AN INTEGRATED SYSTEM APPROACH FOR CRITICAL NATIONAL INFRASTRUCTURE PROTECTION

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Abstract

This paper describes (i) the activities underway to model and assess the performance of a notional integrated system (NIS) in the context of Homeland Security and (ii) the development of an emulator of the NIS itself. Current activities are focused on border control issues via an accurate surveillance of the terrestrial, maritime and overland boundaries, thus involving a wide number of heterogeneous sensors, command and control centres, platforms and communication networks. Follow-on activities are beginning to analyze the inclusion of critical assets, such as airports, harbors, the railway system and power plants to fully address the complexity of the Homeland Security frame.

1. Introduction

This paper describes (i) the activities underway to model and assess the performance of a notional integrated system (NIS) in the context of Homeland Security and (ii) the development of an emulator of the NIS itself. The activity is currently underway within the System Analysis Group of Selex-SI, and involving similar groups within most of Finmeccanica Companies, in the effort of modeling and assessing the performance of an integrated system for Homeland Security.

Homeland Security is a very broad and complex theme that requires coordinated action on the part of national and local governments, the private sector and concerned citizens across the country; it covers issues such as border control, critical infrastructure protection, transportation security and the relationship and interaction amongst these various components needs to be further analyzed. The activity has been focused initially on border control, which may be achieved via an accurate surveillance of the terrestrial, maritime and overland boundaries, thus involving a wide number of heterogeneous sensors and large bandwidth communication links. The aim of border control is to build a smart protection belt all around the country against terrorism and illegal activities and yet it is not resolutive due to the difficulty of controlling the country boundaries along their full and variegated extension, to the non necessarily physical nature of attacks in the current information age, and due to threats which often arise internally to the country itself. For this reason future work will extend the types of heterogeneous sensors and also provide protection of critical assets, like power plants, airports and harbors.

The need of an emulator of the integrated system is to rapidly answer to the following main questions:

- (i) is the designed system compliant with the requirements in terms of correct reaction and response time?
- (ii) has the designed system reached the best trade-off between the selected technology and the requirement?
- (iii) How to achieve and measure situation awareness? which are the best algorithms and procedures to fuse the information collected by the different sensors?

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(iv) are the communication links and bandwidth adequate for the purpose?

This paper is organized as follows: the definition of the system mission is provided in section 2; section 3 is dedicated to the description of the NIS architecture and its main elements, while section 4 describes the currently developed emulator; section 5 provides an overview of follow-on activities and section 6 reports the conclusions.

2. System mission

The system missions which have initially been identified are presented in the following list:

(i) provide a 24h, 365/365, all-weather surveillance of the country borders (air, sea and land), territorial and contiguous waters and Economic Exclusive Zones (EEZ), and therefore be able to intervene to counter activities such as:
  - ✓ terrorism (e.g. attacks to oil and gas plants) and criminality,
  - ✓ illegal immigration,
  - ✓ illegal traffics,
  - ✓ illegal fishing,
  - ✓ smuggling,
  - ✓ sea-pollution by collecting evidence of environment-related crimes,
  - ✓ maritime piracy,
  - ✓ emergency situations.

(ii) provide a real-time assessment of potential threats, thereby providing sufficient time to react to a developing situation;

(iii) Search And Rescue (SAR), e.g. evacuation from ships and oil rigs and first aid assistance;

(iv) tactical and logistic transport (special team transport);

(v) overland surveillance;

(vi) interdict, intercept and search suspect vehicles and sea vessels;

(vii) execute arrest;

(viii) escort, or possibly tow, arrested vessels to port.

The spectrum of capabilities implied by these missions is very wide and requires innovative approaches and competences embracing several different disciplines. The number and typology of assets and sensors required is also broad and needs to be integrated into an effective and coherent architecture.

3. System description

Typical assets of the NIS are depicted in Figure 1 and include:

1. operative centres – a National Headquarter (HQ), Regional or Local Command and Control Centres and mobile centres;
2. surveillance assets – spaceborne assets, Coastal Surveillance Sites (CSS), Land Surveillance Towers (LST);
3. platforms – aircrafts, helicopters, land vehicles and patrol boats, which may be equipped to perform surveillance, law enforcement and/or command and control functions;
4. the communication network – which includes a wide range of links, networks and technologies such as satellite, radio, wideband wireless and PSTN (Public Switched Telephone Network) access.

