, or can indicate high-risk sites and potential imminent attacks which can be countered or prevented, if properly identified.

The project Q-LAMPS ¬– Quantum LAser-based Multi-parametric Portable Sensors – aims at advancing the EU force detection and protection capabilities in terms of surveillance and situation-awareness in both military scenarios and sensitive civil areas. The project, structured as a collaboration between Italian and Polish research institutions and companies headed by CNR, will develop the technological building blocks of a novel multi-parametric sensors platform that exploits state-of-the-art optics, quantum physics, and machine learning, to provide fast and precise assessment of manifold hazards.

The identified solutions will allow to advance in knowledge and availability of quantum sensing technology able to surpass the limitations of currently available field monitoring systems in terms of multiplexing, specificity, sensitivity and detection capability.

INTRODUCTION

The proliferated risk of attacks involving weapons of mass destruction of physical, chemical, biological, and nuclear nature, has sharpened the urgency of developing novel effective tools for threat mitigation. The future technology must necessarily meet the demand for portable multi-parametric sensors, integrated or integrable on a single platform, able to measure simultaneously different quantities, with short response time, high sensitivity and selectivity.

The fields of optics and quantum physics, combined with artificial intelligence (AI) and machine learning (ML), are nowadays able to provide solutions to this problem. Quantum technologies based on diamond Nitrogen Vacancy (NV) centers are integrable and provide high precision measurement of magnetic fields; optical sensors based on mid-infrared lasers allow trace detection of toxic gases or explosives products; fiber optics technology can be designed for detection of ionizing radiations; miniaturized sensors based on Laser Induced Fluorescence (LIF) can be used for detection of biological agents; classical and quantum AI schemes and ML algorithms can be developed for fast data processing and risk identification.

These technologies can provide both military and sensitive civil areas (airports, harbors) with networks of quantum and optical sensors able to map the territory, locate possible risk sources and prevent attacks.

TECHNICAL BACKGROUND

Currently available sensors suffer from various limitations: first, they are very specific sensors, capable of measuring only some of the parameters related to potential hazards; second, they are often inherently low sensitive or selective. For example, portable electronic sensors used for the detection of volatile chemicals suffer intrinsic poor selectivity, resulting in possible false alarms. Fluxgate sensors, the most widespread and high-performance solution for measuring DC or low-frequency AC magnetic fields, are expensive, bulky, and power-consuming devices, and the measurement is affected by temperature drifts. Current sensors of ionizing radiation suffers of saturation effects and/or low damage thresholds limiting the detection range, strong sensitivity to electromagnetic noise interference (e.g. ionization chambers), and high-voltage front-end electronics (e.g. scintillation detectors and ionization chambers) preventing possible integration in a multiple sensors network for in field operations.

The Q-LAMPS project aims at developing the technological building blocks of a novel multiparametric sensor that exploits state-of-the-art optics, quantum physics, and machine learning, to provide precise and accurate assessment of manifold hazards. One keyword of the project is adaptability, which is pursued with a modular approach that makes the systems easily adaptable to different requirements and scenarios. The optical and quantum sensors developed at CNR-INO labs in Sesto Fiorentino will enable nanoTesla measurement of AC magnetic fields, and detection of toxic gases or explosive vapours in concentrations below the parts-per-billion in volume. The fiber-based optical technology developed at CNR-INO laboratories in Naples will detect ionizing radiation with doses in the high range (100-1000 Gy), availing of a very compact architecture. The biological sensor developed at MUT-IOE in Warsaw will enable stand-off and real-time detection of biological aerosols. The partner companies (the Italian FlySight and ppqSense, and the Polish Kenbit and CRW Telesystem-Mesko) will provide key components and develop custom solutions for data collection, integration and analysis.

METHODOLOGY

The quantum sensor for magnetic field measurements is based on Nitrogen-Vacancy (NV) centers in diamonds. NV centers are fluorescent quantum defects in the diamond crystal (Figure 1a). Their quantum state is determined by measuring the spin-dependent photoluminescence under laser excitation. Any magnetic field perturbing the NV spin can be measured with high spatio-temporal resolution by monitoring the photoluminescence intensity. A sensitivity down to ~100 nT/Hz$^{1/2}$ is expected, with a spatial resolution below 1 mm.

The sensor for ionizing radiation is based on Fiber Bragg Grating (FBG) segments, characterized by a periodic refractive index modulation (Figure 1b). Ionizing radiation hitting the FBG segment produces a variation of the fiber refractive index, measurable with a telecom laser coupled to the fiber. This pure passive sensor is totally insensitive from high-intensity background electromagnetic noise and from the interference of other equipment, making it ideal for integration in more complex systems or structures.

Two solutions are proposed for volatile compounds

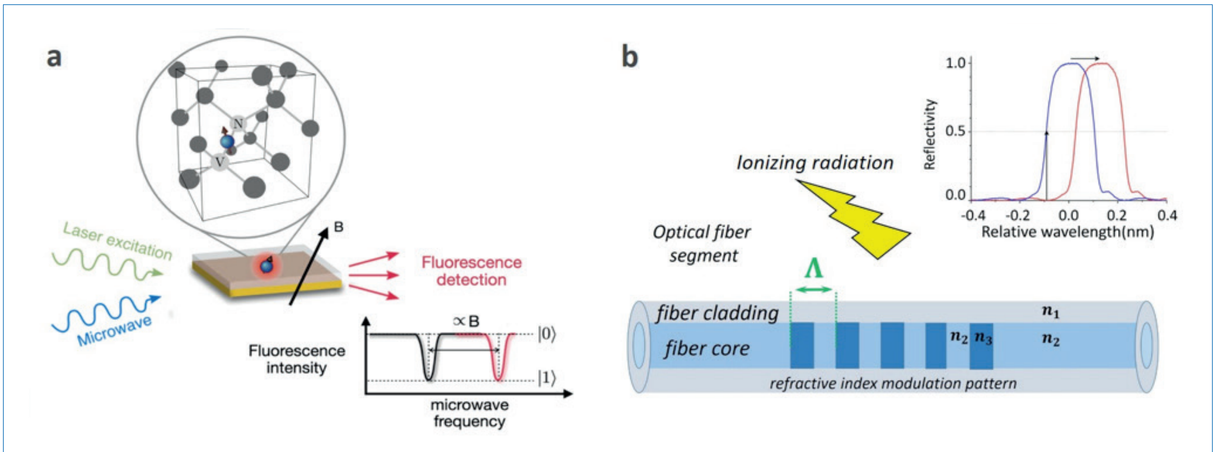

Figure 1 - Working principle of the quantum sensor based on NV-centers in diamonds for magnetic field measurements (a) and of the fiber-based sensor for ionizing radiation (b). mw: microwave; Λ: period of the Bragg grating; n: refractive index of the material.

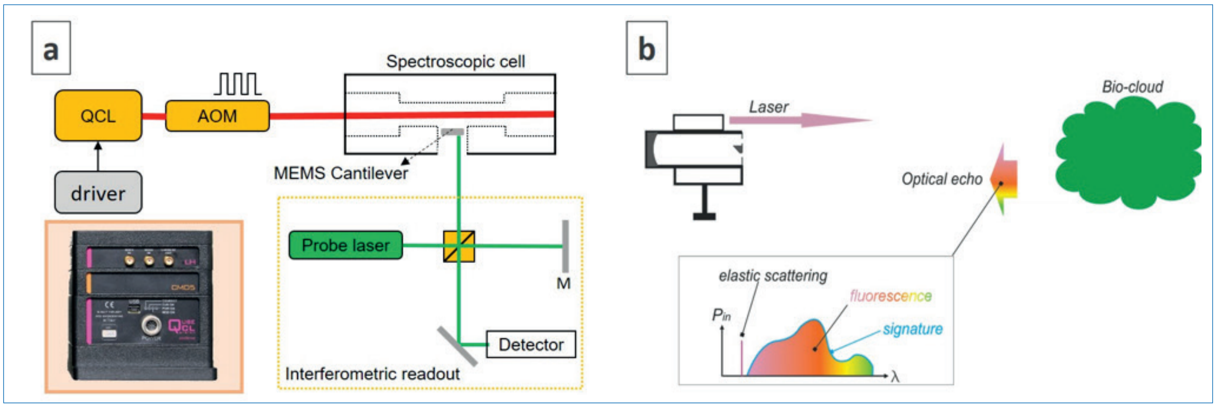

Figure 2 - Schematic of the optical sensor for toxic and explosive gases (a) and of the bio-LIDAR sensor (b). QCL: quantum cascade laser; AOM: acousto-optical modulator; MEMS: micro-electro-machine system; M: mirror. In figure (b) a detail of the driver developed by ppqSense is shown.

detection in air. An optical sensor based on the photoacoustic technique combined with acoustic and optical resonators will detect toxic gases and explosive vapors at concentrations below the part-per-billion in volume. The key components are a mid-infrared laser for target molecules excitation, and a MEMS cantilever used as transducer to measure the target gas concentration (Figure 2a). The second one is a LIDAR based on LIF and Depolarization (Figure 2b), equipped with improved quality laser and advanced data analysis algorithms. The sensor will allow remote detection of bio-aerosols within a range of 10 km. A mobile chamber for releasing aerosols, specifically designed for the project, will be used for testing the system.

Finally, a platform for signal analysis and communication, enhanced with classical and quantum AI schemes and ML algorithms, will enable future integration of the developed technologies into a single multi-parameter detection unit.

POTENTIAL TECHNOLOG APPLICATIONS AND EXPLOITATION

Given the wide range of applications, several companies may intend to invest in R&D of the proposed sensors to respond to military and civilian needs. The commercial interest moves in two main directions: (i) compact and low-cost sensors with a wide diffusion in the civil sector, (ii) advanced sensors that can be installed in industrial and military relevant environments, including areas of high housing concentration and strategic military areas.

A significant boost for the production of the proposed sensors stems from the control of electromagnetic and chemical pollution emissions, also in view of the requests to contain and combat global climate warming. Air quality monitoring in workplaces and urban areas requires reliable and compact sensors, which are only partially available in the market. The magnetometer can find applications in geological and geotechnical investigations, oil and energy industry, civil and aerospace engineering. Optical fiber systems are particularly suitable for the realization of compact and integrated devices intrinsically oriented to the implementation of networks of sensors for remote monitoring. Fiber-based dosimeters have already been successfully explored for low-dose radiation detection in medical applications. Being based on technologies already present in telecommunications market, fiber-based systems guarantees high quality and low production costs.

