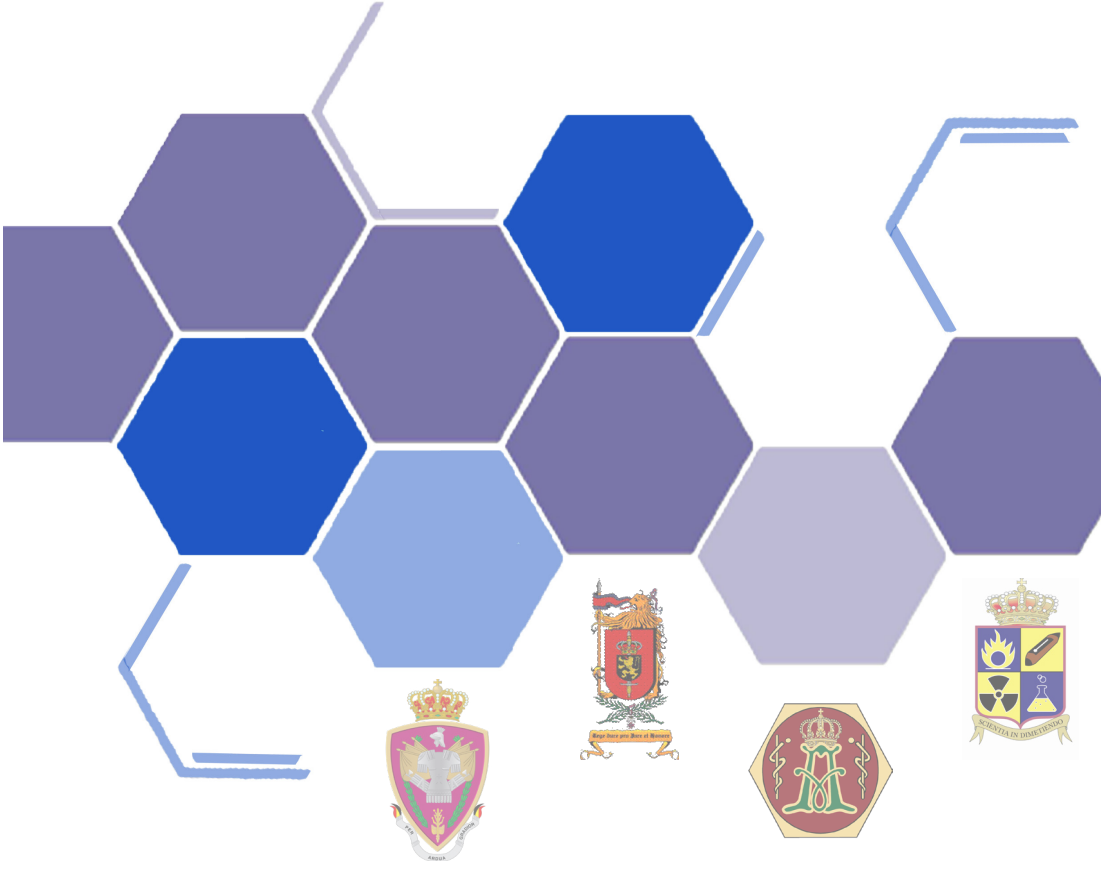
Royal Higher Institute for Defence
Department Scientific and Technological Research of Defence

# SCIENTIFIC RESEARCH
## IN THE BELGIAN DEFENCE FORCES



# 2018

# Introduction

Dear reader,

This military scientific research report provides you with an overview of the projects completed in 2018. Some of them are a continuation of projects ended previously; others are newly started projects in new scientific areas. This brochure presents the result of the hard work made by all the researchers and study directors of the different research institutes in the Belgian Armed Forces.

For the first time, this leaflet includes all the Defence projects finished in 2018, including the research projects done with external financial means, e.g. projects funded by the European Commission or sponsored by regional governmental institutes.

It is our intention to provide you each year with such a review to keep you informed about the developments in our research projects.

We are confident that, while reading this report, your interest in research will thrive, and that this document will be a stimulus for further military research in order to obtain the necessary future capabilities.

Sincerely Yours,
Filip Martel
Director of Scientific and Technological Research of Defence

# Main Defence Research Entities

Royal Higher Institute for Defence (RHID)
website: http://www.rhid.be

Royal Military Academy (RMA/ERM/KMS)
website: www.rma.ac.be

Defence Laboratories (DLD)
website: www.mil.be

Military Hospital Queen Astrid (MHQA)
website: https://www.mil.be/nl/eenheden/militair-hospitaal-koningin-astrid

# Table of content

14. Adaptive distributed TDMA based MAC for tactical mobile ad hoc networks (SIC07)

15. Development of multiplex bead-based assays for rapid detection and identification of pathogens involved in orthopedic infections (DLD05)

16. Improvement of the flame shield (S-POD)

17. Development of modified carbon materials for absorption of toxic gases (KAZ01)

18. Risk assessment for CB exposure after decontamination (RACED)

19. ESA BelSAR Campaign

20. The development of the Walloon know-how value chain for the enhancement of earth observation services in COPERNICUS and the dynamic monitoring of territories at the regional level (EORegions-Science)

21. Radar multivoie de mesure du trafic routier (ROADRADAR)

22. A system for the detection of threats in a maritime border environment (SafeShore)

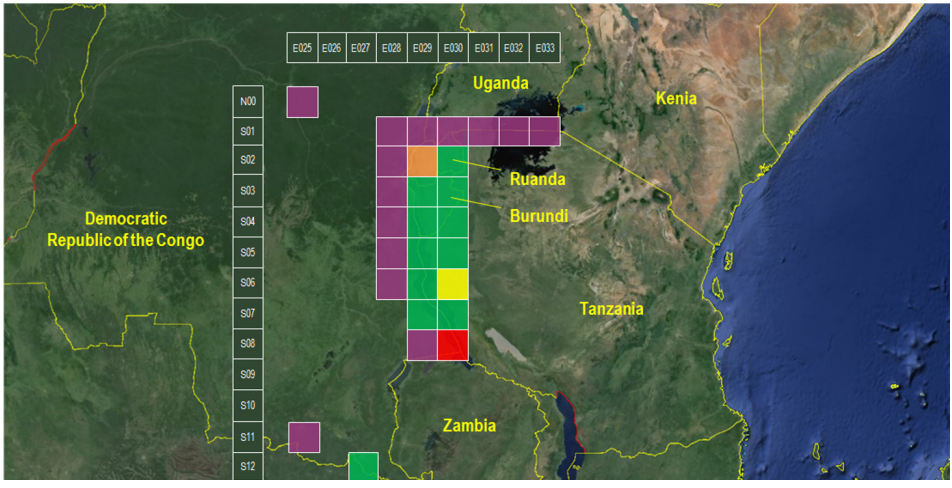
23. Belgian soldiers executed by firing squads in 1914-1918 –
Procedural regularity before Belgian courts-martial (Comité 14-18)


Study Director:
Prof. X. Neyt
Researcher:
V. Lacroix

# Support to Multinational Geospatial Co-production Program

# Background

The need for precise maps of areas in which Defence could be operating is vital. Paper maps form a very good base, when such maps exist. These maps though still need to be vectorised. When no map is available, it is possible to create one from satellite imagery. As the creation of such digital maps required a tremendous effort, the Multinational Geospatial Co-production Program (MGCP) was setup. Nowadays 29 countries participate to the MGCP. The principle is to have a unified production program and to promote exchange between the nations in order to avoid duplication of the effort. The land surface is subdivided in squares of 1° by 1° and the production and exchange are based on these squares. There is also an incentive mechanism in order to encourage every state to produce more maps. The picture below illustrates the state of production in 2014 and the future objective of Defence.




*Situation BEL MGCP Production, 20 Oct 2014*

assigned, not started

in production

completed, internal review

completed, external review

validation OK

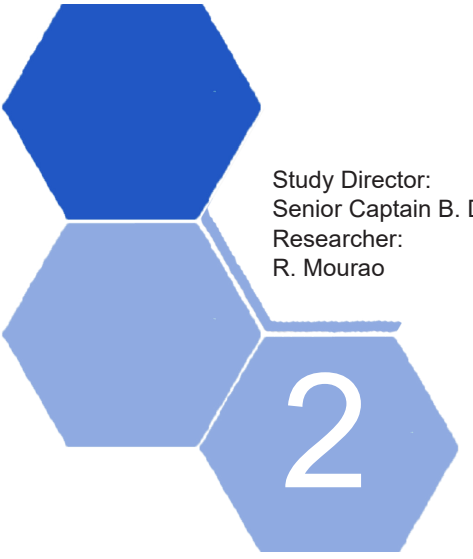
There are currently, within Defence, no automatic or semi-automatic tools to extract objects from satellite imagery. Complex softwares do exist but, besides their price, they require an extensive experience to be used efficiently. In addition, these softwares apply rules that may not easily be generalised from an image to another.

## Objectives

Given the importance of the required effort to produce these digital maps, automation, even if partially used, is highly desirable. The objective of the study is not to have a fully automatic tool able to produce digital maps, but rather to have a tool that aims at the “quick wins”, i.e., automating tasks that are easily achievable by an algorithm while time consuming and error prone for human operators. As the hydrologic network seemingly requires 30% of the operator’s effort, this will be the first target.

## Outcome

The hydrographic network is extracted based on a digital terrain model from SRTM (Shuttle Radar Topography Mission). Given the noisy nature of the DTM (Digital Terrain Model) data, a multiresolution approach has been considered. A sensitivity analysis of the algorithm to the resolution of the DTM was performed.




Study Director:
Senior Captain B. Desmet
Researcher:
R. Mourao

# Improving blast resistance of reinforced concrete structures with externally bonded reinforcement

# Background

In order to analyse and design RC (Reinforced Concrete) structures with the aim to resist blast loads, the Single-Degree-of-Freedom (SDOF) generally represents a simplified and cost-effective method capable of delivering good predictions on the structural behaviour of the component. Besides, it has been broadly used by many authors. Yet, limited research is available when it refers to the use of SDOF methods for FRP (Fibre Reinforced Polymer) strengthened RC structures. Blast performance of FRP retrofitted unreinforced masonry walls was studied earlier using an energetic resolution of the Single-Degree-of-Freedom method, assuming full bond between FRP and the concrete substrate. These results presented a good prediction of the failure mode when compared to experimental results. Other researchers studied the blast performance of CFRP (Carbon Fibre Reinforced Polymer) retrofitted RC walls, where the composite material was included in the analysis assuming it behaves like tensile reinforcement. The solution was controlled by a strain limit representation of the FRP debonding.

