Technological Research and Innovation

State of the Art 2021

MINISTRY OF DEFENCE

SECRETARIAT GENERAL OF DEFENCE AND

NATIONAL ARMAMENTS DIRECTORATE

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PRESENTATION

by the Secretary General of Defence and National Armaments Director

In the wake of a well-established tradition, I am pleased to introduce the 2021 edition of the Technological Research Report of the Secretariat General of Defence and National Armaments Directorate.

As is known, the activities concerning technological policy, research and development fall under the competence of the Secretary General of Defence and National Armaments Director (as per Art. 43 of Legislative Decree No. 66/2010 and following Articles 103, 104 and 105 of Presidential Decree No. 90/2010), and are closely integrated with the Secretariat's activities regarding industrial policy and coordination of armament programmes.

In the last few years, the new global context has highlighted the theme of "technology confrontation" that has to do with the challenges of technological innovation and global competitiveness, whose results determine the possibility to maintain military superiority for the sake of security and protection of the national interests, as well as strategic autonomy, technological sovereignty and economic development.

These radical changes have developed progressively after thirty years of relative detente, making the erosion of Western technological advantage a highly critical factor, as shown by the tragic evolution of the recent Eastern European conflict.

Within its scope, the military technology sector is a great positioning amplifier on the international scene, both in traditional physical domains – land, sea, and air, the latter also including space – and in intrinsically interconnected emerging domains such as cyberspace, effectively integrating strategic effects in the physical, virtual, and cognitive fields.

While this is true from a military perspective, it is even more relevant on a socio-economic level and from the general point of view of industrial policy. Indeed, the development and spread of new technologies constitute the main growth enabler for advanced economies, producing significant knowledge spillover in all economic activities through interactions with other production sectors.

In this general framework, the technological research activities of the Secretariat General are aimed at maintaining technological autonomy in the field of Defence while filling the capability gaps identified by the Defence General Staff, according to the future capability development programmes of the Defence Ministry.

This is also in line with the necessity of actively contributing to the roadmaps identified within NATO and EU in order to effectively master emerging and disruptive technologies, the latter being the ones that can disrupt the adversaries' assets and strategies in the medium term "upsetting their plans, throwing them out of balance and forcing them to react with no coordination" according to the meaning attached to the expression in the planning of military land operations.

Of course, our country expects to fully embody the role it deserves in the field of emerging and disruptive technologies, also expressing it on a geopolitical level.
This obviously requires the following items:
- Reliable human and financial resources, in line with the national ambition level and considering the relevant economic returns;

- Organizational and procedural instruments to update the traditional time frames for project implementation.

In order to tackle these future challenges, the Secretariat General of Defence/NAD deems it essential to strengthen the institutional network for technological research among the Defence, Universities, and research departments of relevant companies and industrial districts.

The final goal is to transcend traditional development models, both technology-driven – based on developing programmes/systems according to technological availabilities – and capability-driven – based on developing programmes/systems according to specific operational requirements/objectives. This should be achieved by implementing an open innovation model characterized by continuous interaction among all relevant actors, with the aforementioned Defence-Industry-University-Research Centres institutional network as a pivotal element to guide research and innovation activities.

This paradigm is proving particularly effective for defining national interests related to the technological research projects that are launched every year within the European Defence Fund (EDF) – Research dimension.

Furthermore, such a structured approach can also be adopted at national level within the NATO initiative *Defence Innovation Accelerator for the North Atlantic* (DIANA), whose aim is to build a federated network of testing centres and innovation accelerators in order to support NATO and Allied countries in their innovation process, helping start-ups to develop the necessary technologies to preserve the Alliance's technological superiority and facilitating cooperation between the private sector and military environments.

In the light of the above, it is clear that the scientific and technological domain will see an ever-increasing level of competition, as already happened in space and cyber dimensions. Our country's advantage in the fields of research, development and application of emerging and disruptive technologies will determine its future capability to maintain strategic autonomy and its role within the international community of technologically advanced nations, able to influence the balance of political and military power so as to protect its own security and economic interests.

In conclusion, scientific and technological innovation is definitely a big challenge at political, technological and industrial level, as well as the main future challenge – along with energy and environmental sustainability – for the Defence and its industry. The future development of the production fabric and the maintenance of advanced military capabilities will continue to depend on Defence investments in programmes with a high content of technology innovation.

Lieutenant General Luciano Portolano

PREFACE

by the Director of the 5th Department – Technological Innovation

This publication about the Research activities of the Secretariat General of Defence is to be framed within a much wider strategic and geopolitical context.

The recent tensions – which highlight the structural and contingent instabilities of countries that are close to Europe, in terms of both geographical distance and their direct or indirect influence – have shown the great importance of structuring an efficient EU Common Foreign and Security Policy, as well as the necessity of fostering more integration within the Defence by strengthening operational capabilities and enabling technologies, so that the industrial base of the EU countries can be strengthened too.

What is happening shows that Europe has become a primary actor on the international political scene, and is ready to take on an even more important position. In this context, Technological Research plays a pivotal role in promoting the integration of technological assets and national competences to make them available at European level.

Indeed, the areas in which we can have a key role in meeting the national and European ambition levels are the identification of common capabilities and the acquisition of critical capacities, with a rationalization and harmonization of the fragmented Defence fabric.

In such a varied context, characterized by growing challenges and increasingly complex geopolitical dynamics, the Strategic Compass – recently approved by the European Council – provides guidance in the fields of security and defence by identifying the tools, time frames and threats and by measuring the progress towards the desired ambition level. In particular, one of its goals is to promote and foster investments in innovation and research for a joint development of enabling technologies, in order to ensure security and protection of the citizens' interests.

The activities related to identifying and promoting Emerging and Disruptive Technologies are still going on, because of their potential impact on the international balance of power and their capacity to provide strategic advantage. In this regard, the EU has developed an Action Plan to which we are called to contribute together with the other Member States, aiming at identifying the most promising technological trends. Those trends are then selected both from a capability-based perspective, and with a view to enhancing civilian technologies that may have dual-use applications. In this process it is also important to consider industrial capabilities at EU level, so that they can be ready to implement and integrate new technologies.

To this end, the European Defence Agency (EDA) has already started – with the contribution of all Member States including Italy – the very important processes of Technology Watch, examining the most promising technologies already existing, and Technology Foresight, studying the technological future in the longer term. The outcome of these processes will also be included in Strand B of the Capability Development Plan (CDP), the CDP chapter dealing with emerging technologies.

Another important theme is Innovation. A joint effort is happening at European level, with direct reflections on individual Member States, to coordinate activities, assets and initiatives that can foster innovation of products, processes, organizations, and also a more effective market offer for the industrial component.

Innovation also regards the forms in which Research activities are proposed, including not only traditional modalities such as "competition" and "awarding" but also other ones such as "challenges", which are already well-established in the American Defence Advanced Research Projects Agency (DARPA) and other entities, but still relatively unknown in a domestic context. This is a form of competition in which participating teams – expressions of European consortiums – compete in physically creating a prototype in a testing scenario that has common features for all competitors.

The framework of national activities and participation in research projects within contexts such as the European Defence Fund is starting to take shape. These projects are strategically connected and/or complementary to those launched at national level, with a wide multi-year perspective that provides the Italian research bodies – both governmental and not – with a transnational dimension, in line with the need for integration and modernization so as to keep high competitiveness in a competition-based context, and in a market that is different from the past. The dynamism, participation and awarding potential of our national research actors in the European Commission calls are an outstanding element at European level, offering invaluable benefits and positive effects for our economic system in terms of capabilities, technologies, production chains development, and image within the EU.

At the same time, the importance of relations with partner countries and our national role within NATO always keeps a central position, especially in the light of the latest geopolitical developments. Like Europe, also NATO is focusing its technological activities on two main directions. The first one is about examining technological trends on a regular basis and summarizing them in a specific report, to the benefit of Member States, in order to identify particularly promising and potentially impactful technologies. Both the EU and NATO have started a dedicated roadmap to enhance this kind of technologies, including specific policies and implementation plans for each one of them. The second direction is about maintaining technological advantage and consists in two specific initiatives: the Defence Innovation Accelerator for the North Atlantic (DIANA), that is a civilian-military tool for developing emerging and disruptive technologies; and the NATO Innovation Fund, a venture capital voluntary fund aimed at supporting Allied countries' startups with a strong emphasis on dual-use technology and a solid potential in the field of security and defence technologies.

All the above clearly shows the essential role played by the Secretariat's Research activities, both at national level and in contexts of international cooperation: on the one hand, they are the driving force of national research activities for both Defence and dual-use purposes; on the other hand, they contribute to promoting and strengthening our country's position on the international scene, which must be maintained in order to further support our strong and competitive industrial base, as well as develop capabilities able to counter security threats and challenges, either conventional or not, such as cyber attacks, sanitary crises and climate changes.

Dr Luisa RICCARDI

ORGANIZATION OVERVIEW

STRATEGIC OBJECTIVES

Scientific and technological research programmes are aimed at allowing the military instrument to fill its capability gaps and calibrate its future intervention capabilities according to multiple operational needs, as well as reducing the risks related to hostile use of new emerging technologies. The Secretariat General of Defence and National Armaments Directorate, through its 5th Department “Technological Innovation”, identifies and promotes Defence technological research programmes at both national and international level, supported by the General and Technical Directorates for carrying out the technical-administrative activities connected with programmes’ implementation.
Activities include a national initiative (National Military Research Plan – PNRM), R&T projects carried out at Defence test centres, Framework Agreements with universities and research organizations, and international programmes developed at EU, NATO and bilateral level.
The renewed military competition among states is becoming more and more technologically advanced, even in emerging domains such as cybernetics and space. As regards technological research, cyber and space technologies are among the primary technological areas on which the Secretariat General of Defence/NAD focuses its Military Technological Research activities.

A serious and concrete investment in research and technological innovation activities is one of the main evolution accelerators of the Defence, and a necessary one to tackle the speed and pervasiveness of changes in the global scenario. The Secretariat General of Defence, and more specifically its 5th Department, moving between capability-pull and technology-push approaches, has implemented several coordination actions in different technical sectors among various organizations, in order to direct the activities of military technological research in full compliance with Defence capability requirements, with particular reference to the following sectors:

- Protection and enhancement of soldiers’ capabilities;
- Development of technologies for 6th-generation aerotactical systems and innovative next-generation rotary-wing platforms;
- Emerging and disruptive technologies such as quantum technology, Big Data, 5G/IoT, especially if associated with the enhancement of ISR, Terrestrial/Airborne/Maritime/Space/Cyber, etc.;
- Autonomous systems, artificial intelligence, navigation safety and security, development of the relevant next-generation sensors, and new forms of optical communication and robotics;
- Core satellite capabilities (SATCOM, Earth observation, PNT and SSA), enhancing the performance of platforms/payload and sensors in order to improve the quality and effectiveness of space services, as well as ensuring the protection of assets in orbit;
- Laser weapons and, more generally, Direct Energy Weapons – DEWs;
- Cybernetics, data analysis and exploitation, to increase cyber security and the protection of critical infrastructures;
- Dual-use defence technologies/capabilities such as space economy and in-orbit servicing, with particular reference to technologies that enable autonomous and reactive access to space at national level (e.g. launch of micro/mini-satellites from mobile platforms as an alternative to traditional launching sites) and access to in-orbit maintenance services;
- Technologies aimed at implementing real and effective capabilities of suborbital and hypersonic flight;
- Innovative technologies in the underwater sector, enhancing the activities of research, development, testing and application of future technologies to be employed on both manned and unmanned platforms operating underwater, with the involvement of several ministries and agencies;
- Technologies for stratospheric platforms that

can ensure support to operational activities, with lower operating costs and higher flexibility compared to traditional satellite platforms, as well as for R&D and Testing&Evaluation activities in a space environment, together with other relevant institutions, as an instrument to foster the growth of national industrial capabilities and promote the country's role within the New Space Economy;
- Technologies for sustainability, security and energy resilience, in order to build Smart Cities and energy sustainable military districts by using innovative building materials/technologies and structures/platforms for centralized and distributed production and storage of energy, also ensuring adequate protection against threats in the domains of energy security and cyber security;
- Development/acquisition of new technologies and materials aimed at reducing the negative effects of infirmities, to support veterans and victims of service-related physical traumas or impairments.

The identification of high-priority sectors also allows for more effective and efficient planning and resource management, directing technological research activities towards objectives that are consistent with the current priorities and capability requirements of the Armed Forces, while minimizing the fragmentation of technological sectors and dispersion of resources among many different activities.

NATIONAL RESEARCH

INTRODUCTION

Below are showed representative results of the technical-scientific activities, either ongoing or concluded, of technological importance for Defence and safety included in the context of the research programs conducted by the Secretariat General of Defence and NAD during 2021:

- hibrid emergency blowing device (HEBD);
- Integration of active/semi-active/passive diagnostic sensors into advanced composites (COMPOSENSING);
- biomimetic Superhydrophobic materials (BIOS);
- Passive radar system for low Earth orbit objects detection(SPIA);
- The "Cyber monitoring (CYMON)";
- Modelling and Simulation as a Service(MASTER);
- Small quantum processor(COPERNICO);
- Multi mission command and control(MMCC);
- Acceptability of Aeronautical Components using Additive Layer Manufacturing (ACARMA) ;
- Hunter Airborne Warfare Killer (HAWK).
- Project: Characterization of a Volumetric muscle loss swine model (RESUMO)

HEBD

The activities related to the National Military Research Plan (PNRM) "HEBD" in question, deal with the design, definition and implementation of an integrated system for the emergency ascent of underwater[1] units, mainly Submarines, to surface in the fastest and safest way from operational depth, through aerospace derived technology. The PNRM, based on a system of gas generators with hybrid technology, aims also to verify the ascent dynamics and behaviour of the system in water both in normobaric and hydrostatic conditions, and the consequent "marinisation" and integration on board with potential focus on the just started construction of Near Future Submarines (NFS) and the refitting of submarines I and II Batch U212A. The current development of the project has enabled the engineering and prototyping of a small-scale generator that will be expanded to full-scale as a starting point for the final realisation of the complete marinised system that can be integrated on board.

[1] EBD, Emergency Blowing Device

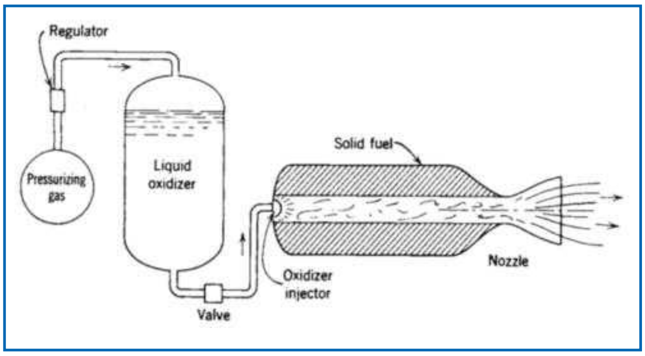

Figure 1 - Functional diagram of a hybrid generator

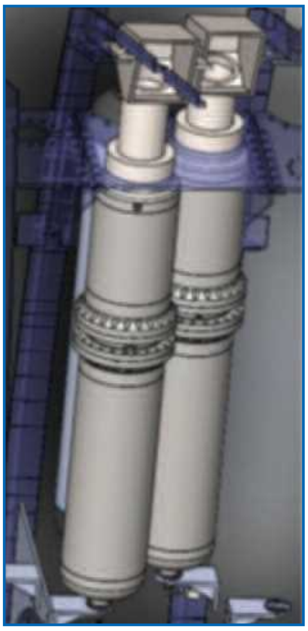

Figure 2 - Representation of an HEBD

Introduction

Current emergency ascent systems are based on the release of high-pressure air to ballast[2] tanks or the fast generation of gas from special aerospace-derived[3] solid propellant generators. The compressed air system is particularly invasive in terms of the amount of air storage containers on board, while gas generators have high acquisition and maintenance costs as well as rather long supply times and operational limitations in terms of inability to stop the gas generation when triggered.

Technical Background

The future for the on board systems is the development of generators with low cost fuel/fuel systems, easy to use and find, fast acting and operationally controllable. The PNRM idea is therefore based on the possibility of using an oxidant in liquid[4] form, and normal polymeric (plastic) materials as fuel, which can be activated, deactivated and recharged at low cost.

[2] For SAURO Class Submarines
[3] For U212A Submarines
[4] High-concentration hydrogen peroxide or nitrous oxide

Furthermore, in a hybrid gas generator, with total elimination of the explosiveness of the solid propellant, the oxidant and fuel are separate and inert: they are made to interact through an activation valve that controls and stops the mass flow of the oxidant entering the combustion chamber.

Methodology

The primary objective for the qualification of the system has been the development of a simulator for the emergency ascent dynamics of the U212A submarine: in collaboration with the company Cetena, starting from a calculation code (SIMOS) of a simulator in 6 degrees of freedom, an activity of porting of the old code has been carried out, implementing the modelling of the X-rudders and introducing the physics of the new generators. Particular attention, according to potentially already known aerospace gas generation dynamics, has been paid to the analysis of the dynamics of the fluid physics in the exhaustion phase.
The calculation tool was validated thanks to a test campaign carried out by the company Fincantieri at the Platform[5] Simulator of the Submarine School in Taranto: tests were carried out for emergency ascent in the event of a water leak, obtaining the relative ascent curves with appropriately identified scenarios.
The basic design of the HEBD system has also been carried out, first of all analysing the configuration of the new Gas Generators inside the ballast tanks (figs. 3 and 4), in collaboration with the company T4i, followed by the risk analysis, in collaboration with the company Cetena; finally the basic design study of the command and control system has been developed in collaboration with the company Seastema.

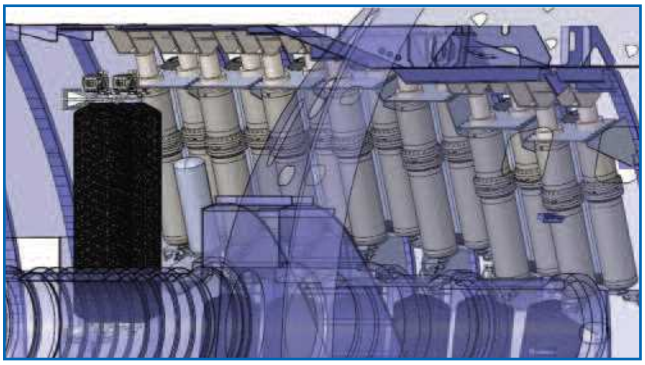

Figure 3 - Model ballast tank 3 (longitudinal view).

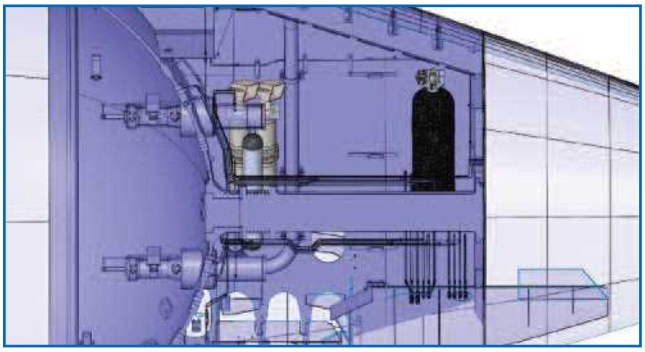

Figure 4 - Model ballast tank 1 (longitudinal view).

An initial comparison with the weights[6], and volumes of the classic and hybrid EBD systems shows a minimal increase in weight, which is a fundamental assessment for a submarine, against increased volumes as a result of increased components, but still compatible with the current configuration of the U212A ballast tanks.

Potential Technology Applications and Exploitation

The Risk Based Design (RBD) process showed the feasibility of installing the technology on the construction of the new NFS submarines, also with a view to refitting U212A I and II Batch. The same technology also guarantees a level of safety and reliability compatible with the intended field of application and a far superior possibility of operational management of the system, due to the

[5] Submarine Control Simulator - CSC

[6] Approx. 20 kg

better possibility of controlling and stopping the gas[7] generation. All of this, with considerable savings in terms of industrialisation economy, and system support, according to the materials used, particularly for the gas generation reaction. The technology used, of proven aerospace derivation, has been further developed in the deep physics of the fluids involved, particularly in its use in sea water and under pressure, with potential spin-offs for use first and foremost on all the world's submarines, which are always equipped with emergency ascent systems. It's the crossover of an aerospace technology in a domain, the underwater one, of increasing worldwide interest.

CONCLUSIONS

The project embraces and amplifies, deepens, 'marinises', aspects of aerospace engineering that are absolutely of high profile, originating from thrusters used for launch systems. It has achieved considerable maturity in the management of the complex physics of the phenomenon, particularly inside the ballast tank of a submarine, and in the maturity of the prototypes tested. The hybrid gas generation system has significant advantages that have a major impact on all phases of the life of the entire product and, above all, its operational use. As far as intrinsic safety is concerned, the hybrid system does not use explosive materials but inert ones, and therefore the entire logistical management phase of the system components is exempt from the explosive materials regulations. In addition, the system allows the management of the submarine's emergency ascent, through modulation of the reaction with the fundamental possibility of stopping and re-engaging the reaction, with absolute control by the operators. In addition, from a cost perspective, both the oxidiser and the plastic material as fuel are much cheaper than those currently used on U212A submarines. At the end of Phase 1, the HEBD technology has been validated in the laboratory to a technology maturity level of TRL 4 and aims to reach TRL 6 for on-board adoption. In the next phase, the objective will be to define the configuration in detail, carrying out an in-depth analysis of the overall dimensions of the command and control system, designing the necessary supports for each Gas Generator inside the ballast tanks and defining the system installation and maintenance procedures. Finally, the system is engineering the physics of fluid interaction between two of the world's most important domains, space and underwater, with potential implications for the global submarine safety systems market.

[7] Hydrogen peroxide and normal plastic polymers

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS	
GG	Gas Generator
HEBD	Hybrid Emergency Blowing Device
NFS	Near Future Submarine
RBD	Risk Based Desing
TRL	Technological Readiness Level

KEYWORDS

Hybrid, Aerospace, Safe, Emergency, Submarine, Submersible, Underwater, Immersion, Space, Sea.

PROJECT INFORMATION:

PNRM card number: a2018.164

Contracting authority: Naval Armaments Directorate (NAVARM)

Authority responsible for the project: FINCANTIERI Cantieri Navali Italiani S.p.A.

City, Region: Genoa, Liguria

Title and name of project manager: Ing. Mariano Cicchetti

Contact details of the project manager: Fincantieri Divisione Navi Militari via Cipro, 11 16100 Genova

Telephone number of project manager: 010-5995954

E-mail address of project leader: mariano.cicchetti@fincantieri.it

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COMPOSENSING

The "COMPOSENSING" project's objective is to investigate and analyze the feasibility of incorporating a variety of sensors into composite constructions.
During Phase 1 of the research program, an assessment of the state of the art of existing sensors, both fiber optic and radiofrequency, was conducted, as well as an analysis of the requirements for sensor use in composite materials and an examination of the interface and technological maturity of the systems. It was determined which solutions could be produced by co-laminating optical fiber sensors of the Fiber Bragg Grating (FBG) type, optical fiber sensors based on OFDR (Optical Frequency Domain Reflectometry) techniques and piezoelectric radiofrequency sensors. In this regard, a series of small-scale representative panels made of composite material with integrated fiber optic and radio frequency sensors were created to assess the manufacturing process's feasibility and, consequently, to lay the groundwork for the subsequent phases of the project's development of the test beds.
These technological advancements offer an intriguing alternative to metals and will enable the development of "intelligent" structures/equipment, that is structures/equipment capable of providing the operator with real-time or near-real-time information about the surrounding environment and/or the device's efficiency.

Introduction

Composite materials are frequently recommended as a weight-saving alternative to metals due to their mechanical and electromagnetic properties. When combined with arrays of different types of sensors (active or semi-active) laminated directly inside, the composite material can acquire significant operational capabilities in the civil and military sectors, particularly in aviation and underwater applications.
The composites equipped with fiber optic sensors will be manufactured using processes that will be studied in the COMPOSENSING project. These composites will be characterized by their lack of electrical signals for reading and thus their immunity to electromagnetic interference, low invasiveness and resistance to hostile environments. They will be tested once connected to the application for signal processing and management of the man-machine interface to ensure proper communication with the transponder responsible for data reception and signal processing. The research will also evaluate the insertion of passive radiofrequency (RF) sensors into the composite, directly during the laminates' manufacturing process.

Technical Background

Due to their features and characteristics, composite materials are now widely employed in the aerospace, automotive, and marine industries. However, components designed for these specific applications may be subjected to high loads and extreme service conditions, which over time can result in delaminations between the composite's inner layers, which are undetectable to the naked eye except via ultrasonic testing and X-rays, which require expensive equipment and intensive work. Structural Health Monitoring (SHM) techniques, which leverage sensor integration in materials, enable real-time monitoring (punctual or diffuse measurement) of the onset of structural problems, allowing for accurate predictive or real-time analysis of the state of preservation of systems/components critical to the operation and safety of a vehicle. Recent advancements in the field of composite material sensing have sparked interest in the development of Integrated Vehicle Health Monitoring (IVHM), which refers to vehicles/components that are capable of delivering real-time operational metrics of interest. In this regard, optical fiber is the perfect sensor for this type of application.

While their use is more favorable than that of standard electronic sensors, there is a trade-off between cost and performance that limits the type of technology that may be employed for a given application. The COMPOSENSING project considers the following: fiber optic sensors with fiber Bragg Gratings (FBG) for static and dynamic strain and temperature measurements; distributed fiber optic sensors with Optical Frequency Domain Reflectometry (OFDR) for distributed static strain measurement with high spatial resolution.

Sensors are embedded into monolithic and sandwich composite materials composed of carbon and glass fibers in both cases.

Methodology

The technique used in the first phase of the project was based on an initial assessment of the state of the art and maturity of current technologies, as well as an assessment of the needs for the use of various types of sensors in composite constructions. After defining the technologies, a series of representative panels was created to test the manufacturing method for integrating fibre-optic and radio-frequency sensors into monolithic and sandwiched carbon and glass composite materials.

Characterization and integration of FBG sensors into composite materials.

The Bragg grating sensors used in this study are made using a femtosecond laser writing technology in the laboratories of the Sant'Anna University.

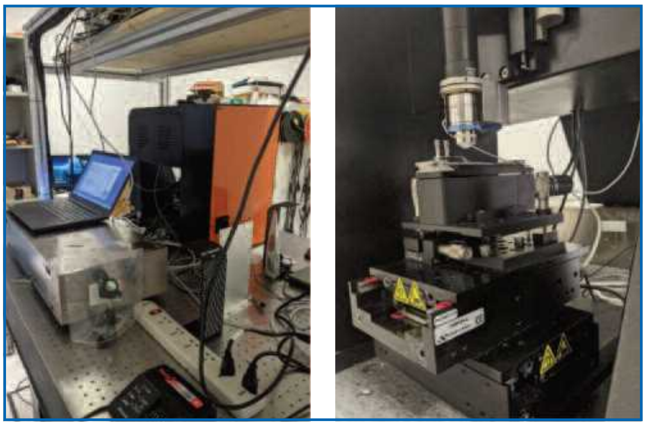

Fig.1 - Workshop on FBG sensor writing at Sant'Anna University

Prior to integration, the written FBGs in the composite were characterized to rule out any deformations caused by resin polymerisation. In light of the satisfactory verifications, the FBGs were incorporated into the lamination phase of the various specimens (monolithic and sandwich structure) for the subsequent flexural tests. During the lamination phase, a variety of controls was implemented to ensure the integrity of the integrated optical fibres throughout the manufacturing process, thereby reducing the danger of inadvertent breakage.