CONCLUSIONS

The Q-LAMPS project exploits the state-of-the-art in optical sensors, quantum sensors and artificial intelligence, with the aim of creating the building blocks of a multi-parametric sensing platform able to detect, simultaneously and in real time, threat factors like magnetic fields due to illicit materials and devices, ionizing radiation, chemical substances, and biological agents. One of the advantages of the developed technology is its adaptability to different scenarios, from monitoring strategic military (or civil) areas to mapping the risks in areas involved in in-fields operations.

The project gathers a European network of research institutions and industrial companies cooperating in developing advanced optical and quantum sensing technologies, with a transformational approach which makes them adaptable to a variety of scenarios and environments. Although it has been specifically thought to answer the demand of technological sensing solutions for safety in sensitive military areas and in field operations, the project is highly relevant also for scientific development and knowledge advancement in the strategic field of quantum technologies.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AC	Alternating Current
AI	Artificial Intelligence
CNR	Consiglio Nazionale delle Ricerche
CNR-INO	Consiglio Nazionale delle Ricerche – Istituto Nazionale di Ottica
DC	Direct Current
EU	European Union
FBG	Fiber Bragg Grating
LIDAR	Light Detection and Ranging
LIF	Laser Induced Fluorescence
MEMS	Micro Electro-Mechanical Systems
MUT-IOE	Military University of Technology - Institute of Optoelectronics
NV	Nitrogen-Vacancy
Q-LAMPS	Quantum LAser-based Multi-parametric Portable Sensors
R&D	Research and Development

KEYWORDS

Quantum technologies, multiparametric sensor, artificial intelligence, magnetic field measurements, trace-gas detection, ionizing radiation measurement, volatile biological compounds, explosive vapors detection

PROJECT INFORMATION

Project number:	EDA B-PRJ-RT-989
Organization:	Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE)
Responsible entity:	Consiglio Nazionale delle Ricerche – Istituto Nazionale di Ottica (CNR – INO)
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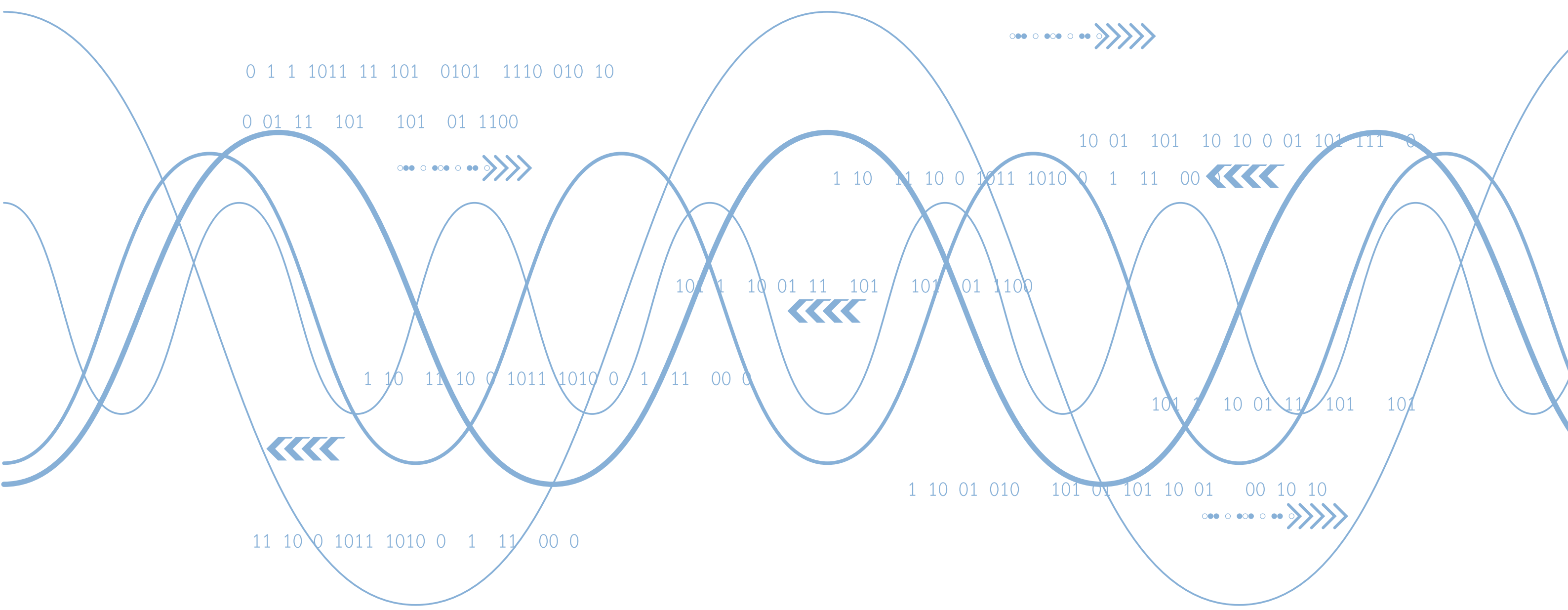
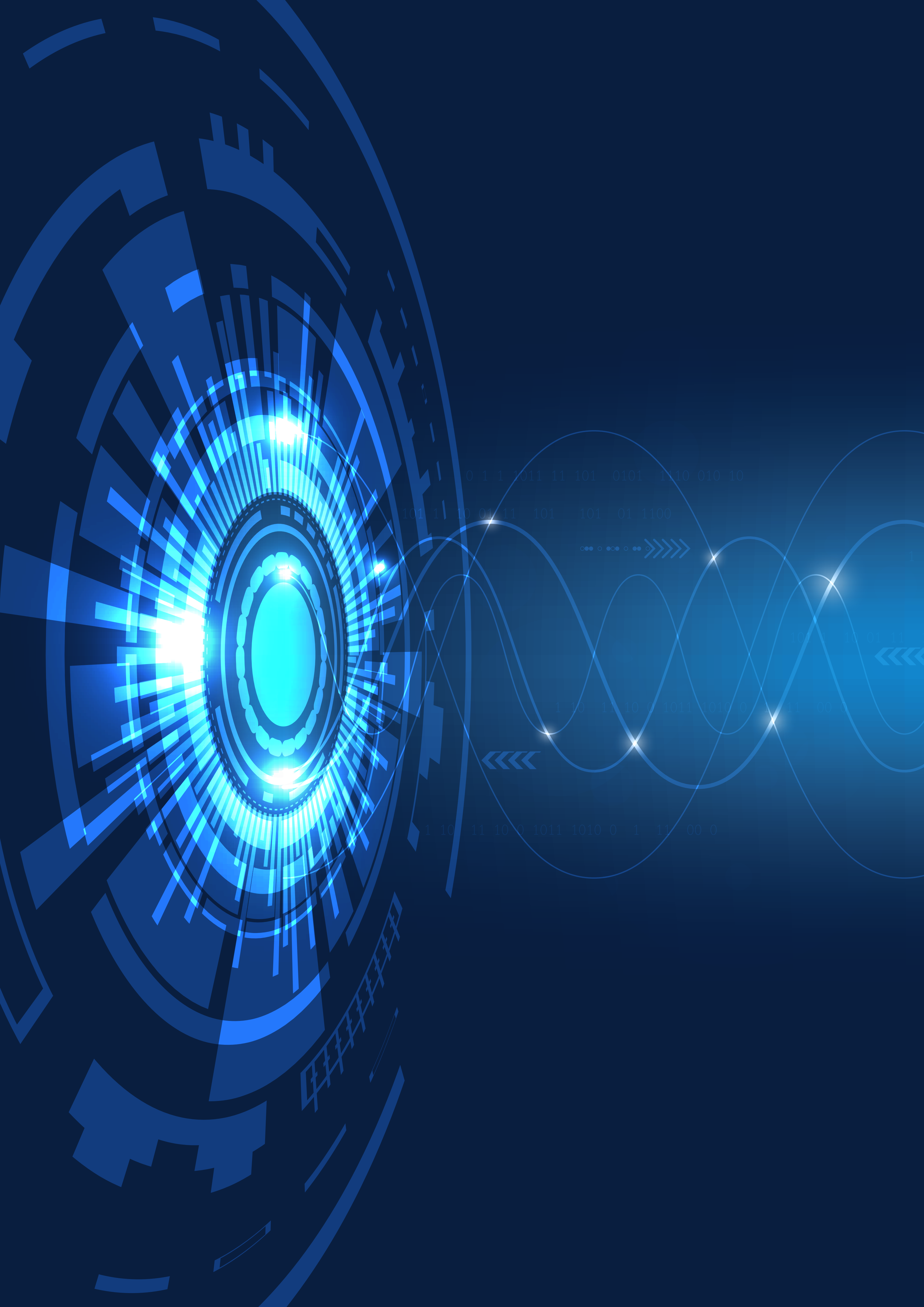




NATO AND EXTRA-EUROPEAN RESEARCH

INTRODUCTION

In the context of bilateral - multilateral cooperation within NATO and outside Europe, Italy has been carrying out a fruitful technological cooperation activity for several years now.

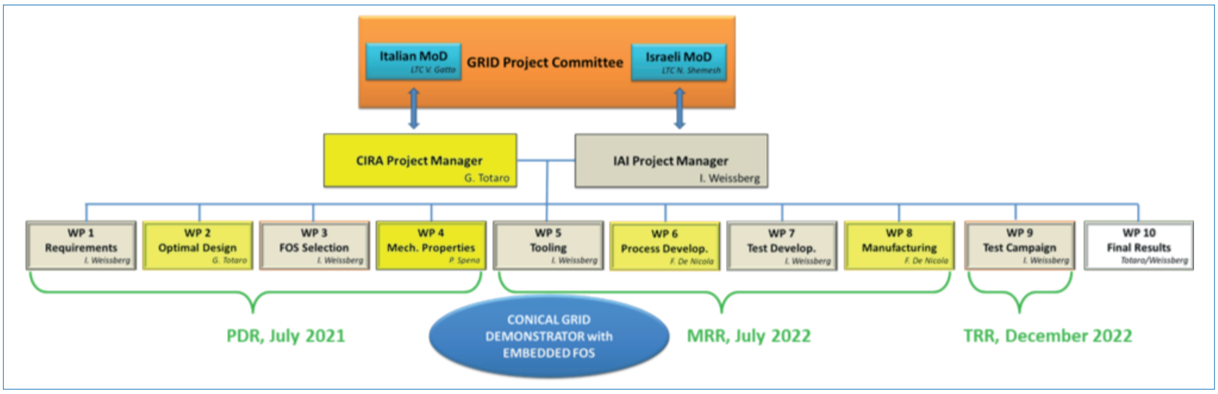
Among the research projects considered exemplary of research activities for the Defense and Security sector, the project "Conical grid spatial structures with built-in fiber optic detection capacity (GRID)" stands out.