A brief description of the main NIS components, typical equipment and functions is provided in the following sections.

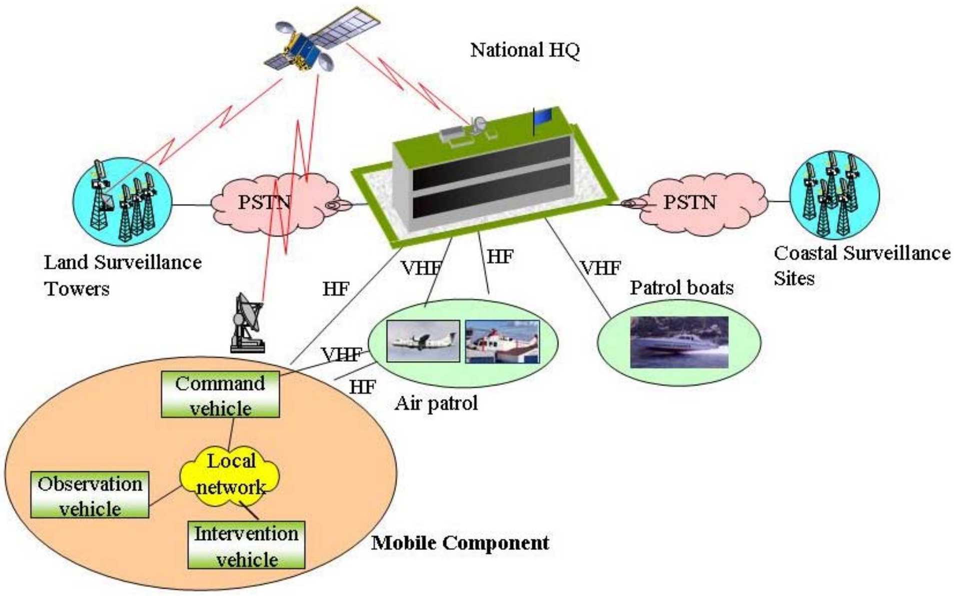

Figure 1 – A Notional Integrated System.

3.1. Operative Centres

Operative centres are responsible to perform the Command and Control functions, at the planning, tasking and execution level. The National Headquarter is typically a fixed centre designed according to the requirements of the overall security mission; local centres may be either fixed, transportable or mobile, and may be hosted on board an aircraft, helicopter, ship or land vehicle. Typical command and control functions are:

- situation awareness: data collection from sensors or other information sources, data fusion, classification, identification and situation display;
- tactical control: threat evaluation, intervention decision and mission allocation;
- operation management: planning, resource and sensor management, force management.

3.2. Surveillance assets

Spaceborne assets
Spaceborne assets are able to cover very wide areas and may provide an early warning capability. They are typically equipped with a synthetic aperture radar (SAR) or EO/IR sensors and a communication equipment to exchange data with the ground stations.

Land Surveillance sites
Land Surveillance Towers (LST) are typically fixed sites for land surveillance. They are equipped with:

- radar sensor for detection of ground and low altitudes targets, including intruders on foot, in all weather conditions, and classification (e.g. vehicle, person, helicopter),

- Infra-Red TV camera to provide videos/images of environment/specific targets;
- local consoles for sensors control,
- communication links (e.g. satellite, radio link and PSTN) and equipment (e.g. crypto) for voice, data and video communications;.

Main functions are automatic radar tracking and classification, system configuration and setting (e.g. filters, alarm zones), full local or remote sensors control (e.g. IR cross-cueing and scanning); the former function is extremely attractive because it allows unmanned sites, and therefore reduction of operating costs.

Coastal Surveillance Sites
Coastal surveillance sites (CSS) are fixed sites for coast surveillance. They are typically equipped with:

- radar sensor for detection of sea targets (including small boats, in all weather conditions),
- electro-optical/infrared (EO/IR) sensors to support vessel classification;
- automatic identification stations for the identification of cooperative targets;
- PSTN connection and radio-link for voice, video and data transmission.

Sites are typically unmanned, and are capable of transmitting tracks and videos to remote centres for surveillance operations; the sensors may be remotely controlled. Main functions are multi-target tracking, cross-cueing and scanning of EO/IR sensor and automatic tracking of specific target by EO/IR sensor.