Using bending tests conducted at the Scuola Superiore Sant'Anna's laboratory, it was determined how the mechanical reaction of the product varies depending to the orientation of the FBG sensor in relation to the carbon/glass fibers and the sensor's distance from the sample's neutral axis. In general, it was found that: measured deformations vary linearly with applied forces; the proportionality factor between measured strains and applied forces is constant.

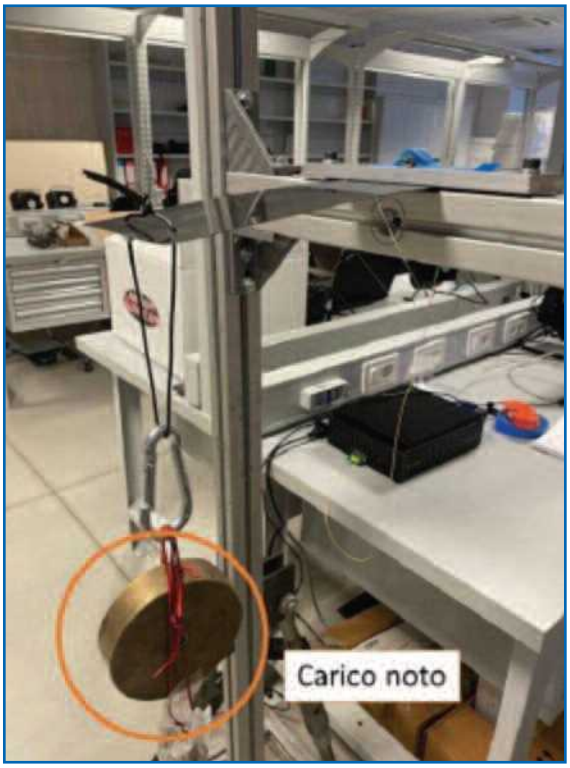

Fig.2 - Mechanical test.

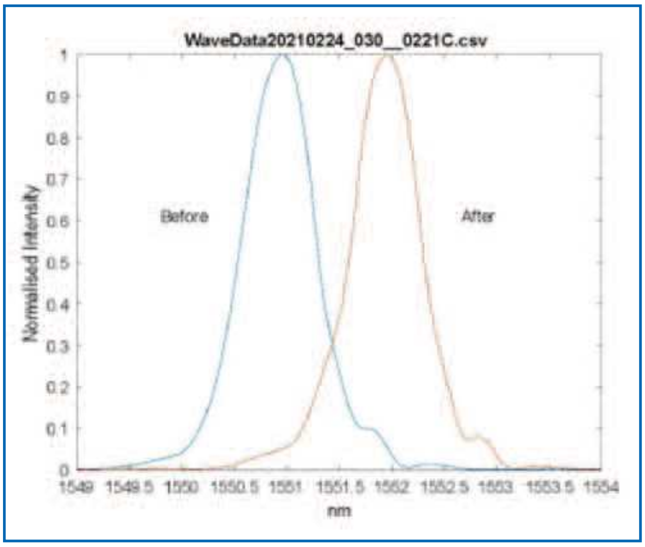

Fig.3 - FBG sensor spectra before and after integration in a carbon sandwich composite.

The FBG spectrum was also characterized before and after the integration procedure in several types of composite materials in order to compare the response curves. In this regard, it was observed that:

when FBG sensors are incorporated into carbon composites, the reflection peaks move by approximately 1 nm to longer lengths as a result of the integration process in a monolithic or sandwich structure;

in the case of integration in a glass fiber composite, however, a peak wavelength drop of around 0.43 nm can be noticed.

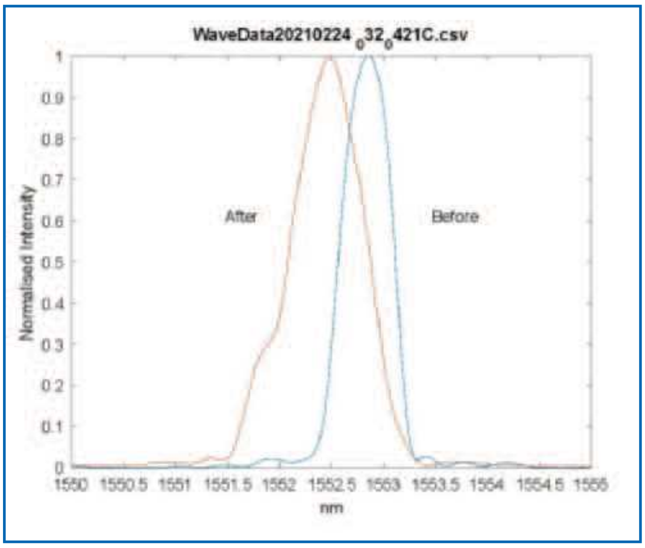

Fig.4 - FBG sensor spectrum before and after integration in a glass sandwich composite.

Thermal characterisations in a climatic chamber confirmed the proportionality of the Bragg gratings' wavelength shifts as a function of temperature, allowing for the determination of sensitivity values in pm/°C for various materials (carbon fiber and glass fiber). These characteristics will be critical for temperature measurements and compensating for material deformations caused by thermal expansion.

Preliminary feasibility study of distributed strain sensors based on OFDR.

Given the complexity of OFDR techniques with high spatial resolution for static and dynamic strain measurements and the difficulty of obtaining commercial instrumentation capable of meeting the project's specifications at a reasonable cost, the experimental laboratory measurements will be considered during the project's development phase, with validation in the relevant environment left to future developments. Laboratory demonstrations may be conducted throughout the three phases of the project, either with experimental setups constructed ad hoc in the laboratories of the Scuola Superiore Sant'Anna or with commercial goods, providing they are commercially available at a fair cost.

The procedure of integrating a radiofrequency sensor ring

Prototypes of the entire radio-frequency (RF) measurement system were created using Printed Circuit Board (PCB) technology, which is often used to create integrated circuits. The integrations of RF sensors were carried out similarly to those of FBG sensors. On the basis of preliminary tests, it was determined that it was necessary to alter the inductors' shape to improve their sensitivity and capacity to detect deformations in the composite laminates.

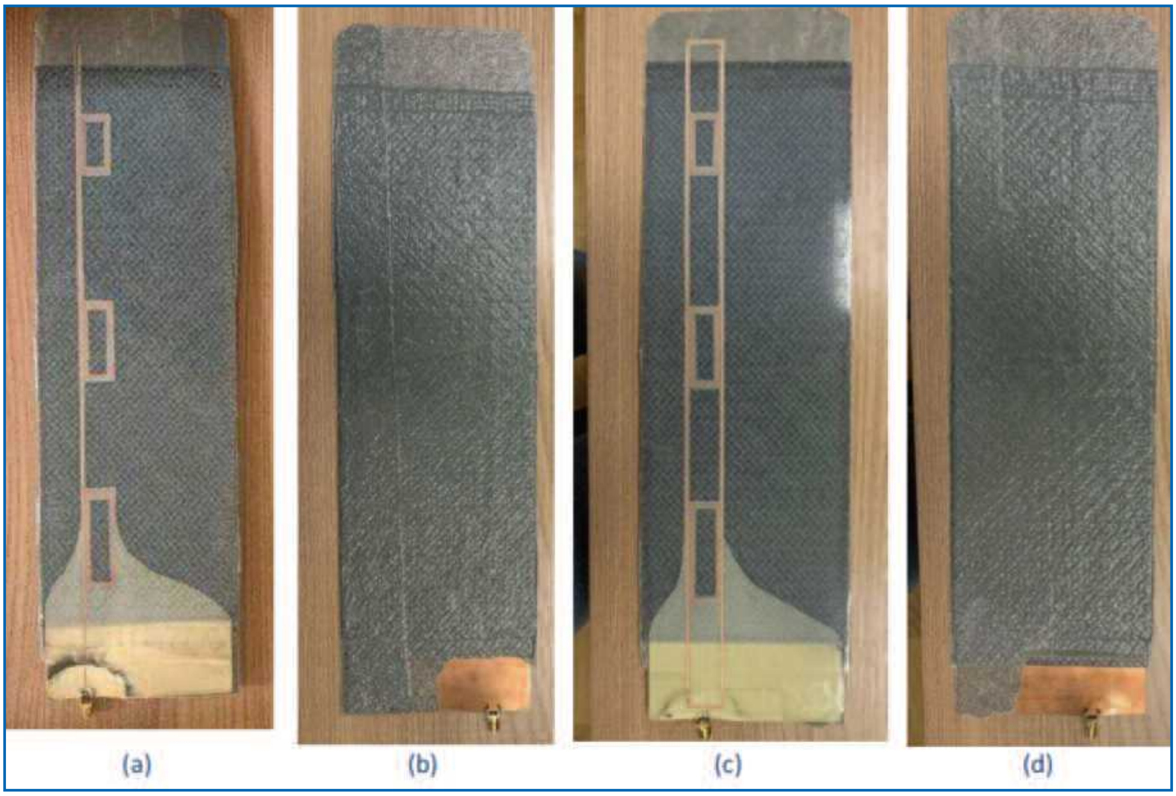

Fig.5 - Front and rear surface of single-wire (a and b) and double-wire (c and d) sensor specimens.

After integration, it was observed that the sensor's frequency response follows the same trend as it did prior to integration. Comparing the findings reveals that the impedance peaks shift slightly following the integration process, but remain well defined and measurable. However, integration results in an increase in ohmic losses, as indicated by the decrease in the amplitude of the resonance peaks when compared to numerical simulations.

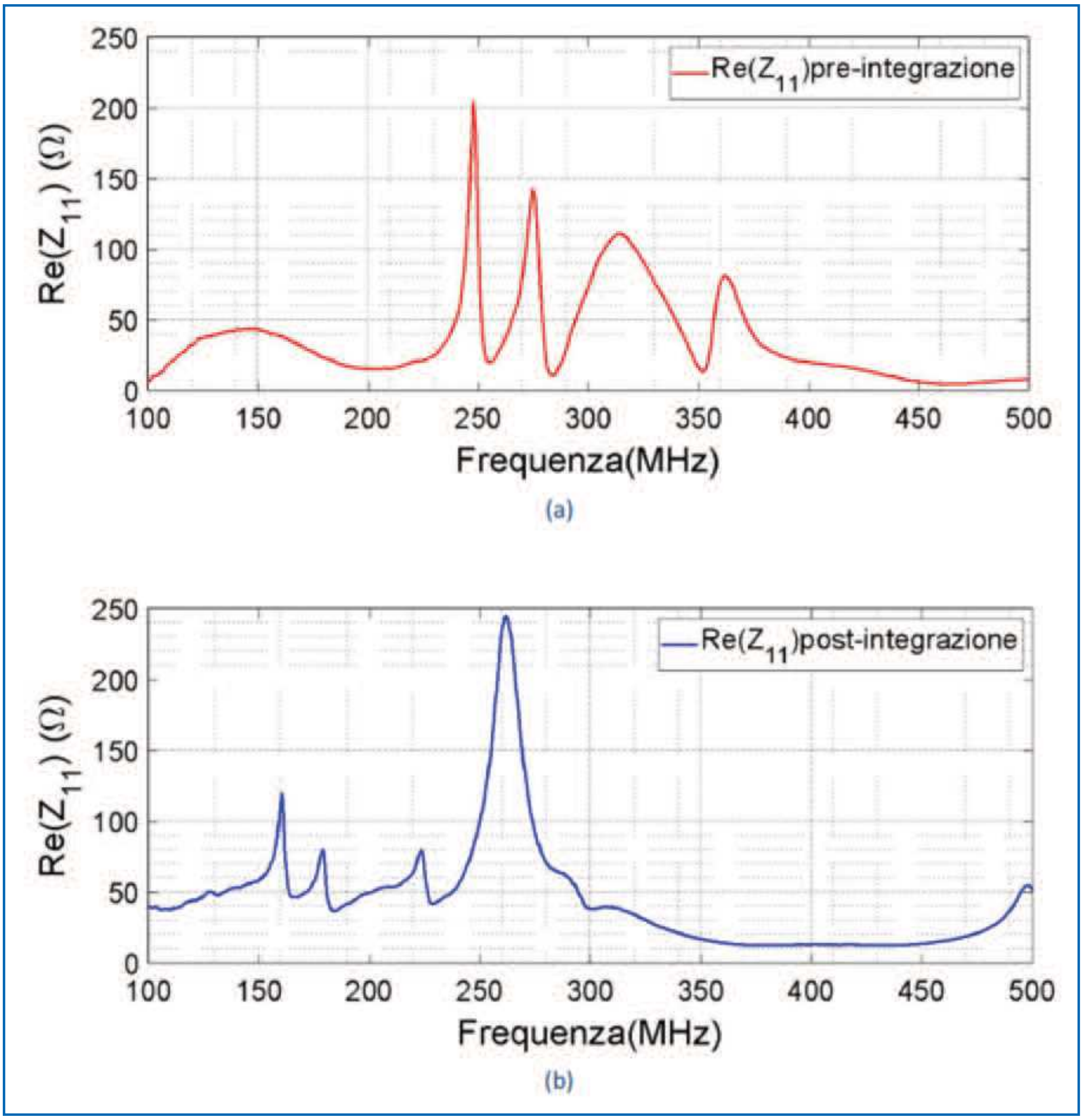

Fig.6 - Graph of the actual part of the impedance recorded at the sensor input before and after integration (a) (b).

Potential Technology Applications and Exploitation

The project's first phase established the viability of combining the sensor families under consideration. Optical fibers, in particular, have demonstrated immediate compatibility with the manufacturing process for glass and/or carbon fiber (or other reinforcing fibers) composite parts; RF sensors, on the other hand, require a specialized cutting process for the support to the copper tracks, in order to facilitate their integration during the lamination phase. More broadly, phase 1 validated the manufacturing method for incorporating fiber optic and radio frequency sensors into composite materials.

Given that the fabrication of test plates with integrated sensors was extensively developed during phase 1, the following phase will concentrate on the integration of sensor matrices and, more specifically, on the design and fabrication of the test-bed for the efficacy verification planned for the final phase.

The study's strategic nature is confirmed by the results and objectives achieved thus far, as it has the potential to develop expertise that is currently unavailable in the underwater sector, particularly in the development of submarines, unmanned underwater vehicles and weapon systems equipped with intelligent structures/hulls that can also take advantage of the operational advantages offered by composite materials.

Conclusions

The acquired results illustrate the efficacy and repeatability of the technique of integrating fiber-optic sensors into composite materials, as well as the high linearity of their response to mechanical and thermal stresses. Thus, the static features of the sensors embedded in the composites enable the achievement of outcomes consistent with project estimates and, in particular, the real-time monitoring of complicated structures. By the end of the program, clear indications will be available regarding the development of design methodologies and the technological evolutions that should be pursued for existing systems as well as those in which to invest due to their untapped potential.

The succeeding phases of the program will focus on consolidating, researching and upgrading national design capabilities in the underwater domain, as well as on identifying and defining technological directions for the building of submarine-based means. In this regard, the Defense Commission's construction of the "National Underwater Pole" demonstrates the importance of the underwater sector among the world's most technologically advanced and industrialized nations. As a result, the aforementioned program is to be regarded as extremely innovative and of vital importance to the A.D.

LIST OF SYMBOLS,ABBREVIATIONS AND ACRONYMS

FBG	Fiber Bragg Grating
OFDR	Opticale Frequency Domain Reflectometry
WDM	Wavelength Division Multiplexing
SHM	Structural Health Monitoring
IVHM	Integrated Vehicle Health Monitoring
RF	Radiofrequenza
PCB	Printed Circuit Board

KEYWORDS

Design, Submarine, Underwater, SSK, Concept Design.

PROJECT INFORMATION

PNRM number: a2019.109
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BIOS

The goal of this research is to improve the hydrodynamic performance of maritime vehicles by applying high-durability superhydrophobic nanostructured coatings on the outer surface. Surface functionalization techniques for surfaces with thin films were employed to meet the project's aims, which are now a research field of significant interest and practical potential. The ultimate objective is to define the major design requirements of Superhydrophobic Surfaces (SH), as suggested by an evaluation of the most recent state of the art in terms of chemical-physical and morphological properties of the coatings. Phase 1 of 2, concluded in July 2021, enabled researchers to evaluate the efficiency of coating deposition processes and their antifouling capabilities in a controlled environment with satisfying findings. These serve as a prologue to a successful conclusion of the real tests, which will be carried out in phase 2, both for the verification of antifouling ability in the open sea and for the measurement of hydrodynamic resistance and self-induced noise.

Introduction

A continuing search for ways to reduce consumption and noise in the water for naval boats is a must for having an innovative naval instrument. As a result, the project's goal is to look for new technologies that might improve the autonomy and noiseless of ship hulls. Surfaces with superhydrophobic qualities, which have already been tested in other fields, represent a major step forward that has to be explored in order to validate the decrease of hydrodynamic resistance, antifouling capacity, and noise reduction, as well as the viability of application on real-world surfaces. The project is divided into two phases, which are mentioned below:

Phase 1: involves fabrication of specimens with superhydrophobic surfaces, conduct of proliferation tests in a controlled environment, and preparation of setups for hydrodynamic experiments in cavitation tunnels.

Phase 2: carrying out proliferation tests in the maritime environment, testing for measuring self-induced noise in cavitation tunnels, data analysis, and determination of surface design standards.

Each phase is split into two work packages (WP).

Technical Background

Resistance and noise propagation are inextricably linked, because the same mechanisms that cause resistance to advancement also cause self-induced noise, which is caused by the movement of the elastic surfaces of the hull by the fluid dynamic structures present in the turbulent boundary layer (SLT) and in the wake. The BIOS project intends to increase the hydrodynamic performance of hulls in terms of resistance to running (i.e. max speed and endurance), and noise by depositing superhydrophobic nanostructured coatings with excellent durability on the exterior surface utilizing surface functionalization processes. Using thin films, which are a research topic of tremendous interest and have a wide range of applications. The project is to follow an experimental path with the ultimate goal of defining the design requirements for superhydrophobic surfaces, classifying their performance, and determining the feasibility of large-scale production.

The proposed solution to reduce hydrodynamic resistance (and, in particular, friction) involves coating the specimens with SH thin films of an organic/inorganic hybrid nature, with surface roughness less than 50 nm, generated by the SLIPS (Slippery Liquid– Infused Porous Surface) with deposition of nanostructured inorganic layers (Al_2O_3, TiO_2 or SiO_2) as a "receptive" component for oils or lubricants deposited. Despite the fact that the external flow of water may cause its removal, limiting the performance of the materials in operating circumstances, the infused oils or lubricants remain trapped in the nanostructures due to the high surface tension and chemical affinity values. These surface properties allow the layer of water close to the hull to retain a relative speed other than zero, allowing for a large reduction in frictional resistance as well as a significant reduction in generated vibrations.

Methodology

The BIOS project includes the following activities divided by Phase and WP:

Phase 1 WP1: Design, manufacturing, and deposition of superhydrophobic coatings Methodologies for deposition of SH coatings on large slabs with varying morphology (dip coating, automated spraying), application of physicochemical approaches (tensiometry, observations in scanning electron microscopy, atomic force microscopy, non-contact roughness assessment) to the characterisation of SH surfaces and correlation with design parameters.

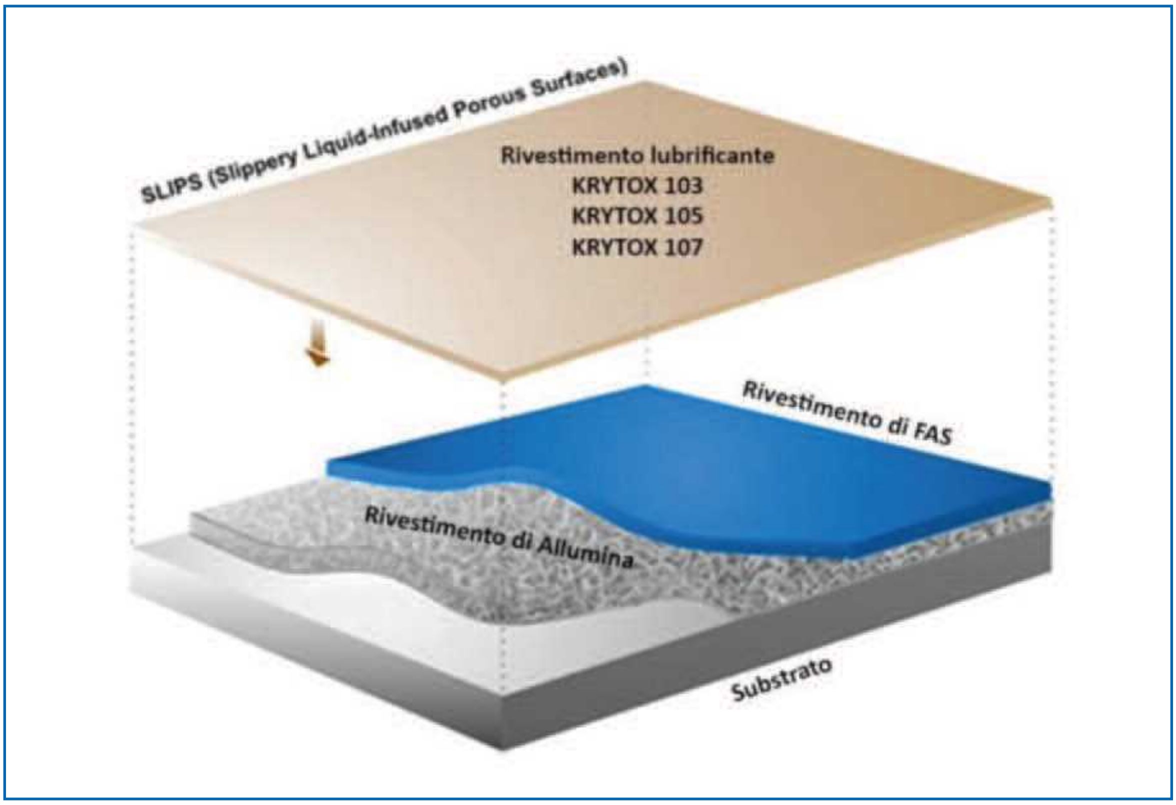

Figure 1 - An example of coating structure using the SLIPS technique. Specifically, an Alumina coating was functionalized with FAS and then infused with lubricant oil.

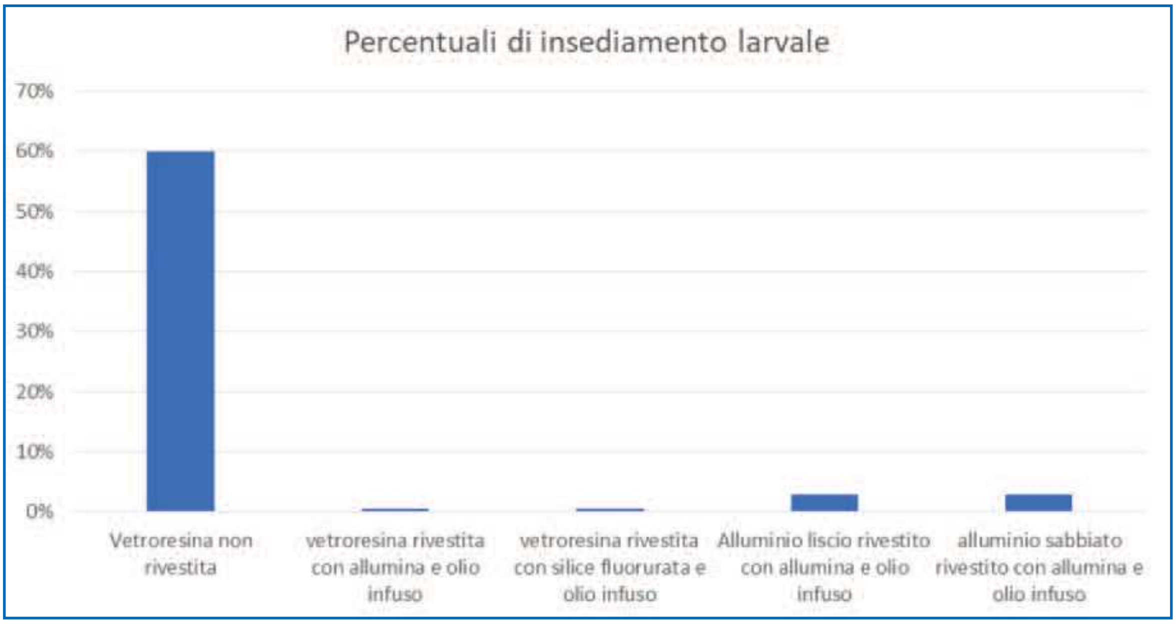

Figure 2 - The proliferation test in a controlled setting yielded diverse findings for the various types of medium.

Phase 1 WP2: Planning the experimental measurement campaign to determine the resistance to advancement and noise propagation in the hydrodynamic tunnel. Evaluation of fouling release capacities in a controlled setting with a consistent presence of microorganisms.

Phase 2:
Phase 2 WP1: resistance measurements in the CEIMM's hydrodynamic tunnel, evaluation of the vibrational response of superhydrophobic coatings (based on precise measurements of acceleration and pressure in the hydrodynamic tunnel), evaluation of the anti-fouling and fouling release performance of surfaces with controlled wettability in a marine environment with the permanence of the samples to be evaluated at the CNR's Marine Experimental Station of Genoa.
Phase 2 WP2: Define the characteristics of superhydrophobic surfaces with regulated wettability, with the goal of identifying and developing the application conditions of surfaces of components and materials used in the naval sector, based on the results achieved in WP1 of phase 2.

Potential Technology Applications And Exploitation

In addition to the ability to minimize drag, vibrations, and fluid dynamics, superhydrophobic coatings have a variety of features that make them particularly appealing for military applications.
When used to other types of structures, such as aeronautical structures, the superhydrophobic feature reduces the chance of ice crystal formation (high antifreeze properties). SuperHydrofobic coatings' water-repellent properties also allow them to slow down the corrosion of the metal surfaces on which they are placed by reducing the contact area between the solid surface and the neighboring corrosive media. Anti-freeze-de-icing capabilities may also be employed in the civil and aeronautical fields, for example, to power line spans, much as corrosion prevention capabilities can be utilized in metal constructions such as bridges, pipelines, or other elements. Civil buildings made of metal.

Conclusions

The BIOS project, phase 1 ended, has produced some extremely intriguing results, including: efficacy of the composition of the coatings, the installation of which will then have to go through the engineering process in order to be offered on an industrial scale (to be developed in the second phase); larval proliferation studies in a controlled setting demonstrated the nano-structured hybrid coatings' outstanding antifouling potential. To fully comprehend the usefulness of this technique, it will be required to wait for proliferation testing in the open sea to evaluate antifouling efficacy, as well as tests for resistance to advances and noise propagation in hydrodynamic tunnels.