INTRODUCTION

The GRID project was developed in the framework of the bilateral technological cooperation between the Italian and Israeli Ministry of Defence (PA n. ISR-ITA-2019/02). The project was undertaken by the Italian Aerospace Research Center (CIRA) in partnership with Israel Aerospace Industries (IAI). The objective of the project is to demonstrate the feasibility and the functionality of a fibers optic sensing system (FOS) based on FBG sensors, embedded into the ribs of a CFRP Grid structure. The project is centred on the design, manufacturing, and test of a final technological Demonstrator characterised by two main research topics:

- It is made of a carbon fiber grid structure, in the shape of a medium-size truncated cone shell, with the highest structural efficiency, and referred to a cone adapter for payload/satellite systems. The grid concept in composite material, indeed, is mainly aimed at space applications, in which the minimum mass design is driven by the local and global buckling mechanism that normally occur under the action of high compression loads typical of the launch phase.
- It is equipped with an integrated system for strain and/or temperature sensing, based on the adoption of optical fibers (FOS) with Bragg grating (FBG), embedded inside the ribs of the grid structure during the deposition of the carbon fibers. There are several benefits inherent to the nature of this kind of sensing system in comparison to conventional counterparts, including: the lightness of harness, insensitivity to electromagnetic interferences, and low power request per sensor.

The following chart summarises the activity between the two partners which ex - plained in the successive paragraph.



MOTIVATIONS

The mass reduction of primary aerospace components while improving their structural efficiency is a constant and relevant challenge in the aerospace business. For this reason, the design concepts, materials, and manufacturing processes are costantly in evolving to explore and find mass optimization solutions at low cost. CFRP grid structures can be lighter and less costly than conventional composite counterparts flown today. Grid structures are usually applied to cylindrical or conical shells and are composed of a regular pattern of intersecting hoop and helical ribs, with or without a thin outer skin, arranged in such a way to maximize the buckling strength of the shell under primary compressive and bending loads. The ribs are made of unidirectional carbon fiber tows exploiting the highest mechanical properties of a composite material. The various grid configurations require optimization sprocedures to explore and address the most efficient solutions for the specific design requirements. Early grid structures were fabricated using filament winding machines in conjunction with wet carbon fibers; currently, more sophisticated Robotic cells with tailored deposition heads are being developed which handle dry fibers or, on the opposite side, prepreg fibers with substantial differences also in terms of initial investment.

Spacecraft monitoring is essential for the successful operation of any space mission. A variety of sensors are required to provide critical information about the spacecraft health during fabrication, qualification testing and service lifetime. Space is a very challenging environment for any sensing system as it is characterized by microgravity, vacuum (causing outgassing), radiations, large thermal variations, mechanical vibrations and shock resulting from the launch phase. In addition, many space structures have a requirement for high dimensional stability and therefore their rigidity and shape are critical and should be monitored. FOS systems are considered for space applications due to the many advantages they have with the potential to outperform their conventional counterparts. These advantages include: insensitivity to electromagnetic interference, freedom from sparking electrostatic discharge, lightweight and flexible harness, low power requirements per sensor, high signal to noise ratio (high measurement accuracy), remote interrogation, and potential to be embedded in composite structures, increasing the survival probability to the harsh external environment.

In this scenario, the proper combination between highly efficient CFRP Grid structures and highly effective and permanent FOS systems represents a relevant and challenging topic for aerospace research.

TECHNICAL BACKGROUND

The manufacturing process of the Grid Demonstrator is based on the automated "Parallel Winding" deposition technique of a carbon fiber dry preform completed with LRI under vacuum bag and oven cure, of which CIRA has been the developer for many years with a specific Robotic Winding patent, rather than through several publications involving both manufacturing and design aspects. In the recent past, it is worth mentioning the design and manufacturing of the Interstage 2/3 prototype developed for Avio and intended for the space launcher VEGA-C.

The knowledge of optical fibers, and their selection, installation and use in conjunction with general CFRP structures is mainly of the IAI partner, but not in combination with the LRI process as advanced by CIRA. On the other hand, IAI has large competences on design, analysis and test of general CFRP structures, but not specifically grid-related.

The sharing of project activities was therefore addressed with the aim to enhance the respective competences and foster a fruitful exchange of know-how between the partners. In short, here are the shared activities:

- CIRA has developed and addressed all the aspects related to: the optimal design, modelling and preliminary FE analysis of the conical Grid Demonstrator, the selection of composite materials and their characterization in terms of essential mechanical properties and process parameters, the production of intermediate test-articles for early feasibility verification of integrated FOS, the sizing of specific manufacturing tooling, and finally the production of the demonstrator with the aid of the new in-house robotic cell facility.
- IAI has developed and addressed all the aspects related to: the design requirements of the demonstrator, the selection of FOS and the definition of the embedding procedure into the ribs of the Grid structure, the production of intermediate test-articles, the procurement of the manufacturing tooling with the support of an external supplier, the design, FE analysis and production of substructures and interfaces necessary for the mechanical testing campaign of the Demonstrator, and finally the conduction of the testing campaign at IAI premises and validation of the experimental results.

ADDRESSED TOPIC AND TECHNOLOGICAL SOLUTION

The GRID project has at two main purposes:

1) To demonstrate the feasibility and the functionality of a sensing system based on optical fibers and FBG sensors, embedded into the ribs of a composite grid structure made by dry carbon fibers, robotic winding and LRI. The scope, in perspective is to achieve an efficient and "permanent" health monitoring system , since it is largely protected from the harsh space environment by being inserted inside the relatively thick ribs of the grid structure.
   - In this case, in the face of benefits promised by the integrated FOS system, the technological challenge is just represented by the survival of the system itself during the various phases of the manufacturing process of the grid structure, which include: winding of the first half of the Dry preform, installation of FOS and interfaces, winding of the second half of the Dry preform, vacuum bag assembly, resin infusion, oven (or autoclave) curing, component demoulding, and trimming.
2) To evaluate the structural efficiency and the effective performance of an optimised Grid structure, in relation to consolidated solutions in composite materials, such as represented by sandwich architectures or solid laminates.
   - In this case, the design requirements of the demonstrator in terms of geometry, dimensioning loads (12 t at Limit Load), bending stiffness,and mass target (8.2 kg) were defined at the beginning of the project in a specific report, together with a reference solution in composite material, identifying, as the primary objective of the Grid structure, a significant weight saving of 20%.
   - Concerning the effective performance of the Demonstrator, the challenge in this case was to set-up a rather complex test facility able to manage stiffness and strength properties of the demonstrator, until catastrophic failure, and to consistently capture deformation data from a conventional strain-gauge as well as from the integrated optical fibers.

METHODOLOGY AND RESULTS

Early technology development

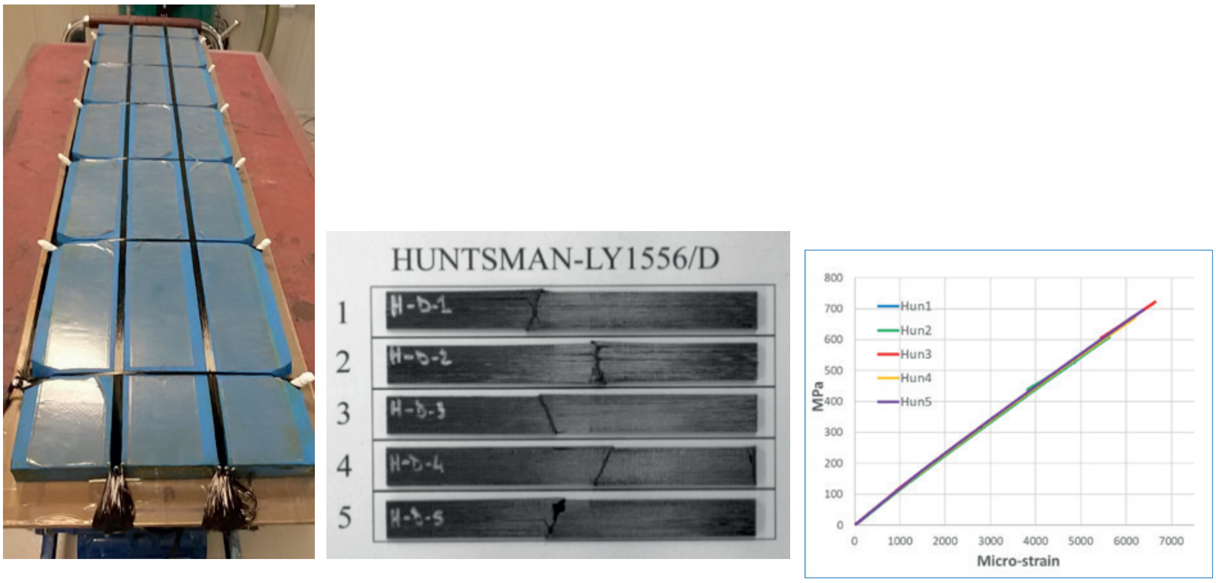
The initial technology development included the basic mechanical property characterization of ribs and the preliminary feasibility demonstration of embedded FOS by the use of "ortho-grid" panels. These panels are composed of two longitudinal ribs interlaced with transverse ribs and present, on a small-scale level, some basic similarities with the full-scale manufacturing process of the demonstrator. As a consequence, the basic mechanical properties of coupons extracted from such ribs are representative of the final process and support the material selection in a proper way. Three candidate resin systems were tested in conjunction with IM carbon fibers . The outcome of this experimental campaign was the selection of the Huntsman LY556 epoxy resin for the demonstrator due to good mechanical properties and process parameters.

Moreover, for each resin system, additional coupons with artificial defects were produced. These defects were inserted in the centre of the ribs in order to simulate the presence of the Teflon coating which typically covers the optical fibers. The result of this verification was a certain insensitivity of the rib compressive strength to the maximum size of "defects" that are introduced by the FOS.