Although these studies have included the FRP contribution into the analysis, they did not include the full characterisation of debonding into the SDOF modelling.

The post-FRP failure force/deformation characteristics of retrofitted RC flexural members are of extreme importance, especially when the structure is subjected to unexpected or accidental loads, such as blast loading, where the structure can still offer some resistance after the premature debonding appears.

Since the accuracy of the SDOF method significantly depends on the accuracy of the adopted resistance function, it is important to correctly model it, where debonding predictions must be included in order to better estimate the maximum displacement and overall blast performance of the structural member. This project combines the experimental and numerical testing of one-way slabs retrofitted with FRP under quasi static loading with the analytical resolution of a SDOF system to analyse the influence of the FRP to concrete failure on the blast resistance of a RC structure.

# Outcome

*Test Specimens and Material Characterisation*

Two 2.2 × 0.3 × 0.06 m one-way slabs are manufactured with C25/30 concrete and S500 structural steel. Six 6 mm rebars are used in the longitudinal direction, where 17 rods equally spaced are used in the transversal direction to keep a uniform 4 cm spacing between the longitudinal reinforcement. One of the slabs is externally reinforced by two CFRP strips applied on the concrete surface with the epoxy resin.

The pictures below shows the manufacturing of the slabs and FRP application.

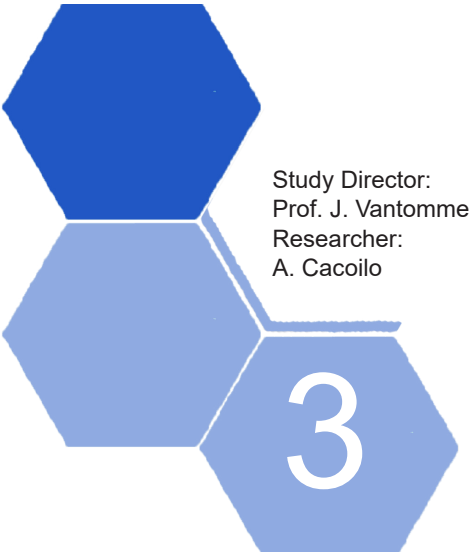
The average 28-day compressive strength of the concrete was found to be 32.88 MPa and it was determined using 3 identical standard cubes. Mix proportions of concrete is summarised in Table 1.

Deformed steel rods of grade 500 with a diameter of 6 m are used as reinforcing steel. The FRP strengthening of the concrete members is done using uniaxial Sika CarboDur S1.525 strips with 15 mm width and 2.5 mm thickness. The strips have a Young modulus of 165 GPa and a tensile strength of 3.1 GPa. The epoxy system SikaDur-30 is characterised by a Young Modulus of 9.6 GPa and a tensile and shear strength of 24 and 14 MPa, respectively.

Pictures (a): preparation of the specimens and (b) CTRP bonding

# Conclusions

In this project, a 3-point bending finite element model of a RC slab strengthened with FRP is validated against experimental measurements. A good match was found between the numerical and experimental data. The model is used to predict the load-displacement behaviour of the structure when different strengthening schemes are employed to further analyse the structure under the action of two blast threats. The resistance of the structure was also predicted using the crosss-ection member analysis approach. The results of the SDOF analysis show that the analytical structure's resistance prediction is acceptable for blast analysis when the structure behaves in the elastic domain, where the maximum difference in the structure's deflection between the two methods was found to be 3.4%. However, when the threat is big enough to push the structure into the plastic domain (with debonding of the EBR), the analytical approach to characterise the structure's resistance leads to an underestimation of the deflection. This is mainly due to the inability of this method to predict debonding and consider the structure to be failed after the concrete crushing. These results reveal the critical need to correctly characterise the resistance of the structure when the SDOF modelling is to be used in blast analysis, especially when concrete-to-FRP interface failure appears.




Study Director:
Prof. J. Vantomme
Researcher:
A. Cacoilo

# Resilience of corrugated steel panel structures to blast loading: a combined experimental and numerical approach applied to the evaluation of the compound survival container

# Background

It is often said that steel structures and components provide ideal systems for blast resistance due to their ductile nature and their significant plastic deformation capacity. Yet, this potential is still to be documented in the domain of engineering applications with respect to blast loading. This project aims to develop fundamental insight and design guidance for blast resistant steel structures, with the emphasis on corrugated panels and their typical applications in industrial and military facilities. As a practical application and a demonstrator case, the survival container – widely used in compounds during military operations abroad and mostly based on the commonly known standard ISO container – will be considered.

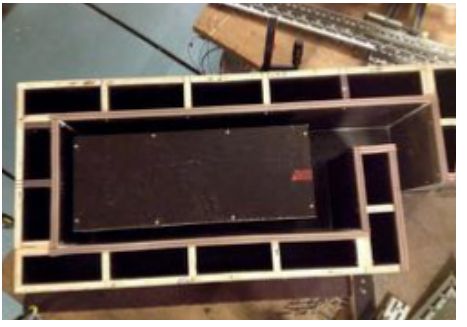
# Objectives

The most important goal of this research project is the study, evaluation and optimisation of the Belgian survival shelter configuration confronted to a realistic threat scenario. The relevance of the study is to understand in a more detailed way the behaviour of corrugated steel panels under blast and to develop validated numerical models of both blast wave propagation and blast wave/structure interaction.

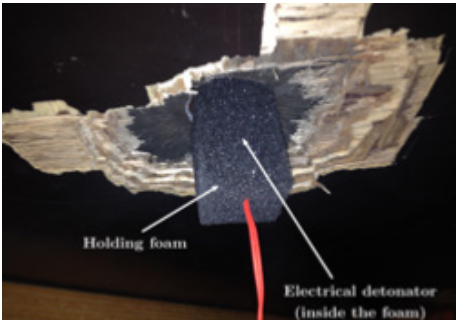
The project started testing a small-scale model of the survival container in order to address the problem of blast wave propagation and to know the pressure profiles in a complex configuration. The actual loads in terms of pressure and impulse on the façades of the container were determined. It was found that the back face of the container is where the highest overpressure occurs while the lowest overpressure results take place in the top face.

A validated numerical model simulating only the air was developed and a detailed analysis was performed to study the influence of different numerical parameters: number of ambient layers, advection method, time step-size and the mesh element size.The work will involve small-scale blast testing of a reduced model of the survival container in order to address the problem of blast wave evolution and pressure loading profiles in a complex configuration and the associated numerical model validation. Next, a blast test set-up for component testing will be developed to enable validation of the structural finite element modelling.

Finally, the survival container will be evaluated and optimised, based on the exploitation of the experimental tests and validated numerical models both for pressure and deformation prediction.



Picture 1: Modular building system




Picture 2: Initiator device: the picture shows the bottom side of the work platform on which the charge is positioned

Picture 3: Comparison between the experimental and numerical results of the container

# Outcome

It was concluded that a third ambient layer improves the quality of the results and avoids a leakage of pressure at the entrance. The advection method has no significant difference on the results. However, van Leer algorithm captures better the overpressure peaks.

A better agreement of the results is obtained by decreasing the time-step size. Finally, the overpressure curve is dependent on the mesh element size. Studies were also made on an optimisation of the shelter configuration and some numerical parametric studies, such as location of the detonation, configuration of the protective roof, dimensions of the interior corridors of the shelter and the effects of venting and its locations, were performed. It was found that the location of 45° presents the most critical results of the overpressure and specific impulses. Bigger covered area by the roof leads to higher results since the confinement level increases. An increase of the corridors decreases the overpressure and specific impulse values. Last, an opening in the survival shelter helps to decrease the results.

Study Director:
Prof. M. Lefebvre
Researcher:
L. Jeunieau

4

# Explosive precursors' inhibition

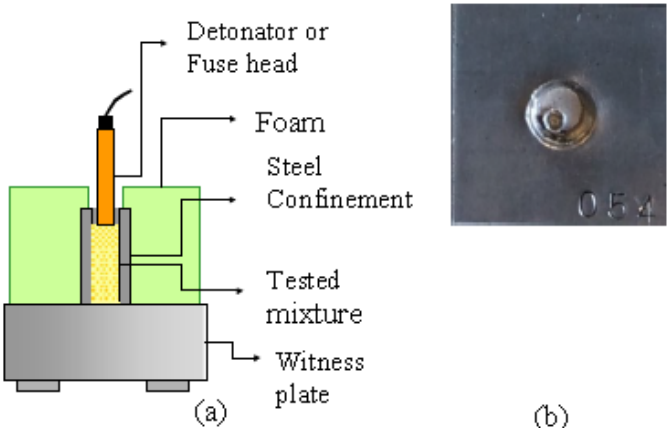
# Background

Improvised explosives are easily synthesised from products used in everyday life: basic chemicals and/or household products. These explosives are increasingly used in terrorist attacks around the world and constitue an ever higher danger. Following the attacks in Paris and Brussels, this study was partially oriented. Among other things, it was decided to study specifically the phlegmatisation of the TATP and HMTD.

# Objectives

The following objectives are targeted:

- Synthesis of improvised explosives from laboratory and commercial products;
- Characterisation of these explosives and detonators;
  - Study of inhibition method to determine whether it is possible, by adapting legislation, to prevent the manufacture of improvised explosives and/or detonators.




Picture: (a) Set-up of the witness plate test, (b) example of an indent observed on the witness plate after performing a test.

# Outcome

The study tested some improvised explosives, determined whether they could be used as detonators and characterised their properties (breakage, initiation temperature, etc.).
A first study of the phlegmatisation of the TATP and the HMTD was carried out. This study is not complete and will be finalised in a follow-on study. This first study made it possible to determine that some of the methods currently used are not effective. The results were discussed and communicated to SEDEE.


Study Director:
Prof. X. Neyt
Researcher:
F. Bettens

# Radar Interferometry using opportunity emittors

# Background

Airborne/spaceborne radar imaging offers the major advantage to be able to provide ground images regardless of cloud cover. It is thus the ideal tool for monitoring purposes. The vast majority of radar imaging instruments are monostatic, which means that the transmit antenna is collocated with – or indeed the same as – the receive antenna.

The possibility however exists to operate another receiver not collocated with the transmitter; such a configuration is called “bistatic”. The transmitter can either be cooperative or non cooperative. In the non-cooperative case, it is called a “transmitter of opportunity”. Transmitters of opportunity are for instance existing telecommunication transmitters (GSM, DVB-T, etc.) or, indeed, an existing radar satellite.

Besides the tactical aspects (the receiver is inherently stealth), there are indications that such bistatic configuration may also provide additional benefits in terms of imagery data.