The results of phase 1 demonstrate how shifting the frame of view may improve material performance by seeking to manage the nanometric detail and leveraging the micro/nano structures of materials to improve their attributes. The potential ramifications of this technology in the naval industry might include a reduction in the frequency of maintenance pauses as well as a reduction in ship consumption and harmful emissions. The research of nanostructured materials in the military area suggests a number of advantages, both in terms of weapon-system performance enhancement and environmental protection.

LIST OF SYMBOLS,ABBREVIATIONS AND ACRONYMS	
BIOS	Superhydrophobic BIOmimetic materials
SH	Superhydrophobic
WP	working package
SLT	Turbulent boundary layer
SLIPS	Slippery Liquid–Infused Porous Surface

KEYWORDS

Superhydrophobicity, nanostructured coatings, hydrodynamic resistance.

PROJECT INFORMATION

PNRM number: a.2018.186
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SPIE

Interest in satellite technologies has increased significantly in recent decades. However, due to the rising complexity of the orbital environment, space assets are more and more at risk of collision with other spacecraft or debris. To mitigate these risks, the need to monitor such objects has arisen. The SPIA project (Passive radar system for low Earth orbit objects detection) studies the feasibility and development of a passive radar system based on an array antenna that exploits signals transmitted by TV services geostationary satellites to detect objects in low Earth orbit. The use of passive radar provides a good cost-performance trade-off with respect to active radar and optical systems. The project is conceived in two phases: the first phase concerns the definition of the system requirements, the study and definition of the array antenna system and the processing techniques; the second phase focuses on the definition of the technological demonstrator requirements, its realization and validation in a relevant environment. The results obtained during the first phase show signal-to-noise ratio levels that guarantee the detection of the International Space Station in orbit under realistic distance and speed conditions.

Introduction

The significant increase in the number of orbiting objects means that the probability of collisions between space assets and other spacecraft or debris is growing. Hence the need to develop systems and technologies for monitoring low-orbit objects. Radar is a viable solution because it is all day/all weather and can provide accurate distance and radial velocity measurements. The use of ad-hoc passive radars would allow continuous surveillance without the use of own transmitters, thus minimising costs and energy consumption. The SPIA project investigates the feasibility and development of a passive radar system for space surveillance. The advantages of the proposed solution with respect to the scientific state of the art are:

- Reduced costs, power consumption and electromagnetic emissions;
- High availability of broadband signals guaranteed by the exploitation of geostationary satellites devoted to video broadcasting;
- Flexibility in beamforming, fine angular resolution and high reception gain guaranteed by the use of sparse array technology.

This system could be integrated with a national or European space surveillance network, for the construction of an independent catalogue or for adding data to the existing one, for safety, security and maintenance of services related to the space assets.

Technical Background

Recent decades have seen a dramatic increase in the number of objects in orbit (Figure 1) and a higher risk for operational satellites to collide with each other and with other debris in orbit. Hence the need to monitor these objects. Some of the sensors used in Europe are TIRA, GRAVES in France, the Teide optical observatory in the Canary Islands and Matera Italian Laser Ranging [2],[3]. In Italy, several experiments have been carried out to evaluate the use of radio telescopes in the context of Space Surveillance and Tracking (SST). In this project, the proposed technological solution is based on the use of a passive radar equipped with an array antenna that exploits signals transmitted by satellite platforms (e.g.: DVB-S/DVB-S2) as illuminators of opportunity.

The use of passive radars in SST is a topic that has been little explored so far. In literature only one applied research work can be found, where the array antenna of an Australian radio astronomical observatory is used as receiving antenna and FM radio transmissions from ground antennas are exploited as IO (Illuminator of Opportunity) [4]. The possibility of using TV broadcast signals from geostationary satellites has been recently proposed by the CNIT-RaSS Lab in [5]. The approach proposed in this project represents an opportunity of particular interest for the detection of space debris thanks to the very wide coverage that geostationary orbit transmitters are able to guarantee and the continuous surveillance, without the use of own transmitters, minimising costs and energy consumption. Detection performance is achieved through an array antenna, digital beamforming techniques enabling electronic beam scanning and flexible broadband receivers capable of taking advantage of the energy radiated by the satellite which is distributed across various transponders.

Methodology

The focus of the project is the study and realisation of a passive radar system for detecting objects in Earth orbit. The system will make use of a planar receiving array antenna with electronically scanned beam and flexible wideband receivers, able to maximize the signal-to-noise ratio (SNR) by exploiting multiple satellite transponders. The project is organized in two phases of 12 months each:

- Development of a passive radar system based on geostationary televised satellite IOs for the detection of objects in low Earth orbit:
- Definition of system requirements;
- Study and definition of the architecture of the system, the receiving array antenna geometry and the digital beamforming and signal processing techniques.
- Design, implementation and testing of the technology demonstrator:
- Definition of the requirements of the technology demonstrator;
- Implementation of the demonstrator based on COTS devices with ad-hoc implemented processing algorithms;
- Validation and verification of performance in relevant environment.

Starting from the geometry of Figure 2 and assuming as IO the Eutelsat HOTBIRD 13C satellite [7],[8], whose footprint is reported in Figure 3, the SNR map in Figure 4 obtained for a target with RCS of 20 dBsm, shows SNR levels >9 dB such that a cumulative detection probability can be obtained, with a cumulative false alarm probability by exploiting 5 channels of 90 MHz bandwidth each, as a result of the cumulative detection strategy. Figure 5 shows the baseband spectrum of the simulated DVB-S2 signal used as the reference signal in the scenario of Figure 6 relative to a real pass of the ISS over the Italian airspace. Figure 7 shows the related range-Doppler map. Despite the target Doppler response broadening, the expected SNR is sufficient to allow the detection of the ISS passing at high speed over Italy.

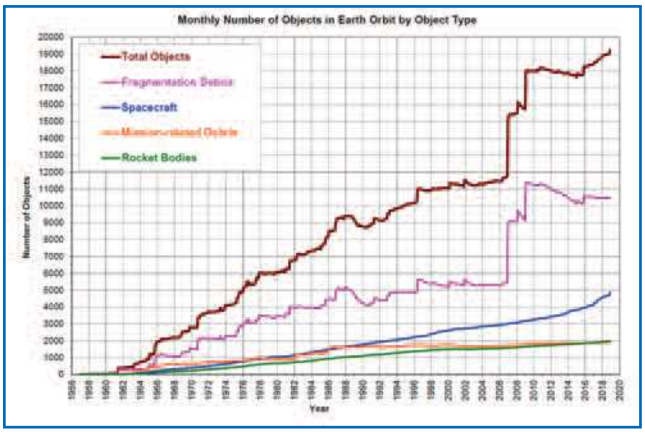

Figure 1 - Monthly number of catalogued objects in Earth orbit with respect to objects type [1].

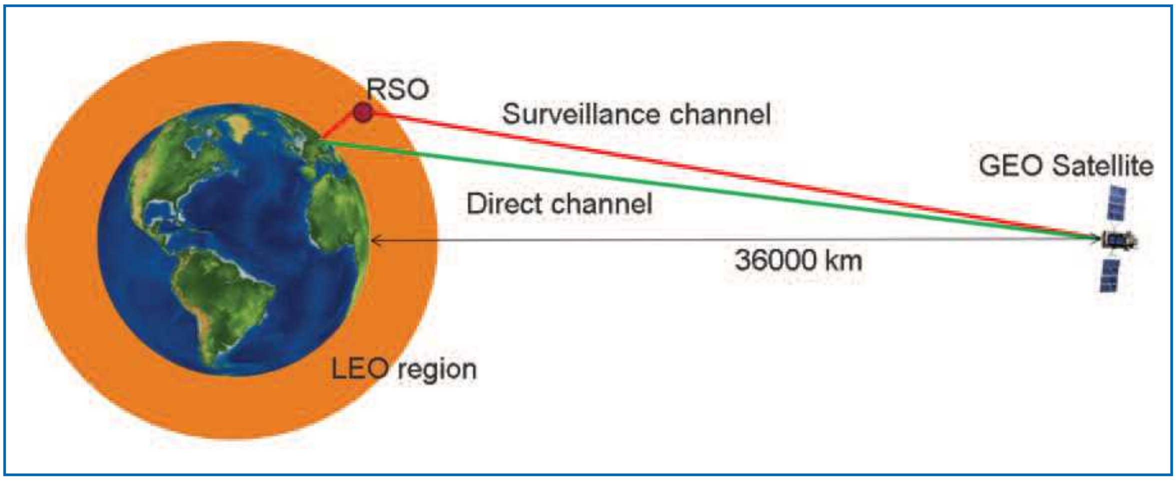

Figure 2 - Geometry of a satellite-based passive bistatic radar.

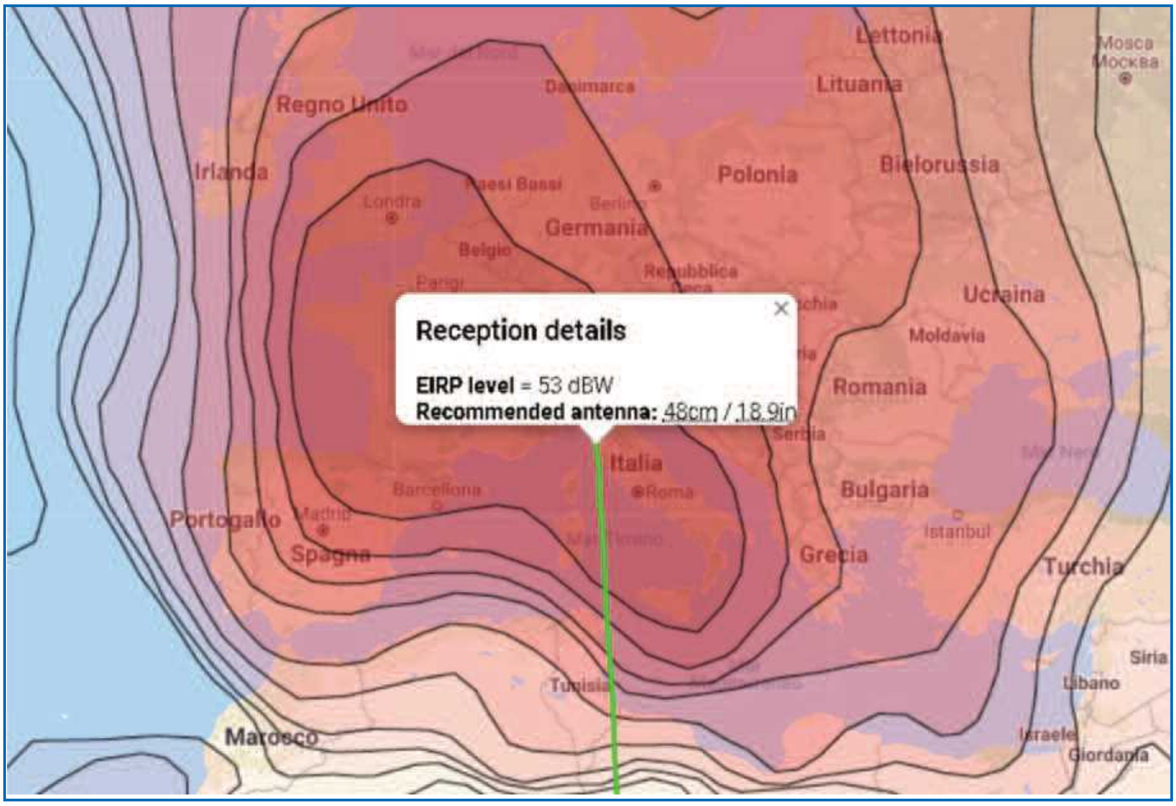

Figure 3 - Eutelsat Hotbird 13C footprint [6].

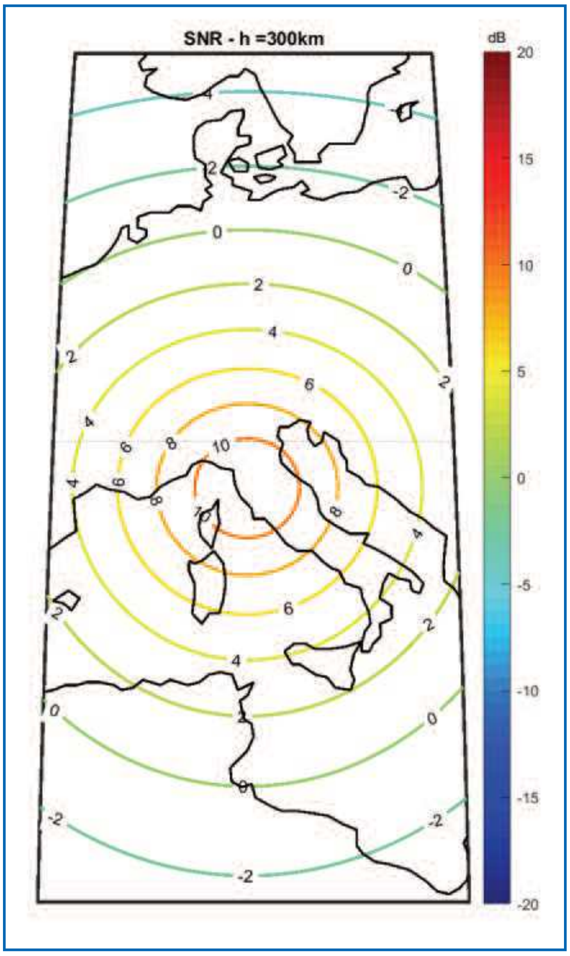

Figure 4 - Expected SNR map obtained for a target with RCS=20 dBsm at an height=300 km.

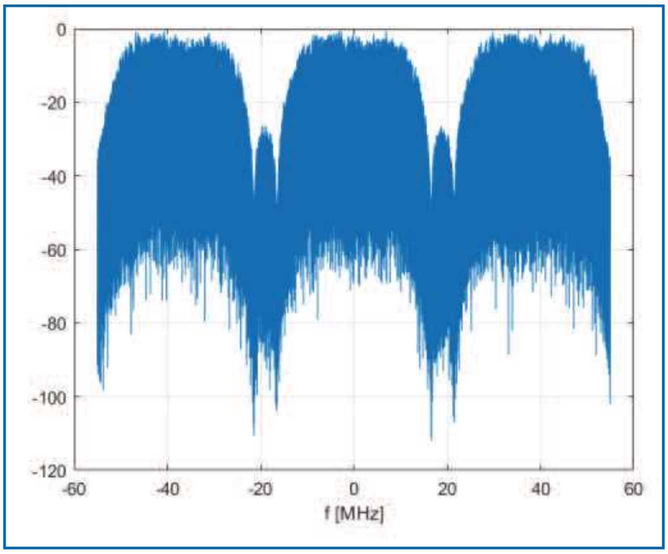

Figure 5 - Three channel DVB-S2 simulated signal spectrum.

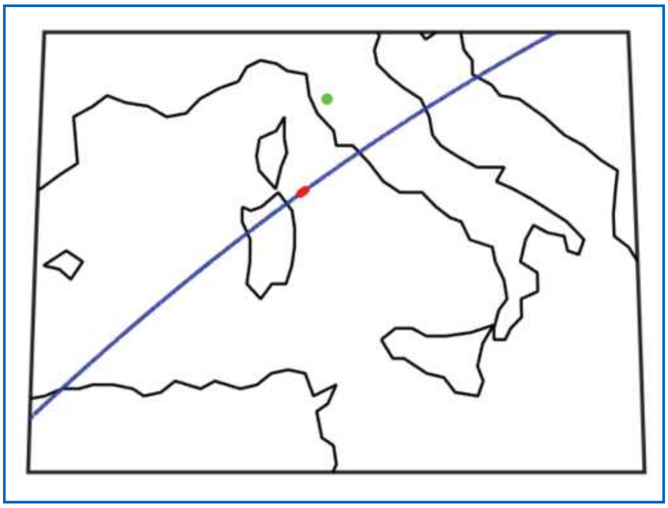

Figure 6 - International Space Station recorded data of a pass over Italy used for simulation purposes (30/10/2019 – UTC 03:10:00).

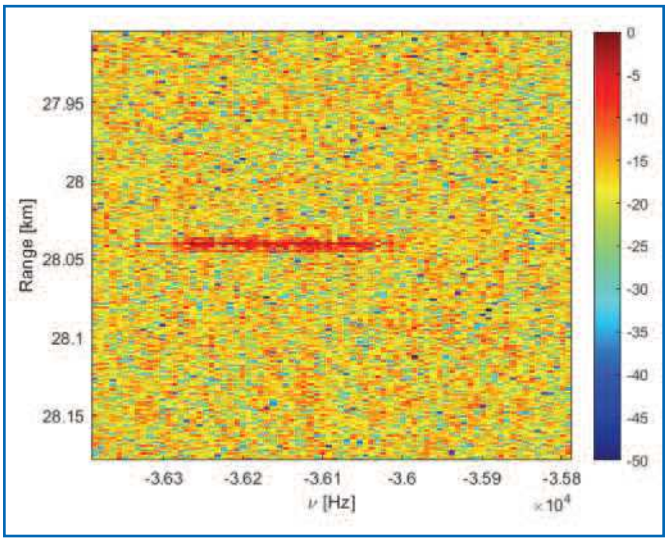

Figure 7 - Simulated range Doppler map (3 channel DVB/S2) related to the ISS pass over Italy.

Potential Technology Applications And Exploitation

The proposed technological solution adopts a modular and scalable architecture based on innovative and low-impact technologies, able to monitor the orbit of satellites for diagnostic and prevention purposes, while at the same time allowing the possibility of planning countermeasures to the inefficiencies caused by any natural or intentional malfunctions. This functionality is strategic to guarantee continuity in the maintenance of all those services offered by space assets and defined as essential for the management of Critical Infrastructures (e.g. government agencies, regions and local authorities, security, telecommunications, transport, electricity and energy systems, health, banks and financial services).

The synergy between ECHOES and CNIT-RaSS, dictated by common strategy and objectives, ensures the deployment of complementary skills necessary for the design and development of the technological solutions proposed within the project. As far as the system is concerned, ECHOES has the design and production capabilities for the development of a mini-series. ECHOES can also benefit from the support of CNIT-RaSS in terms of measuring equipment and technical consultancy. CNIT-RaSS has a consolidated expertise in the defence sector and has already successfully accomplished studies and implementation of passive radar demonstrators in previous projects.

Conclusions

Interest in passive radar for SST applications is growing rapidly. The SPIA project is focused on the study and realisation of a passive radar system for the detection of objects in low earth orbit, exploiting TV geostationary satellites as illuminators of opportunity. This architecture guarantees the right trade-off between efficiency and cost. Starting from the detection requirements defined in the EU-SST and ESA-SSA programmes, decision strategies (e.g. cumulative detection on sub-bands) were first analysed to improve the system performance. Potential coverage was evaluated under the assumption of obtaining a sufficient SNR for detection. Subsequently, the main technical/functional requirements of each subsystem were defined and commercial technological solutions for the realisation of a demonstrator were proposed. The work continued with the study of the possible configurations of the receiving array antenna and the digital beamforming and signal processing techniques. These techniques have been verified on a real pass of the ISS over the Italian airspace on the morning of 30th of October 2019. The results obtained from the Phase 1 of the project show expected SNR levels sufficient to guarantee the detection of a LEO orbiting object moving at high speed over the Earth surface.

LIST OF SYNBOLS,ABBRECIATIONS AND ACRONYMS

COTS	Commercial Off-The-Shelf
DVB-S	Digital Video Broadcasting Satellite
EIRP	Equivalent Isotropic Radiated Power
ESA	European Space Agency
EU	European Union
FM	Frequency Modulation
GEO	Geostationary Earth Orbit
IO	Illuminator of Opportunity
ISS	International Space Station
LEO	Low Earth Orbit
RaSS	Radar and Surveillance Systems
RCS	Radar Cross Section
RSO	Resident Space Orbit
SNR	Signal to Noise Ratio
SSA	Space Situational Awareness
SST	Space Surveillance and Tracking

KEYWORDS

Passive radars, SST, digital beamforming, sparse array, DVB-S2, ISS, scalability, wideband, fine resolution

PROJECT INFORMATION

PNRM number: a2019.435
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CYMON

The "Cyber MONITORING (CYMON)" project aims to provide to the the Military Air Force the capability of "Cyber Security Monitoring", by means of a new designed avionic equipment, able to identify and report in "real time" external attempts of altering the normal computing behavior of the Avionic System.
The project has been organized in two consecutives phases. Phase 1, completed in September 2020, involved the creation of a Simulator, representative of a real architecture of a generic Avionics System, useful to inject cyber threaths and analyse the corresponding effects.
A Real Time Monitoring System has been developed and connected to the Avionic Simulator, in order to record the data exchanged on the communication backbone (Bus MIL-STD-1553), extract the data correlation and analyze the data in terms of correctness and integrity. Innovative Machine Learning algorithms has been used to accomplish these tasks.
The results of this phase have demonstrated the feasibility of the proposed solutions, capable of modeling the dynamic behavior of a complex avionic system, enabling the funding of the subsequent Phase 2 of the project currently in progress. Supervised and unsupervised Machine Learning algorithms are under development, in order to detect and identify cyber threats, by an iterative analysys of the data acquired passively from the mission data bus.

Introduction

The evolution of the cyber threats nowdays affects not only the processing and networking infrastructures used to support IT services, but also jeopardizes the integrity of aerial platforms, attempting to corrupt the embedded software components installed onto the Avionic Mission Systems.
The CYMON project involves the study and demonstration of techniques for detecting and recognizing “malware” injected into the on-board Avionics Computer System, by means of innovative Artificial Intelligence algorithms. Once the threat has been detected and identified, an alert message will be reported to the pilot only if the degree of confidence is higher than a preset threshold. This message will include the suggested "recovery" actions to mitigate the malware effects.
So, the final objective of the CYMON project is the design of an “on board equipment”, capable of acquiring mission data in "real time", incoming from logical "probes" installed in specific points of the Avionics System, analyzing them and sending immediately to the pilot notifications about malicious intrusions.
The purpose of CYMON project is by its nature dual use, because the acquired techonological capabilities are applicable in both civil and military contexts. In the latter case, the effect of a "malware" could have serious consequences on national security, if used to intercept or alter classified communications or mission data.

Technical Background

The identified problem is the vulnerability of IV°Generation avionic computing platforms, conceived when cyber security was not supported by technologies and entrusted exclusively by means of robustness of the development and maintenance process.

Vulnerability analysys (Ref. R.Patel) reveal the existence of "weaknesses" of the Avionic Mission Systems, origins of possible attacks cause of critical effects on the aerial platform, for example : insertion of errors in sensors data (GPS, Radar Altimeters ..), false indications , fake symbologies, corruption of IFF data etc.
Therefore, real time monitoring of on-board systems behaviour, in order to detect and identify functional anomalies without affecting the performance, seems to be a MUST. AMI tested similar products but those have not met the expected performance, because limited in configurability and adaptability to the different operating contexts.
The CYMON project, conceived in close cooperation with the Reparto Sperimentale di Volo/Gruppo Gestione Software (RSV / GGS) in Pratica di Mare, aims to fill this technology gap. A cyber avionics test environment including a "general purpose" Avionics System Simulator has been developed, providing the mechanisms for controlling and exporting mission data using commands and "scripts", capable of dynamically altering the data contents and/or insert "fake" transactions emulating cyber attacks activated on events ("Spoofing"). Another complementary component of the system is the Knowledge Creation Environment - KCE, designed for modeling the dynamic behavior of the Avionics System, able to correlate data produced by the Simulator. The construction of Knowledge Data Base is mandatory for the "off line" training of the algorithms for threat identification and recognition, which are based on advanced Artificial Intelligence techniques ("Machine Learning" and Neural Networks). Note that in real case the KCE will manage data generated by the Mission RIG or Telemetry.

Methodology

The System resulting from the CYMON project is composed by two main components (see Figure 1).

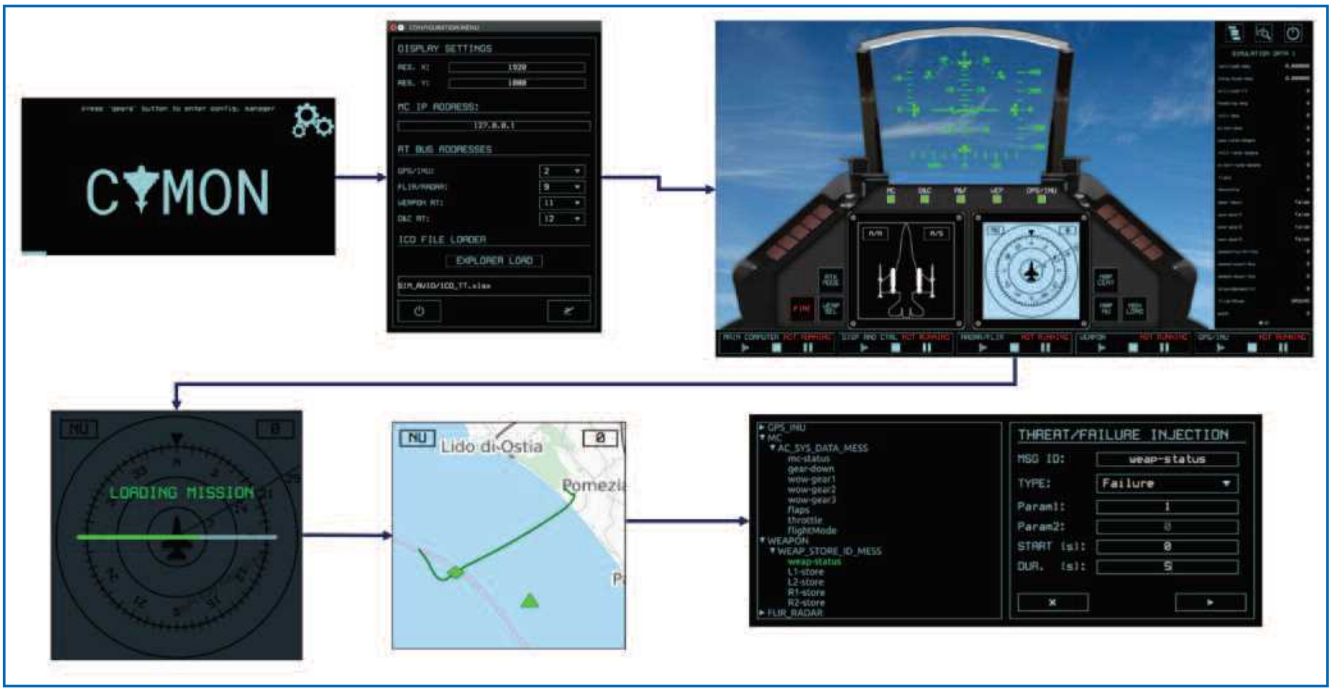

Figure 1 - Avionic Simulator.

The "OFF LINE" component, called Knowledge Creation Environment - KCE, has been developed for acquisition and management of mission data produced by the Avionic System to be monitored and modeled.

Data acquisition will be done when both in normal behavior and in the presence of "malware", injected by using the "Scripting editor" tools. This component is essential for the training of cyber threat detection and identification algorithms based on advanced Artificial Intelligence techniques.

Figure 2 - Knowledge Creation Environment - KCE (CYMON Phase 1).

The "ON LINE" component for the dynamic monitoring of the avionics system is based on three main iterative and cooperating functions: detection, identification and management of the cyber threats.