The final important task faced in this experimental phase was the elaboration of representative test articles in order to evaluate: 1) the efficacy of the embedding procedure of FOS and interfaces, 2) the impact on the LRI process and on the vacuum bag details and consumables, 3) the functioning and benefit of such FOS as strain and temperature sensing system.

The early test cases oriented to these tasks were developed by IAI in the shape of triangular units representative of a generic Grid structure. These units were tested in tension and compression using both continuous and discrete FOS systems, with a final selection of the latter typology. Nevertheless, the manufacturing approach was the wet carbon fiber deposition.

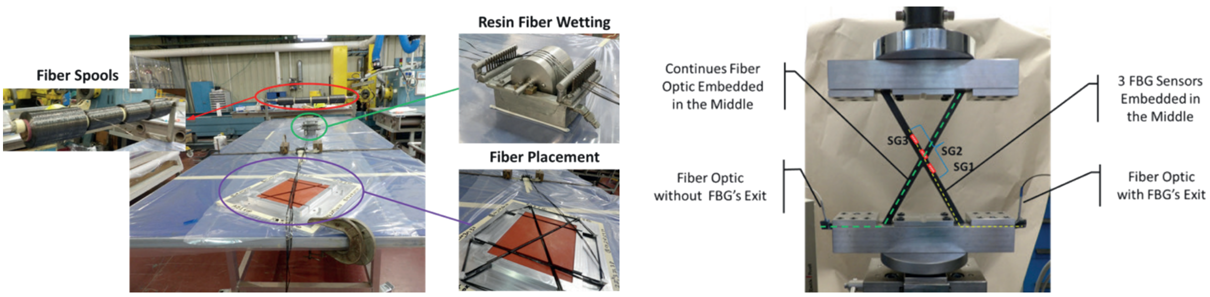
Based on this experience, CIRA produced and tested a final ortho-grid panel with embedded FOS as a representative test case of the real manufacturing process, thus achieving a preliminary feasibility demonstration.



Ortho-grid panel and example of mechanical characterization of rib coupons

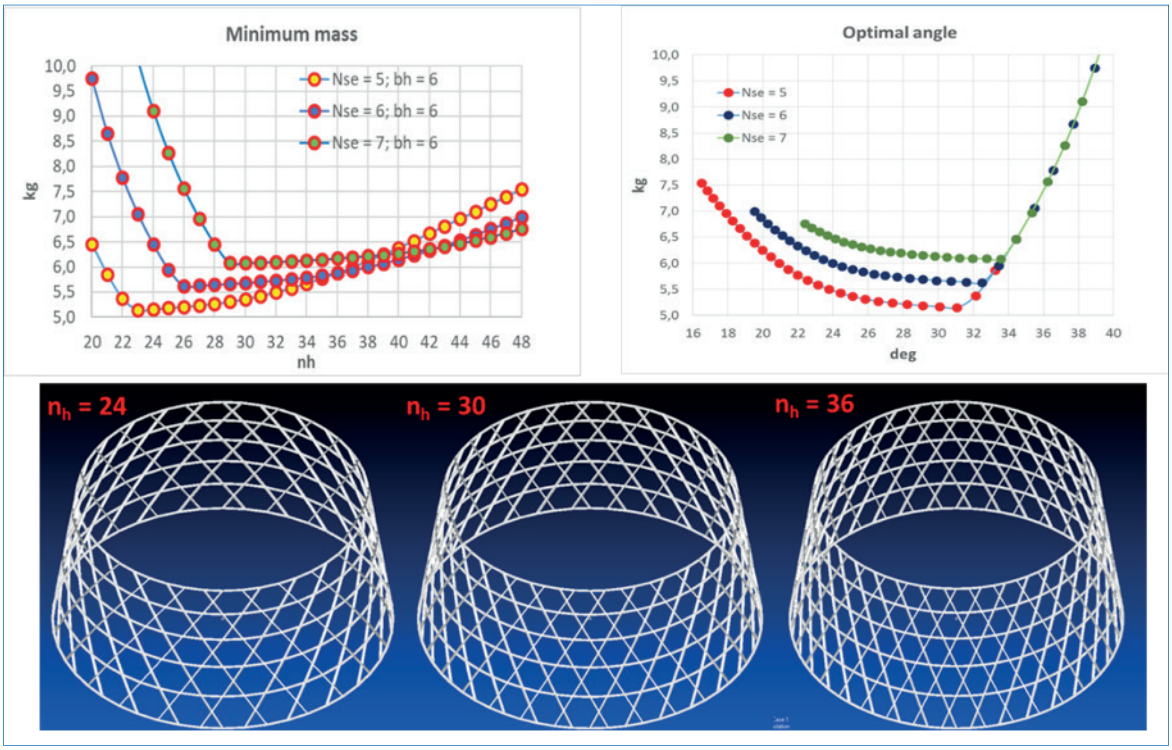
Minimum mass design of demonstrator

The minimum mass design of the grid demonstrator was addressed with the aid of a semi-analytical method which is part of the CIRA background. This method involves the approximate formulations of the mass of the conical Grid structure and of the main global mechanical properties which characterize each configuration (stiffness, strength, and buckling). These formulations are handled by an optimization routine based on a commercial constrained minimization algorithm in which the objective function is represented by the mass of the Grid shell. Some steps related to the search phase of the optimal grid configuration and to the subsequent phase of FE analysis are proposed in the following figures. With this approach a very lightweight solution was found at 7.2 kg only, 1.0 kg less than the prescribed mass target. This solution (the central configuration in the figure) is characterized by 30+30 helical ribs, 5 hoop sections, and specific

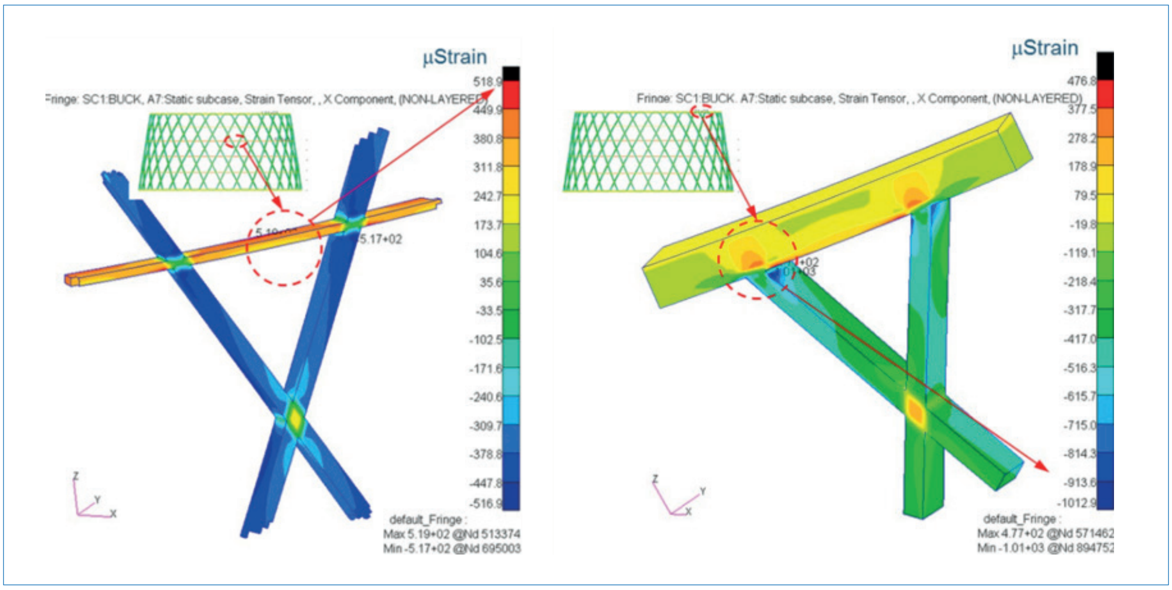


Manufacturing and testing of triangular units with embedded FOS

cross-sectional dimensions of such ribs.
Following the identification of the demonstrator characteristics, the manufacturing specification was issued and the CAD models of tooling were constructed. Special care was given on the parts that were strictly related to the specific design of the grid structure, that is, the conical mandrel for robotic winding, provided with specific anchor points, and the mould for the casting of the rubber carpet sectors to be installed on the mandrel.



Some steps of the optimal design phase of the Conical Grid Demonstrator



Example of 3D FE analysis of the designed Grid Demonstrator

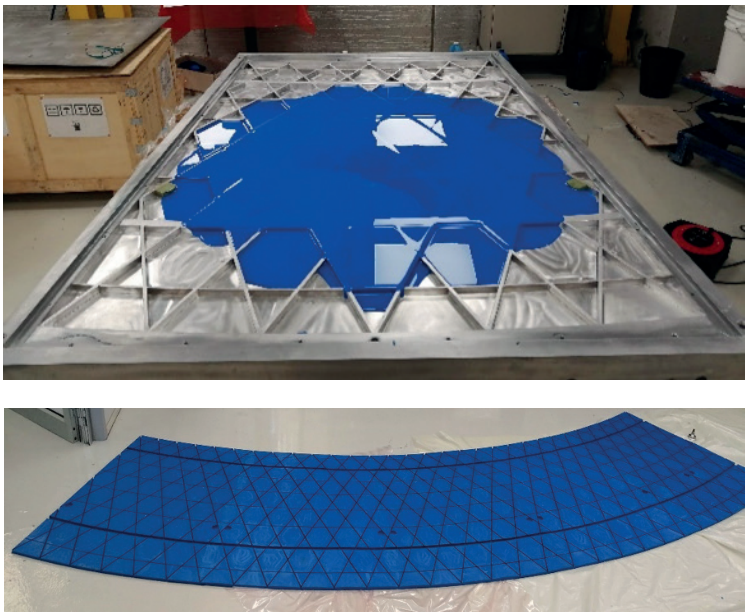
Manufacturing of Demonstrator

The manufacturing of the Grid Demonstrator with embedded FOS was efficiently undertaken by CIRA. The overall developed process is cost-effective, efficient and versatile, and replaces the wet filament winding approach that presents operating difficulties and regulatory problems related to the use and exposure to liquid resin. The following figure shows a step of the production of the rubber carpets to be installed on the mandrel. Five batches of liquid silicon rubber were poured into the male mould sector reproducing the pattern of ribs. The Mould was also provided with inserts in specific positions in order to obtain corresponding cavities in the rubber tool for the insertion of FOS interfaces. An overall rubber carpet was then assembled and installed on the conical mandrel.