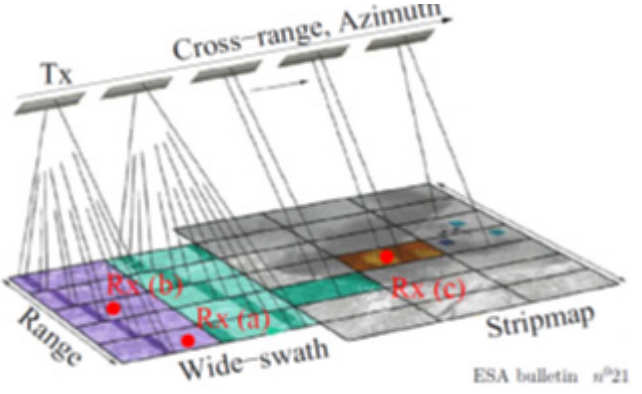
# Objectives

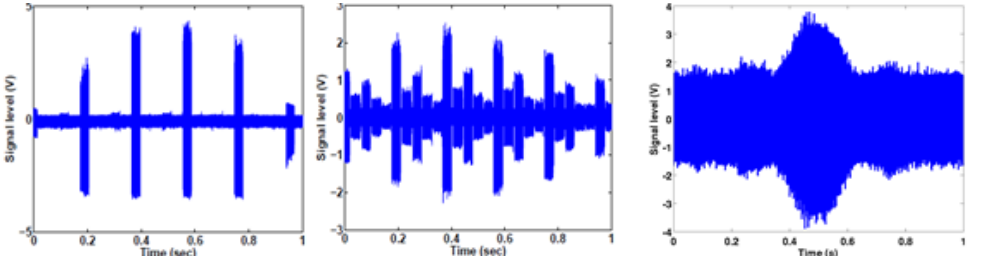
The objective of the study is to assess the feasibility and the usefulness of bistatic radar imagery using a spaceborne transmitter of opportunity. One of the challenges of bistatic opportunistic configurations is the so-called synchronisation between the transmitter and receiver. Radar imaging systems are indeed particularly sensitive to phase errors. One of the goals of this study will thus be to assess to what extent missynchronisation between the transmitter and the receiver affect the quality of the image in terms of geometric distortion and phase error.

Our 24/24h operational and fully automated receiving system led us to conclude that the occurrence of satellite passes in Stripmap high-resolution mode is not as frequent as passes in wide-swath mode such as ScanSAR and the novel TOPSAR modes.

In opportunistic SAR for a receiver close to the imaged area, the bistatic geometry offers the opportunity, in some favourable geometries, to enhance the coarse monostatic cross-range resolution of wide-swath mode by exploiting the sidelobe emissions of the beams illuminating the adjacent sub-swaths.

This method can restore the cross-range resolution of the Stripmap mode provided that the amplitude of the signals transmitted in the sidelobes is sufficient. This can occur when the receiver is close to the imaged area and when the receiver and the imaged area are at the centre of the global swath. This novel technique will result in an increase in opportunities to obtain high resolution interferograms.



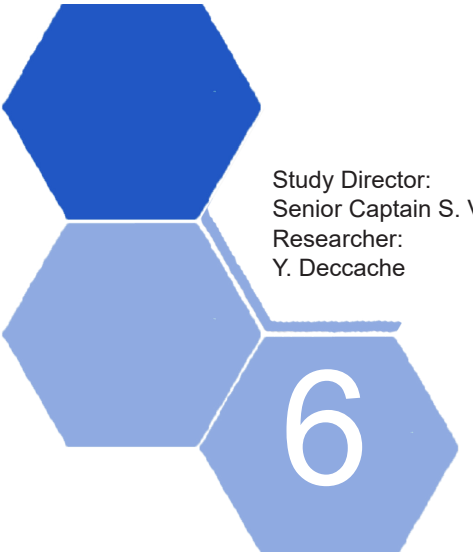

Picture 1: Acquired signals during an overpass of ENVISAT -(a) and (b)- and Sentinel-1A (c) over the receiving systems.

Picture 1 depicts some acquired signals in wide-swath mode from radar satellites operating in C-band. For a Stripmap illumination, the receiver is continuously illuminated by the space borne transmitter as shown on Picture 1 (c) where the azimuthal antenna pattern of the transmitter can be recognised. In ScanSAR mode, the antenna beam is electronically steered to different contiguous range sub-swaths leading to an azimuth modulation which depends on the position of the receiver/imaged area in the global swath, and thus on its elevation angle, i.e. the angle scatterer-transmitter-nadir. Picture 1 (b) and (c) show the amplitude modulation function for two different ScanSAR passes of ENVISAT (Wide Swath Mode) over Brussels.

If the receiver is at the very edge of the swath, only one beam during the along-track illumination will be received (Picture 1(a)), leading to gaps in the along-track direction. However, if the receiver and its surrounding are in the center of the swath (Picture 1(b)), all the beams are received and the cross-range resolution enhancement method can be used.

# Outcome

- C-band satellites, i.e., ERS-2, Envisat, RadarSat-2 and Sentinel 1A/B have successively been considered. A receiver able to receive signals from these satellites has been developed. That receiver is able to operate autonomously, i.e., acquisition of the signals from the satellites are scheduled and performed without manual intervention.
- On the one hand, the study has shown that satellite operating modes had grown to become extremely complex. On the other hand, that complexity paradoxically enables – by a creative exploitation – to increase the azimuthal resolution of the low-resolution modes, thus dramatically increasing the number of useful images.
- Finally, the study has shown that the synchronisation issues where manageable in terms of geometric distortion and that the phase error was typically not significantly affected.




Study Director:
Senior Captain S. Verberckmoes, MSc Eng
Researcher:
Y. Deccache

# New method for multiplex identification of genetically acquired or modified bacterial resistance mechanisms; direct analysis on clinical or environmental samples

# Background

The therapeutic attitude in the event of a bioterrorist attack recommends the use, even preventive, of broad spectrum antibiotics. Unfortunately, bacteria may have genetic resistance determinants that allow them to completely inactivate these antibiotics. A rapid determination of the resistance pattern of biological agents is therefore a prerequisite for controlling the spread of biological agents in a bioterrorist attack.

Conventional screening techniques for antibiotic resistance require prior growth of the bacterium on a culture medium resulting in a delay of at least 72 hours to obtain a result (Picture 1). Given the risk associated with the culture of bioterrorist agents (biosafety level III or IV), the CTMA/DLD-bio is developing DNA-based methods for rapid identification and characterisation, without prior culture of infectious agents.

Picture 1: Traditional method for determining antibiotic resistance after isolation and culture on solid medium.

Bacterial resistance to antibiotics is, at the genetic level, a large-scale phenomenon. Hundreds of genes are involved in various resistance mechanisms. These resistance genes can be located directly in the chromosome of resistant bacteria or located on moving elements (such as transposons or plasmids) that can be exchanged between bacteria.

# Objectives

The objective of this study is twofold. On the one hand, the implementation of a multiplex pyrosequencing technique (Picture 2) and, on the other hand, the development of a diagnostic tool evaluating the most clinically significant bacterial resistance mechanisms, and which mainly concerns the families of antibiotics recommended in the event of a bioterrorist attack (beta-lactams, fluoroquinolones, aminoglycosides and tetracyclines). In addition to common infectious bacteria, the study will therefore include some of the pathogens known as bacteriological weapons (*Bacillus anthracis, Yersinia pestis, Brucella melitensis, Burkholderia mallei* and *Francisella tularensis*).

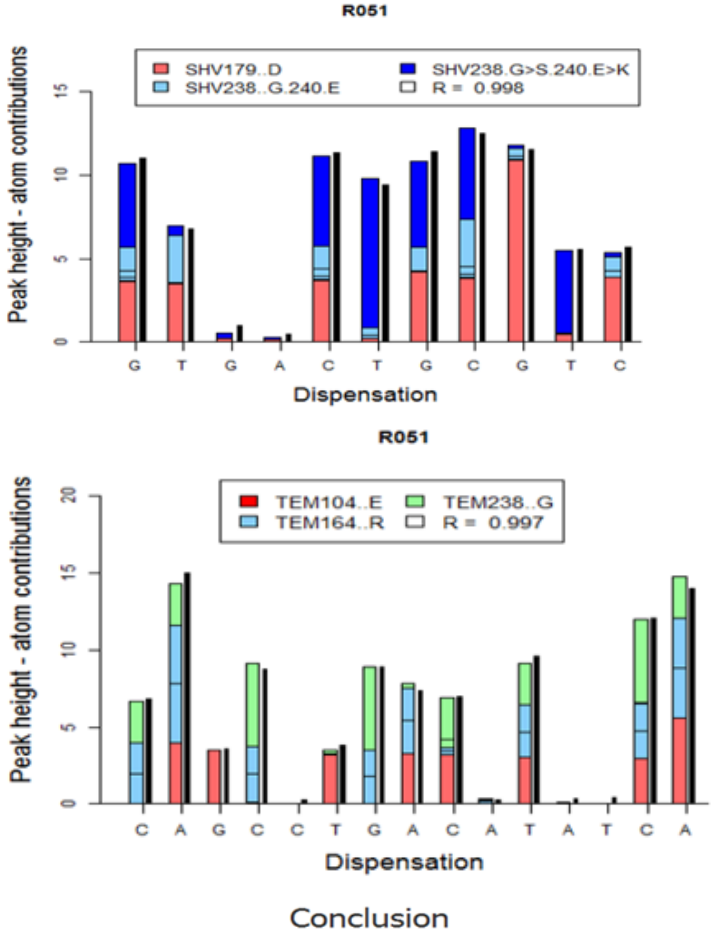
# Outcome

The study allowed the implementation of a unique, simple, rapid and sensitive analytical procedure applicable to clinical and environmental samples, in hospital and operational environments, and defining a "resistance pattern" of pathogens. This test is based on a combination of qPCR and "multiplex pyrosequencing" techniques that simultaneously analyse different genetic resistance markers by processing complex signals using analysis software specifically developed by CTMA/DLD-Bio biostatisticians for this new pyrosequencing application.

## Presence of PCR product

| | blaCTX | blaSHV | blaTEM |
|---|---|---|---|
| R051 | yes | yes | yes |

## Interpretation of the blaSHV and blaTEM pyrograms




## Conclusion

Isolate R051 is considered as ESBL-producer because :
- a blaCTX-M gene is detected
- an ESBL-associated substitution is detected in blaSHV

Picture 2: Interpretation software interface for multiplex pyrosequencing results created for the HFM-14/8 study (application for Extended Spectrum Beta-Lactamase (ESBL) producing bacteria).