These functions will retrieve information from the knowledge data base, created during the learning phase (OFF LINE), in order to compare the "run time" behavior of the avionic system with the expected one.

In particular, the detection function will perform a continuous analysis of the data acquired, in order to discover eventual anomalies. After a preliminary filtering phase, the potential threat data will be passed to the identification function for validation. Once the threath is recognised, the confidence and severity of the impact on the integrity of the aerial platform is evaluated and an alert message is sent to the pilot, including the probability of the event and the recommended "recovery" procedures.

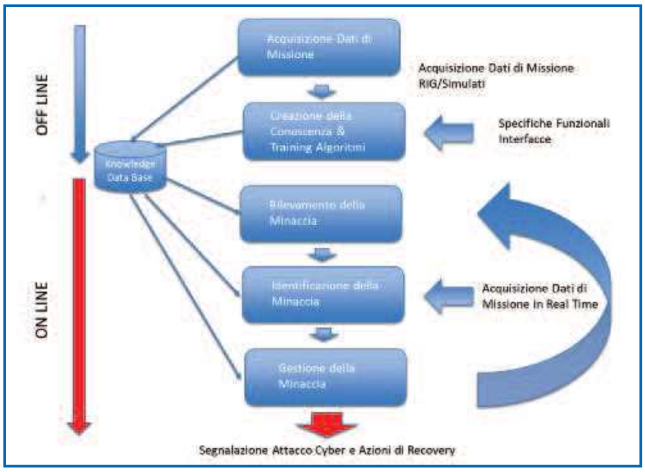

Figure 3 - CYMON Continuous Monitoring Process.

The "OFF LINE" components has been developed and tested in Phase 1 of the project.

A mission scenario has been set up, simulating a IV° generation aircraft which performs the target acquisition and executes the load release. The dynamc mission data generated by the Navigation Sensors and graphical formats on the displays have been replicated, too.

The cyber test environment (KCE) allowed the acquisition of transactions data on Bus MIL-1553, both correct and in presence of a cyber threat

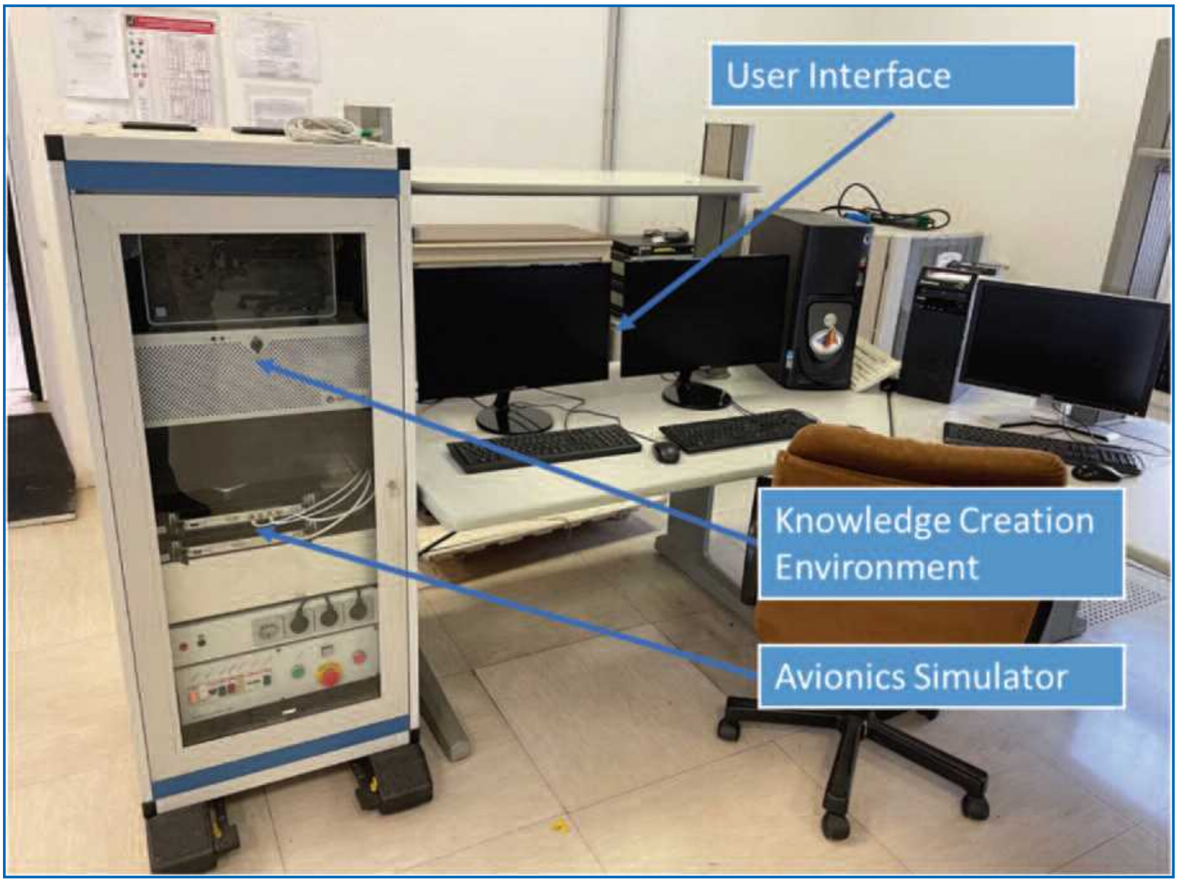

Figure 4 - CYMON – System Prototype.

injected , demonstrating the capabilities of the Machine Learning algorithms for data recording, interpretation and correlation. This phase has been considered propedeutic to accomplish the subsequent Phase 2, where the "ON LINE" algorithms will be developed and tested.

Potential Technology Applications And Explotation

The concepts and the technologies to be studied and experimented in the context CYMON project are applicable in the "critical" applications characterized by high-performance and complex processing architectures, whatever they are, avionic systems or land/naval command and control systems.

The timely detection of anomalous situations in "real time" and the consequent management and "recovery" actions due to cyber attacks may be crucial for the safety of human lives, the conservation of operational capacity, as well as for the protection of national security, in case of interception or corruption of classified information.

So the installation of "passive" monitoring units, with low architectural and performance impact, represents a valid solution capable of providing innovative cyber protection tools, first of all the aerial platforms currently in operation, minimizing retrofit costs for upgrading the legacy platforms. Finally, the techniques of detection, analysis and treatment of cyber attacks in "real time", should be required in those contexts where the attack is usually generated during operational use, mainly from the external environment, for example remotely piloted aircraft , railway signaling equipment or self-driving vehicles.

Conclusions

The objectives planned in Phase 1 have been successfully achieved.

The versatility of the Avionics Simulator, extended with the capabilities of editing and dynamic activation of executable scripts, represents a "Cyber Avionic Test Bed" where is possible to experiment the effect of cyber attacks on the dynamic behavior of Avionic Systems.

The same concept applies to the Knowledge Creation Environment - KCE, able of analyzing and correlating real traffic data incoming from the Avionic Buses, applying transactional reconstruction algorithms for computing behavioral modeling.

The KCE capabilities will be used in the development of threats Analysis, Recognition and Management algorithms to be performed in Phase 2 currently in progress.

In this phase, the effectiveness of the selected algorithms will be tested and validated in order to evaluate their performance, in terms of reaction times and reliability of the results, with the aim of reducing as much as possible the percentage of false alarms. So the studies and experiments will build the technological pillars for the development of a "General Purpose" cyber protection equipment, interoperable with different standard communication backbones (MIL-STD 1553, AFDX, CAN Bus), and therefore able to be integrated on different types of aerial platforms at low costs.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

AFDX	Avionics Full-Duplex Switched Ethernet o anche ARINC 664
AMI	Aeronautica Militare Italiana
CYMON	Cyber Monitoring
GGS/RSV	Gruppo di Gestione Software / Reparto Sperimentale di Volo
GPS	Global Position System
ICT	Information & Communication Technology
IFF	Identification Friend or Foe
KCE	Knowledge Creation Environment
PNRM	Piano Nazionale per la Ricerca Militare

PROJECT INFORMATION

PNRM Number**:** a2017.028
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MASTER

Modelling and Simulation as a Service is one of the main research topics addressed by the NATO Modelling and Simulation Group and one of the pillars of the new next generation simulation concept that the Allied Command for Transformation is developing.
The methodology applied for the development of the first two MASTER project research lots is based, initially, on the study for the definition of research objectives. Furthermore, on the development, integration, experimentation, testing and validation of a technological demonstrator, and on an implementation phase.
The demonstrator prototype includes a cloud computing-based solution (OCEAN), able to provide simulation services to support training, exercise and experimentation activities. Such services are made usable and provided to an end user (consumer) adopting easy and intuitive innovative software interfaces (ADONE), in a service-oriented architecture. In addition, the MASTER prototype implements a use case for maintenance and operational training (MORPHEUS) also available in virtual reality environments and a use case in Cyber Defence.
The solution deployed at the NATO Modelling and Simulation Centre of Excellence, will be usable by the Defence personnel after the delivery of the lot 3. At its state-of-the-art, the MASTER project could be used to experiment further possible implementations of the Modelling and Simulation services concept and potentially, also to support operational activities in a NATO Federated Mission Networking environment.

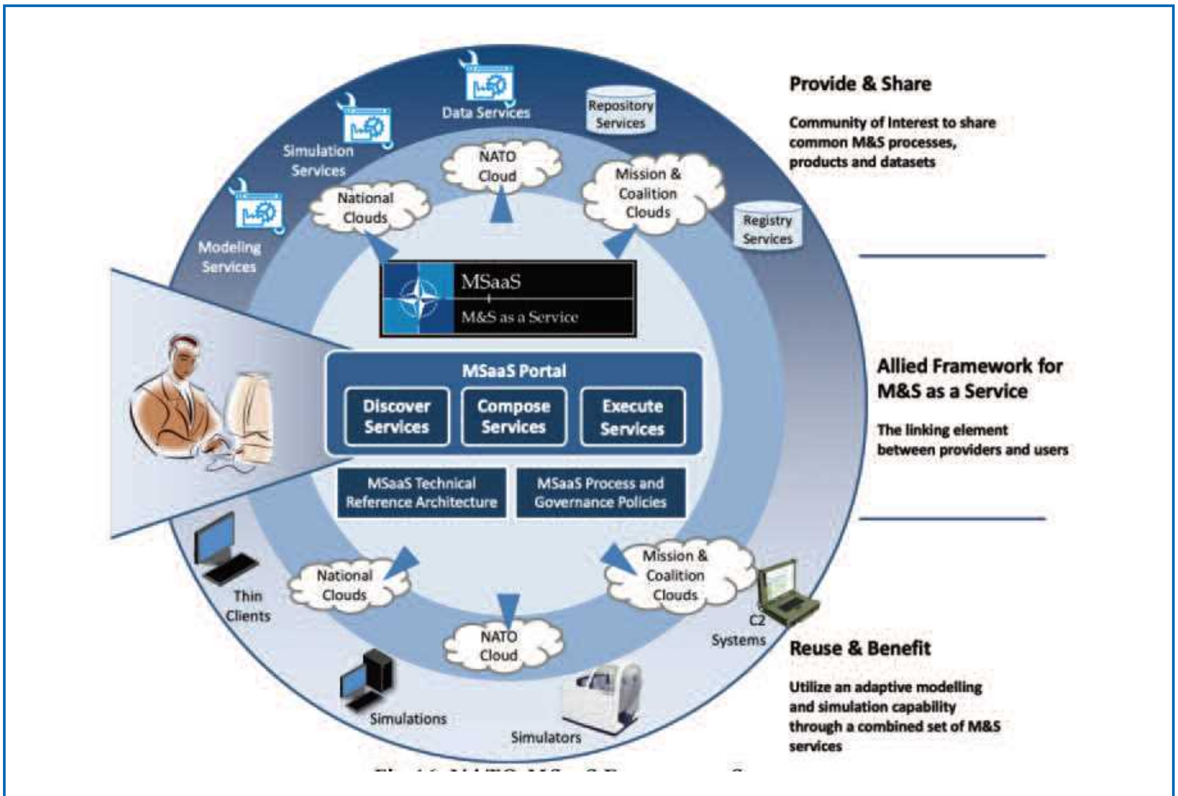

Figure 1 - MSaaS Ecosystem. Source: https://nmsg.sto.nato.int/user/pages/03.themes/07.msaas/03._callout/msaas.png

Introduction

The use of modelling and simulation (M&S) tools is assuming an increasingly decisive role in international and joint force military contexts, in which these tools play a fundamental role in planning, management and execution of training, exercise and experimentation activities. In addition, M&S tools are also operationally used to support analysis and decision-making activities. The NATO Command for Transformation Headquarter and the NATO Modelling and Simulation Group have started study, research and development activities to investigate about possible next-generation service-oriented M&S technology implementations for defense applications. In 2018 the NATO Scientific Technology Organization recognized the Scientific Award to the Modelling and Simulation as a Service (MSaaS) research group.
MASTER aims to create a MSaaS platform that implements innovative solutions (ADONE) based on government cloud computing technologies (OCEAN), integrating emerging and disruptive technologies a core architecture to potentially interoperable services within NATO FMN.

The MASTER project main objective is to demonstrate the potential of the MSaaS solution through two case studies, which offer the opportunity to create, provide and make use of M&S applications and services in a distributed and permanently available environment. Such services should be provided in a cost-effective manner and easy to use by end users, with the aim to reduce the technical staff for the management and administration of computer systems and networks, optimizing hardware and software resources.

Technical Background

The use of models and simulators in the Defense requires military qualified personnel to updated systems, with the ability to reconfigure HW, SW, dedicated networks, and furthermore adequate financial resources. MSaaS approach aims to reduce and optimize the resources needed by increasing the efficiency, usability and reproducibility of applications, introducing the simulation services approach in highly scalable

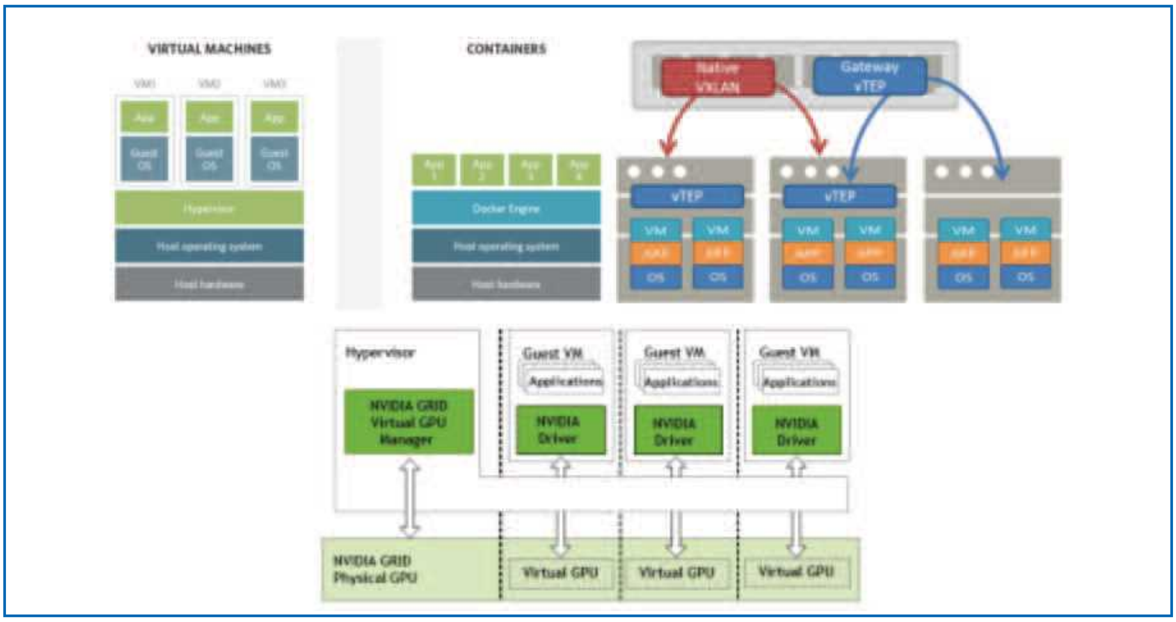

Figure 2 MASTER enabling technologies.

environments. The development of the MASTER project is based on state-of-the-art technological solutions like openstack, bare metal, VMWare NSX, SW automation deployment, 3D graphic streaming, NVIDIA Grid. Such implementation made possible the orchestration and provisioning (Discovery, Composition, Execution) of simulation applications and services via virtual and physical machines, containers, virtual and physical networks. The final objective is to integrate, making interoperable, applications and simulation services with real systems (like command, control and information systems) used by the Defense personnel.

The environment has been developed taking into account specific performance and security requirements and the Federated Mission Networking (FMN) specifications, also implemented by the Italian Defense.

In this context, the environment has been developed:

- to prove to be applicable and certifiable for use in the military, with particular regard to security aspects;
- to be usable and easy to use even by non-specialized personnel for the management of cloud environments, networks, set up and software configurations. Inparticular, the system must guide the user through the phases of discovery, composition and execution of applications, and / or services, starting from a set of available assets with the possibility of recomposing them in different combinations. The latter, depending on the activities (i.e. exercises) to be supported and the objectives (i.e. training) to be achieved;
- to comply with the existing international guidelines (NATO) on used techniques, in order to apply as a future reference standard in the design of service infrastructures (MSaaS), and hopefully also in the FMN environment;
- to implement emerging 3D graphics technologies for Virtual Reality (VR) and immersive cloud applications.

Figura 3 - VR scenario for Radio and C2 Systems operator training.

Methodology

The project was divided into three lots. The methodology applied to the development of the first two was based on the study for the definition of the research objectives (lot 1), on the development, integration, experimentation, testing and validation of a technological demonstrator (lot 2), and on its finalization and implementation (foreseen with lot 3 execution).

The excellent results achieved with the research and study activities, supported by the University of Tor Vergata, permitted the activation and the successful execution of the second lot that delivered a technological demonstrator (TRL 6).

The project main core activity was the design and development of innovative software components (ADONE) and the delivery, installation,

Figure 4 - Immersive Maintenance Image (Leonardo).

configuration and operation of the planned hardware and software supplied in at the state-of-the-art, thanks to a contract update.

Two case studies have therefore been developed: MORPHEUS: immersive virtual environment for training and operational support regarding maintenance activities and operation of electronic equipment (Immersive Maintenance).Cyber Synthetic Environment: services for training and exercises support in a cyber threat environment for Commanders and staff operating in command posts (CPX/CAX). In addition, for personnel operating in security operation centers and cells for cyber operations involved in analysis and augmentation of the Recognized Cyber Picture and the Cyber Situational Awareness in operating environment.

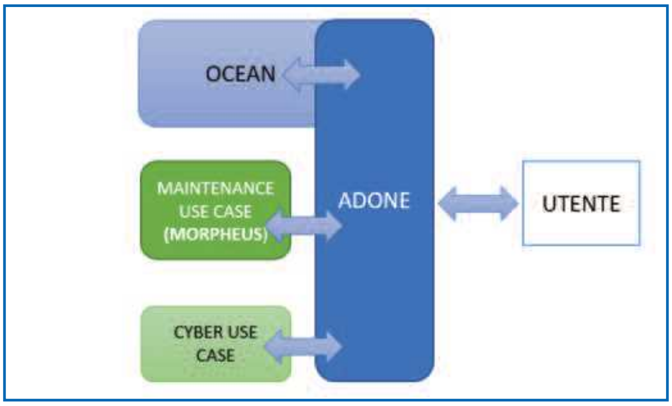

Figure 5 - MASTER Architecture.

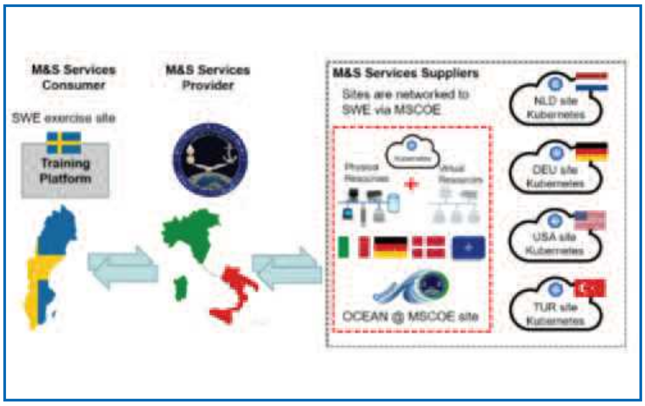

Figure 6 - MASTER Architecture.

The latter was tested with excellent results by participating to NATO and international exercises such as CWIX, NATO Cooperative Demonstration of MSaaS Technology (CAX FORUM), CETATEA and Locked Shields, in order to demonstrate effectiveness of the MSaaS approach supporting training and exercise as a services, and operational support in the areas of Cyber Defence and FMN. The third lot will involve a further development of the demonstrator by bringing elements of innovation, use cases, and the training for Defense personnel to operate with the platform. In particular, research and study activities within NATO will continue, which will be the input for the final project documentation delivery, including conclusions and proposals for future developments and possible implementations for the Italian Defense.

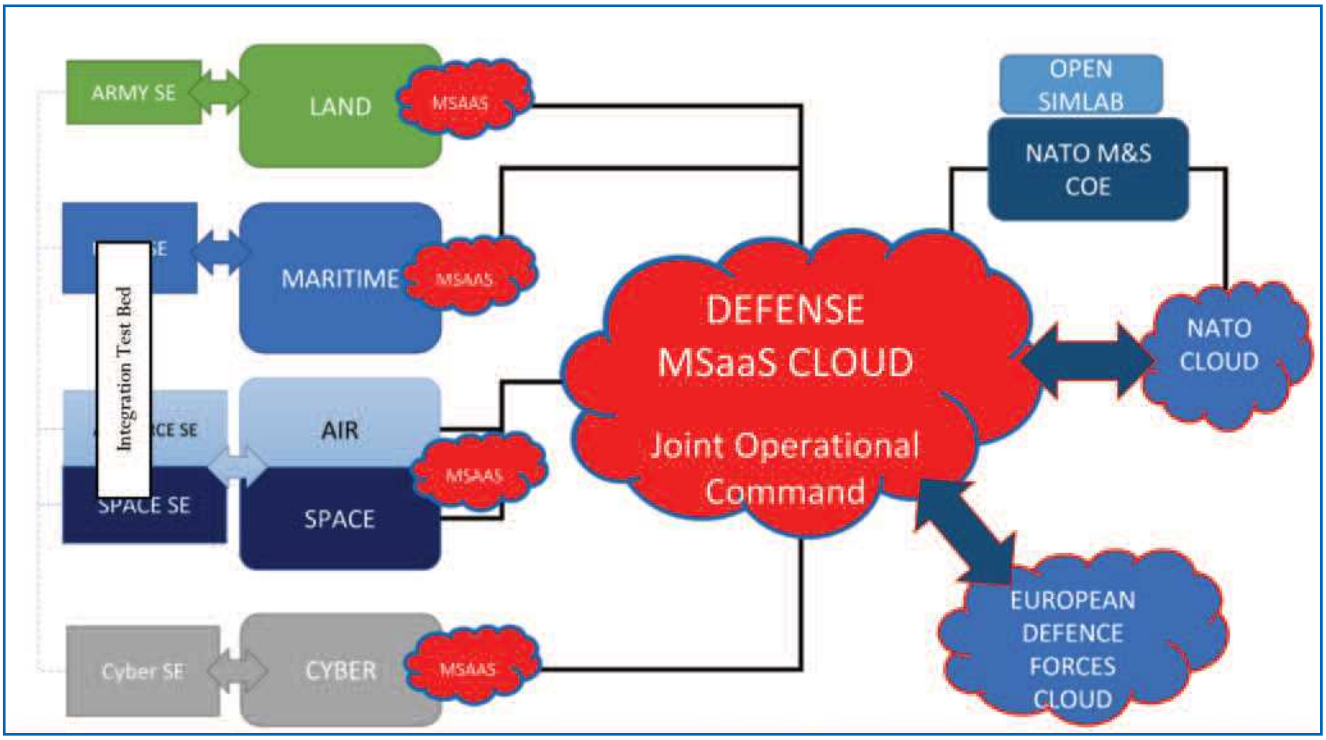

Figure 7 - Concept for a multi-domain synthetic environment for the Defense.

Potential Technology Applications And Exploitation

The experimentation activity conducted during CWIX in collaboration with NCIA demonstrated the possibility of implementing MASTER, and in particular the OCEAN platform, to set up a synthetic FMN environment for training, exercise and operations support, and with specific applications, in the cyber domain. The NCIA itself recognized the operational value of the architecture designed and implemented to proof the concept for a Cyber Joint Vignette to support NATO exercises and for the activities of rapid automatic deployment of FMN nodes. Furthermore, allowing an easy integration of NATO Functional Area Service tools with domestic and foreign C2 systems, within a cross domain network environment. This successful activity posed the basis for possible further developments and verticalizations of the OCEAN solution for the Italian Defense.

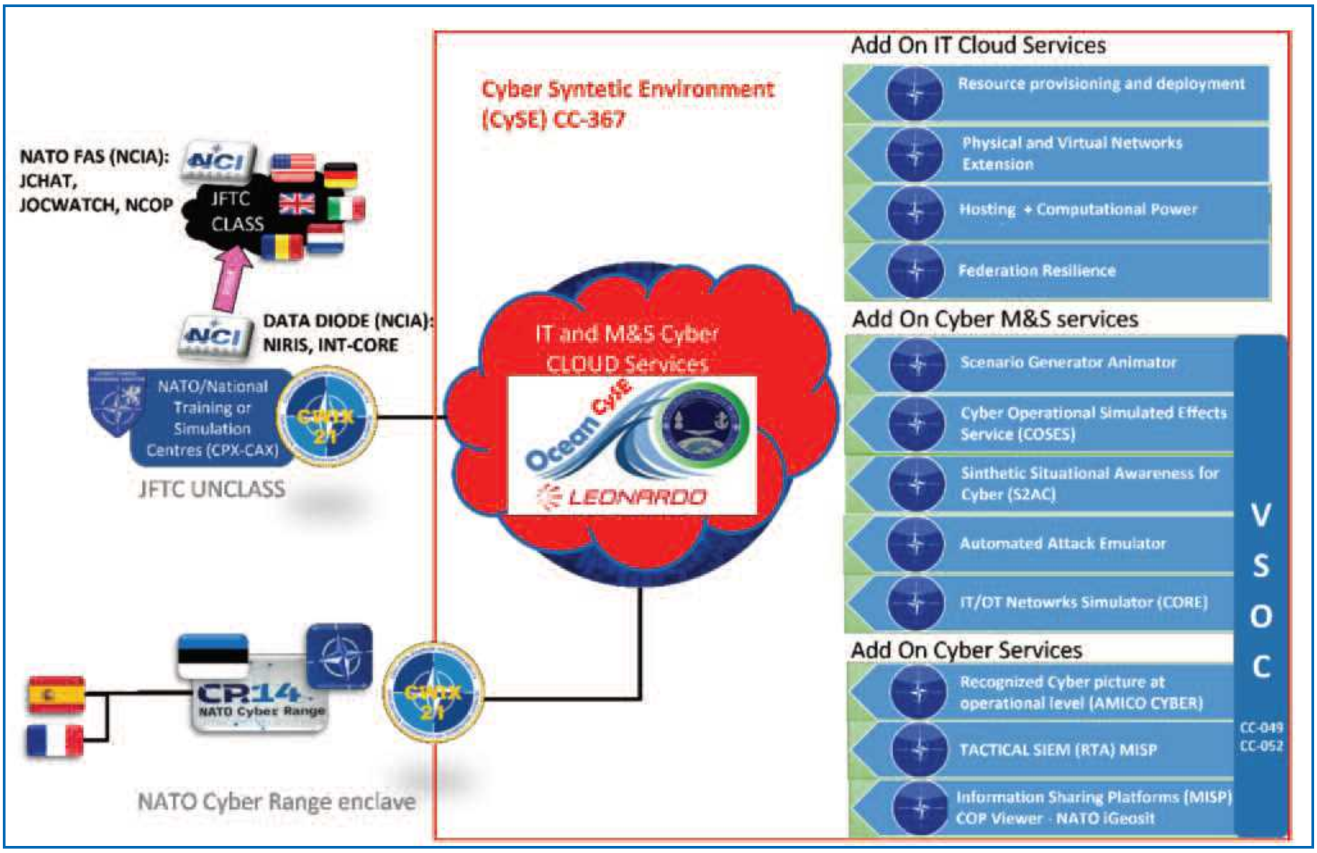

Figure 8 - CWIX 21, OCEAN Cyber Synthetic Environment.