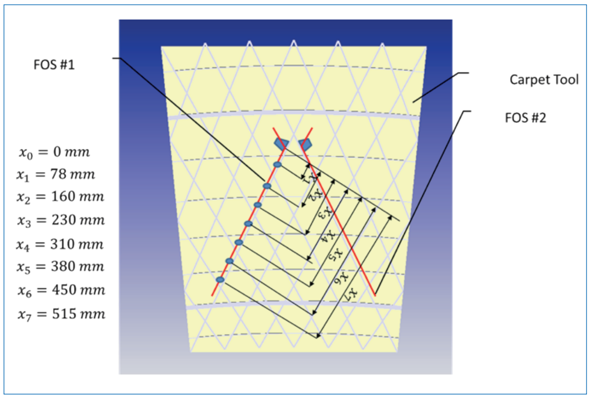
For this project, the new robotic cell facility available at CIRA consisting of positioner, robot and creel, was adopted for the very first time. After an intense set-up of the overall cell, the winding strategy definition, and subsequent fine-tuning of the specific deposition trajectories, the new robotic cell is able to lay down a single layer of the carbon dry preform of the demonstrator in only 20 minutes (the preform includes 28 layers).

The "Parallel Winding" approach allow us to interlace simultaneously hoop and helical ribs which normally define the grid structure, assuring a regular preform in which carbon fiber tows are uniformly distributed along the ribs and across their intersections.

The feasibility demonstration of a FOS system embedded inside the ribs of a full-scale Grid structure was fully achieved. After the deposition of half the rib thickness of the dry preform, according to the schedule, 10 FOS including 7 FBG sensors each, were inserted into the respective helical ribs in order to obtain an adequate coverage of sensors for the testing campaign of the demonstrator. The

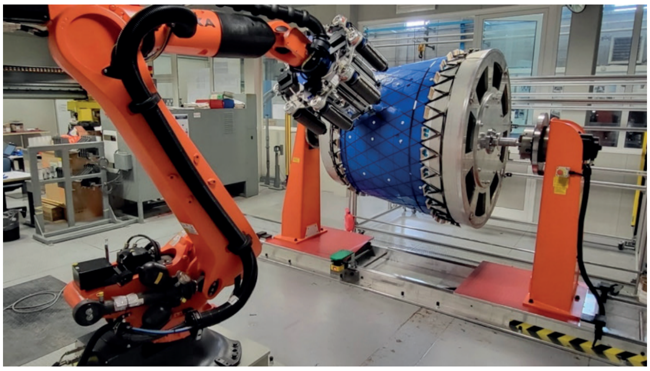


Mould for rubber casting and complete rubber carpet



Schema del sistema FOS e posizione degli FBG lungo specifiche rib elicoidali

FOS insertion was conducted manually by means of the interposition of specific interfaces conceived to act as clamps, in order to guarantee a firm connection between the ribs and the optical fiber at the entry point: a slight shear effect would be fatal for the integrity of the fiber itself.

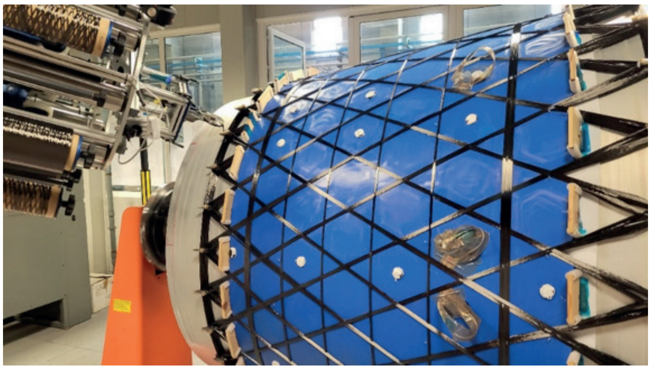


New Robotic cell for "Parallel Winding" of the carbon Dry preform

Once all the interfaces were installed into the respective cavities of the rubber carpet, and the optical fibers were glued to the carbon fibers, the dry preform deposition was started again, in order to embed the sensors in the middle of the rib thickness.

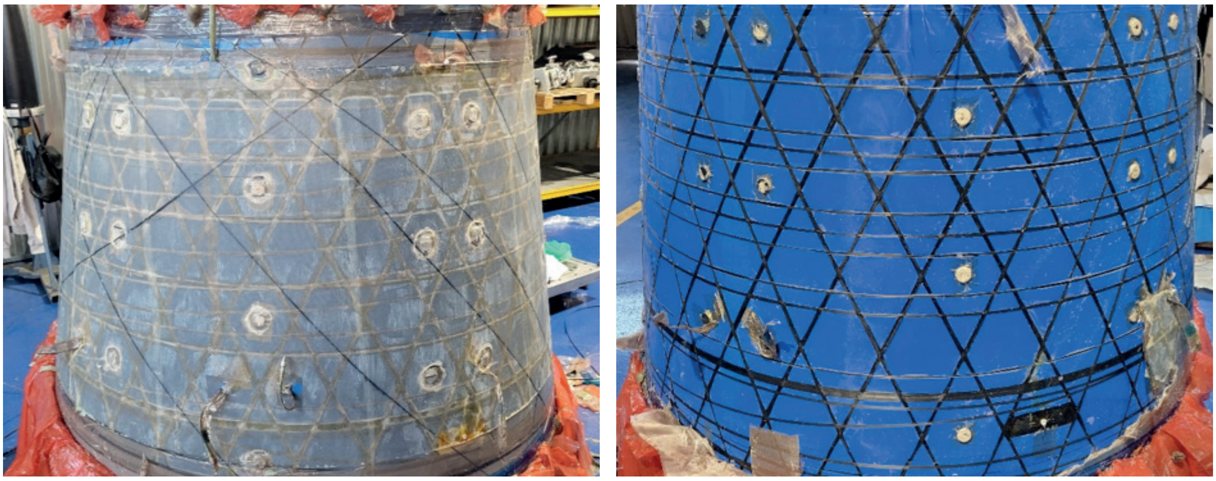
At the end of the complete manufacturing process, only one FOS was damaged. Nevertheless, it was necessary to mechanically remove the solid resin that was accumulated inside the optical fibers connectors, despite the effort and measures adopted to avoid this occurrence. Successively, the proper functioning of all the available sensors was checked.

The final outcome was the production of a perfectly grid structure demonstrator of the highest quality, with nominal dimensions, and equipped with the integrated and working FOS system. The demonstrator was finally shipped to Tel Aviv for the conduction of the testing campaign.

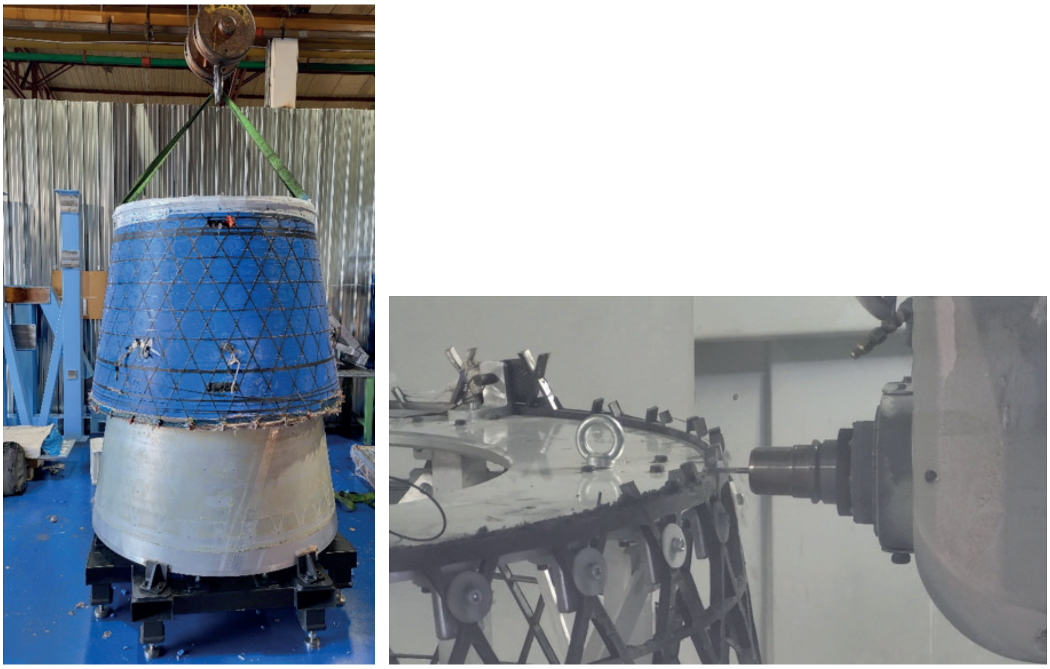


Final stages of the Dry preform winding of the Demonstrator

Resin infusion and oven curing



Removal of consumables after curing



Extraction and trimming of Demonstrator

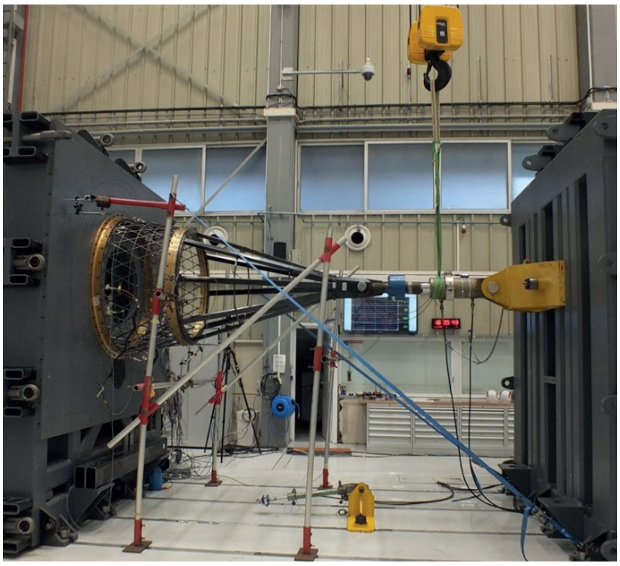
Grid Demonstrator with embedded FOS

Testing campaign of Demonstrator

The final phase of the project was finalised in the testing campaign with the objective to assess the expected performance of the demonstrator with reference to the prescribed requirements, and the functioning of embedded FOS. This task was efficiently undertaken by IAI. The testing campaign was based on a rather complex set-up including: displacement transducers for axial and bending stiffness evaluation, several strain-gauges, high-speed camera, and the acquisition system of strain data provided by the FOS. Two hydraulic pistons were used to transmit the axial compression force and the lateral force. The first load was finalised to evaluate the strength in compression, the second one for the bending stiffness of the demonstrator. All the scheduled tests were successfully performed, as summarised in the following table.