Study Director:
Prof. M. Zizi & Major A. Noterman
Researchers:
K. Paarikka & G. Steurs

# Professionalisation of phage properties for human applications

# Background

The study has begun with the search for phages in natural environments that have an action against four species of pathogenic bacteria: *Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa* and *Staphylococcus aureus*. All these bacteria are commonly met in patients and are responsible for many serious illnesses, amongst others nosocomial illnesses (in particular in patients suffering severe burns).

Phages have been isolated from natural water sources (canals, etc.) as well as wastewater. The reasoning was to collect phages where their hosts (the aforementioned pathogenic bacteria) live. In order to maximise the diversity of collected phages, a collaboration with Zaventem airport has been set up, as its water treatment plant collects its own wastewaters, the airport being frequented by a large population in terms of number, but especially in terms of diversity (its tourists, to be precise). Several phages could have been isolated against pathogenic bacterial strains supplied to us by Lab MCT (which maintains a strain library with bacteria isolated in patients).

# Objectives

The analysis of the in vitro behaviour of phages and the professionalisation of their properties were the principal study approach, because this step was the most important in terms of innovation and interest for phage therapy. The necessity of this analysis was based on the fact that phages isolated in nature are adapted to environmental conditions (temperature, pH, salinity, etc.) that can radically differ from those in patients. By using the principle of in vitro site-directed Darwinian selection, phages had to be directed against infectious bacteria in order to increase their therapeutic performance. The analysis of phage behaviour and their site-directed Darwinian evolution represented a new step to be added in the phage production process for therapeutic purposes, and thence in a potential phage therapy unit within Defence.

The project concerned the use of bacteriophages with the aim of struggling against pathogenic bacteria in patients. The objective was to result in cocktails of phages. The project was built around three principal approaches:

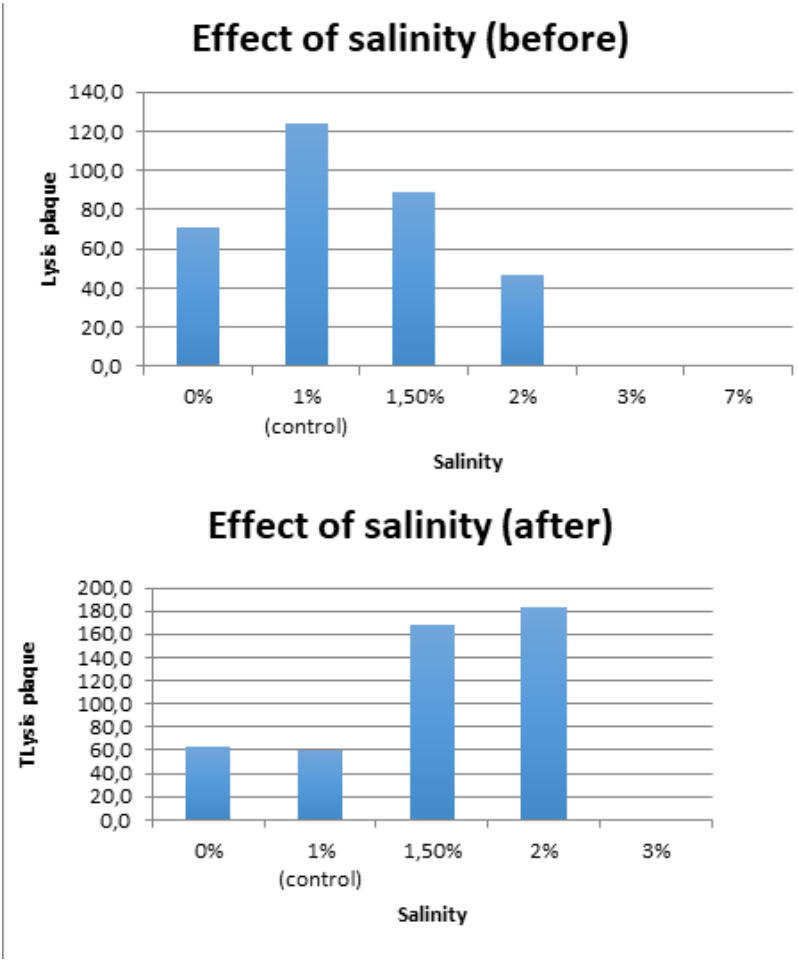
1. Isolation of phages collected from the environment,
2. Analysis of the in vitro behaviour of phages in various physicochemical conditions and their site-directed Darwinian evolution (or "professionalisation") against human pathogens, and
3. Stability tests in various pharmaceutical solutions.

# Outcome

Laboratory manipulations aiming to investigate the hypothesis postulated in this project – i.e. phages work best in physicochemical conditions that are different from those in the human body – suggest that a professionalisation step is necessary for **each** isolated phage. This step, for as much as we know, is neglected in the other laboratories working on phage therapy, and is little time consuming once standardised. It brings a major advantage in terms of efficiency of the phages used. Moreover, it would be advisable to adapt phages to various physicochemical conditions that can be met in patients, and then to mix them to create cocktails (e.g. phages adapted to 37°, to 38°, to 39°C, etc.). Even if these phages then breed in the patient's body – an adaptation step will probably be necessary during this procedure – it is **anyway** important that the first phage generation (thus those integrated in the therapeutic cocktail) should be efficient and can efficiently adsorb onto its target.

Note that the results of this study are preliminary and still should be confirmed with other more sophisticated laboratory manipulations, in the interest of scientific rigour. Its confirmation would also enable the publication of these results in a scientific review. However, the obtained results leave no room for doubt on the validity of the hypothesis that, in our opinion, has been confirmed in this study. Budgetary restrictions (see below) and logistical concerns have not enabled us to achieve more detailed and complex manipulations. With respect to logistics, investments in terms of material ordering would have been necessary (using the "KUR" form). However, the management service informed us in 217 that no investment could be done as a result of logistical limitations blocking orders for several months (whose length would probably exceed the study length, knowing

that any receipt of material in 2018 could not have enabled us to complete manipulations). The third approach of project HFM15-6, i.e. stability tests in various pharmaceutical solutions (e.g. in gels, isotonic solutions, in the presence of antibiotics, etc.), could not be completed for the same (logistical and budgetary) reasons. It would though be an ideal and necessary project for hospital pharmacy. Among other trails explored to achieve a phage-based therapy, we have studied the economic benefits of such a therapy compared to antibiotherapy. Although some data were missing (hindering their publication), a business case can be set up in order to convince the decision makers that a phage-based therapy would be beneficial both on a medical and economic level.




Study Director:
Prof. P. Merken
Researcher:
G. Lewis

# Surface infrared signatures of ships

# Aim

The objective of this project is to research the IR signature from ships so as to assess their vulnerability to IR guided threats.

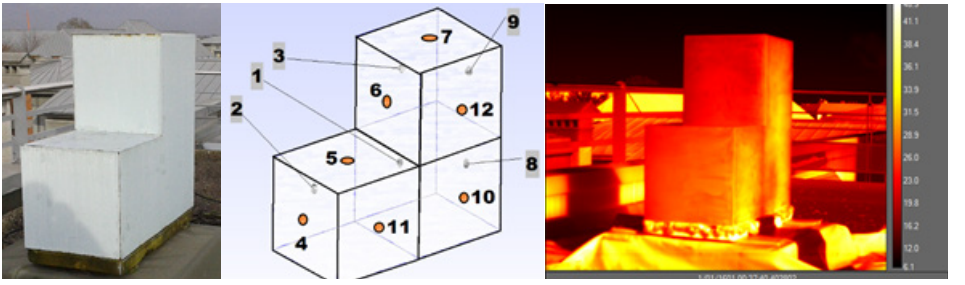
# Objectives

The homing device of future anti-ship missiles is likely to contain two sensors, passive and active (dual-mode), where the passive imaging sensor complements the existing radar to both improve the target discrimination and reduce the missile's own emission signature during the terminal phase of the missile attack. Hence, the missile becomes more difficult to track with onboard sensors due to the likely reduction in radar emissions. Importantly, the susceptibility of a naval vessel to an infrared-guided attack (sea or shore-based) is not fully appreciated. Consequently, experimental data and observations to validate simulations of a ship's infrared signature would be a valuable operational tool as well as an important training aid.

# Outcome

The key scientific results of this project focus on two areas:

1. Digital calibration reference: refitting of a geometrical calibration object with digital network temperature sensors, to evaluate the dynamic thermal signature of a Navy grey painted object and contract a representative monitoring system for ship hull measurement;
2. Tests and evaluation of imaging data gathered from the Belgian Navy vessels BNS Leopold I, myself and BNS Castor, from the trials CUBI-MET and NEMO




Picture 1. Three images of a geometrical target known as CUBI painted in Navy gray (left), instrumented with digital temperature sensors (center) and viewed with a mid-wave infrared thermal camera (right).

## *Key findings*

The important findings of this study can be split into two groups: those of scientific significance and those of military research value.

### *Scientific*

- We applied a wavelet approach to decompose temperature signatures into fluctuation scales, which will aid the validation of infrared signature prediction models;
- We applied a wavelet approach to decompose temperature signatures into fluctuation scales, which will aid the validation of infrared signature prediction models;

### *Military*

- We evaluated data gathered from the mid-infrared imaging systems of the BNS Leopold I and BNS Castor as qualitative data for the assessment of a warship's relative thermal signature;
- While investigating the BNS Castor data, we discovered images that subsequently led to a classified report and a new research project due to start in 2018.


Study Directors:
Prof. A. Muls & Division Admiral Y. Dupont
Researcher:
O. Lopera

# Machine intelligence and environmentally adaptive sensing for mine search based on high-resolution sonar imaging

# Background

Mine hunting requires searching for all the mines in an area before disposing them, and is generally decomposed in four stages: detection (finding contacts in an image), classification (determining if contact is mine-like or friendly object), identification (send a diver or AUV-based camera) and disposal (neutralising the mine). The trend in maritime mine countermeasures (MCM) operations goes towards the use of (semi-)autonomous underwater vehicles, (S)AUVs, equipped with high-resolution (HR) sensors (e.g., sonars and cameras) and employing computer-aided detection and classification (CAD/CAC) algorithms, more recently called "automatic target recognition (ATR) algorithms". In order to achieve multi-aspect classification, conventional mine hunting vessels rely on a sequence of images acquired by a hull-mounted sonar (HMS) following a pre-defined angular sampling list. Those images can be obtained in HR using synthetic aperture beam forming and very high frequency transducers generally mounted in remotely operated vehicles (ROVs) and/or (S)AUVs. In principle, obtaining images of the target at all aspect angles (over a rotation of 360° around the target) with ROV/AUVs should give excellent classification performances. While this is encouraging, high-density sampling of the aspect angle does not significantly accelerate the classification process based on the cumulative analysis of the multi-aspect images; therefore AUV's autonomy is not fully exploited, which is one of the concerns of the MCM community. This motivates environmentally adaptive algorithms that take into account effects related to the environment and to the vehicle itself. However, these algorithms do not solve some very important effects such as multipath or high-density clutter, which have a significant impact in classification performances as well. In such cases, the input from an experienced deminer could give better classification results than the CAC/ATR program alone.