The implemented solution with the PNRM MASTER is part of Leonardo's corporate strategy which envisages, in the medium-long term, the development of new solutions based on the Training, Exercise and Experimentation as a service paradigm. In addition, a further application of MSaaS approach to high performance computing, quantum computing and artificial intelligence sectors, will be investigated to use M&S services for decision and operational support. Thanks to the spin-offs of MASTER's project, Leonardo will be able to propose itself as a supplier of complex systems and advanced M&S services using innovative technology and business models. Furthermore, extending as service solutions the portfolio in a better competitive position in national and international markets.

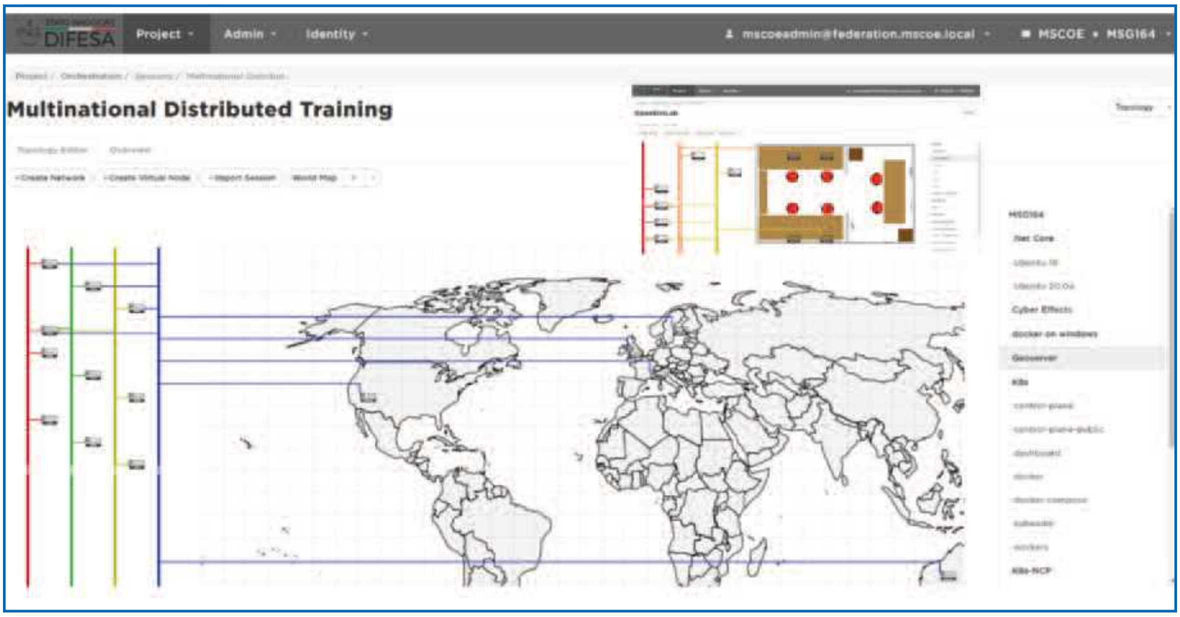

Figure 9 - MSaaS architecture for Distributed Synthetic Training Applications.

Conclusions

The MASTER project produced very positive results from a technical point of view, raising a serious interest from the Defense at joint and single service levels. The addressed topic is one of those of strategic importance as repeatedly mentioned in the various international, NATO and European contexts. In addition, the project taken place so far with the full satisfaction of the NATO M&S CoE of Rome, which remarked about the extremely positive and promising results of the experiments and tests, carried out during international and NATO experimentation activities. Such results are extremely important for the project continuum and for the execution of the third lot. Lot 2 deliveries results from the research program activities were excellent, in particular, the achievements with the development of the demonstrator, which reached an overall level of maturity comparable to TRL 6. With the second lot, all the expectations from the Defense were satisfied, and such results have also raised the interest of some international partners in NATO and Europe. At the same time, the company has invested just in OCEAN further, considered as a PNRM's spin-off. Such additional investment allowed the company to attribute the status of product to the OCEAN platform. Presumably, a subsequent security accreditation of this platform would allow the Defense to be able to acquire a government cloud solution, suitable also to provide M&S services, which could be re-used in other major Defense projects.

LIST OF SYMBOLS,ABBREVIATIONS AND ACRONYMS	
CAX	Computer Assisted Exercise
Coe	Center of Excellence
CPX	Post Exercise Command
FMN	Federated Mission Networking
M&S	Modelling and Simulation
MSaaS	Modelling and Simulation as a Service
OCEAN	Open Cloud Environment ApplicatioN
PNRM	National Military Research Program
TRL	Technology Readiness Leve

KEYWORDS

Modelling and Simulation, Cloud Computing, Service Oriented Architecture, Cyber, Virtual Maintenance, Maintenance, Training, Exercise, Experimentation, Service Oriented Architecture

PROJECT INFORMATION

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COPERNICO

The goal of project was to create a new class of "building blocks", based on a photonic platform integrated in InP , designed to create different functionalities of a "small quantum processor". Although in the present project we developed quantum processing based on integrated photonics schemes, the research will aim to arrive at a parallel, fast and efficient computational hardware, such as to be exploited in AI applications.

Introduction

Quantum technology is a fundamentally new way of harnessing Nature and it has potential for a truly revolutionary innovation and promise the next generation of products with exciting and astounding properties that will affect our lives profoundly. They will have a great influence in defence, aerospace, energy and telecommunications sectors. If this process is to continue in the future, new, quantum technology must replace or supplement what we have now. In particular, Quantum Information Technology can support entirely new modes of information processing based on so called quantum bits or qubits. Its eventual impact may be as great as or greater than that of its classical predecessor.

There is almost daily progress in developing promising technologies for realizing quantum information processing with various advantages over its classical counterpart. Logic gates and wires are becoming smaller, and soon they will be made out of only a handful of atoms.

Photons are unsurpassed as qubits in terms of decoherence times, mobility, and achievability of high-fidelity single-qubit operations. Thus far, entanglement experiments in optics have been very clean, and an optical quantum processor would obviously have an advantage in connecting to a quantum "network" (no need to convert between stationary and flying qubits).

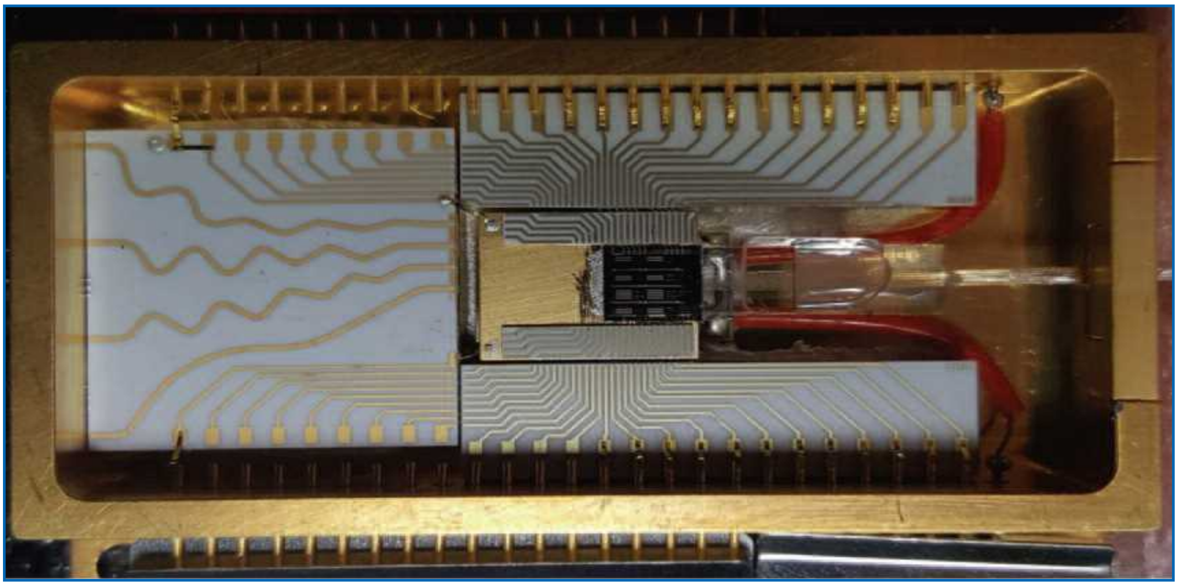

Figure 1 - Integrated Entangled State Generator on chip.

Technical Background

China claims to have made with the Zuchongzhi processor, the most powerful quantum computer in existence. The processor is based on superconducting technology and requires an operating temperature close to absolute zero. There are several architectures on which a quantum computer can be built, each of which is based on a different physical system: quantum computation can be done using ion or atomic traps, magnetic resonance, Jopheson junctions, quantum dots, nuclear spin or photonic circuits. Each of these physical implementations has its own peculiarity and limitation.

An interesting perspective is related to quantum computation that uses linear photonic circuits: it has the advantage that the smallest unit of quantum information, the qubit, is potentially free from decoherence, i.e. the information stored in a photon tends to remain unchanged. The disadvantage is related to the fact that photons do not interact naturally with one another, when instead it is necessary that there is such an interaction to build two-qubits logic gates.

An alternative way to achieve an effective interaction between photons is to make a projective measurement with photodetectors. Also in this case there is a difficulty related to the fact that in this way the logical gates become probabilistic.

The need for scalability makes the search for "nanoscale on chip" systems indispensable. Light-based "on chip nanoscale" systems deliver on the promise of scalability for quantum information applications through high-density component integration and parallelization. The novel on chip photonc device, developed in the frame of COPERNICO PNRM, reduce the overhead due to multiple single photon sources with very high degree of reciprocal coherence and exploits the possibility to encode the whole state space in a complex optical circuit based on MultiRail Architecture: a particular state in input is encoded in the quantum superposition of a coherent light beam trough the different waveguides, so that it is possible to reproduce the mathematical and physical aspects of quantum entanglement.

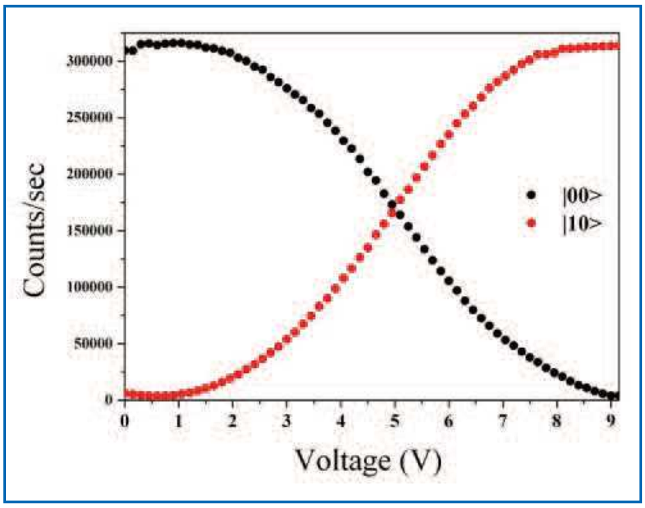

Figura 2 - Discrimination of entangled states by a Bell measurement. By changing the voltage applied to the external phaseshifter the state F^+ is transformed in the state F^-. The chip provides unambiguos Bell measurements with a visibility better than 99%. The error bar is smaller of the dot dimension.

Methodology

The InP PIC platform was exploited. This solution allowed to build the smallest (irreducible) set of functional building blocks that are required to realize the full functionality of the circuit: Passive waveguide section, Electrooptics modulator, Spot-size converter, Waveguide termination. This platform provided to build a 2-qubit, and 24 building-blocks so that a number of reconfigurable Quantum Gates could be written in the processor as a Quantum FPGA.

Multiple Rail Architecture provided the realization of so called Intra- System Entanglement. In this way it was possible to realize quantum devices that show deterministic and not probabilistic behavior, as quantum entanglers and Bell measurements and teleportation schemes (Fig. 1-2).

Bell measurements, jointly projecting two qubits onto the so-called Bell basis, constitute a crucial step in many quantum computation and communication protocols, including dense coding, quantum repeaters, and teleportation-based quantum computation [1-2].
Multirail Architecture provided a novel class of small or intermediate-scale quantum processors (NISQ). Present-day, noisy, small or intermediate-scale quantum processors -although far from fault tolerant- support the execution of heuristic quantum algorithms, which might enable a quantum advantage, for example, when applied to combinatorial optimization problems. In particular a Quantum Approximate Optimization Algorithm was implemented (see Fig.3).
The Quantum Approximate Optimization Algorithm (QAOA) is designed to run on a gate model quantum computer and has shallow depth. It takes as input a combinatorial optimization problem and outputs a string that satisfies a high fraction of the maximum number of clauses that can be satisfied. For certain problems the lowest depth version of the QAOA has provable performance guarantees although there exist classical algorithms that have better guarantees.
Beyond its possible computational value the QAOA can exhibit a form of "Quantum Supremacy" in that, based on reasonable complexity theoretic assumptions, the output distribution of even the lowest depth version cannot be efficiently simulated on any classical device.
Moreover, a number of experiment was implemented on the Quantum processor, as an example, the experimental demonstration of Cognitive Bias (Fig. 4)

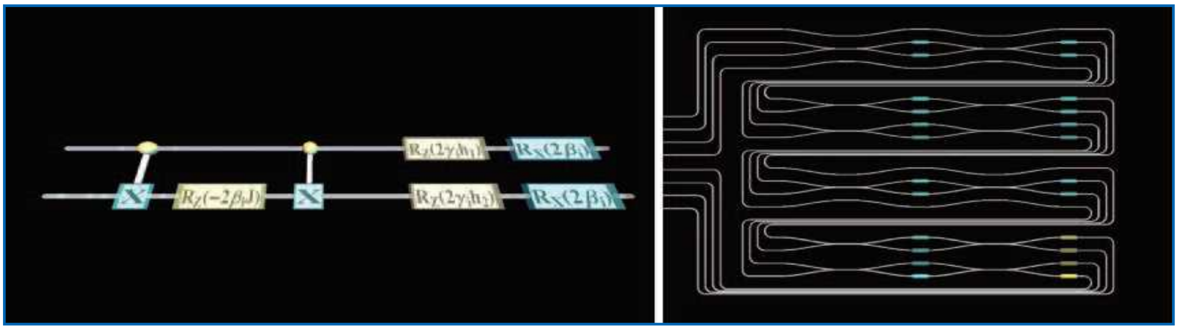

Figure 3 - Logical and physical Implementation of a Quantum Approximate Optimization Algorithm.

Potential technology applications and exploitation

The short-term applications of the processor will be the use as building block for Quantum Key Distribution, as Node in Quantum Internet, as Transmitter/ Receiver for optical link between manned/unmanned aircraft, in particular: *Small quantum processor product* for *academic investigation* on Quantum Based Artificial Intelligence, but novel material platform will be required. A new quantum cyphering product for implementation of quantum communication and cryptography protocol and to solve the problem of wireless Quantum Cryptography (not only QKD).
A Quantum Random Number GeneratorA Quantum Personal Computer, a novel Olivetti Program 101: superconducting architecture cannot guarantee the widespread diffusion of quantum technologies: *only a practical, room temperature, and embedded technology can win the quantum race*. The "long term vision" is to create "a reconfigurable light brain" able to learn and take autonomous decision. Although we focus on quantum processing, the research will bring high the potential of integrated photonics for parallel, fast, and efficient computational hardware in data-

heavy, A.I. applications, such as autonomous driving, live video processing, and next-generation cloud computing services.
Given recent advances in ultralow-loss Silicon waveguides, and high-speed on-chip detectors and modulators, the use of this alternative technological platform will be investigated because it could ensure a path towards full complementary metal–oxide–semiconductor (CMOS) wafer-scale integration of the photonic core.

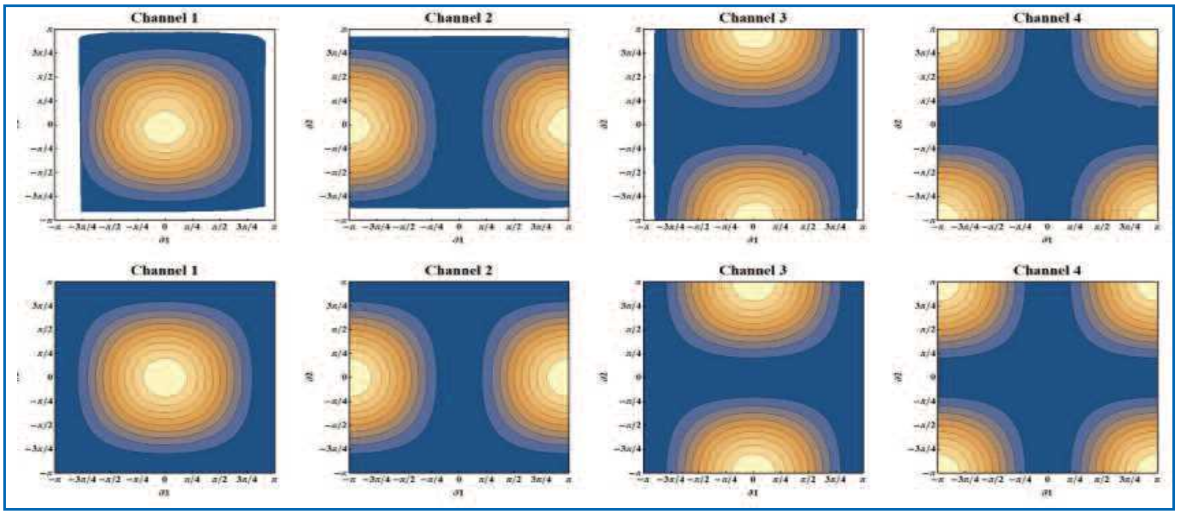

Figure 4 - Experimental demonstration on photonic chip of quantum explanation of Cognitive Bias. Up) experimental results. Bottom) Theoretical predictions.

Conclusions

We demonstrated the operation of Bell state synthesizer on chip based on InP technology. With the same chip an unambiguos Bell measurement was performed with very high visibility. The high level experiment and the results show that more complex circuits can be built with the same architecture and technology to perform more complicated logic operations. Finally, the introduction of the multiple rail architecture could make a practical quantum computer a reality. The investigation has started from the designing of building blocks, and it follows up with their engeneering and final integration in a first pototype of reconfigurable quantum processor able to perform complex operations.
The architecture is efficient and can be extended to high number of qubits. The important difference with other schemes of quantum computing is that we do not need to repeat the calculation a lot of times with "single photon states", but we just perform the operation in a single shot by using a pulse with a lot of photons. In fact, with this architecture each photon of the pulse will interact only with itself, and it will contribute to the total result of the computation in a single shot. . As an example, to complete an elaboration with a "conventional" optical quantum computer we need to repeat calculation for 1 sec with a clock of 1GHz; with this new architecture we can perform one calculation per clock's cycle: we can perform 1 Giga operation per second. An other amazing property of this architecture is the possibility of reconfiguration of the gate: it realizes a sort of quantum FPGA. This demonstrates that, in principle, the same device can solve different kind of computations. This feature will provide the use of off-the-shelf integrated laser systems and classical detectors: then the engineering, and the realization of large circuits able to perform very complex calculations is possible with the current technology

LIST OF SYMBOLS,ABBREVIATIONS AND ACRONYMS	
QKD	Quantum Key Distribution
PIC	Photonic Integrated Circuit
InP	Indium Phosphide
A.I.	Artificial Intelligence
FPGA.	Field Programmable Gate Array
QAOA.	Quantum Approximate Optimization Algorithm

KEYWORDS

Quantum Information Processing; Quantum Computing; Quantum Entanglement; Quantum Communication; Quantum Materials.

PROJECT INFORMATION

PNRM number**:** N.168 di Rep. del 18-03-2016 - Repubblica Italiana - Ministero della Difesa
Organization: Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE)
Responsible entity: Dept.di Scienze di Base e Applicate per l'Ingegneria – SAPIENZA University of Rome
City, Region**:** Roma, Lazio
Project lead: Prof. Fabio Antonio Bovino, Prof. Concita Sibilia
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Journal articles:

Fabio Antonio Bovino - Intrasystem Entanglement Generator and Unambiguos Bell States Discriminator on Chip - ICASSP 2019 - 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) - IEEE DOI: 10.1109/ICASSP.2019.8683820(INVITED TALK);

Fabio Antonio Bovino - On chip intrasystem quantum entangled states generator - 2017Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference(CLEO/Europe-EQEC) - IEEE - DOI: 10.1109/CLEOE-EQEC.2017.8086532 (INVITED TALK);

Fabio Antonio Bovino - Practical Quantum Communication and Processing - 2021 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC); IEEE DOI: 10.1109/CLEO/Europe-EQEC52157.2021.9542352 (KEYNOTESPEAKER).

Patents:

Fabio Antonio Bovino EP2543957 - Interferometer and method for controlling the coalescence of a pair of photons (granted);

Fabio Antonio BovinoEP16175834 – "STRUCTURE AND METHOD FOR PROCESSING QUANTUM INFORMATION" (GRANTED).

MMCC

The Special Forces, in recent times, have found themselves facing a new type of threat (to the past): the operational requirement is to counterattack the new irregular forces with the conduct of particularly sensitive missions and with a proportionate, selective and responsible use of force.
The military commands therefore increasingly have the need to organize ad-hoc missions with minimum notice. Consequently, it becomes essential to guarantee the availability of the best set-up in the shortest possible time and therefore a modular system with rapid configurability, ready to be loaded on an area platform, can be the right answer.
Therefore, the research capacity of the aforementioned peculiar results be the foundations on which this research is based, with exclusive national capabilities, which has foreseen and included all the phases, from the design to the realization of a prototype in order to guarantee to the troops infiltrated on the ground a continuous connection with the rear controls, spreading inside the dedicated umbrella, all the information reported by the sensors, accessible to all operators on the ground.

Introduction

The research program has as its object the development of organizational capabilities for the conduct of ad-hoc military missions with proportionate and selective use of force, ensuring the availability of the best asset in the shortest possible time.
The goal was to arrive at a solution of a highly modular multi-mission set-up, easily re-explained and intended for use on cargo aircraft capable of:

- deliver a sufficient level of C&C capability;
- increase the capabilities of «Situational awareness» and «Decision Superiority»;
- provide a communications support system for the distribution of information among the forces in the field.

The aircraft equipped with the MMCC system, orbiting in the holding point, will be able to ensure a continuous safety frame, guaranteeing the electro-optical and electromagnetic surveillance of interest through the EO / IR sensors on board the aircraft itself and covering with an umbrella radio, LTE and V / UHF, the whole area of operations.

Technical Bsckground

The objective of the Project was to identify a solution capable of operating in support of special operations forces (SOF), both in the context of complex Joint & Combined operating contexts, and in the stand alone mode of Single Service, conducted independently for reasons of confidentiality and timeliness; develop and implement a prototype capable of delivering a sufficient level of C4ISTAR capability, allowing for a dedicated structure to support the operation, aimed at increasing the capacity of «Situational awareness» and «Decision Superiority» both at a Tactical and Strategic level.

Methodolgy

The developed system is composed of 2 different subsystems:

- Command and Control Software System: based on the specific Vitrociset Framework and integrated with the Safe Strike solution, this solution integrates all the features of a C2 operating console for the representation of information both for the on-board system and for the deployed FS to the ground. The solution was designed to integrate all national and international

systems of Blue, Green and Read Force Tracking and weapon systems solutions such as GUNSHIP;
- Configurable electro-mechanical infrastructure: modular and multi-mission, fixed on a NATO standard pallet (463L System Pallet - HCU-6 / E), made with a strengthened structure in order to obtain an optimal efficiency in fixing the equipment and to avoid loss of flatness, over time, of the pallet itself.

Potential Technology Applications And Exploitation

The project has achieved the set objective, as the technological demonstrator carried out envisaged the integration, for the most part, of COTS components already existing on the market and/or tested by the companies forming the RTI, thus allowing a technical-functional verification in an "innovative" simulated operating context with high added value. In fact, the total integration and therefore the correct interfacing of the processing subsystems, local and remote communication, presentation of data to the operator has been demonstrated, showing that from a technical point of view the system can respond to the operational needs taken on by the project development from the first phase.

Conclusions

The final evaluation of the result achieved was carried out on a set of checks aimed at validating all the components of the system in an independent and therefore integrated mode, with particular attention to the usability of the functions provided. Furthermore, we want to emphasize here the modularity of the system which, by keeping the "core" component steady, guarantees high flexibility in terms of types of devices that can be installed and technological "upgrades", also with a view to making available a potential product with an extended life cycle with minimal impact in relation to obsolescence problems.