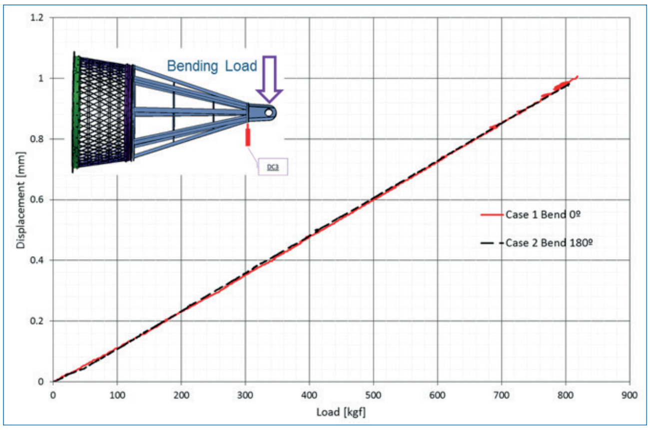
Exp.	Name	Load	Remarks
1	Compression LL	12 Tons Axial	Successful
2	Bending at 180°	800 Kg Vertical	Successful
3	Bending at 0°	800 Kg Vertical	Successful
4	Compression UL	24 Tons Axial	Successful
5	Failure Load	TBD	80 Tons

Test matrix performed on the Demonstrator

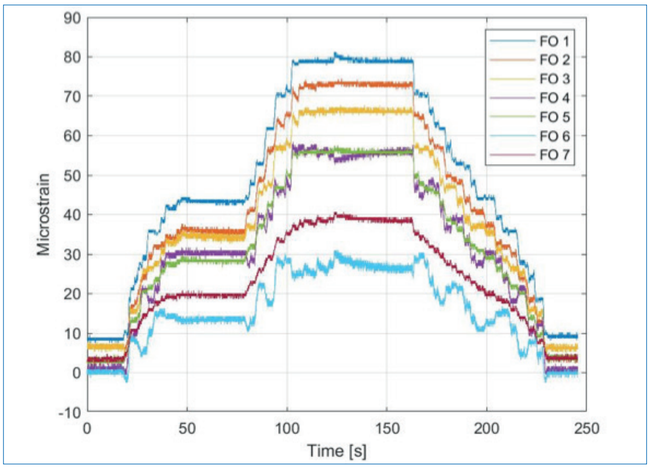


Test jig for axial compression and bending

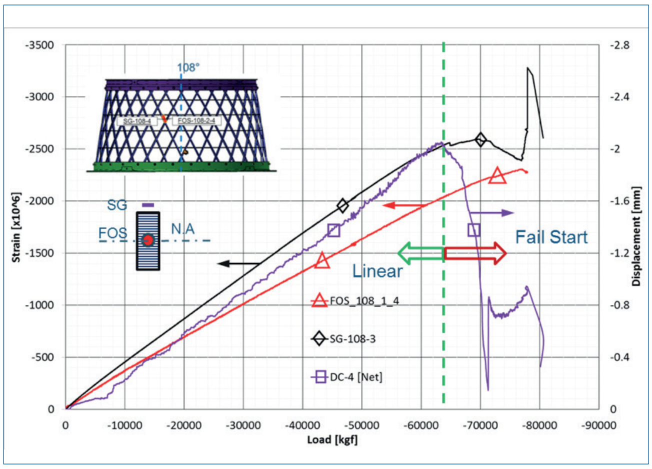
A considerable amount of data was recorded during the testing campaign by the FOS system, the strain-gauges and the displacement transducers. This experimental data seems in general terms, well correlated with simulations. A deviation is observed between these values during the compression tests, which is emphasized as corresponding to the final non-linear displacement phase. The FBG sensors, indeed, are located on the neutral axis of the ribs, whereas the strain-gauges are glued on the inner face of the ribs and thus experience flexural contributions. The following plots show only few examples of the experimental results: 1) the linear behaviour during the bending stiffness test with tip displacement equal to 1.0 mm (20% less the maximum prescribed value), 2) the gradient of strain along a specific helical rib as recorded by the optical fiber during the same bending test, 3) the occurrence of a non-linear behaviour of the test-article during the final compression test which anticipates the catastrophic failure at 78 t. Some frames of the high-speed camera show this failure, captured in a few seconds, which manifests itself in a kind of global buckling mode.



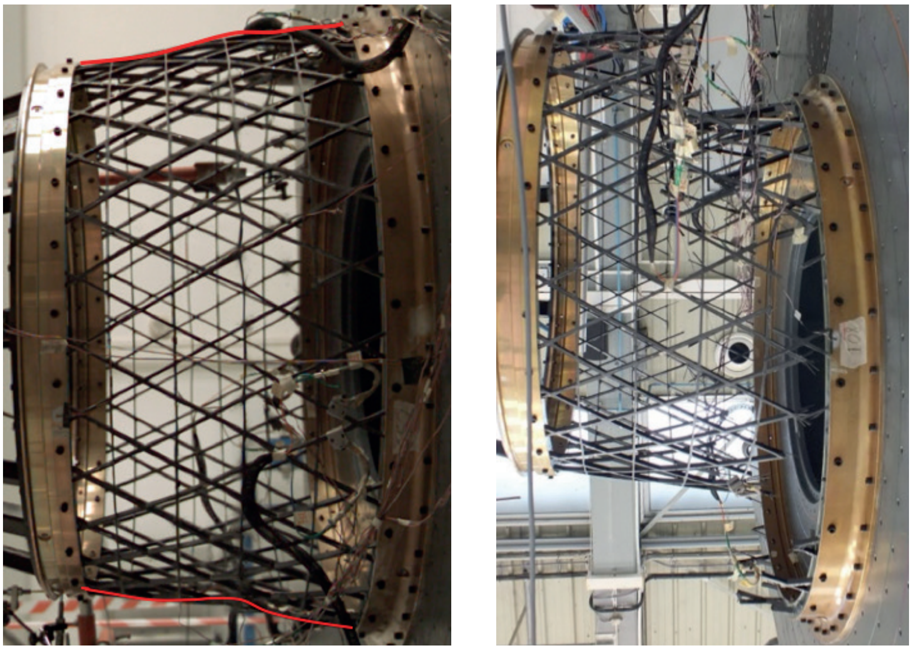
Displacement vs. transverse load during the bending tests



Example of FO strain values vs. time during the bending test



Non-linear structural behaviour starting from 65 t



Catastrophic failure of the Demonstrator at 80 t

POTENTIAL TECHNOLOGY APPLICATIONS

Embedding a FOS system into a grid structure provides several benefits, including: evaluation of the internal strain field which develops during the qualification testing campaign of a new component, and the state-of-health monitoring of the same component during its operational life, in relation to the various stresses caused by the external environment (e.g., vibrations, impacts). Moreover, many structures designed for space are subjected to dimensional stability requirements that could be controlled by means of a mesh of thermal sensors properly distributed. Finally, a FOS system for temperature reading could be adopted during the cure phase of the component as quality control and/or optimization of the manufacturing process. Overall, the dual use of FBG sensor makes the FOS system suitable for strain and temperature mapping of especially valuable structures during all phases of operation, from fabrication to in service monitoring to decommission . Such mapping is useful for determining structural deformation, detecting vibration, detecting and classifying micrometeorite impact , and validating of the satellite thermal management system.

CONCLUSIONS AND OUTLOOK

The demonstrator features the CFRP mass of 7.2 kg, that is, 1 kg less than the prescribed mass target of the reference payload adapter. This is an important mass saving near 30% in comparison to the reference solution in composite material. In addition, since the loading capacity was very high and the stiffness requirement was fully achieved with a positive margin near 20%, a similar mass reduction could be further obtained on a refined version of the demonstrator, bringing the maximum saving close to 40%. The rupture load near 80 t, in conjunction with the geometry and the mass of the structure, brings the top performance of this article in an ideal ranking of structural efficiency.

The use and feasibility of the embedded FOS system was successfully demonstrated. The embedding procedure and the interfaces designed by IAI for the FOS protection performed well from the installation and the mechanical point of view, securing the optical fibers in the correct place and the sensors in the centre of the helical rib segments. The information provided from the FOS during the mechanical testing campaign, in conjunction with conventional sensors, was useful to understand the structural behaviour of the component. The thermal use of FOS was also demonstrated by recording the temperature history that develops inside the typical rib of a grid structure during the cure cycle. In addition, the FOS embedded into relatively thick ribs are more protected against the environmental influences and this fact can increase the survivability of the system during the lifetime of the component. However, these benefits present a manufacturing challenge represented by the increased complexity deriving from the FOS insertion and the necessity to guarantee the survival of the FOS itself during the various process phases of the CFRP structure made by LRI. As experienced in this project, the capillary permeation of the liquid resin in the very thin interfaces, which were supposed to be glued and "resin proof", is very difficult to avoid. This inconvenience, however, is not fatal for the proper functioning of the sensors.

In conclusion, the project has successfully expressed most of the potentialities offered by the proposed concepts. All lessons learnt and possible improvements/refinements in terms of design/manufacturing/FOS embedding procedure can be regarded more as "industrial" rather than R&D activities.

In a more general perspective, the CFRP Grid structure concept could evolve towards more complex shapes, such as double curvature shells, even not axisymmetric, aiming at fuselage sections of aerospace vehicles, for example, or could undergo a complete change of technology paradigm by the adoption of Ceramic matrix materials aiming at space re-entry vehicles applications (thermal protection system) or at thermally stable structures for optical payloads, for example. However, it is clear that the starting TRL in this scenario is lower and the potential benefits in terms of mass saving has to be verified from case to case.