3.3. <u>Platforms</u>

Airborne Platforms
Airborne platforms include reconnaissance platform and effectors, mainly helicopters, to operate law enforcement. A reconnaissance platform carries a sensor suite, which may include a radar sensor for surface target detection, EO/IR for day and night operation, and eventually hyperspectral sensors. Additionally typical airborne platform equipment consists of:

- binocular to aid operator vision,
- radio links (HF, VHF/UHF-AM/FM) for voice, data and video communications;
- satellite phone communication;
- Command and Control workstations.

Main functions are: tactical situation compilation and presentation, presentation of navigation parameters, mission sensor control and also command and control functions.

Land vehicles
Land vehicles are mobile units capable of providing local command functions, surveillance and communication functions and interception; In particular:

- Command Vehicles are tactical command rooms mounted on trucks;
- Observation Vehicles are equipped with sensors and radars and transmit data towards the Command vehicle;
- Interception Vehicles are deployed by the Command vehicle.

Patrol boats
Patrol boats perform coastline surveillance and law enforcement at sea. They are equipped with:

- radar for target detection at sea;
- day and infrared binocular to aid operator vision;
- voice radio links;
- police siren for acoustic signalling / warning.

3.4. Communication Network

The communication network is a crucial element of the system since it guarantees the connectivity amongst the various entities of the system:
- the communication bandwidth has to permit the transmission and reception of videos, pictures and radar tracks;
- the reliability of the network and the quality of services has to be high;
- many sites could be unmanned and the surveillance operations must be controlled via communication links;
- the network design should take into account that the performance of the link depends on the site positions, the expected weather conditions and so on.

The following links will generally be included:

- Satellite links for voice, video and data transmission;
- radio-links (HF, VHF, UHF and Wide Band Data Links) for voice, video and data transmission;
- PSTN connection for voice communications within the system and external agencies;
- High speed backbone networks.

4. The NIS emulator

A mission which has been modelled and evaluated within the NIS emulator is the one in which non cooperative and silent vessels are approaching the coast. The NIS configuration for this case includes: a spaceborne surveillance asset, an airborne platform dedicated to long range surveillance, a coastal asset devoted to Vessel Traffic Control (VTC) and equipped with radar and electro-optical sensors, a Command & Control Centre and naval/air intervention units to counter the “potential hostile” target intrusion. Purpose of the study case is to analyze the reaction time and the overall probability of correct reaction as a function of time. Figure 2 shows a pictorial view of the emulator mission.

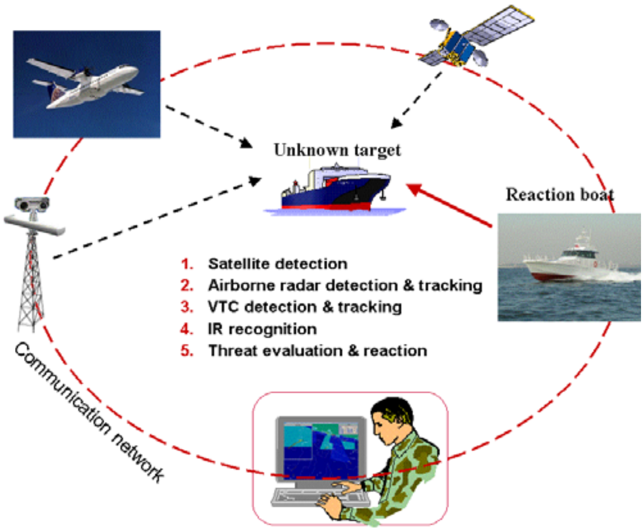

Figure 2 - Emulated mission of the NIS.

In order to react properly to the threat, the following events may be envisaged:

1. target detection by means of the spaceborne platform and cueing to the airborne platform;
2. target detection via airborne platform and cueing to the VTC;
3. target detection and tracking via VTC;
4. target cueing to IR via VTC;
5. classification/identification via IR;
6. threat assessment;
7. reaction.