# Objectives

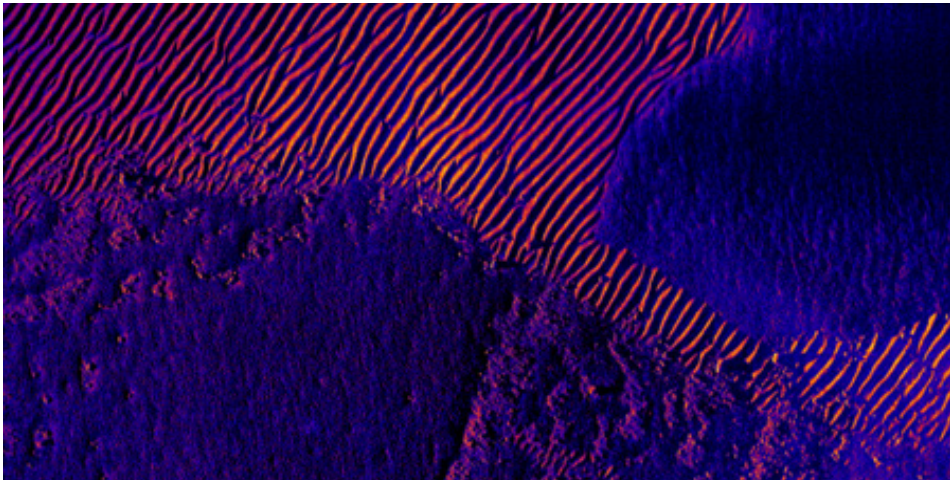
This study focuses primarily on the classification phase, particularly on the application of machine intelligence and adaptive sensing with the aim of gathering the best possible sonar data in order to improve classification

performance and optimise the recognition time and number of manoeuvres. This is a very challenging task, owing largely to the difficulty of estimating and predicting classification performance given the data collected, the ocean environment and the vehicle behaviour. Some examples that can illustrate these difficulties:

i. Partially buried objects can lead to misclassification when only one look angle (aspect) is considered;
ii. Rippled seabed can compromise classification at a certain aspect with respect to the developed ripple field due to an occlusion phenomenon;
iii. Multipath echoes (or reverberation) can obscure object echoes;
iv. Crab angle (vehicle continuously drifts sideways due to cross currents) can affect classification due to blurring.

It is commonly admitted that multi-aspect classification is a key element for a successful automation of the classification task and deals with some of the problems mentioned above.
As a second objective, this study aims to define a strategy in order to evaluate the optimal moment for human-in-the-loop intervention in the CAC/ATR chain and to determine the added value of automated classification approaches. By addressing all these issues, this project contributes to
NATO Mine Warfare Mission Support Center (based in Zeebrugge and Oostende) in the following: (i) capitalising on and improving the operation of existing (S) AUVs of the Belgian Naval Component, which include ROV-mounted HR synthetic aperture sonar (SAS), SHADOWS, and AUV-mounted HR side-scan sonar (SSS), REMUS; and (ii) stressing the interaction with human capital.
In order to perform these tasks, one shall:

1. Determine a confidence level map, in order to predict CAC performance, given the ocean environment, vehicle behaviour and data collected, by analysing some of the elements that affect image quality (e.g. seafloor roughness, sea state, navigation accuracy).
2. Improve the classification performance by adaptive mission re-planning, with the aim of maximising the classification accuracy while minimising the classification time and number of manoeuvres.
3. Analyse when human intervention is required and study the added value of CAC algorithms.



Picture 1. Example of an image collected using MUSCLE system (CMRE's system, 300kHz, 2.5 cm along track and 1.5 cm across track resolution). Rippled fields, vegetation and some rocks can be seen on the sea-floor. Image dimensions are 50m (along track) x 110m (across track).

# Outcome

In order to evaluate the benefit of automated target recognition (ATR) algorithms, sea trials involving ATR and human operator data analysis for target classification are carried out during this part of the study. Images collected by unmanned maritime vehicle systems equipped with SSS and SAS tasked with naval mine hunting and route surveillance operations in the area of Picture 3 during real mine countermeasures (MCM) exercises are analysed by expert human operators (4 deminers with 7 to 25 years of experience in sonar imaging, 5 scientists with 10 years of experience in sonar imaging) and by 2 automatic classification algorithms (Markov Chain Monte Carlo [1] and Adaptive Boosting Decision Trees [7]). The total surveyed area corresponds approximately to 18km² in which 35 mine-like objects were deployed on the seabed and in the water column (positions were unknown to the operators and the algorithms during the object recognition process and were released afterwards for the analysis). The area presents 20-30 meters of water depth, and a field of sand-waves with height between 2 to 4 meters and wavelength around 150 meters occupy the Northern half of the area, whereas the Southern half part is characterised by a flatter bottom,

showing different environmental characteristics (see Picture 3). In the human-computer experiment, a total of 1.124 images from 4 different sonar systems, each of them covering the entire area, are used. Image resolution is divided in two categories: very-high resolution, from 1.5cm to 5cm pixel size, and high resolution, over 5cm pixel size. Following the strategies suggested in [8], data are analysed in different ways by the expert operators and the algorithms. Additionally, a seafloor segmentation map based on lacunarity and representing how difficult or how benign the seafloor is for object-recognition [6,9] is used as a new strategy in order to divide the database between operator and computer. It is worth noting that time allowed to perform detection and classification tasks is limited for both operators and computer; and that all operators work independently and do not discuss or share results with others during the experiment.

Different mines are considered for the analysis: cylindrical (GM), manta (MA), rockan (RC) and conical (KV). It can be seen that PoD and PoC decrease with pixel resolution. The PoD for cylindrical and rockan mines are slightly higher for the algorithm than for the human operator. In terms of classification, the human operator performs better only for the manta mine in very HR images.


Picture 2. Example of some objects deployed for data collection. From left to right: manta mine, cylindrical mine, rockan mine, oil barrel.

| ***Target*** | ***Dimensions*** |
|---|---|
| Manta mine | Height: 44 cm<br>Diameter: 98 cm |
| Cylindrical mine | Length: 160 cm<br>Diameter: 50 cm |
| Rockan mine | Width : 100 cm<br>Length: 80 cm<br>Height: 40 cm |
| Oil barrel | Length: 90 cm<br>Diameter: 50 cm |

Table 1. Geometrical characteristics of the objects shown in Picture 2.

Results improve when dividing the database between the algorithms and the human operator, following the lacunarity map. Data included inside the “benign” soils is treated by the detection and classification algorithms directly, while detection in the “complicated” soils is first performed by the human operators and their results used as input for the classification algorithm. Following this strategy, the number of false alarms is reduced and the number of correct classification is increased, compared with the first strategy. It is worth noting that in this second strategy, extra time is added during the analysis of the human operator in combination with the algorithm, compared with an analysis of the algorithm alone. This crucial factor has to be considered during the planning and evaluation of a mission.

The impact of different factors on the object-recognition performance using different strategies are analysed: working on images with different resolution, working with previously unseen images (i.e., not previously used for training operators or algorithms), working with two kinds of operators: end-users and scientists. Additionally, combinations of different strategies are evaluated in order to improve the performances. Results demonstrate the utility of considering the human operator as an integral part of the automatic underwater object recognition process, and demonstrate how automated algorithms can extend and complement human performances.


Study Director:
Prof. J. Leysen
Researcher:
P. Alonso Peña

# From individual traumatism to organisational traumatism: theoretical definition and measurement instruments

# Background

An organisational trauma (OT) is defined as an *"organisation's 'over'-adaptation to the rupture of its protective emotional membrane, caused by a potentially traumatising event and involving the appearance of emotional and organisational disturbances."* In chaotic economic and political times, ever more organisations are confronted to such potentially traumatic events. Hence, the probability grows that an organisation will develop this organisational pathology. Because of its role, its missions and the difficult context, also the Belgian Defence is at risk of being impacted by organisational trauma.

# Objectives

In order to evaluate to what extent the Belgian Defence is affected by an organisational trauma, this research has focused on two points. First, conceptualising the symptomatology of the pathology and its underlying process. Second, operationalising this in order to measure the impact on the organisation.

# Outcome

The research resulted in the design of a diagnostic tool (OUDITO) validated and applied to the Belgian Defence. The questionnaire has allowed to highlight the impact of organisational trauma and the stage of traumatisation on the Defence organisation. OUDITO is composed of 48 items which measure 6 symptomatic dimensions, corresponding to the successive stages of an organisational trauma: internal communication and cohesion, relationship with the organisation, organisational functioning, emotional reaction, employee wellbeing, and leadership.


Study Directors:
Major R. Haelterman & Colonel P. Lodewyckx
Researcher:
M. Shimoni

# Detection and identification of chemical warfare and hazardous materials using thermal hyperspectral and spectropolarimetric imaging

# Background

Remote sensing detection and measurement of chemical, biological, radiological or nuclear (CBRN) agents and hazmat (i.e. hazardous materials) is becoming more important and is receiving much greater emphasis within military and security communities. The choice of the detection technique depends on the agent being sought, expected background interferences, and the required ranges. Most species can be detected and quantified due to their unique spectral properties in the thermal infrared wavelength regions. With tens to hundreds of spectral bands, thermal hyperspectral sensors constitues an advantage over traditional open-path sensors in their ability to detect and quantify chemical molecular absorption and concentration along a large area of interest. Novel spectropolarimetric imaging provides complementary polarimetric information in large spectral dimension and therefore enables improving confidence in chemical identification and reducing false alarms rate. These pioneer technical combinations expect to outperform other spectral methods.

This project addressed the detection of chemical elements of CBRN warfare. Specifically, it explored the phenomenology behind the detection and identification of chemical agents and hazmat using thermal hyperspectral and spectropolarimetric imaging. This was achieved by the collection of a large set of realistic scenarios using sensor data, development of physics-based models and dedicated spectral and spectropolarimetric detection methods.