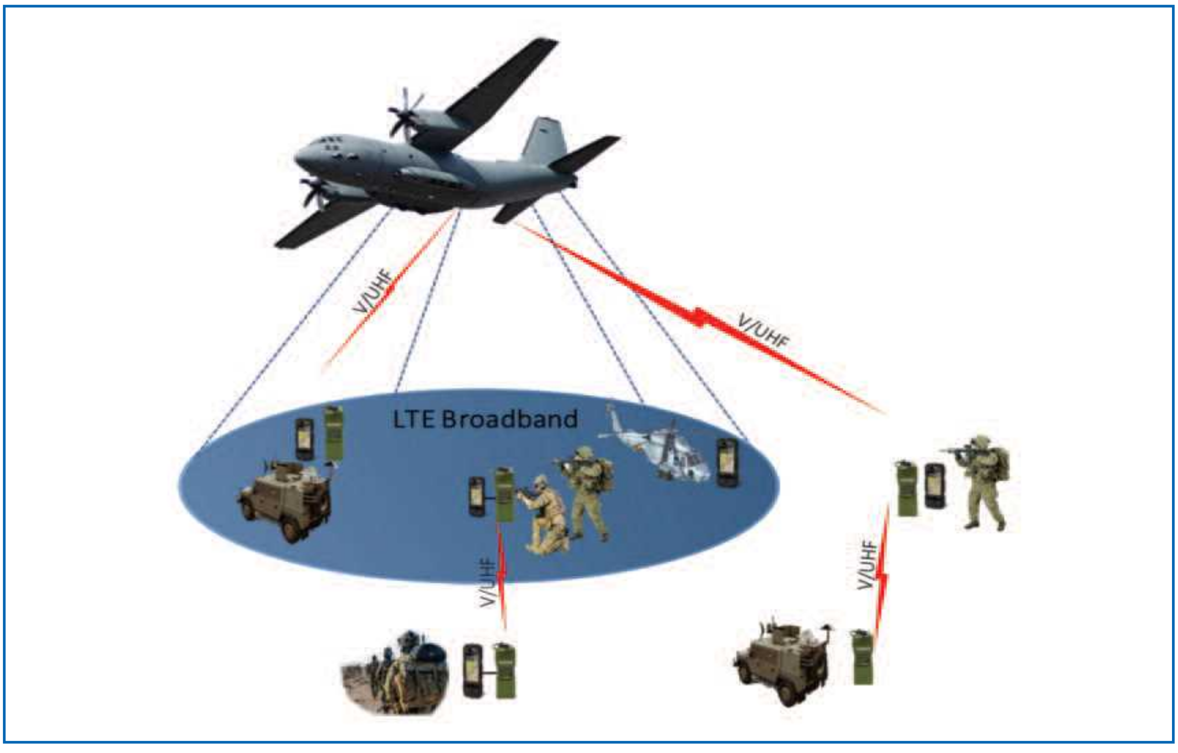

Figure 1 - Reference operational situation.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

MMCC	Multi Mission Command and Control
EO/IR	Eleptro optical/Infra Red
C&C	Comando e Controllo
LTE	Long Term Evolution
V/UHF	Very/Ultra high frequency
SOF	Special Operations Forces
C4ISTAR	Command, control, communications, computers Intelligence, survelliance, target acquisition, reconnaissance
C2	Command, control
FS	Forze Speciali
NATO	North Atlantic Treaty Organization
COTS	Commercial Off-the-Shelf
RTI	Raggruppamento Temporaneo di Imprese

KEYWORDS

MMCC, Multi Mission Command and Control.

PROJECT INFORMATION

PNRM card number: a2017.049
Contracting Administration: Directorate of Aeronautical Armaments and Airworthiness (ARMAEREO)
Entity in charge of the project: Temporary Grouping of Companies (R.T.I.) constituted by Vitrociset S.p.A. (authorized representative), ELE.SI.A. S.p.A. (principal), REBEL Alliance S.r.l. (principal).
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ACARMA

Additive manufacturing is a technology that will have a disruptive impact on the civil and military aeronautical sector in the next decade. Now, one of the main obstacles for the achievement of an accelerated aeronautical certification of the components manufactured in this way is given by the excessive number of tests required to consider the effect of all possible parameters of influence related to the process/product. The ACARMA project aims at developing a methodology based on the use of numerical simulation to provide tools able to predict failure conditions in the most different operational scenarios validated on a limited experimental database. In the first phase of the project, knowledge on the two alloys behavior, AlSi10Mg and Ti6Al4V, has been consolidated with reference to the possible failure mechanisms (quasistatic failure, failure under dynamic conditions and different temperature regimes, in the presence of defects and fatigue). Based on this knowledge a process/product simulation model able to predict the behavior of the generic component under operating conditions has been developed. This model, finally, has been validated on ballistic impact tests that realize stress conditions different from those of the tests used for the calibration of the parameters.

Introduction

Over the next decade, *Additive Layer Manufacturing* (ALM) will replace or flank more traditional manufacturing methods, enabling a reduction in the time, cost, and energy required to produce new components or replace those already in service. The aeronautical sector, both civil and military, is one of those that will benefit most from this technology through on-demand production, simplified component construction, and the elimination of warehouses for the storage of materials and spare parts. Components made in ALM are eligible for aeronautical certification if the use of appropriate design critical values, that account for variabilities associated with materials, geometries, and the manufacturing process, is demonstrated (FAA, 2015). The currently available approach, developed for unconventional materials such as composites, is the "building-block" approach. It consists of acquiring information on allowable stresses starting from specimen-level response to full-scale component response. ACARMA project has developed a methodology for the definition of a Simplified Building-Block approach (BBS) for the identification of allowable stresses based on a reduced experimentation, in order to accelerate and contain time and costs for the achievement of aeronautical certification.

Technical Background

In general, properties and allowable stresses are correlated with the microstructure which, in the case of printed materials, is determined by the additive manufacturing process, the geometry of the component and the nature of the powders used. Therefore, the high number of parameters that can affect the resulting properties implies that, for a rigorous implementation of the building block approach, a prohibitive number of experimental tests are performed resulting in long production times and very high costs. The proposed solution consists in the use of numerical simulation tools (for process simulation) integrated with computational models for the material behavior description (for the prediction of critical states and allowable stresses) properly verified and validated on a limited experimental data base. In this way, it is possible to realize a tool to predict the response of the material and, therefore, of the component, in the most different operational scenarios, through the estimation of the "virtual allowable stresses", i.e. limit values deduced exclusively from simulation and not from specific experimentation. This approach aims at a paradigm shift: to replace the building-block approach, totally experimental, with an integrated approach of multiscale simulation and dedicated experimentation. The proposed approach is organized in three levels: the first, at the laboratory sample level, for the definition of modeling relating to process/microstructure/property; the second, at the component level, for the verification of the interactions between the parts; the third, at the structure level, for the definition of the final lay-out of the part, Figura 1.

Methodology

ACARMA project has been realized by the University of Cassino and Southern Lazio in ATS with BEAMIT S.p.A., Techdyn Engineering S.r.l. and with the contribution of the RTMAS of DASAS. The project is organized in two phases with a duration of 12 months: the first one is focused on the material, that is level 1 of the BBS scheme, while the second one is focused on the component level, (level 2 of the BBS). The activities carried out in phase 1 can be summarized as follows.

Planning and implementation of a test campaign. Based on the indications provided by DASAS, two alloys of aeronautical interest have been selected: an aluminum-silicon alloy (AlSi10Mg) and a titanium alloy (Ti6Al4V). For each material about 200 tests were carried out with the aim of obtaining the necessary information to identify the constitutive model and the failure models for: quasistatic failure (simple and complex stress state), failure under dynamic conditions (also considering the different temperature regimes), failure in presence of defects, fatigue.

Development of a model for describing the process-property interaction through the integration of a numerical finite element code (MSC.MARC) for the simulation of the printing process and an analytical code (JMATPRO) for the determination of the microstructure and related material properties.

Development of a constitutive model for the description of mechanical behavior at large strains considering the effects of strain rate (Figura 2), temperature (Figura 3), and anisotropy (Figura 4) and for the prediction of failure conditions (damage model, Figura 5).

Validation of the model on ballistic impact tests with the aim of verifying its transferability under stress conditions different from those of the tests used for parameters calibration, Figura 6.

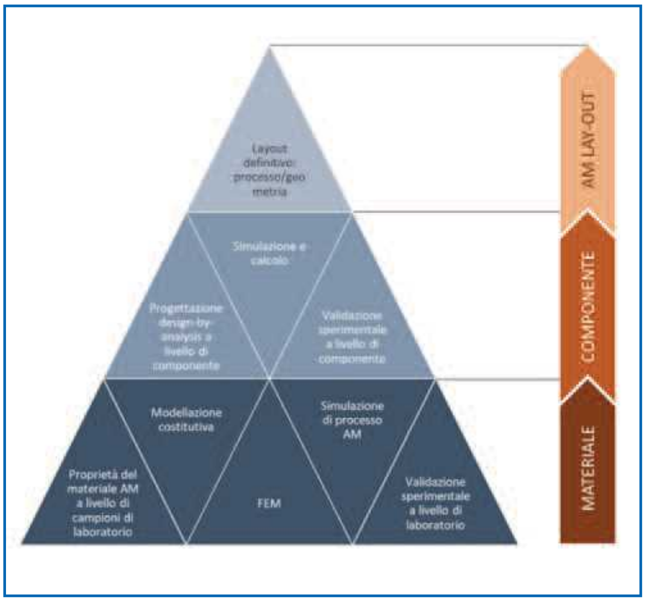

Figure 1 - BBS approach for the development of a design methodology of ALM components.

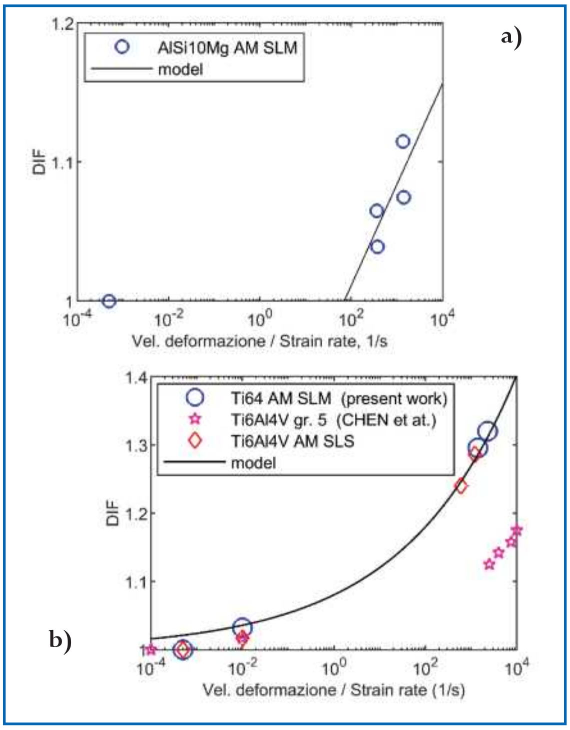

Figure 2 - Strain rate effect: a) AlSi10Mg; (b) Ti6Al4V (The Dynamic Increase Factor (DIF) is the dimensionless stress with respect to the quasistatic value).

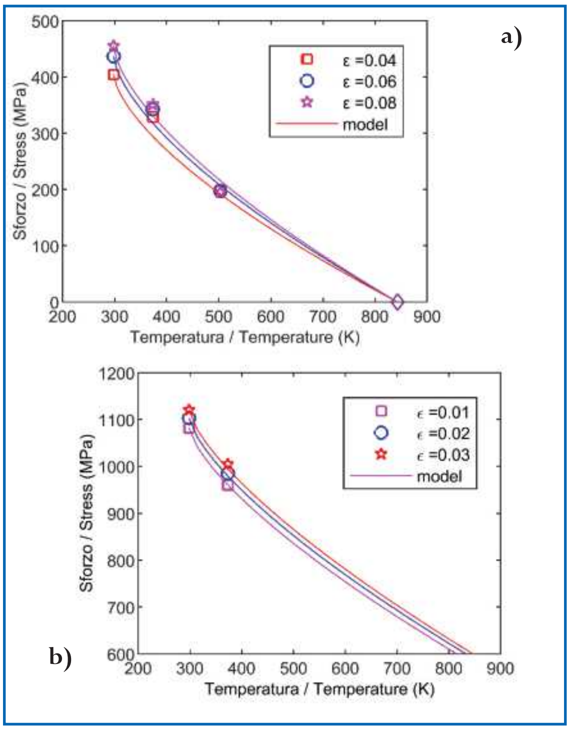

Figure 3 - Stress values as a function of temperature at different strain levels: a) AlSi10Mg; b) Ti6Al4V.

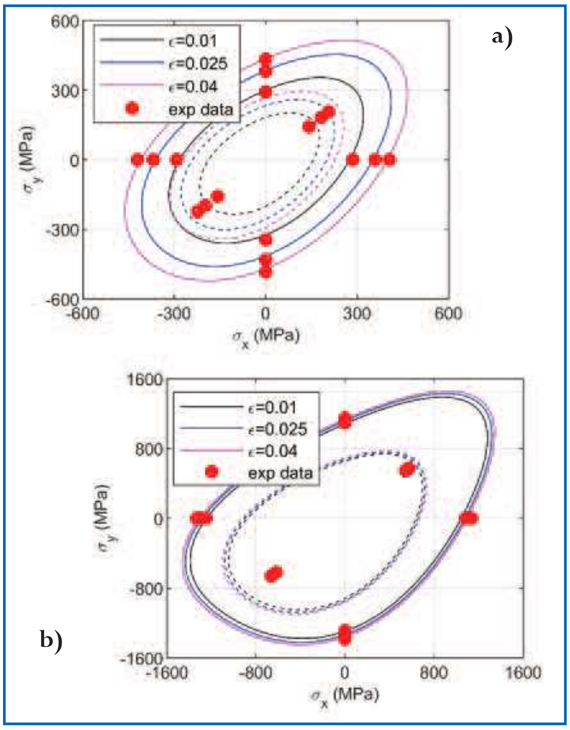

Figure 4 - Asymmetric and anisotropic yield surfaces: AlSi10Mg; b) Ti6Al4V.

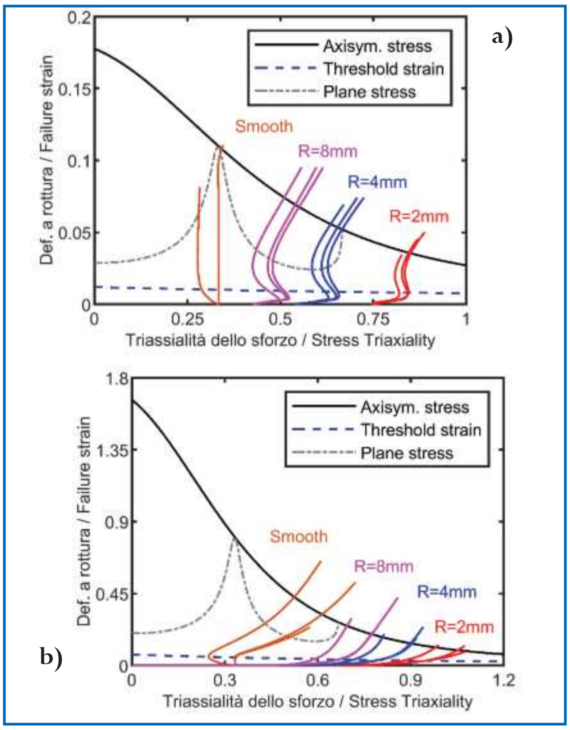

Figure 5 - Failure loci for different states of stress: a) AlSi10Mg; b) Ti6Al4V.

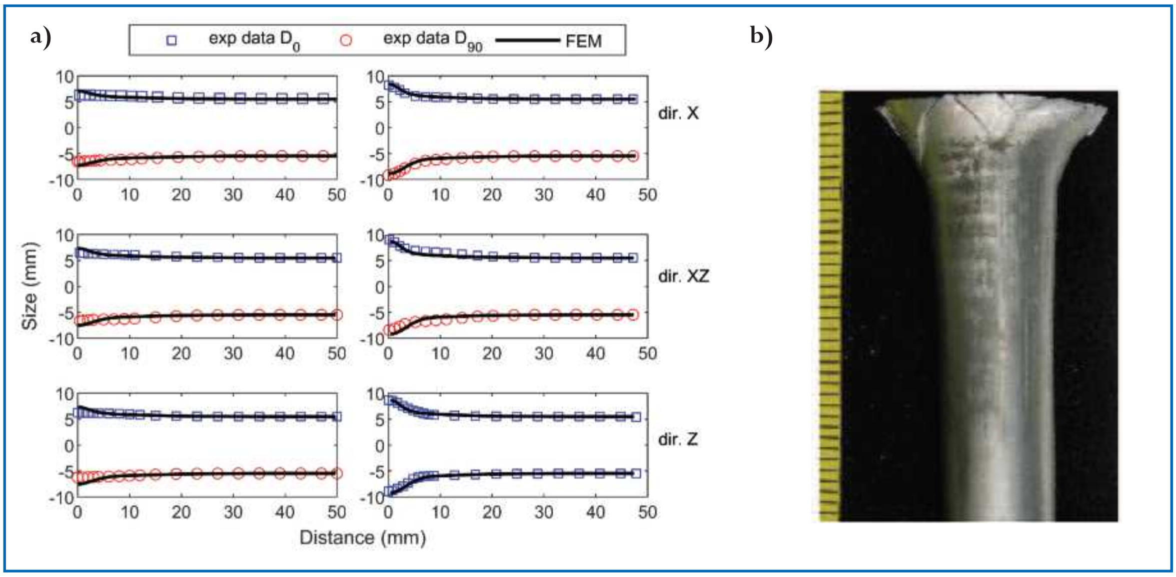

Figure 6 - Taylor Cylinder Impact test (AlSi10Mg): a) comparison between experimental and FEM profiles for different impact velocities (~190 m/s left; ~245 m/s right) and build directions; b) shear band crack initiation in the impact region for AlSi10Mg specimen impacted at 264 m/s.

Potential Technology Applications And Exploitation

Tools developed within ACARMA project represent a concrete contribution to the development of the ability to quickly qualify and certify components in ALM. In particular, the work developed in phase 1 has allowed to define the criteria for the selection of the types of characterization tests actually necessary for the determination of the allowable stresses, while the development of a verified and validated modeling has shown how it is possible to extract a large amount of information about the behavior of the material from a low number of experimental tests. The knowledge gained from the project could be used to build an accelerated certification process for additional classes of materials.

Conclusions

The goal of ACARMA project is the development and implementation of a methodology for the characterization and predictive analysis of behavior and strength of components made in ALM, aimed at their aeronautical certification. In phase 1 of the project, the knowledge on the mechanical behavior of two printed materials (AlSi10Mg and Ti6Al4V) has been consolidated with reference to the possible failure mechanisms due to both the printing process and the different stress state conditions. A process/product simulation model has been developed that is able to predict the mechanical behavior, under operating conditions, of the generic component made by ALM. One of the most relevant results is that, at least for components with not very thin sections, the temperature histories, which define the final microstructure - with the only exception of the points close to the free surfaces - do not show significant variations from point to point. This result, confirmed by experimental observations, disproves the claim that point properties must vary as a function of position. This evidence allows, in the case of a frozen-parameter printing process, to reduce the number of influence parameters to be considered in the construction of a building block approach, significantly reducing the number of tests required. On the contrary, the printing direction is confirmed to be an essential parameter in the variability of the resulting properties that, therefore, has to be considered in the (re)design of components in ALM optics.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS	
ALM	Additive Layer Manufacturing
ATS	Associazione Temporanea di Scopo
BBS	Simplified Building-Block
DASAS	Aeronautical and Space Experimentation Air Division
RTMAS	Department of Aircraft and Space Materials Technologies

KEYWORDS

Additive Layer Manufacturing, Aircraft Certification, Mechanical Characterization, Constitutive Modeling, Failure Models, Anisotropy, High Strain Rates, Fatigue, Numerical Simulation.

PROJECT INFORMATION

PNRM number: a2017.079
Organization: Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO),
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The project aims to develop, build and test an avionic jammer (for installation on UAVs or ultralight aircraft) capable of making the navigation system of a UAV inoperative by jamming its GPS system.
The project aims to overcome some limitations existing in the systems and techniques currently in use for the GPS disturbance, carried out through the implementation of terrestrial "area" GPS disturbance systems (i.e. that create a "dome" of defense around the sensitive area), or with technical solutions capable of directing the disturbance signal towards the enemy vehicle, consisting of "fixed" jamming stations or "jammer rifles". However, these techniques do not guarantee operating ranges exceeding 300m-1Km. This operating range limitation prevents these systems from being effective from a prevention perspective, i.e. in operational scenarios in which it is required to intercept the hostile vehicle before it approaches the sensitive area, or better still before it approaches an inhabited area, as exemplified in Figure 1

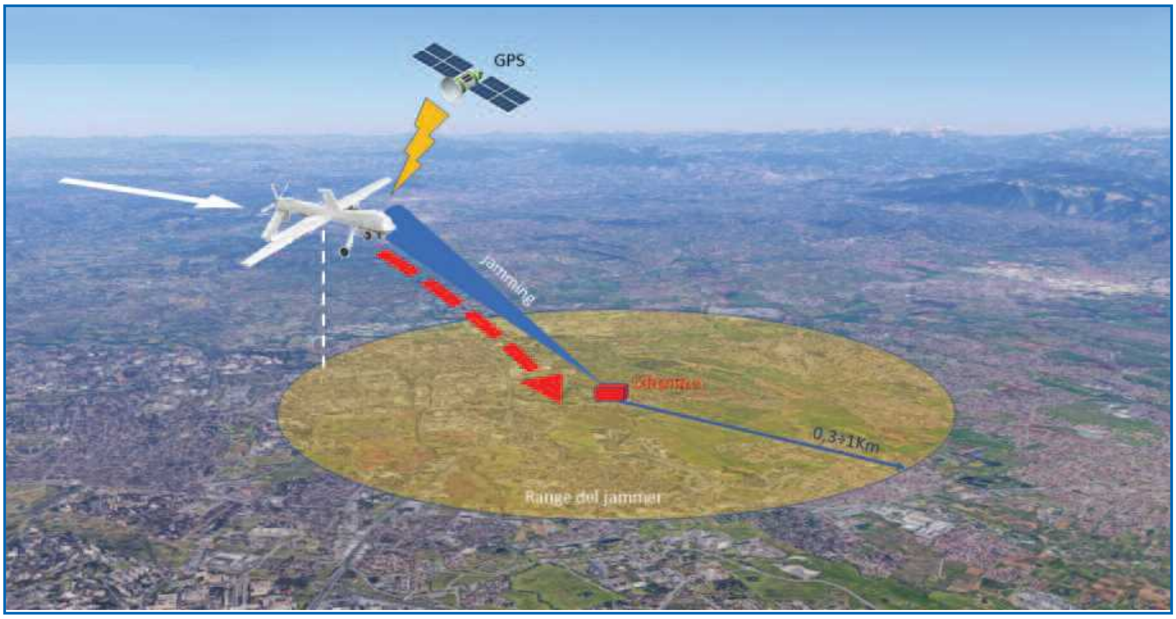

Figure 1 - Typical fixed point jamming scenario and possible efficacy problems. In this case, the enemy UAV can reach the target.

The solution proposed in this project, and specified in this specification, aims to overcome these limitations by promoting the development of a jammer that can be installed on aerial platforms (UAVs or ultralights), thus allowing the interception of the hostile vehicle from its first sighting and in any case far away from the sensitive area, as shown in Figure 2.

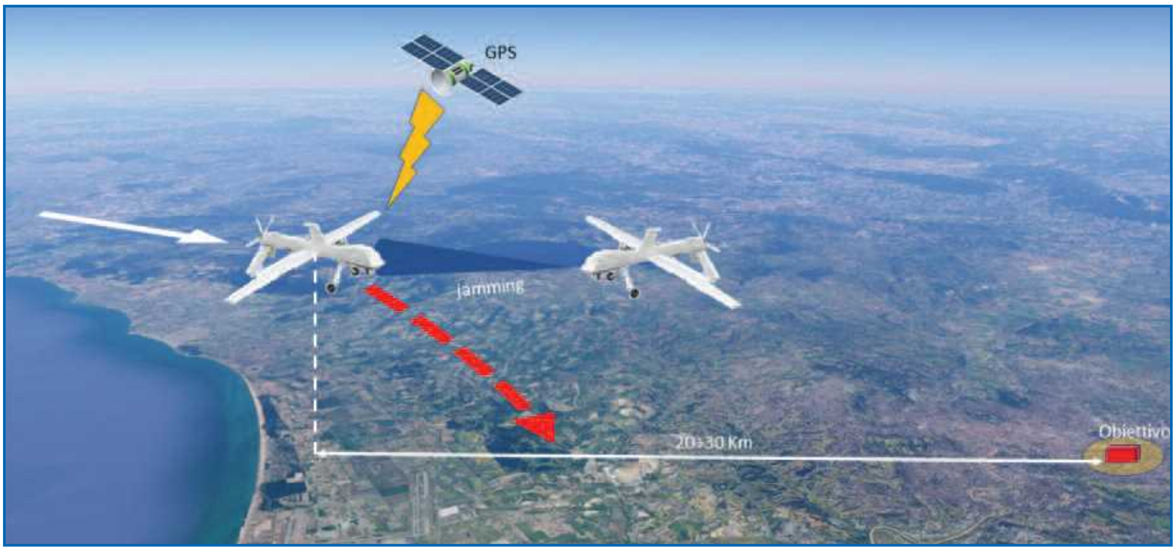

Figure 2 - Solution proposed in this project: jamming operated by one or more UAV jammers and greater operational effectiveness because carried out at a safe distance from the target to be defended.

The innovation of the proposal therefore consists in moving on board UAVs or ultralights a capacity that today is already developed at the product level but operated from a fixed point, radically changing the operational concept, currently based on point defense. With this solution, the search and jamming of the enemy UAV would be conducted away from the site to be defended.

Introduction

The reference scenario identified for this project is the defense of sensitive areas from attacks by hostile UAVs, such as, for example, drones launched by terrorist groups towards sensitive targets in an urban environment. The jamming of the GPS system of the UAV is an effective response in this area, because it can cause, depending on the complexity of the piloting system of the hostile aircraft, its fall or homing, or rather its return to its departure base, eliminating, in both cases, the threat.

One of the ways in which the disturbance can be implemented consists in the implementation of terrestrial disturbance systems of the "area" GPS; that is, a defense "dome" is created around the sensitive area. This solution has many contraindications if the sensitive area falls within a city environment; in this case, in fact, the disturbance produced would also affect the functionality, over a large urban area, of the satellite navigators.

An alternative solution, already implemented, consists in directing the disturbance signal towards the enemy vehicle from “fixed” jamming stations or “jammer rifles”; in this case an operator, aiming at the target to be "disoriented" with a viewfinder, can "fire" a disturbing signal from the GPS. Net of their validity and effectiveness, the aforementioned disturbance systems do not guarantee, however, an operating range greater than 300m-1Km.

Technical Background

For the above, the proposed system, to be implemented as part of the project, will consist of two units: an antenna and a transmitter.

Antenna

In the study, in order to enhance the characteristics of the antenna to be used in "unmanned" flight actions, a configuration that aims at competitive characteristics both in terms of electrical performance A particularly productive trend from a scientific point of view, which has generated great interest in applications both in the Radar field and in telecommunications in general, is given by the use of metamaterial (MM) configurations. The possibilities represented by MM range from the production of high-frequency components to antennas, with properties quite different from those of traditional antenna components and systems, both in terms of overall dimensions and performance.

The two main properties of MM antennas concern the possibility of drastically reducing the size and orienting the beam and increasing its directivity, hence the antenna gain.

Antennas showing MM properties have been studied by means of numerous other types of basic element, contemplating both the aforementioned ring resonators, and the variants derived from the same geometry, and periodic structures with extremely different shapes. The structures can be superimposed rings in 2D and 3D geometry or arrays of quasi-circular elements or even multilayer structures that foresee different geometries, superimposed on several planes.

Planar geometries, or constructions that involve the use of multilayers, are naturally characterized by greater ease of integration. On the other hand, the combination of an element that meets the power requirements by definition, as is the case of the horn antenna, and a structure inspired by the MM design, can guarantee better electrical performance, especially in the power emitted, nevertheless achieving a disadvantage on the integration.