4.1. Achieved results

Even the analysis of this relatively simple configuration would require to go to into much more detail and specify how the cueing is performed between the various sensors or identify the orbit of the spaceborne asset and the geographical distribution of ground stations so to be able to derive parameters such as the satellite revisit time and response time.
For sake of simplicity, it is assumed that the time period for computing the system response time starts when the VTC is cued towards the un-identified target. The reaction time is then reported in equation 4.1:

$$T_{reaction} = T_{VTC}+T_{IR}+T_{class}+T_{response} \qquad (4.1)$$

where

T_{VTC}: time required by the VTC to initialize the target track with probability higher than 0.9;
T_{IR}: time needed to correctly classify the target by the IR sensor;
T_{threat}: Operator-based threat level assessment;
$T_{response}$: time required to intercept the target.

The radar devoted to VTC is asked to detect and track naval targets approaching and running alongside the maritime border. As soon as the tracked target reaches a distance enabling the recognition mode of operation of the IR sensor, the radar cues it, designating the target position with a certain accuracy. The radar can start designating the target position to the IR director at around 21 km, where the IR sensor detection probability is 0.5. In our application, the typical slewing time of IR directors (2 seconds) is not meaningful, so we can assume that the radar cues the IR instantaneously. The recognition process can start only at around 7 km, having fixed to 0.8 the required value of the correct classification probability achievable with the IR sensor. In the configuration examined, the capacity of the IR sensor to provide the information quality needed to support the classification process has revealed inadequate and yet classification represents one of the really difficult task in this kind of scenarios where engagement rules are much more soft and variegated. The other two quantities T_{VTC} and T_{threat} can be neglected with respect to the other quantities.

Another interesting parameter is the probability of correct reaction ($P_{reaction}$). Following a procedure similar to the one followed for equation 4.1, it is found that:

$$P_{reaction} = P_{VTC} \cdot P_{IR} \cdot P_{class} \qquad (4.2)$$

where

P_{VTC}: VTC probability of continuously tracking the target (practically equal to 1);
P_{IR}: IR probability to correctly classify the target;
P_{class}: Operator-based probability of correct reaction.

In correspondence of T_{IR}, i.e. when the IR, cued by the VTC along the target direction of arrival, correctly classifies it (P_{IR}=0.8), it results: $P_{reaction} = 1 \cdot 0.8 \cdot 0.86 = 0.69$. This value rapidly increase as the IR and the Operator confidence increase and it reaches in few seconds values higher than 0.9.

5. Way ahead

Current work is devoted to provide more accurate modeling related to: (i) performance prediction of spaceborne and airborne radars, (ii) prediction of IR performance, (iii) probability of correct classification and (iv) precise effect of communication networks. The follow-on activity will address the inclusion of additional sensors such as electronic support measures (ESM) and arrays of hydrophones. ESM sensors are extremely suited to detect radio-frequency emissions from on board emitters and effectively complement active radar sensors. Arrays of hydrophones can be deployed to protect the coast front or to protect small apertures, like the harbor entrance; such arrays provide a complementary capability, detecting small vessels in rough sea conditions when radar performance typically degrades, or exclusively revealing underwater targets.
The inclusion of critical assets is also being investigated; ports and airports, railways and power plants represent vital assets essential to the life of a nation which must be secured and protected. Airports and ports represent an extension of country borders, the so called “virtual borders”, separating international zones from national territory, but they are themselves critical assets of the country’s transportation system; the railway system has similar characteristics, even though it poses very serious difficulties due to its peculiarities. Power plants are another example of vital asset essential to the life of the nation also due to the interdependency amongst national infrastructures.

6. Conclusions

This paper describes the activities underway within the System Analysis Group of Selex-SI, and involving similar groups within several Finmeccanica Companies, in the effort of modeling and assessing the performance of an integrated system for Homeland Security.
The paper also presents the results achieved in the activity dedicated to:
(i) define an integrated system architecture with a number of heterogeneous sensors, command and control centers, platforms and communication links, co-operating for the successful execution of the mission;
(ii) predict the system performance in a study case of interest.
The paper also describes follow-on activities, which intend to extend the integrated system to address much wider and complex Homeland Security missions; it is an ambitious goal, yet due to the strong and widespread competence of Finmeccanica companies in many, if not all, relevant fields, there is the confidence to be able to progress rapidly and provide overall integrated solutions to Homeland Security issues.

7. References

[1] F.A. Studer, M.R. Toma, and F. Vinelli (1998). Modern Software Tools for Radar Performance Assessment. In *Proceedings of International Radar Symposium* (IRS-98), Munich, Ge.