ACRONYMS

GRID	Conical Grid Space Structures with Embedded Fiber Optic Sensing Capability
CAD	Computer Aided Design
CFRP	Carbon Fiber Reinforced Plastic
FE	Finite-element
FOS	Fiber Optic Sensor/Sensing
FBG	Fiber Bragg Grating
IM	Intermediate Modulus
TRL	Technology Readiness Level

KEYWORDS

Grid structure, optical fiber, health monitoring, structural efficiency, robotic winding

PROJECT INFORMATION

Bilateral project Italy/Israel:	PA n. ISR-ITA-2019/02 GRID
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E-mail:	g.totaro@cira.it

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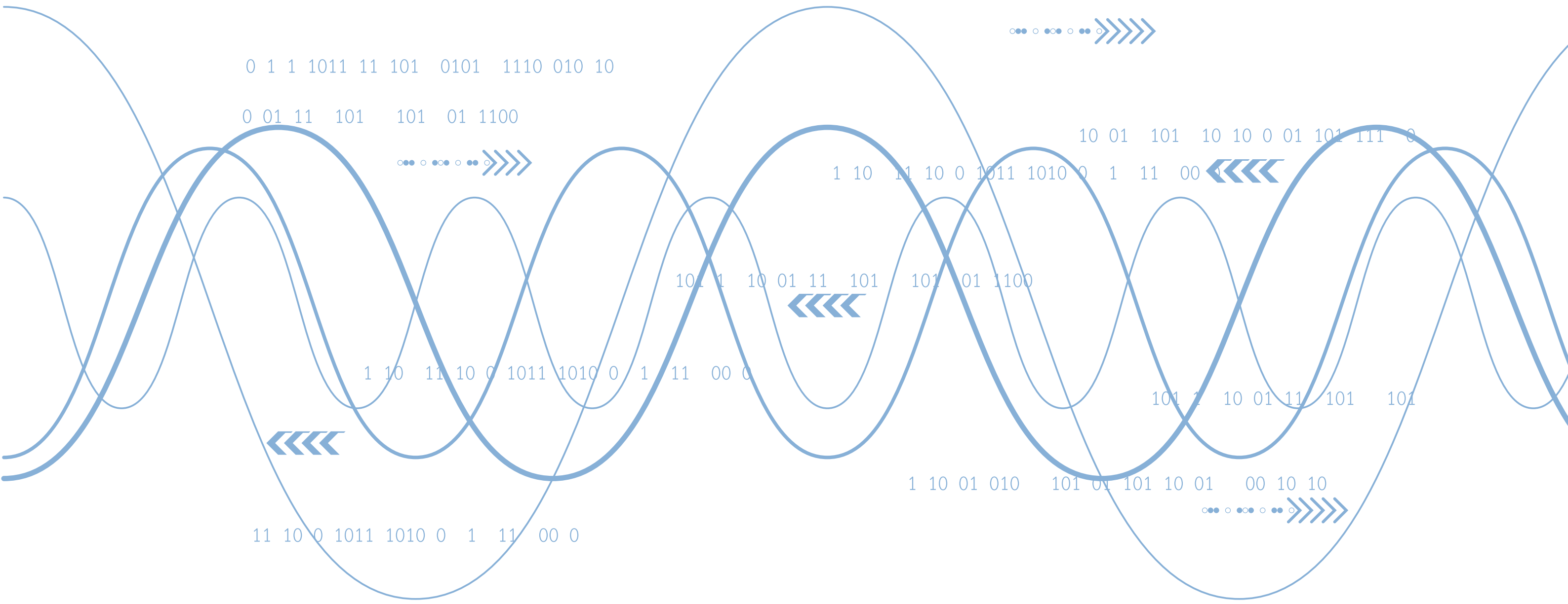
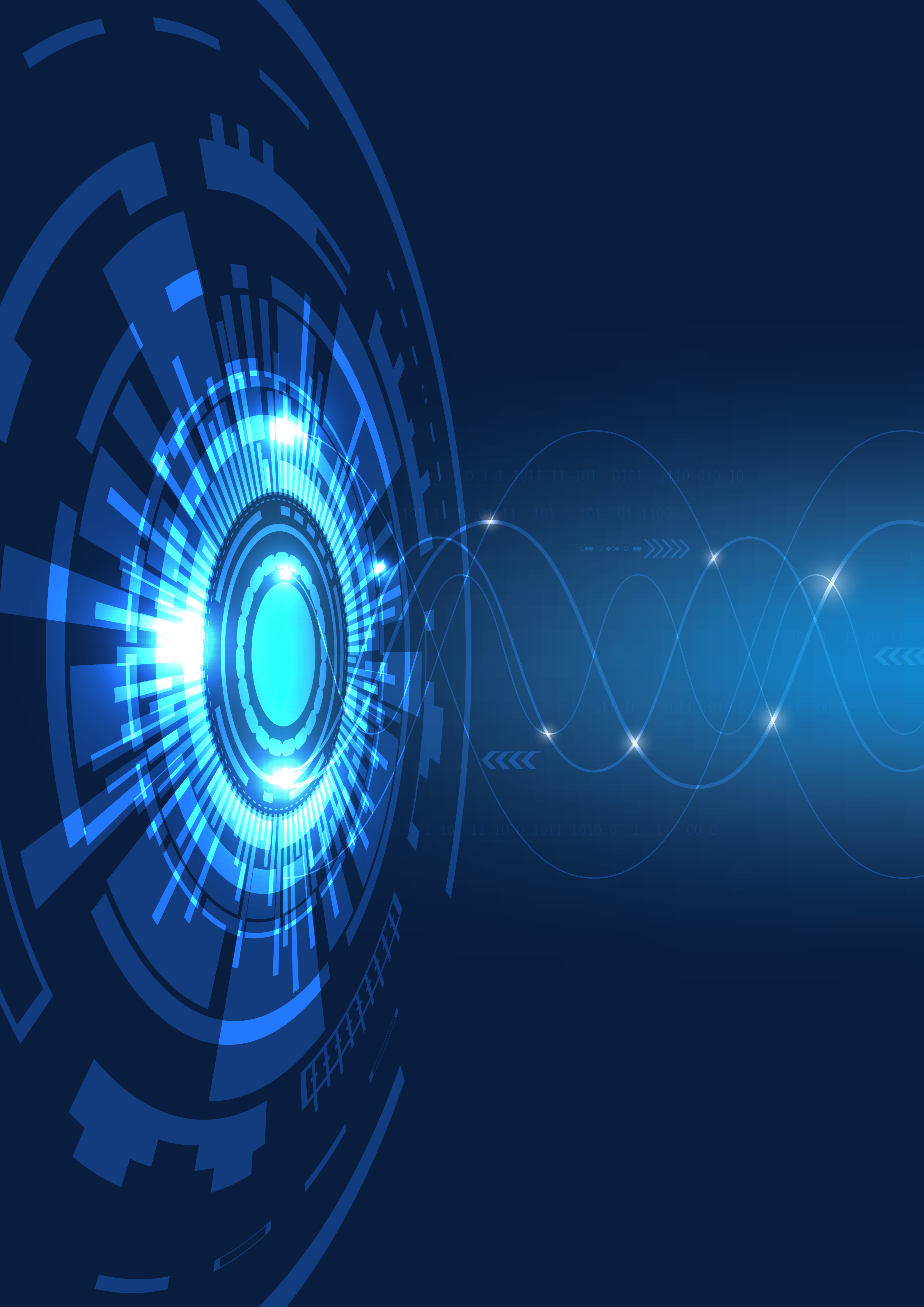




STATISTICS

STATISTICS

Distribution of funds among PNRM and international programmes

Table 1 shows the distribution of funds among projects of the National Military Research Plan (PNRM), projects of the European Defence Agency (EDA), projects derived from Framework Agreements with universities, technological research activities of Defence Testing Centres, and international programmes (multilateral and bilateral) in the year 2022..

Type	No. following phases of ongoing projects	No. new projects
PNRM	61	21
EDA	1	5
Framework Agreements	/	2
Testing Centres	3	4
BI-MULTILATERAL	3	3

Table 1 - Distribution of funds in the year 2022.

Distribution of national funds per capability/technology area

The annual distribution of national funds per capability/technology area may vary according to the operational priorities identified within the Defence.

National projects for the year 2022 were selected according to the criteria set by the Defence Minister and updated by the Chief of Defence Staff, prioritizing project proposals related to the following application/ technology clusters:

- Cluster 1: Innovative technologies of Intelligence Surveillance Reconnaissance (ISR) and information distribution through innovative Command and Control systems;
- Cluster 2: Autonomous systems, artificial intelligence, navigation safety and security and related sensors, autonomous weapon systems;
- Cluster 3: Satellite technologies;
- Cluster 4: Cyber security, cryptography and Big Data analysis;
- Cluster 5: Enhancement of soldier's capabilities and protection/support to veterans;
- Cluster 6: Defence technology – sensors, devices, weapon systems, ammunition and innovative materials;
- Cluster 7: Technologies for sustainability, energy resilience and infrastructures.

The identification of priority clusters has allowed for a more effective and efficient planning and management of resources. Hence, technological research activities steer towards goals that are consistent with the capability requirements and current priorities of the Armed Forces, minimizing the fragmentation of technology sectors and the dispersion of resources over many different activities, as not all of them specifically address the operational capability gaps identified.

Technology Area (Cluster)	% Funds	Number of projects
Innovative technologies of Intelligence Surveillance Reconnaissance (ISR) and information distribution through innovative Command and Control systems	23.8%	5
Autonomous systems, artificial intelligence, navigation safety and security and related sensors, autonomous weapon systems	19,0%	4
Satellite technologies	19,0%	4
Cyber security, cryptography and Big Data analysis	14,3%	3
Enhancement of soldier's capabilities and protection/support to veterans	9.5%	2
Defence technology – sensors, devices, weapon systems, ammunition and innovative materials	14,3%	3
Technologies for sustainability, energy resilience and infrastructures	0%	0
TOTAL	**100%**	**21**

Table 2 - Distribution of the new national projects started in 2022 among the priority capability/technology clusters identified by the Chief of Defence Staff.