Configuration

The geometries of the elements of the periodic structures will be chosen according to the performance and dimensions of the antenna to be built, and may include different types of the basic element, in addition to the integration between conventional and innovative solutions. For example, in addition to the configurations introduced in the previous figures, a characteristic to be verified as a realization possibility will be given by the case of planar structures with the presence of MM configurations superimposed on ordinary patches; this arrangement can result in a lens that improves the focusing properties of the beam.

Transmitter

The transmitter will be the unit responsible for generating the jamming signal transmitted through the antenna. It will consist of Commercial off-the-shelf (COTS), radio frequency and digital components including:

A digital board (Central Processing Unit, CPU, a generator of the jamming waveform).

Radio frequency components, in particular a power amplifier (High Power Amplifier) that allows you to amplify the jamming waveform to the desired transmission power.

Methodology

The HAWK project aims to overcome the limitations referred to in the previous point, promoting the development of a jammer that can be installed on avionic platforms, thus allowing the interception of the hostile vehicle from its first sighting and, in any case, well away from the sensitive area.

Potential Techology Applications And Exploitation

The unquestionable growth in the use of UAS systems, both in the civil and military fields, makes the approach of this project interesting which, however, considering the state of the art, is innovative especially in the part concerning the miniaturization of the antenna obtained for means of meta materials. On the other hand, there is no notable innovation from the stand alone GPS jammer point of view as described; much more incisive, and less similar to what already exists, would be an integrated system, such as to allow the tracking, tracking and disturbance of a hostile UAV (Hunter Killer). The program allows you to independently acquire the technologies aimed at creating a jamming apparatus for UAVs.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

ADC	Analog to Digital Converter
CPU	Central Processing Unit
COTS	Commercial off-the-shelf
DAC	Digital to Analog Converter
EMI	Electromagnetic Interference
FPGA	Field Programmable Gate Array
GPS	Global Positioning System
J/S	Jamming to Signal ratio
MM	Metamaterial
TRL	Test Readiness Level
SoM	System-on-Module
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Aerial Vehicle

PROJECT INFORMATION

PNRM number: a2017.026
Organization: Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO)
Responsible entity: Associazione Temporaneo a Scopo formata dalla Ditta ITS (Information Technologies Services) s.r.l. con sede a Roma e dall'IMM (Istituto di Microsistemi e Micromateriali del CNR) con sede a Catania
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RESUMO

Volumetric Muscle Loss, resulting from severe trauma or surgical ablation, is a pathological condition that prevents the regeneration of skeletal muscle, which owns remarkable ability to restore tissue damage but only when limited in size. The current surgical therapies employed in the treatment of this pathology, which particularly affects military personnel, do not provide satisfactory results so far. By proposing the tissue engineering approach, already proven effective in the reconstruction of extensive muscle damage in mouse models, the aim of this work is the validation of a porcine model of Volumetric Muscle Loss to be used in the development of a 3D bioprint-based reconstructive therapy, using autologous stem cells. For this purpose, part of the peroneus tertius muscle was surgically ablated in the pig model *Sus scrofas domesticus*, and the reparative process was monitored over the following 6 months by ultrasound, histological and fluorescence analyzes. The model developed in this study demonstrated to be valid in reproducing Volumetric Muscle Loss pathology, as it shows the inability of the muscle to regenerate due to extensive damage and the formation of a fibrotic and disorganized repair tissue replacing the damage site.

Introduction

In vertebrates there are three distinct types of muscular tissue: cardiac, smooth and skeletal; the latter, in particular, allows performing fundamental activities for the normal course of daily life, such as walking, maintaining correct posture and talking. Due to its intense use, as well as its wide extension within the body, the integrity of skeletal muscle tissue is, unfortunately, subject to continuous stress. Deleterious and significant events such as traumatic injuries, degenerative diseases, or surgical ablations can lead to a large muscle damage (VML, Volumetric Muscle Loss). This could result in a permanent loss of muscle mass that reduces or, in the worst cases, totally compromises muscle function, and a dramatic impact on the lives of affected people. VML is a common pathological condition that particularly affects military personnel, where it represents one of the main types of disabling injuries reported on the battlefield. The RESUMO project aims to characterize the self-healing process of VML damage in the *Sus scrofas domesticus* animal model: the development of a valid model of VML is the first fundamental phase of a broader project with the purpose to develop a therapeutic technology for muscle reconstruction by means of 3D-Bioprinting.

Technical Background

The therapies currently available for VML are based on surgical interventions aiming at minimize wounds rather than amputation when it is not possible to save the limb. The procedure consists mainly in the transplantation of free muscle flaps transferred from a donor area to a recipient one. Unfortunately, the results obtained by these methods in terms of restoring muscle mass and functionality are still completely unsatisfactory. For this reason, the development of alternative reconstructive therapies is increasingly necessary. Hence, the presented work, focused on a novel medical approach which exploits innovative technologies, such as tissue engineering, aimed at developing constructs that can guide the regeneration of damaged tissues and/or organs.
The constructs, composed of stem cells and bio-

materials, are fabricated using a state-of- the-art technique, 3D-bioprinting, whose effectiveness has already been demonstrated in experiments conducted in mouse models. However, translating this approach to humans involves remarkable complications associated with the significant increase in the size of the tissue to be replaced (scalability). Thanks to the comparable muscle physiology and overall size between humans and pigs, the attention has therefore focused on the development of a porcine model of VML in order to test this muscle reconstructive strategy. It is therefore necessary to validate the effectiveness of tissue engineering in an animal model with dimensions comparable to those of humans. The work described in the following article fits into this context and aims to demonstrate the validity of a porcine model that has undergone the surgical ablation of a large muscle area, as a model of VML to be used in the tissue engineering project (Figure 1). For this purpose, morphological, histological and fluorescence analyzes were carried out on the scar tissue formed following the surgical ablation of swine *Peroneus Tertius* muscle.

Methodology

In this study, part of the *Peroneus Tertius* muscle was excised in 4 mini-pigs in a surgical chamber under the supervision of veterinary anesthetists (Figure 2). One animal was not operated so that it works as healthy control. The size of the muscle damage was monitored by ultrasound examinations at 30, 60, 90 and 150 days after the removal of the muscle. From late examinations, it was possible to note the replacement of the damage site with an autologous tissue that appears disorganized and granular compared to the surrounding muscle fibers (Figure 3). This tissue was periodically analyzed by means of eco-guided needle biopsy

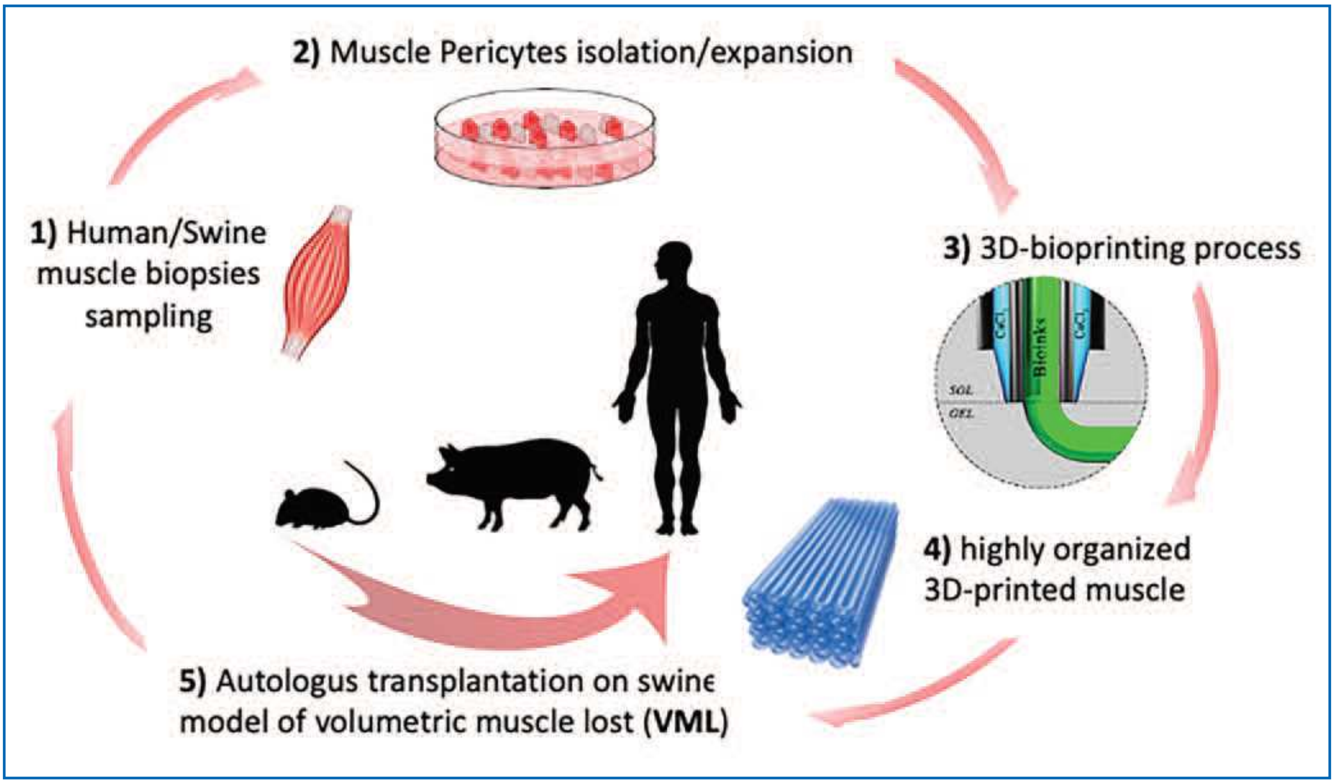

Figure 1 - RESUMO project idea graphical representation with the development of a reconstructive biotechnology exploiting 3D bio-printing.

samples, of which histological stains were obtained for rapid diagnosis: the analysis allowed to observe the formation of fibrotic tissue over time (Figure 3). To assess the level of inflammation at the damage site, the samples obtained from the needle biopsy were analyzed by means of immunofluorescence. Macrophage infiltrations were evaluated and represented in the graphic in Figure 4, showing a high macrophage rate at early time points and a progressive decrease at later time points, up to the return to basal levels at 150 days (Figure 4). Finally, to evaluate whether the reparative process followed by VML was able to regenerate new muscle tissue, the sections obtained from the needle biopsies at the different experimental times were analyzed by histological staining, showing exclusively scar tissue formation upon VML damage. *Peroneus Tertius* muscle is not able to regenerate presenting at the damage site solely scar tissue.

Potential Technology Applications And Exploitation

The porcine VML model validation represents the starting point in the development of a biotechnological therapy based on the combination of autologous stem cells and human-sized 3D bio-printing for muscle reconstruction. Morphological analyses conducted by histological staining highlighted the evident formation of scar tissue well distinguished by the control muscle tissue and then the absolute lack of autologous muscle regeneration.

Following this first step, the preliminary results we obtained exploiting murine and human pericytes - perivascular stem cells revealing robust proliferative and myogenic capabilities - indicate that these cells possess optimal potential for tissue engineering purposes. In particular, by virtue of stemness they represent an excellent candidate for the development of bio-printed constructs for skeletal muscle tissue engineering. Moreover, the bio-printing technique has been already demonstrated being an optimal deposition strategy to promote skeletal muscle architecture reply. Hence, taken together all these data, demonstrate that the use of tissue engineering for skeletal muscle recovery could soon represent a valid strategy for remedying the dramatic and irreversible outcome following VML trauma in humans.

Figure 2 - Surgical set-up, bioptic needle and OCT embedded resulting muscle biopsy.

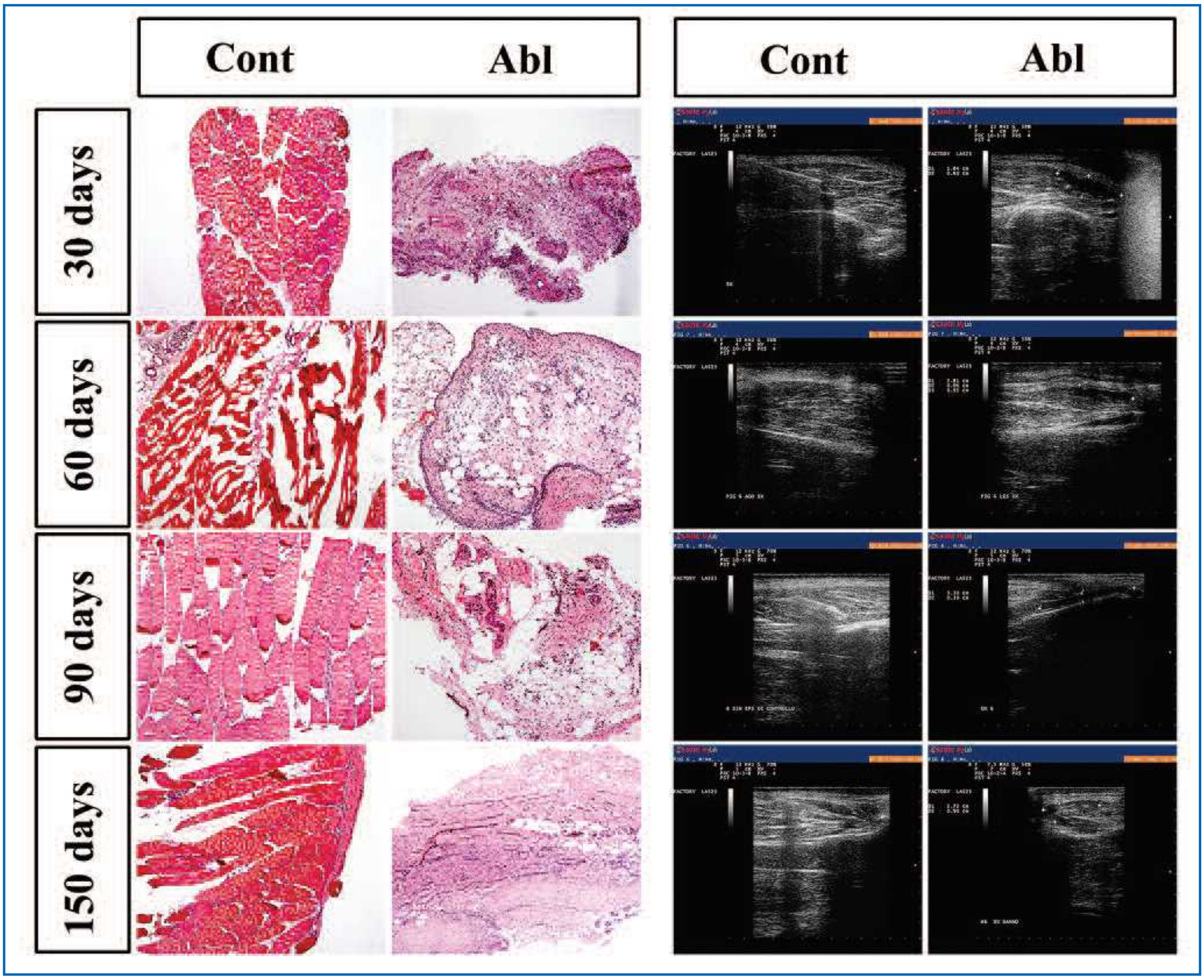

Figure 3 - Left panel: sections of control and ablated muscle biopsies stained with H&E at 30, 60, 90 and 150 days after muscle injury, nuclei are labelled in purple. Right panel: ultrasound examinations after surgical removal of the *Peroneus Tertius* (3X2x1 cm). The ablation area is black because it is empty at 30 days, unlike the white and orderly muscle fibers in the control. At 60, 90 and 150 days after ablation, the lesion is filled with disorganized and granular tissue.

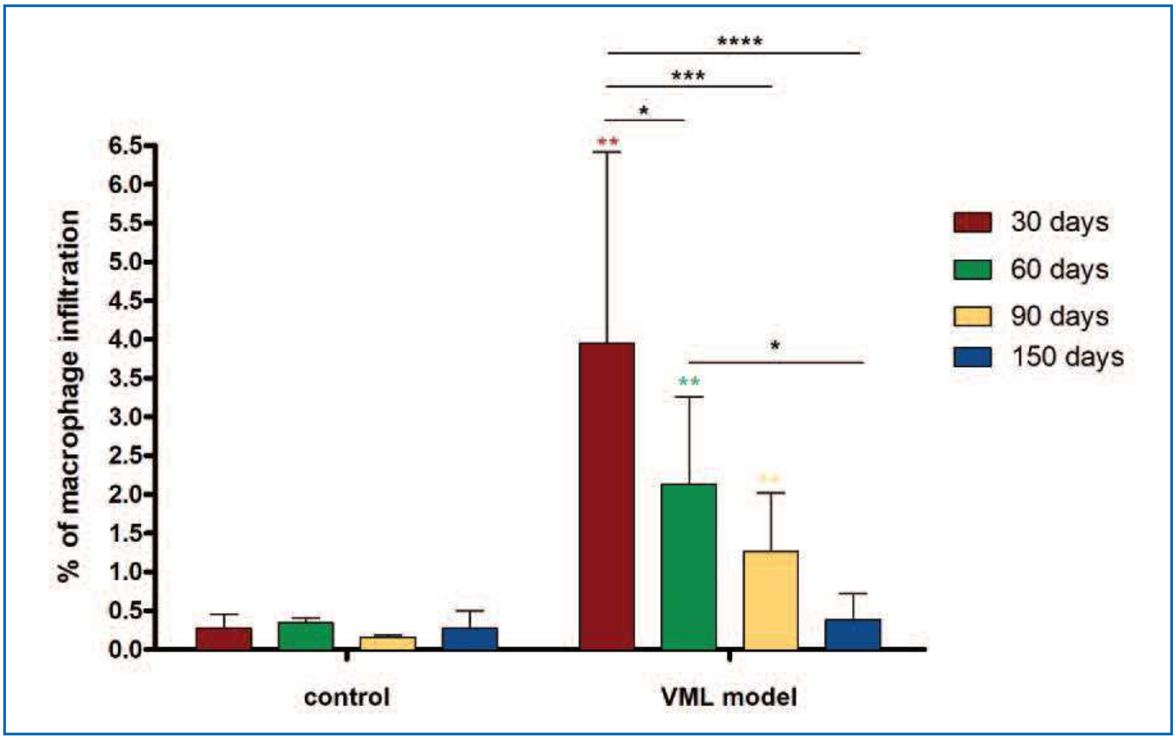

Figure 4 - Evaluation of the macrophage infiltrate rate at different experimental time points upon F4/80 immunolabelling.

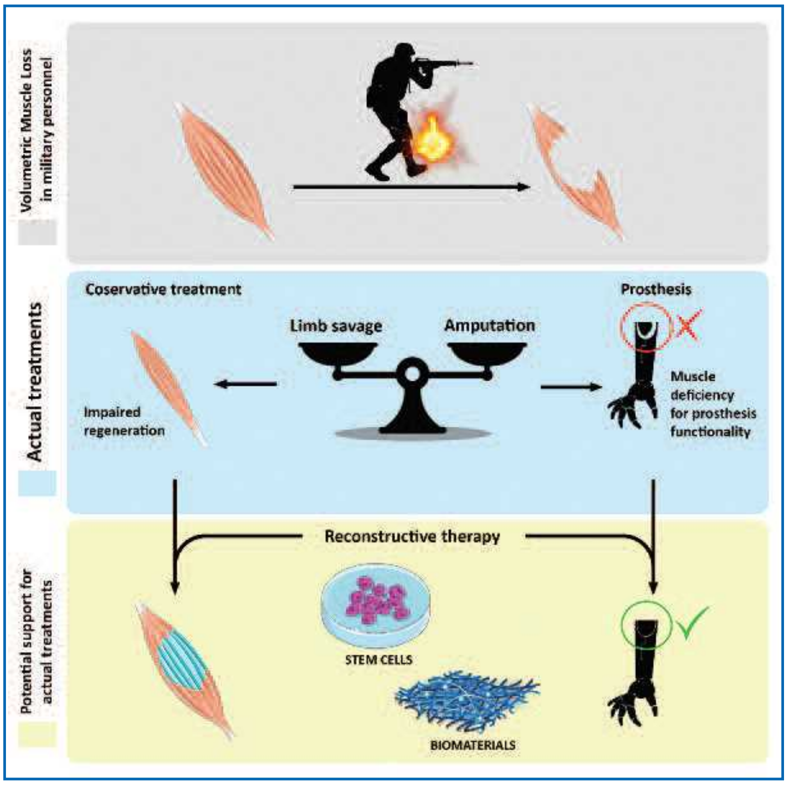

Figure 5 - Schematic representation for RESUMO cell-based muscle reconstructive approach application. (Image from Testa et al., 2021 Biomedicines. 2021 May 18;9(5):564).

Conclusions

Although great advances have been made in military medical science regarding VML over the past 20 years, there are still several hurdles that complicate the treatment of this severe condition, such as donor-site morbidity of muscle flaps or reduced functional muscle tissue in the prosthetic socket (Figure 5). In an attempt to take a step forward in this area, this work demonstrates how, following the ablation of a portion of the *Peroneus Tertius* of the size of 3x2x1 cm in the mini-pig model of the pig, the formation of a granular scar tissue occurs. This tissue devoid of regenerating muscle fibers and is rich in granular/scar tissue replaces the damaged muscular area. The results obtained, which mimic what happens in skeletal muscle following massive tissue loss, show that the model developed in this study is a valid VML example, thus representing a step forward towards the translation of tissue engineering methods from small rodents to humans.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

VML	Volumetric Muscle Loss
H&E	Hematoxylin and Eosin staining
F4/80	Antibody against Mannose-Receptor

KEYWORDS

Tissue engineering, skeletal muscle, Volumetric Muscle Loss, reconstructive therapy, mini-pig, muscle regeneration, 3D printing.

PROJECT INFORMATION

PNRM project number: a 2018.019
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EUROPEAN RESEARCH

RING

The RING (3D Radar Imaging for Non-Cooperative Target Recognition) project is a Research and Technological Development project funded within EDA framework. The RING project aims to develop novel non-cooperative target recognition (NCTR) systems that make use of three-dimensional radar images.
The operative needs that have led to this proposal concern the operational needs of military groups in terms of target identification. The basic target recognition is based on an identification friend of foe (IFF) system, which answers only to a single question, *is the detected target a friend or not*? It does not provide any other information about the type, size and significance of the target. The 3D image of a target can be used for target identification and prioritization for operational and tactical purposes. For example, the technology developed will be able to provide information in order to decide whether a detected target can be treated as an attacking aircraft, or if it is a fighter or bomber, if it is armed, and so on.
At its current stage the project has already seen the development of the imaging and classification algorithms and the development of three demonstrators, specifically a ground-based, a ship-borne and a drone-based 3D ISAR imaging systems.

Introduction

Radar imaging of non-cooperative targets uses a specific technique to form images, namely Inverse Synthetic Aperture Radar (ISAR). This technique was introduced in the literature several decades ago and allows for 2D em. images of non-cooperative targets [1][2]. Such images are an effective source of information for NCTR.
The use of interferometric radar systems has been proposed recently [3], to reconstruct 3D images of moving targets, instead of 2D images. Some papers have recently been published that show the value of such systems [4][5][6][7]. The proof of concept has provided encouraging results regarding the accuracy of the 3D reconstruction and its robustness against different types of targets and scenarios.
A 3D InISAR algorithm makes radar imaging systems significantly improve the NCTR performance in terms of effectiveness and robustness with respect to NCTR algorithms that use 2D ISAR images since the information embedded in a 3D reconstruction provides the means to better separate different targets and therefore classify and recognize them.
The RING project proposes the use of interferometric radars on different platforms, as well as the development of target recognition techniques that make use of 3D ISAR images. More specifically, the RING project is leading to:

1) The development of refined and robustified 3D ISAR imaging algorithms,
2) The development of 3D ISAR image-based classification
3) The development of three technological demonstrators, namely a ground-based, a ship-borne and a drone-based ISAR imaging system.
4) Testing and validating this technology with all three platforms and in various scenarios, which include different types of targets, such as airplanes, ships and ground vehicles.

Technical Background

NCTR based on 2D ISAR images is a well-established technique. Many papers have shown that 2D ISAR images are a valid support for NCTR since, unlike high resolution range profiles, provide information about the target in a 2D domain. However, 2D ISAR implies a projection from a 3D domain to a 2D domain, namely the Image Projection Plane (IPP). Although we are used to representing 3D objects in a 2D domain (e.g. optical images), in the case of an ISAR system this projection is not known a priori and cannot be controlled, since it depends on the target motions. This unknown is often the cause of ISAR image interpretation problems, which can significantly complicate and negatively affect the target classification process.

Hence, NCTR that makes use of 2D ISAR images requires a database of either real data or simulated data that is densely populated in terms of IPPs and view angles.

A NCTR algorithm based on 3D reconstructions can directly use target CAD models without introducing variations due to the target aspect angles or projection on the IPP, therefore independently of the radar-target geometry. This aspect greatly simplifies the problem by significantly reducing the size of the database and the costs of obtaining it.

The RING project has the following scientific and technological objectives:

1) Development of ISAR 3D image formation algorithms and NCTR algorithms, including methods employing deep-learning (DL) based methods.
2) Design and development of three radar demonstrators:
   - A ship-borne 3D radar imaging for the identification of naval and air targets.
   - A ground-based 3D imaging system for the identification of ground and air targets.
   - A drone-based 3D radar imaging system for the identification of naval, land and air targets.
3) Test and validation of the developed algorithms using data collected using the demonstrators.

Methodology

The RING project lasts 45 months. The project is divided into the three main phases that refer to the scientific and technological objectives described previously.

To date both 3D InISAR algorithms and NCTR algorithms have been designed, implemented and tested using simulated data. Demonstrators have been built and partners started the hardware tests in laboratory.

The study of the state of the art oriented us towards the implementation of interferometric methods because they are a good compromise between hardware complexity and accuracy of the results, [5][6][7]. An InISAR system can consist of only one TX and 3 RXs arranged to form 2 orthogonal baselines, as shown in Figure 1.

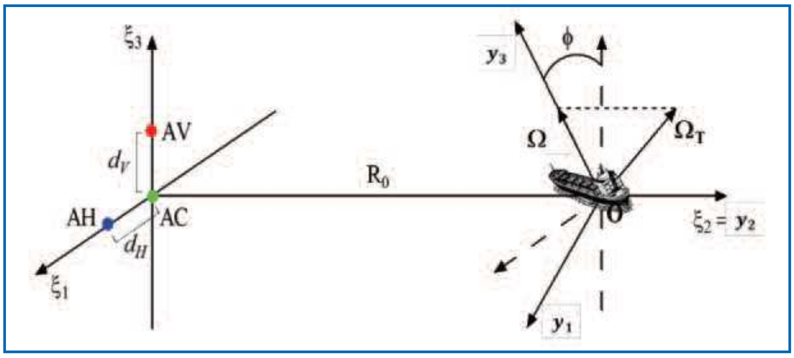

Figure 1 - Geometry of the interferometric radar system. *AC* is both a transmitter and a receiver, while *AV* and *AH* are just receivers. The three receiving antennas are arranged in such a way as to form two baselines, d_V and d_H between them orthogonal and orthogonal with respect to *LoS*. Ω and ϕ are the modulus and orientation of the target rotation vector.

A high-level block diagram of the 3D InISAR proposed algorithm is depicted in Figure 2 and consists of 4 basic blocks.