[2] A. Farina, and F.A. Studer (1985). *Radar Data Processing, Vol. 1: Introduction and Tracking*. Research Studies Press John Wiley & Sons, New York.

[3] P. S. Maybeck (1979). *Stochastic Models, Estimation, and Control*, Volume 1, Academic Press, Inc.

[4] J.A. Ratches (1976). *Static Performance Model for Thermal Imaging Systems. Optical Engineering*. Vol. 15, No. 6.

[5] NATO STANAG N° 4347 (1995). *Definition of nominal static range performance for Thermal Image System*.

[6] G.C. Holst (2000). *Electro-Optical Imaging System Performance*. 2nd edition, ISBN 0-9640000-6-7.

[7] Sagem MATIS STD MWIR Camera Technical Specification.

[8] Sagem MATIS LR MWIR Camera Technical Specification.

[9] Eng. Glauber, EICO TV Camera, private communication.

[10] J.L. Melsa., D.L.Cohn (1978). *Decision and estimation theory*. McGraw-Hill International Student Edition. ISBN 0-07-041468-8.

[11] D.K. Barton (1988). *Modern Radar System Analysis*. Artech House. ISBN 0-89006-170-X.

[12] M. Athans (1971). On optimal allocation and guidance laws for linear interception and rendezvous problems. *IEEE Trans. on Aerospace and Electronics Systems*, vol. 7, no. 5.

Authors Biographies

Annarita Di Lallo received her Doctor Degree in Electronic Engineering from "Roma Tre" University in Rome, in May 2000, with a thesis titled: "Innovative technologies for optical second harmonic generation in lithium niobate waveguides". She spent eighteen months in Ericsson Lab Italy, working on optical communications systems and technologies. In July 2002 she joined Alenia Marconi Systems (now SELEX-SI), specifically the System Analysis Group of Radar and Technology. Her present area of investigation is NCTR (radar signals backscattered by the rotating parts of helicopters and aircrafts, bi-dimensional signal processing by means of Short Time Fourier Transform and Wavelet Transform, high range resolution radars).

Alfonso Farina (Fellow of Royal Academy of Engineering, Fellow of IEEE and Fellow of IEE) received his doctor degree in electronic engineering from the University of Rome (I) in 1973. In 1974 he joined Selenia, now SELEX-Sistemi Integrati, where he is a manager (since May 1988). He was Scientific Director in the Chief Technical Office. Today he is director of the Analysis of Integrated Systems Group. In his professional life Alfonso has provided technical contributions to detection, signal, data & fusion, image processing for radar systems. He has provided leadership in many projects – also conducted in the international arena – in surveillance for ground and naval applications, in airborne early warning and in imaging radar. Since 1979, he has also been *Professore Incaricato* of Radar Techniques at the University of Naples; in 1985 he was appointed Associate Professor. He is the author of more than 350 peer reviewed technical publications and the author of books and monographs: *Radar Data Processing (Vol. 1 and 2) (translated in Russian and Chinese), 1985-1986* ; *Optimised Radar Processors, 1987 ; Antenna Based Signal Processing Techniques for Radar Systems, 1992*. He has written the Chapter 9 on “ECCM techniques” in the Radar Handbook (2^{nd} Edition 1990), edited by Dr. M. I. Skolnik of Naval Research Laboratory. He has been session chairman at many international radar conferences. He uses to lecture at universities and research centres in Italy and abroad; He also frequently gives tutorials at the Intl. Radar Conferences on signal, data and image processing for radar; in particular on multi-sensor fusion, adaptive signal processing, space time adaptive processing (STAP) and detection. In the 1987 He received the Radar Systems Panel Award of IEEE-AESS *for development of radar data processing techniques*. He is the Italian representative at the International Radar Systems Panel of IEEE-AESS. He is the Italian industrial representative (Panel Member at Large) at the SET (Sensor and Electronic Technology) of RTO (Research Technology Organisation) of NATO. He has been in the BoD of the International Society for Information Fusion (ISIF). He is the executive chair of the International Conference on Information Fusion, Fusion 2006 (Florence, 10-13 July 2006). He has been nominated Fellow of IEEE with the following citation: *"For development and application of adaptive signal processing methods for radar systems."* Recently he has been nominated international fellow of the Royal Academy of Engineering (UK). He is a referee of numerous publications submitted to several Journals of IEEE, IEE, Elsevier, etc., He has also cooperated with the editorial board of ECEJ (Electronics & Communication Engineering Journal) of IEE. More recently, Alfonso has served as a member in the Editorial Board of Signal Processing (Elsevier). Also he has been the co-guest editor of the Signal Processing (Elsevier) special issue on “New trends and findings in antenna array processing for radar”, September 2004. He is the co-recipient of the following best paper awards: entitled to Mr. B. Carlton, of IEEE Trans. on Aerospace and Electronic Systems for the years 2001 and 2003; also of the International Conference on Fusion 2005. Alfonso has been the leader of the team that received the 2002 AMS CEO award for Innovation Technology. Alfonso has been the co-recipient of the AMS Radar Division award for Innovation Technology in 2003. Moreover, Alfonso has been the co-recipient of the 2004 AMS CEO award for Innovation Technology. Recently, He has been the leader of the team that has won in 2004 the 1^{st} prize award for Innovation Technology of Finmeccanica. Finmeccanica (Italy) is the holding of 19 Companies (including Selex-SI) with about 55000 employees. This award context has seen the submission of more than 320 projects. This award has been set for the first time in 2004.