# Outcome

For realising the project objective, the Belgian team collected thermal hyperspectral and spectropolarimetry imaging data of chemicals and aerosols during the NATO's PRONGHORN campaign using several advanced airborne and ground hyperspectral and spectropolarimetric sensors. The configurations of the sensors used for achieving this scientific work are summarised in the table below.

| Name | Nation | Type | Wavelength (µm) | Nr of bands | Scenario |
|---|---|---|---|---|---|
| LACHI (hyperspectral) | USA | Ground | 8.12-13.12 | 251 | Gases |
| SEBASS (hyperspectral) | USA | Airborne | 7.5-13.5 | 128 | Gases, Calibration |
| Aisa OWL (hyperspectral) | FIN | Airborne | 7.7-12.13 | 100 | Gases, Calibration |
| TASI (hyperspectral) | CA | Airborne | 8.0-11.5 | 32 | Gases, Calibration |
| P-iCATSI (spectropolarimeter) | CA | Ground | 7.5-13.5 | 35 | Aerosols |

A general plume dispersion model (GPDM) for a point source emission, based on a Gaussian plume dispersion equation, was developed in MATLAB. It considers five atmospheric stability conditions and two types of plume rise formulations.
To evaluate the detection capability at different concentrations, we used the LACHI (USA). The LACHI is an operational hyperspectral imager with very high spectral resolution in the LWIR (see picture on the next page). It scans the area in its field of view from a vehicle from 2 m high. Because of the low altitude scanning, there is no atmospheric effect and the only relevant parameters are the spectral resolution and the noise.

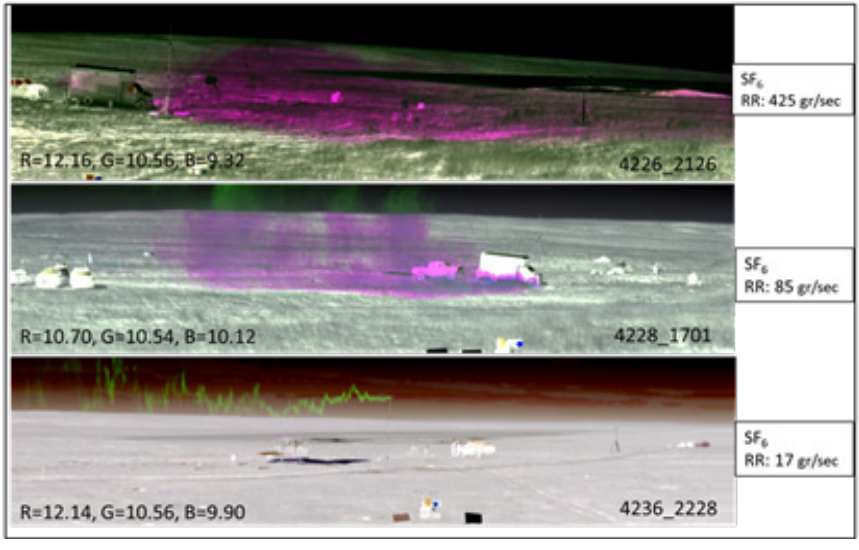
During the PRONGHORN campaign we located white cement, soil and grass surfaces with a size of 5-by-5 m over a flat and homogenous background. The width of each surface was 3 cm to limit the emittance from the background. Spills of methyl silicone (SF96) and methyl salicylate (MS) were spread during 5 days, raising the concentration over the surfaces from 0 to 16 ppm. Airborne and ground hyperspectral imagers scanned the surfaces at different day times. In-situ spill temperatures were regularly collected from each surface using a ground thermometer.

To demonstrate the advantages of spectropolarimetry in the detection of chemicals, we released two gasses to the atmosphere that share spectral absorption features during the campaign. Specifically, we released at the same time 85 g/sec of sulphur hexafluoride (SF6) and 85 g/sec of ethylene. In the spectra it can be observed that the two chemicals share their main absorption feature in 10.51 μm. However, ethylene has a secondary absorption at 10.0 μm that may serve to distinguish spectrally the two chemicals. It should be noted that at low concentration of gasses in the atmosphere (i.e. far from the release point), the signal from the gasses is reduced as well as the radiance in the various wavelengths.

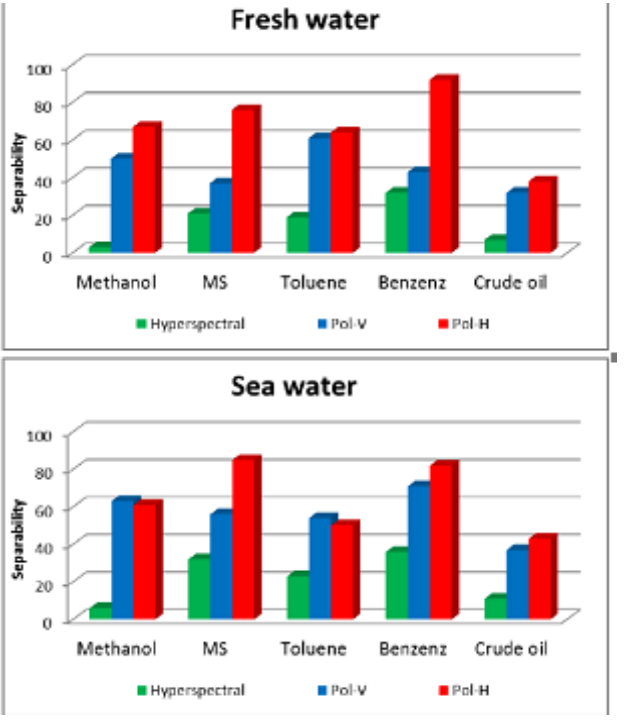
LACHI installation

| LACHI LWIR HSI | |
|---|---|
| Spectral resolution | 20 nm |
| Spectral band | 8.12-13.12 μm (251 bands) |
| FOV | 12 deg Vertical x 48 deg Horizontal (260 x 1024) |
| IFOV | 0.8 mrad |
| NESR | 0.5 – 1.0 μflicks depending on band |

LACHI main characteristics



During the PRONGHORN campaign, we also released 240 g/sec of dimethyl sulphoxide (DMSO) and we scanned the plume from 25 ft using the P-iCATSI.
in order to demonstrate the capacity of the spectropolarimeter to detect pollutants in water, we filled six pools with 11,624 gallons of sea water (SW) and fresh water (FW), respectively. Everyday we increased the pollutants concentrations of five chemicals (methanol, methyl salicylate (MS), toluene, benzene and crude oil) in each type of pool, respectively, and we left two pools without chemicals for thermal and spectral calibrations. Each chemical has a different texture, molecular mass and colour. On the day of the spectropolarimetric scanning, these ten pools contained 6.34 gallons of chemical (about 0.05% of the volume of each pool).
The picture below shows the results of the spectropolarimetric scanning. From the spectral measurements of the calibrated pools we established that sea water has a higher radiance in POL-H than in POL-V. Fresh water has as many spectral absorption features in POL-H as in POL-V.



# Conclusions

From the results of this study one may conclude the following:

- Detection of chemicals at the atmosphere requires a thermal hyperspectral imager with a very high SNR, and a high spectral and spatial resolution. This is mainly the case when the concentration is low and the detection is required at large distances (i.e. ~ 50 m) from the source;
- Detection of chemical spills from the surface is mainly dependent on the difference of their temperature and their texture rather than their spectrum;
- This study found that spectralpolarimetry offers important complementary information for the detection of hazmat/chemical warfare agents against any background environment;
- Horizontal polarisation has a higher detection capacity of pollutants in the atmosphere, in water or as a spill;
- Scanning from nadir was found to offer the best scanning view for the spectropolarimeter for the detection of chemical spills.


Study Director:
Major M. Vandewal
Researcher:
E. Christofani

# Affordable tera-hertz systems for CBRNE and structural health monitoring applications

# Background

Despite all the theoretical discussions and assessment of prospective applications, there are still no clear hardware advances towards implementing a real compressed sensing (CS) sensor in any field, or at least not publicly announced. This suggests that research groups are still exploring all possible options and testing methods to soundly affirm that CS is worth the paradigm change and the huge economic impact for conventional sensors companies, which will have to be convinced eventually. CS would imply to them high initial development costs in prototyping CS sensors which should be available at significantly reduced prices during their commercialisation stage.

# Objectives

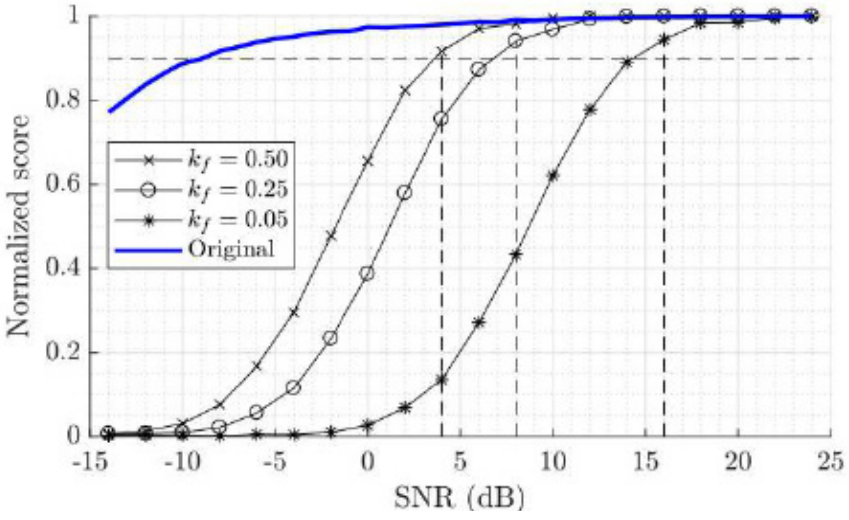
During the definition phase of this project some questions were still unanswered by the available state of the art or, to say the least, at their infancy stage. Already in the execution stage of this project, those questions have been answered whether it was by fellow colleagues in the same field or by discoveries made within the project, which have been documented in the form of deliverables and scientific publications.
The recurring questions when treating compressed sensing CS as a tool for existing applications were:

1. assessing the compressibility of a signal, or how sparse a signal can be for an accurate reconstruction using CS;
2. finding the minimum amount of samples that must be selected for an adequate reconstruction in order to minimise hardware complexity;
3. increasing a signal's sparsity by applying data transformation;
4. assessing the CS reconstructions compared to conventional THz techniques;
5. testing CS reconstruction algorithms and considerations on an actual CS sensor.

CS techiques have been examined in 3 areas: Non-Destructive Testing (NDT), Ground Penetrating Radar (GPR) and Through Wall Imaging (TWI).