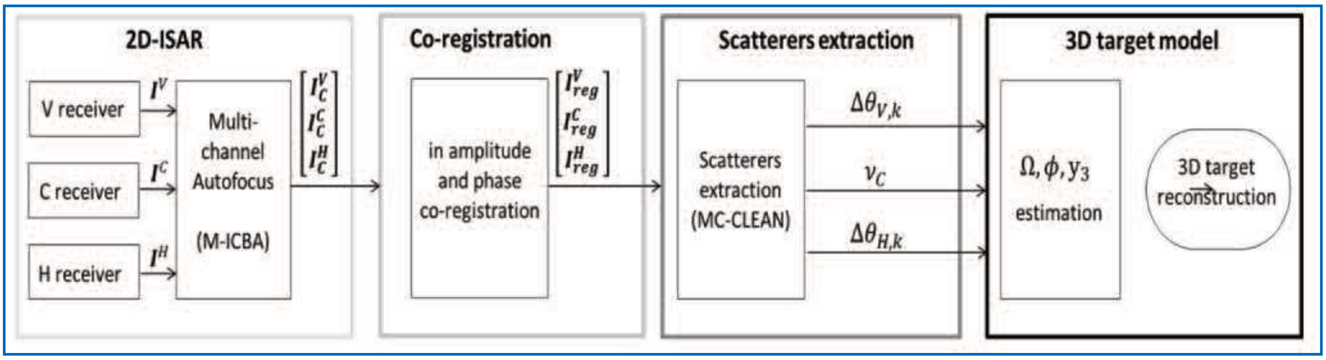

Figure 2 - Block diagram of the proposed 3D InISAR algorithm. Ω and ϕ are defined in Figure 1, while $\Delta\phi_{V,k}$ and $\Delta\theta_{H,k}$ indicate the interferometric phases of the scatterator k.

Figure 3 shows an example of a simulated result. The interferometric radar system is supposed to be on board of a ship and the positions of the three antennas were identified in the points indicated with the letters A, B and D. The target is a MIG35 aircraft. Figure 3 shows the 2D ISAR images at each receiver after the co-registration step. Subsequently, the brightest scatterers are extracted from the ISAR images and their information in terms of Doppler coordinate and phase, used to reconstruct the 3D target model.

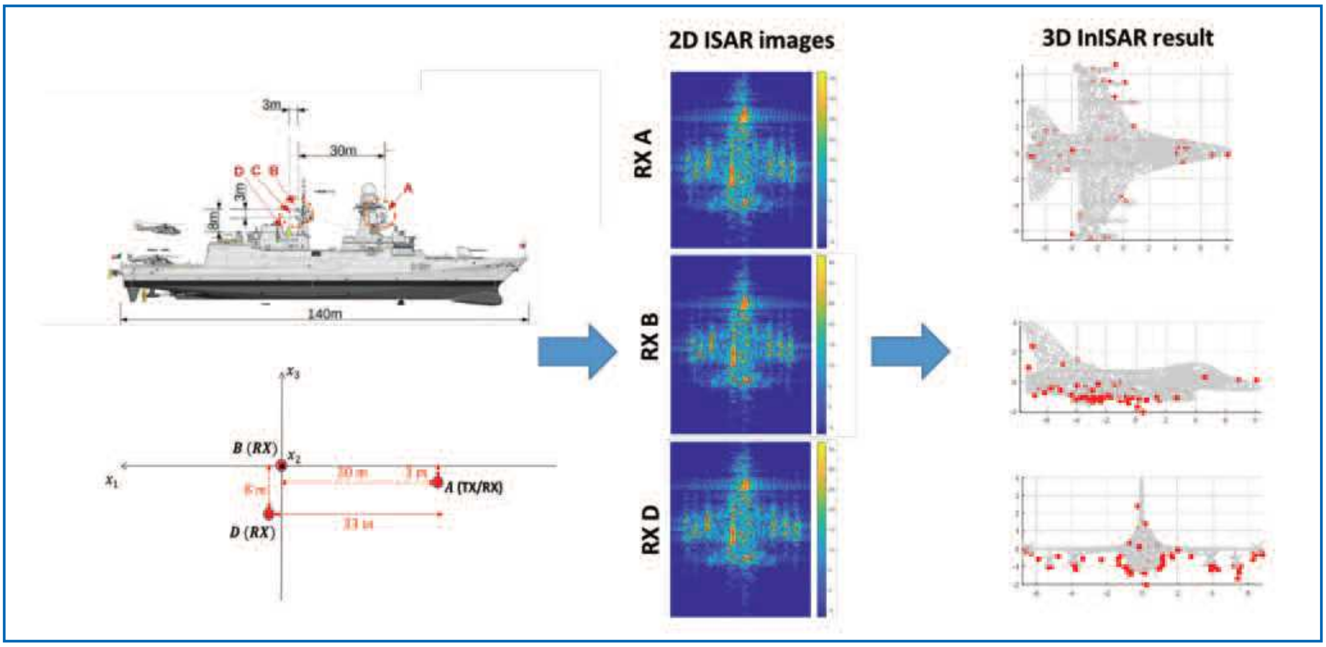

Figure 3 - One of the project results. The antenna in A transmits and receives, while the antennas in positions B and D are only receivers. The radar data was simulated by WUT while the processing of the radar data was performed by the CNIT. The central images show the ISAR images relating to the three receiving channels. The images on the right show the results of the 3D reconstruction. The 3D target reconstruction (red points) has been aligned to the target CAD model.

A deep study of the literature on NCTR, triggered the development of four different algorithms, that have been implemented and validated by using simulated data: (i) two model-based methods, one that compares a 3D reconstruction with the CAD model of the targets in the database, and the second that compares a 3D reconstruction with the 3D ISAR image of each target in the database (simulated by using a ray-tracing based simulator), (ii) a DL based algorithm, (iii) a database-free method that compares the shapes of the 3D reconstruction and of the targets in the database. Figure 4, 5 and 6 show pictures of the three radar demonstrators.

Figure 4 - drone-based radar system. In particular, 4 drones are planned, one carrying the TX and the other three carrying the three RXs. The selected drone is an octocopter named Horus. The images on the right show the radio controller and the flight control software.

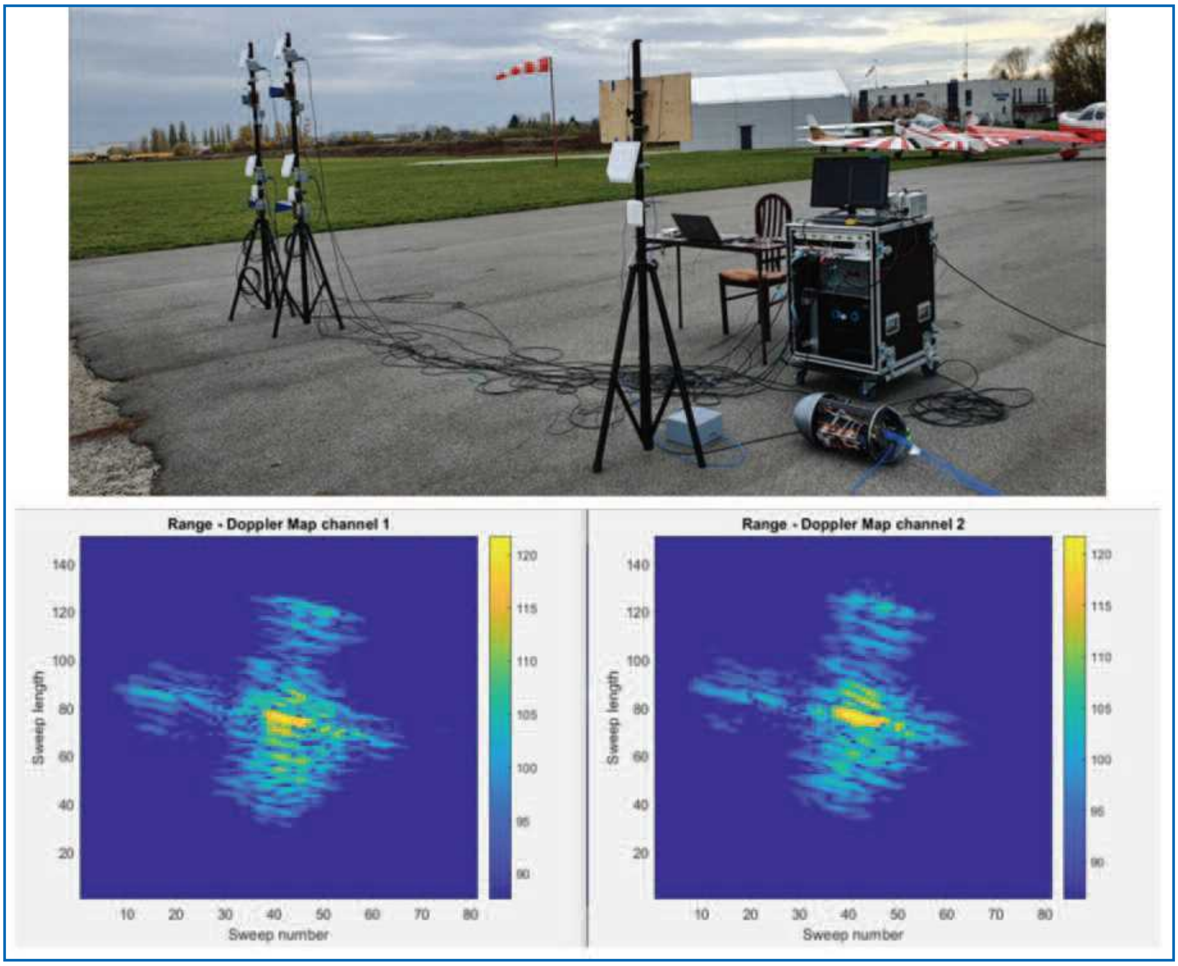

Figure 5 - The ground based radar system and a first test showing preliminary results in terms of 2D ISAR images. The two ISAR images have been obtained at the two receivers.

Figure 6 - The three receiver of the ship-borne radar system.

Potential Technology Applications And Exploitation

3D InISAR techniques can provide more robust support for NCTR. This technique can become strategic to support Joint Intelligence, Surveillance and Reconnaissance (JISR) operations, which is of considerable importance for all military operations, as for example target identification and prioritization for operational and tactical purposes. Furthermore, it is evident that the RING project has a full dual value since the algorithms developed in this project can be applied in civil scenarios where it is necessary to strengthen maritime and border surveillance and recognize and classify the detected targets.

Conclusions

The RING project, although not yet concluded, has already produced notable results, with the realization of accurate and robust algorithms for the reconstruction of 3D images of non-cooperative targets. Such algorithms have been refined and tuned to be implemented on systems that employ different types of platforms, such as terrestrial, maritime and drone-based. The work done so far has also led to the development of NCTR algorithms that are based on the use of 3D ISAR images. The classification algorithms that have been developed are diverse in nature with the aim to explore different avenues and therefore maximise the probability to obtain effective and robust algorithms that can be employed in operational scenarios. All the developed algorithms have been intensively and successfully tested using simulated data. Additionally, three technological demonstrators have been realized, specifically a ground-based, a ship-borne and a drone-based 3D radar imaging systems. Such systems have been completed and they will be tested in the next project phases, including the planning and execution of trials to gather enough real data to validate the developed algorithms and, consequently, the proposed technology.

The success of this project may lead, in the near future, to the adoption of this technology with a positive impact on EU defence capabilities.

LIST OF SYMBOLS,ABBREVIATIONS AND ACRONYMS	
CAD	Computer Aided Design
CNN	Convolutional Neural network
IFF	Identification Friend of Foe
InISAR	Interferometric ISAR
IPP	Image Projection Plane
ISAR	Light Detection and Ranging
LIDAR	Concept of Operations
NCTR	Non Cooperative target Recognition

KEYWORDS

Radar imaging, NCTR, ATR, CNN, 3D ISAR.

PROJECT INFORMATION

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Lead entity: CNIT
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CERERE

The future of Offensive Cyber Operation is currently focusing on CEMA (Cyber Electromagnetic Activities) kill chains, which combine the EW possibilities given by a shared communication layer in the electro-magnetic spectrum with the Cyber possibilities given by the full softwarization process of the military digital transformation. Unfortunately a reliable impact evaluation process for such kill-chains doesn't exists and standard cyber security testing methodologies cannot address the complexity of a combined Cyber/EW approach especially if unknown vulnerabilities come in place.
The CERERE solution wants to overcome the limitation of such methodologies moving from cyber security evaluation to cyber resilience evaluation, i.e. the capability of a complex system to maintain the desired performances during an operation, by providing an automated framework able to chaotically synthetize unknown CEMA kill-chains, e.g. a sequence of actions able to generate an impact on a target subsystem, and evaluate it inside a algorithmically re-configured synthetic environment with all the cyber security countermeasures modelled and coordinated also in terms of response procedures, scoring the effective surviving capability of the entire asset.
CERERE will introduce an innovative approach based on "kill-chain virtualization", i.e. emulating the expected effects sequence on the exploited subsystems, and a hybrid re-configurable simplified environment (including countermeasures and response processes) where an equivalent evaluation process can be executed measuring the resilience in an easier way.

Introduction

CEMA attacks are usually complex unknown kill chains that combine multiple exploiting techniques using wireless connections as starting point to reach a critical target. While their threat increases, especially in military environments, usual methods such as automated adversary emulation, penetration testing or test ranges do not analyse their impact on real systems and do not provide a measurable and explainable result about the systems' cyber resilience that is an essential characteristic, especially when considering military operations and assets.

The CERERE projects aim to supply an automated testing environment that simulates attacks, detection, response and recovery processes over a synthetic environment using an incremental approach that supports cyber and electromagnetic activities. This approach will enable:

The detection of *unknown threats* and the possibility of *assessing the risk introduced by new technologies* allowing an up-to-date assessment of the environment essential in military tactics

A measurable methodology to evaluate the *efficiency of existing countermeasures* and their ability to make the system able to withstand complex attacks by handling the domino effects created by complex kill chains helping assess the reliability level of the underlying system supporting an operation

The identification of *future improvements* and *best remediation strategies* to support the decision-making process.

Technical Background

The CERERE concepts build over a combination of technologies and techniques to generate a solution capable of simulating the behaviour of a complex system under unknown cyber and electromagnetic-based kill chains attacks to measure the systems' cyber resilience.

Modelling and simulation technologies will be the main base for the CERERE concept. Traditional simulation environments, like cyber test ranges, accurately replicate the real scenario taking advantage of actual hardware and software or a combination of actual and virtual components making the architecture rigid and time-consuming in the set-up. CERERE aims instead to generate an abstract synthetic environment based on parameterization of emulators, component simulators, and virtualized systems, where possible, describing the corresponding physical and logical constraints behaviours in a flexible and modular way. These features simplify running incremental validations of heuristically increased complex systems, ensuring improved result quality compared to single-shot simulations.

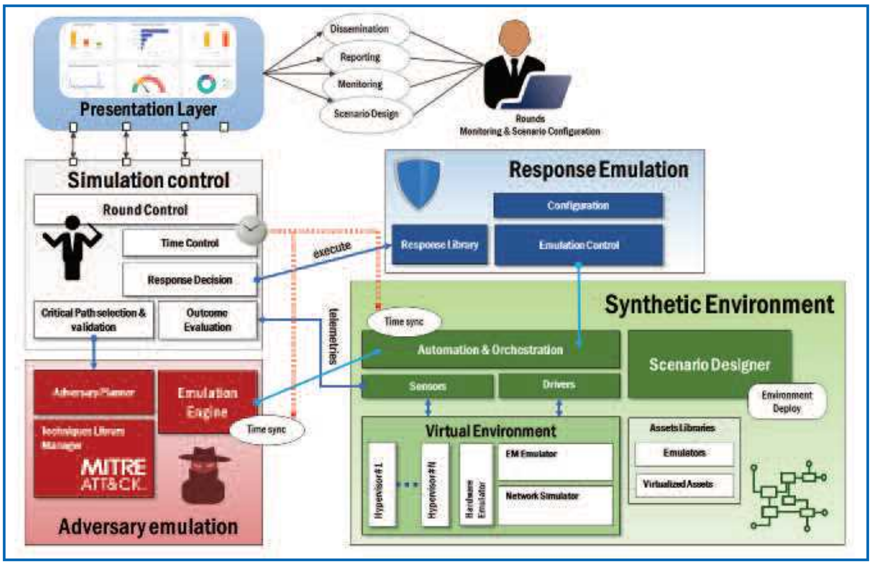
Regarding the offensive automation, CERERE wants to demonstrate that it is sufficient to emulate the effects of an attack's kill-chain and not its process in executing them, reducing the required time to run the analysis and the complexity of constructing kill-chains. Moreover, the construction of kill chains will use well-known Chaos Engineering concepts, combined with Situation Calculus applied to the MITRE ATT&CK Matrix to generate feasible kill chains without using an already established sequence of attacks and, hence, discover unknown attack procedures.

Finally the response process emulation will leverage recovery and response activities derived from the NIST SP-800-160 v2 specification, which classify and define the possible cyber resilience approaches that can be chosen and automatized to respond to an incident once it has been detected by one of the security countermeasures modelled inside the environment.

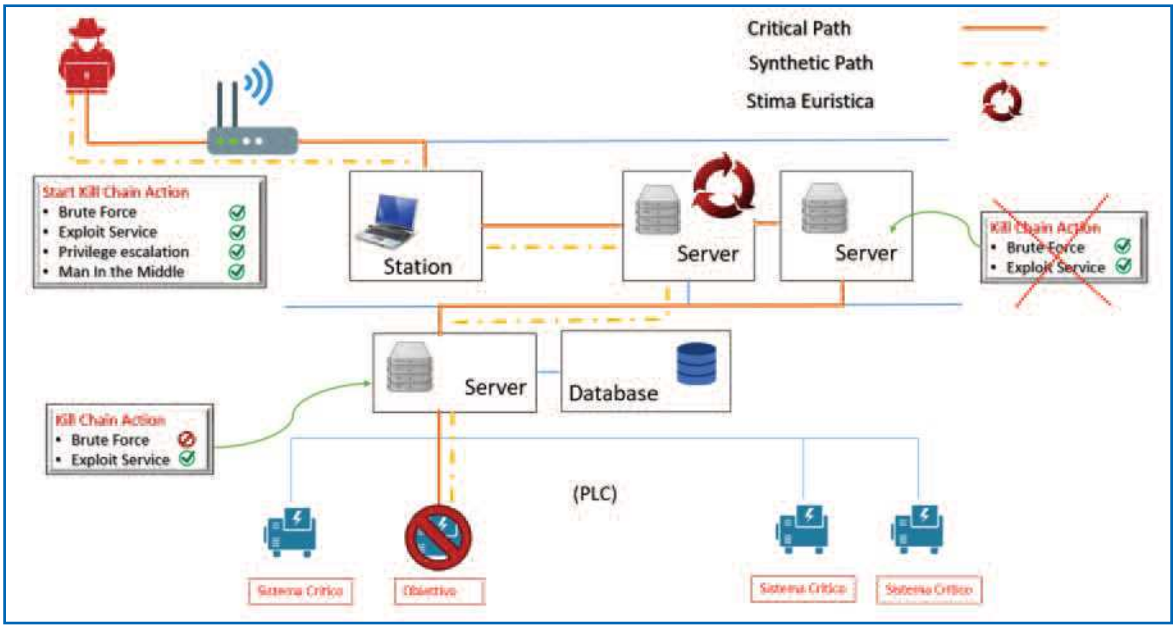
Methodology

The project is expected to be two years long. It will provide a prototype addressing the main research activities and background capabilities (software libraries, models, algorithms, etc.) to put the basis for further development.

The CERERE solution is structured as typical cyber-war gaming exercises where the interaction of modules provides the result at each simulation round.



The simulation control module is the framework orchestrator that initializes the scenario's descriptor, i.e. deployed assets, infrastructures and parameterized elements, used in each round, monitors the execution status and the simulation clock, chaotically select the critical path to exploit and evaluates the attack plan, collects telemetries and activates the defence, at last, provides the simulation outcome through a Graphical User Interface (White Team). The synthetic environment deploys and configures the Cyber/EW scenario, resets it at each simulation round, provide the telemetries produced during the execution for resilience measurement and the API to execute offensive and defensive effects over the environment (Green Team). The adversary emulation emulates the opponent by heuristically identifying an adversary attack plan (i.e. sequence of kill-chains) for a given critical path starting from the electromagnetic spectrum and leveraging concepts from the MITRE ATT&CK matrix and executing its effect on the environment (Red Team).



At last, the response emulation emulates the defender running the defined response strategies based on a standard framework resiliency strategies like NIST (Blue Team).
Cyber resilience is computed by measuring the following parameters:
Execution time: time to obtain the desired execution by the emulated attack
Surviving time: time needed to generate a "domino effect" able to make the operation fail
Detection time: system's capability to detect and evaluate the attack and the time needed by the countermeasures to understand the situation.
The parameters are computed at each round and all together suggest the level of the system's resilience.

Potential Technology Applications and Exploitation

Modern Military scenarios have to face the synchronization and coordination of cyber and electromagnetic activities both from the offensive and defensive sides to obtain and guarantee operational success. The Cyber resilience concept is strictly connected to mission success. It focuses on the system design to reach the desired objective independently by the damages generated by a cyber-attack instead of designing it never to be attacked. This approach is particularly true in military missions where it is unthinkable to suppose the opposite. Resilience against CEMA attacks becomes a pivotal capability to ensure the success of a military scenario.

From a defensive point of view, the CERERE solution provides the ability to evaluate the current efficiency of the countermeasures in place in the system against unknown CEMA attacks by computing the current resilience level. Using the incremental validation approach allows discovering the system's best configuration to use in a given military operational context delivering a significant operative advantage.

From the company's point of view, the solution can be used as a future validator for monitoring and response platforms developed for both the military and civil domains incrementing the reliability of the proposed solutions.

Conclusions

CERERE aims to provide a framework able to automatically evaluate the cyber resilience of a complex system against CEMA attacks, filling the gap in state-of-the-art technologies that do not consider the Electromagnetic spectrum a starting point for Cyber-attacks. The strength of the solution is based on the intuition that a system is cyber resilient if it has been designed to prevent the execution of specific actions (i.e. effects) on one or more critical subsystems necessary to guarantee the continuity of the operation, it can understand in advance the attacker intentions by observing the impact it generates, and it can efficiently react, and recovery before the kill chain objective is fulfilled.

CERERE makes these concepts measurable and explainable, leveraging a complex emulation of chained attack effects and evaluating the effective detection capabilities offered by the existing security countermeasures and the effectiveness of the response procedure chosen to recover the system performances. The implementation builds over cutting edge-technologies of chaos engineering, situation calculus and parameterization of complex systems, and it improves the knowledge base about the impact of Cyber/EW attacks.

This technology can contribute to assessing the efficiency of current countermeasures and response procedures in place in the military environment, support planning of future operations by identifying scenarios' best resilience posture and be the validator technology of innovative monitoring systems and response strategies.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS	
CEMA	Cyber Electro-Magnetic Activities
EW	Electro-Magnetic Warfare

KEYWORDS

CEMA, Cyber Resilience, Simulation and Modelling, Adversary and Defence Emulation

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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 2021.

Table 1- Distribution of funds in the year 2021.

TYPE	NO. FOLLOWING PHASES OF ONGOING PROJECTS	NO. NEW PROJECTS
PNRM	15	21
EDA	2	5
Framework Agreements	/	3
Testing Centres	2	5
BI-MULTILATERAL	1	/

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 2021 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.

Table 2- Distribution of the new national projects started in 2021 among the priority capability/technology clusters identified by the Chief of Defence Staff.

TECHNOLOGY AREA (CLUSTER)	% FUNDS	NUMBER OF PROJECTS
Innovative technologies of Intelligence Surveillance Reconnaissance (ISR) and information distribution through innovative Command and Control systems	25.6%	6
Autonomous systems, artificial intelligence, navigation safety and security and related sensors, autonomous weapon systems	28.6%	6
Satellite technologies	14.3%	3
Cyber security, cryptography and Big Data analysis	9.5%	2
Enhancement of soldier's capabilities and protection/support to veterans	9.5&	2
Defence technology – sensors, devices, weapon systems, ammunition and innovative materials	9.5%	2
Technologies for sustainability, energy resilience and infrastructures	0%	0
TOTAL	**100%**	**21**

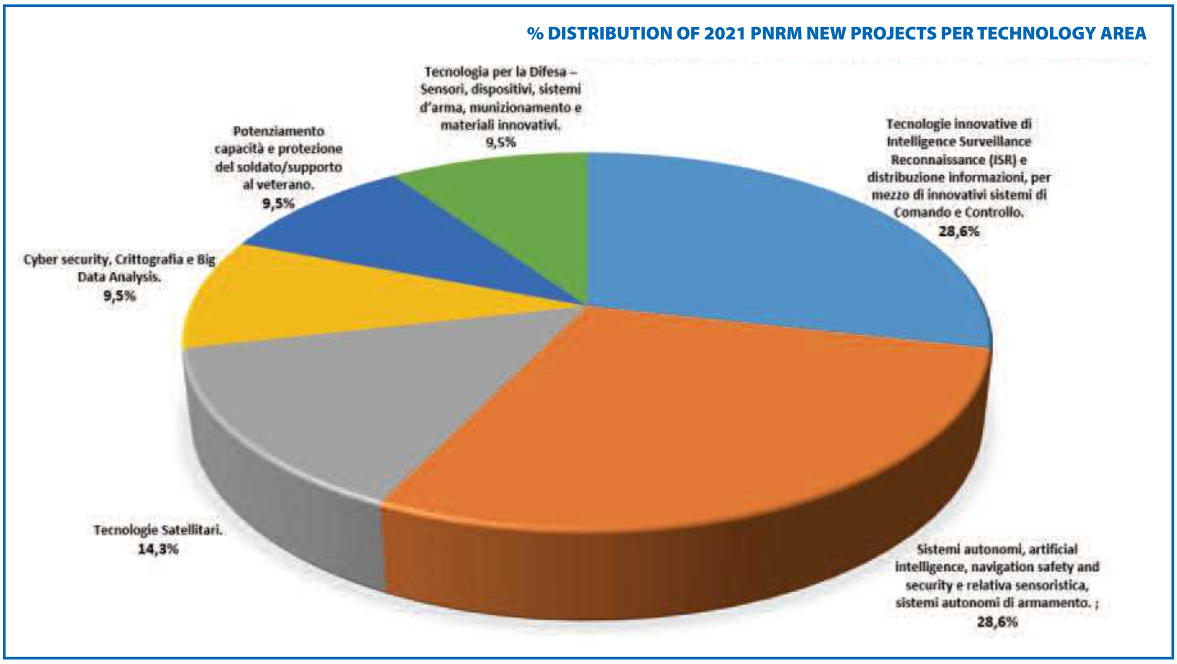

Figure 2 - Distribution of the new national projects started in 2021 among the priority capability/technology clusters identified by the Chief of Defence Staff.

ACRONYMS AND ABBREVIATIONS

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

ACRONYMS AND ABBREVIATIONS

GIM	Gimbal motor
GIS	Geographic Information System
GPS	Global Positioning System
GPU	Graphical Processing Unit
GEOINT	GEOspatial INTelligence
HfB_2	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
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)
ZrB_2	Diborure di Zirconio

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