Antonio Graziano received the Doctor Degree in Electronic Engineering from the University of Palermo (I) in 1988. In the same year, he started his professional activity in Ericsson-Fatme as a System Analysis Engineer taking part into European research projects. In 1990 he joined Selenia S.p.A., now Selex-SI, where he has been involved in the areas of data fusion, decision support, Command and Control, system analysis, system architectures and network-centric warfare (NCW). He has been project leader on several national and international studies and projects. He is currently leader of Systems and C4I Analysis in the Engineering Division.

Luciana Ortenzi received the Doctor Degree in Telecommunications Engineering in October 2001 from the University of Rome, "La Sapienza". She developed a thesis supervised by Alfonso Farina (SELEX-SI) entitled: "Maximum Likelihood Techniques for Detection and Estimation of the Target Direction of Arrival with Generalized Antennas Arrays" the University of Rome.
She joined AMS in February 2002, and since then she is within the Radar System Analysis Group of Radar and Technology Department. Her present areas of investigation are oriented towards phased arrays and adaptive signal processing, detection and estimation.

Luca Timmoneri received the doctor degree in electronic engineering from the University of Rome, Italy, in 1989. In 1989 he joined Selenia S.p.A. now SELEX-SI, where he is currently the Leader of the Radar System Analysis Group of the Radar and Technology Division. His working interests span from the area of synthetic aperture radar (image formation and moving target detection and imaging), to space-time adaptive processing for AEW and ground-based radar, to parallel processing architectures with VLSI and COTS devices. He is presently involved in the areas of adaptive signal processing, detection and estimation with application to tri-dimensional ground and ship based phased array radar. He is the author of several peer reviewed papers (also invited) on journals and conference proceedings. He is the co-author of three tutorials on adaptive array and space-time adaptive processing presented at the intl. IEEE radar conference in Washington DC (1995), Boston (1999) and Boston (2003). Dr. Timmoneri received the 2002 AMS CEO Award for Innovation Technology, the 2003 AMS MD Award for Innovation Technology, the 2004 AMS CEO Award for Innovation Technology and the Primo Premio Innovazione Finmeccanica 2004.

Tiziano Volpi received the Degree cum laude in Electronic Engineering in 2001 at 'Roma Tre' University, Rome, with a thesis titled: "Coded excitation in ultrasound systems". He has a Master's Degree in General Management, funded by Finmeccanica (2004).
In 2002 he joined 'Alenia Marconi Systems', now 'Selex-SI'. He works in the 'Integrated Systems Analysis' unit of the 'Engineering' function. His present areas of investigation are data fusion (from satellite, airborne radar, coastal radar, infrared sensor) and 'Non Co-operative Target Recognition' (radar signal backscattered by rotating parts of helicopters and aircraft; bi-dimensional analysis by means of 'Short Time Fourier Transform' and 'Wavelet Transform'; estimation of target length from high resolution range profile).
His main hobbies are: soccer, beach volley and kundalini yoga (ancient practice that balances body, mind and spirit through posture, breathwork, rhythm, chanting and meditation).