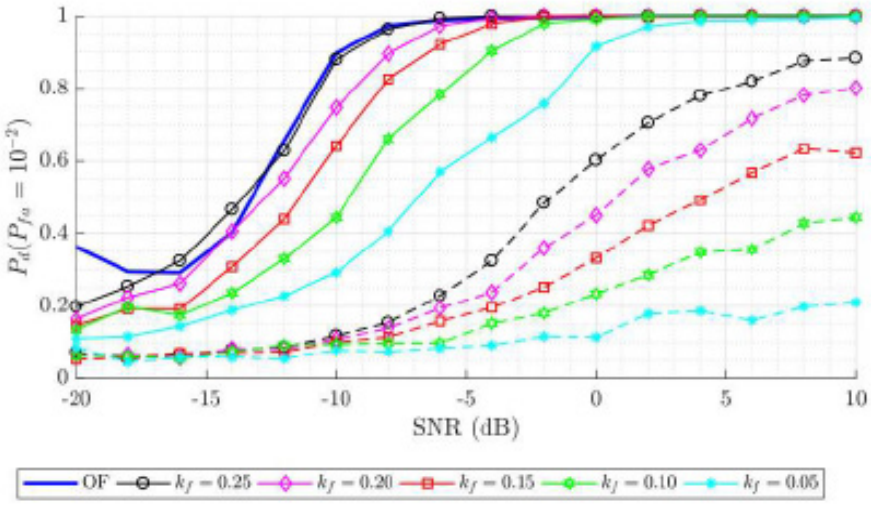
# Outcome

**a. Non-Destructive Testing (NDT) results**




The combination of NDT and CS – with the OMP algorithm as main choice – gives overall promising results for media interface reconstruction. Conservative (50% of the original data) and moderate (25%) subsampling rates can be safely applied in most situations, whereas extreme subsampling rates (just 5%) are exploitable in relatively noise free measurements and for reconstruction scores above 90% but never reaching 100%, or perfect reconstructions.
Signal reconstruction using an IFFT preconditioner yields the best reconstruction results.

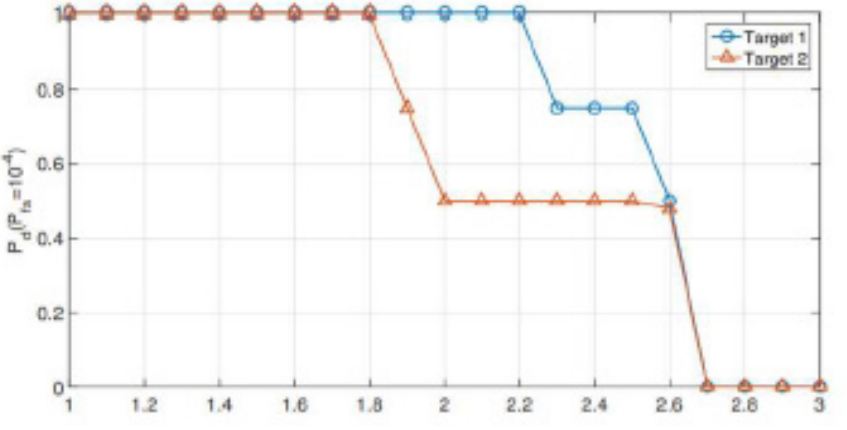
**b. Ground Penetrating Radar (GPR) results**




Given the nature of GPR measurements, it is common to find small targets buried superficially. Such targets can be masked by the strong first return from the air-soil interface. GPR imagery in that case becomes unexploitable unless a model is incorporated to the imagery as it is presented in this work. The model must account for the air-soil interface as well as the internal antenna reverberations. Only then can GPR imagery be fully exploitable regardless of the location of the target.

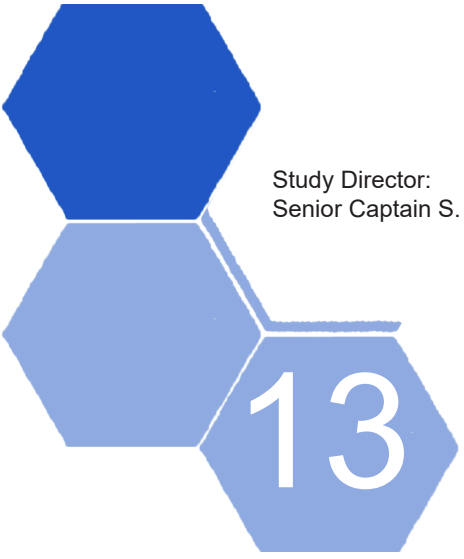
### c. Through Wall Imaging (TWI) results

Sequential CS leverages the problem of determining the number of samples needed to reconstruct a radar image with unknown sparsity and enables an automatic decision on the number of samples based on the operator's choice of reconstruction quality. This makes possible a new way of sensing.
The sequential CS approach was implemented online, reconstructing range profiles while the TWI sensor was moving along the wall and meanwhile expanding his prior knowledge with the profiles obtained from previous scanning positions. The proposed solution enables a severe subsampling and autonomously adapts the sampling rate along the scanning path in order to achieve a desired reconstruction quality.




Probability of detection, for a probability of false alarm equal to 10-4, of human target 1 (blue curve) and human target 2 (red curve)

In general, it has been found that current research trends seem to be aligned with finding methods to further improve performances such as increasing data sparsity, or applying sensor fusion, rather than focusing on how to adapt existing applications. Given the findings discussed in this project and those extracted from the literature, it can be assumed that most applications are good candidates to exploit CS as a tool since most signals show a certain degree of sparsity. However, it is required to test whether low sparsity levels yield exploitable performances, as it was done throughout this project. It is recommended to perform this type of analysis on a per-application basis.




Study Director:
Senior Captain S. Lo Bue

# Improving military selection: psychological resilience screening

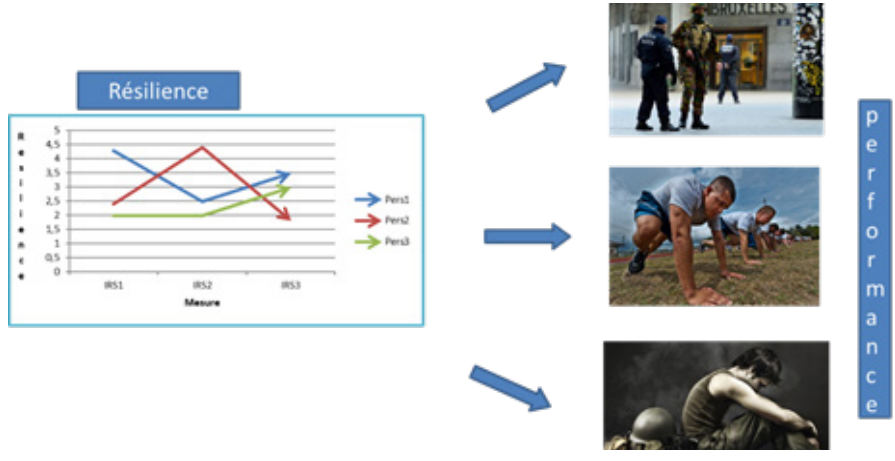
# Background

Military members deployed abroad are confronted with physical and mental challenges that require resilience. Resilience is the capacity of military members to (1) maintain an optimal level of performance during stressful situations, critical incidents and adversity, (2) recover positively after those events in the short and in the long term as well, and (3) preserve their professional engagement towards the armed forces and their motivation regarding their occupational objectives. Therefore, it is important for the armed forces to screen and monitor the resilience level of operational personnel, as soon as at the moment of the recruitment, during the initial training and during the whole career.

# Objectives

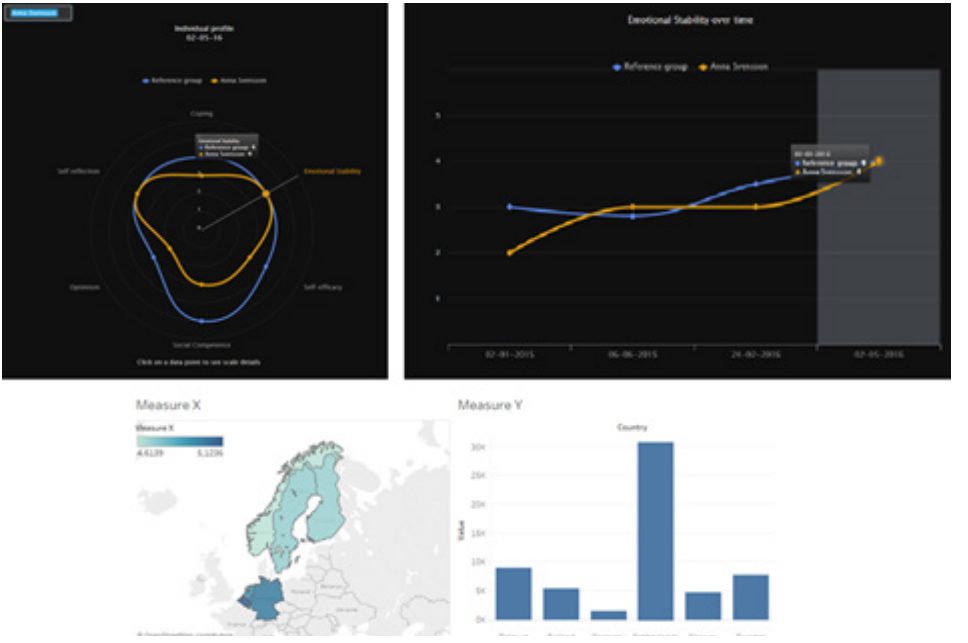
The EDA project on "Improving Military Selection: Psychological Resilience Screening (INSPIRE)" aimed at developing an instrument to screen and monitor resilience among military members for selection purposes and monitor resilience during the whole career. The study RSDT/WTOD HFM 14-10 fitted in that European project.

# Outcome

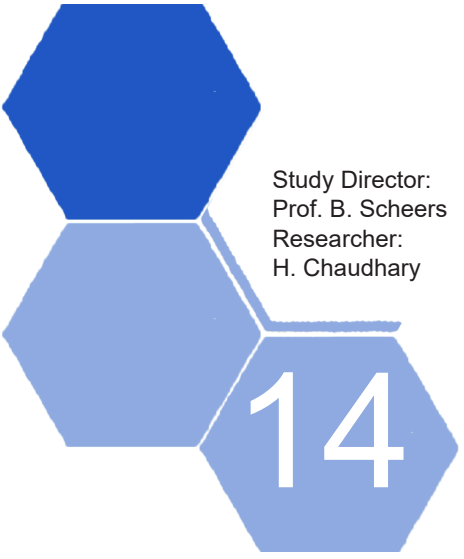



Picture 1: Results showed different profiles of resilience during the first phases of the military career. IRS 1 = selection; IRS 2 : Basic Training Phase; IRS 3 = Specialised Military Training.