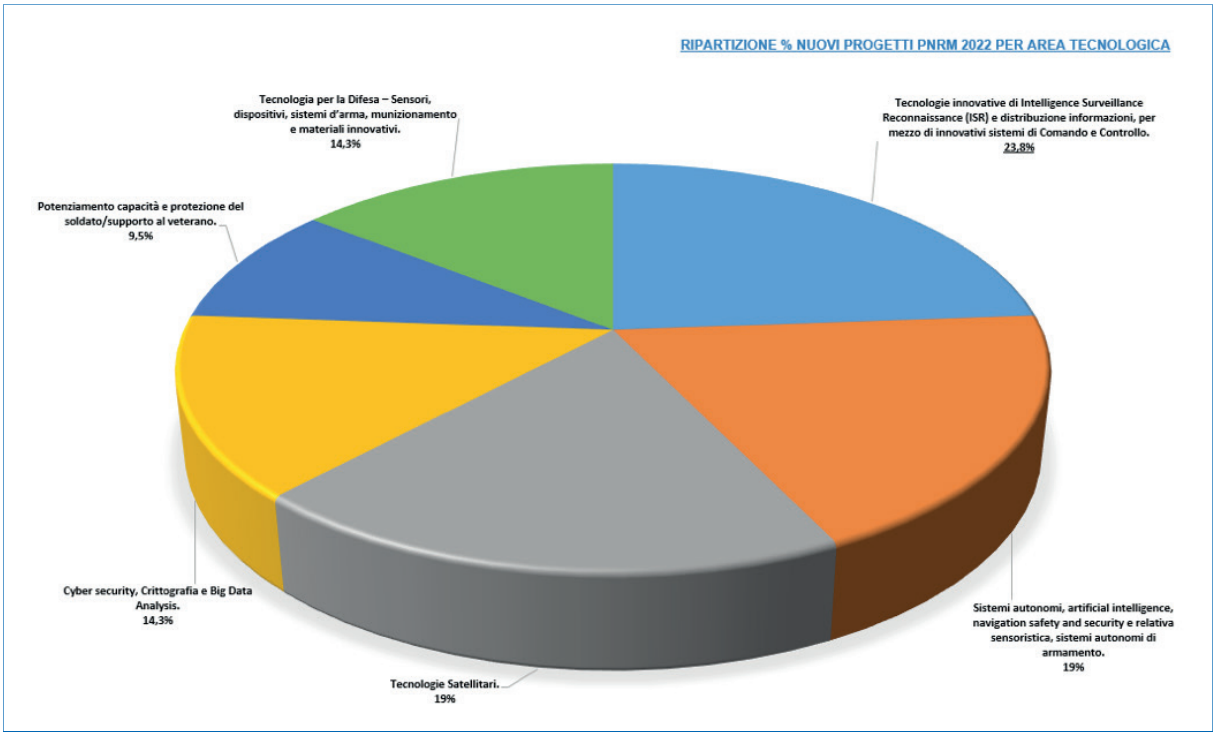
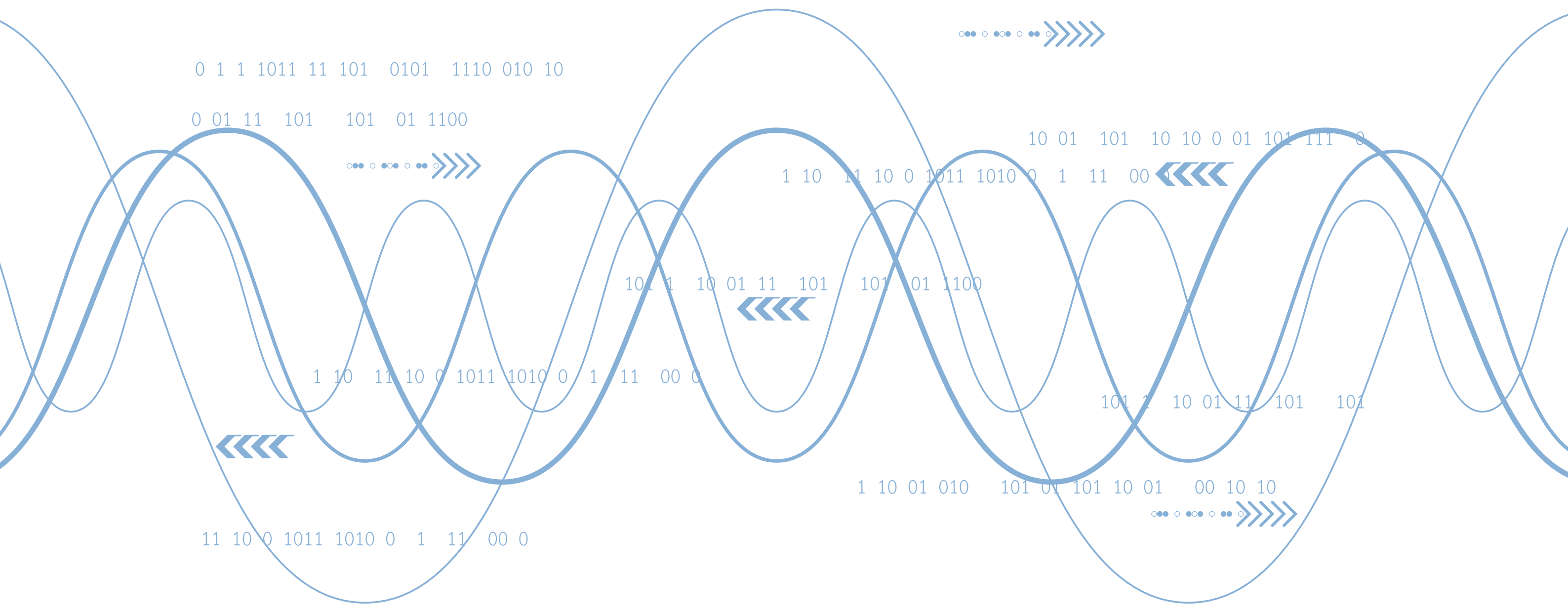


Figure 1 - Distribution of the new national projects started in 2022 among the priority capability/technology clusters identified by the Chief of Defence Staff..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ABBREVIATIONS AND ACRONYMS

2-MF	Multi-Functional Modular Frame
AD	Amministrazione Difesa
AES	Advanced Encryption Standard
ALW	Airborne platform effects on laser systems and warning sensors
AODV	Ad Hoc On-Demand Distance Vector
AU	Actuation Unit
BEE DDS	Implementazione Leonardo dello standard DDS
BER	Bit Error Rate
BFN	Beam-Forming Network
BLOS	Behind Line Of Sight
C2	Comando & Controllo
CDMA	Code Division Multiple Access
C4ISTAR	Command, Control, Communications, ,Targeting Acquisition and Reconnaissance
CIRA	Centro Italiano Ricerche Aerospaziali
CPA	Sistema Cooperativo basato su Percezione Aptica
COFDM	Coded Orthogonal Frequency Division Multiplexing
CMC	Materiale Composito a Matrice Ceramica
C/SiC	Composito con matrice di SiC rinforzato con fibre di Carbonio
COTS	Commercial Off-the-Shelf
CSM	Communication Spectrum Monitoring
CU	Control Unit
DIRCM	Directed Infrared Countermeasure
DDS	Data Distribution Service
DF	Direction Finding
DM	Directional Modulation (Modulazione Direzionale)
DT	Dimostratore Tecnologico
DVB-T	Digital Video Broadcasting-Terrestrial
EMI	ElectroMagnetic Interference
ESM	Electronic Support Measures
EFT	Electronic Functional Tray
ETSI	European Telecommunication Standards Institute
ELINT	Electronic INTelligence
EM	Engineering Model
E2E	End-to-End
EGSE	Electrical Ground Support Equipment
EDA	European Defence Agency

ENIVD	(European Network for Diagnostics of "Imported" Viral Diseases)
EOT	Energy on Target
FM	Flywheel motor
GHIBLI	Galleria la plasma da due MW presso il CIRA
GUI	Graphical User Interface
GFT	Geometric Functional Tray
GIM	Gimbal motor
GIS	Geographic Information System
GPS	Global Positioning System
GPU	Graphical Processing Unit
GEOINT	GEOspatial INTelligence
HfB2	Diboruro di Afnio
IDS	Intrusion Detection System
INS	Inertial Navigation System
ISR	Intelligence Surveillance and Reconnaissance
It-MoD	Italian Ministry of Defense
IMINT	Image INTelligence
ISL	Inter Satellite Link
IR	Infrarosso
J/S	Jammer-to-Signal ratio
LEO	Low Earth Orbit
LC	Load Case
LT CES	Communication Electronic Support Measures
LICOLA	Low Interceptable Communication Link Antennas
MCMG	Mini Control Momentum Gyroscope Assembly
MAC	Medium Access Control
MALE	Medium Altitude Long Endurance
MANET	Mobile Ad-hoc Networks
MCS	Mission Control System
MS-DEP	Multi-Sensor Data Exploitation Platform
MWS	Missile Warning System
NEC	Network Enabled Capability
NCS	Network Control System
OBL	Optical Break Lock
OMG	Object Management Group
OTW	Other Than War

ABBREVIATIONS AND ACRONYMS

OBP	On-Board Processing
PCR	(Polymerase Chain Reaction)
POC	Posto Operatore Centralizzato
P/F	Piattaforma
P/L	Payload
POI	Point Of Interest
RMSE	Root Mean Square Error
RIFON	Rete Interforze in Fibra Ottica Nazionale
RPAS	Remotely Piloted Air System
RSV	Reparto Sperimentale di Volo
SATCOM	Satellite Communication
S/C	Spacecraft
SIMP	Solid Isotropic Material with Penalisation
SHF	Super High Frequency
SIC	Carburo di Silicio
SICRAL	Sistema Italiano per Comunicazioni Riservate ed Allarmi
SiC/SiC	Composito con matrice di SIC rinforzato con fibre di SIC
SOTA	State Of The Art
TA	Technical Arrangement
TAPR	Aeromobile a Pilotaggio Remoto
TAS-I	Thales Alenia Space Italia
TAKS	Topology Authenticated Key Scheme
TRL	Technology Readiness LevelDMA
TRM	Traffic Resource Manager
TRM-DB	TRM Data Base
UV	Ultra Violetto
UHF	Ultra High Frequency
VANET	Vehicular Ad-Hoc Networks
VFT	Volumetric Functional Tray
VHF	Very High Frequency
WP	Work Package
WIFI	Wireless Fidelity
WIDS	WPM-based Intrusion Detection System
WSN	Wireless Sensor Network
WHO	(World Health Organization-Organizzazione Mondiale della Sanità)
ZrB2	Diborure di Zirconio

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