The outcome of the study is an instrument (a questionnaire) measuring resilience of military personnel, called the Inspire Resilience Scale 2.0 (IRS 2.0.). In this study, we showed that the scores on the IRS 2.0. were related wellbeing and performance of military members (infantry and paratroopers) during the initial (basic and specialised) training. This instrument can also be used to monitor resilience during the whole career of military personnel.




Picture 2: The EDA project resulted in the development of a dashboard allowing to compare an individual to a reference group (left above), to follow the evolution of an individual during his/her career (right above), or to make geographical comparisons (under). The latter could be particularly useful to compare the mental burden on different deployment theaters.




Study Director:
Prof. B. Scheers
Researcher:
H. Chaudhary

# Adaptive distributed TDMA-based MAC for tactical mobile ad hoc networks

# Background

A mobile ad hoc network is a network created by spatially distributed mobile devices on demand as the need arises to accomplish an assigned mission with a little or no support infrastructure. Such networks are useful for ad hoc mission-critical applications, both for military and emergency response services. Medium access control (MAC) protocol design is one of the important components of such networks. In wireless networks two or more simultaneous transmissions in the same channel may not be successful if their intended receivers are in the radio interference range of more than one transmission. Thus, for efficient channel use, a mechanism to control access to the shared wireless channel is crucial. For mission-critical networks, time division multiple access (TDMA) based MAC is a good candidate for channel access scheduling.

# Objectives

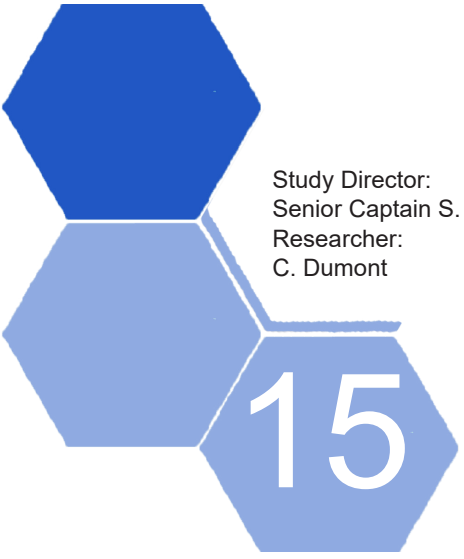
The aim of this project is to study and evaluate TDMA-based MAC design techniques suitable for tactical mobile ad hoc networks. Concretely, we will:

- do a comparative analysis of the state of the art,
- develop distributed time-slot assignment methods, and methods for time synchronisation to have a fully functional TDMA-based MAC, and
- evaluate their performance by simulations and by implementing on a hardware test bench.
-

As a part of the outcome of the project, we have proposed methods for slot assignment and time synchronisation. We implemented these methods in the firmware of a development board. Using these boards, we established a testbed in our lab, and verified performance of different aspects of the proposed schemes. We showed that the nodes can synchronise time, assign time-slot in a distributed way, and adapt their assignment dynamically with time as the network topology changes, due to nodes joining and leaving the network, as well as changing wireless channel conditions. The performance validation tests were focused on static and semi-static scenarios. Tests with different levels of mobility are left for future researches.

# Outcome

In this project we studied adaptive distributed TDMA medium access control scheme. We implemented the proposed schemes, for time synchronisation as well as slot and frame length assignment, in firmware of a development board using C/C++ programming language. Using these boards, we established a testbed in our lab, and verified performance of different aspects of the proposed schemes. We showed that the nodes can synchronise time, assign slot and frame-length in a distributed way, and adapt their assignment dynamically with time as the network topology changes due to joining and leaving the nodes, as well as wireless channel conditions. The performance validation tests were focused on static and semi-static scenarios. Tests with different levels of mobility are left for future researches.




Study Director:
Senior Captain S. Verberckmoes, MSc Eng
Researcher:
C. Dumont

# Development of multiplex bead-based assays for rapid detection and identification of pathogens involved in orthopedic infections

# Background

Culture is currently used to identify pathogens involved in orthopedic infections and is considered as the gold standard. Yet cultures have limited sensitivity and frequently do not provide a result due to difficult growth of some challenging bacteria or in case of a prior antibiotic therapy. Moreover, this approach is time consuming, sensitive to environmental contamination and is contributory in only 40-50% of proven infections. Clinician must frequently deal with negative culture caused by (a) the nature of the pathogen (the culture of some bacteria and most of the fungi is challenging), (b) the use and sometimes misuse of antibiotics prior to the sampling, or (c) the biofilm development complicating or preventing any microbiological identification. Broad range amplification targeting 16S ribosomal RNA (16S rRNA) has proven to be an alternative to culture for clinical samples however is not widely used due to some design and experimental challenges.

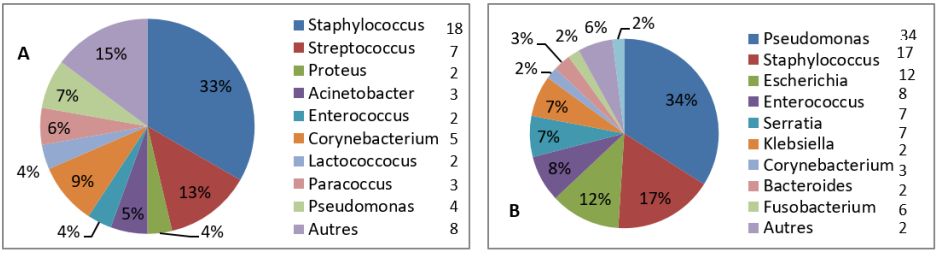
# Objectives

To circumvent these drawbacks, this study focused on the development of a culture-independent, rapid, reliable and operational protocol for the identification of the most relevant pathogens involved in orthopedic infections. This assay is an in-house developed multiplex qPCR assay targeting 9 specific bacteria combined with a 16S rRNA-based broad range qPCR assay. The multiplex qPCR assays' targets are either species-specific or genera-specific genes aiming at the detection of anaerobic or difficult-to-grow bacteria involved in orthopedic and/or nosocomial infection. All along the project, clinical samples from burned patients (High and Medium Care from MHQA) and orthopedic patients (from Cliniques Universitaires Saint-Luc, Woluwe-Saint-Lambert) were collected to validate the developed tool.

# Outcome

Throughout this project, 147 orthopedic samples and 84 burn patient samples were analysed with specific and/or 16S rRNA qPCR assay.

Regarding the orthopedic samples, 57 were found positive by PCR and in 52 cases we were able to identify the genera of the bacteria involved by amplicon sequencing (Picture 1A). For the burned patients, 74 out of the 84 samples were found positive but for approximately 20% of the samples, the identification was compromised by the presence of background noise (Picture 1B). More interestingly, in about 30% of the burned cases a co-infection (presence of 2 or more pathogens) was revealed. This occurrence was notably higher than the 1,3% detected in orthopedic samples. The "burned samples" were also tested with the multiplex specific qPCR assays and 5 samples came out positive for either one or two of the targets. Importantly, those pathogens were not previously identified with the 16S rRNA assay demonstrating the need to use both strategies (i.e. specific and 16S rRNA-based broad range qPCR assays) in parallel in order to obtain clinically relevant data.




Picture 1:
A. Identification results for orthopedic samples by 16S rRNA qPCR assay.
B. Identification results for burn patient samples by 16S rRNA qPCR and multiplex assays.

Study Director:
Prof. M. Pirlot

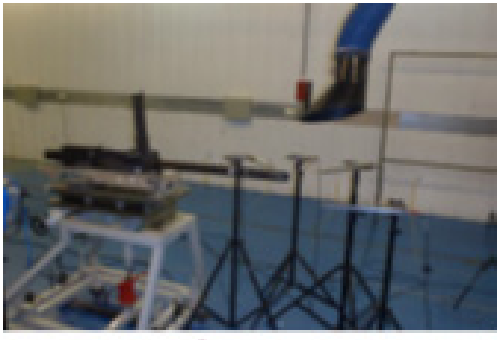
16

# Improvement of the flame shield

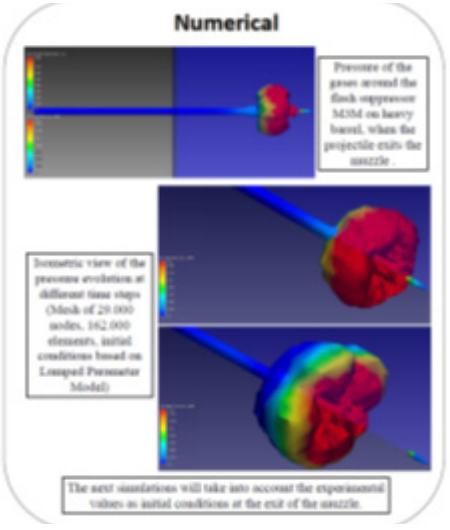
# Background

Anti-material weapons and ammunition are evolving towards longer range, better penetration or higher precision. Along with these positive effects, negative ones, such as high recoil or high pressure shockwaves, are coming.
S-POD project had as its main goal the deviation and reduction of the shockwaves generated by a M3 machine gun upon ejection of the projectiles.
Because these types of weapons are usually mounted on a vehicle, in our case on a helicopter, the shockwaves generated by the machine gun are inducing vibrations into the electronic equipment found on board causing malfunctions. Due to their placement, with the muzzle ending aside of the cockpit at 60cm from the pilot, the shockwaves generated by the weapon have a negative influence on the pilot's health, too.
In order to avoid these two negative aspects, the research of the propagation of these shockwaves was needed, to assess guidelines in designing future blast deflectors.

# Objectives




As mentioned before the project has as its main objective the study of the shockwave propagation.
To achieve this goal, firstly, a characterisation of the blast field produced by existing muzzle accessories for the M3 machine gun was performed by measuring the shockwave pressure at different distances from the muzzle (30cm, 60cm, 90cm and 120cm) and orientations (0deg – direction of shooting, 45deg, 90deg – perpendicular on the shooting axis, and 135deg) using blast pencils.




Then a methodology for CFD (Computational Fluid Dynamics) simulations, optimising the input parameters so that the simulation results fit the experimental ones.

The third step was to use numerical simulations, using the developed methodology to determine the acoustic signature and the orientation of the muzzle flow for the prototypes of the muzzle accessories.

# Outcome

In this study, we showed that using a single baffle deflector is more appropriate to reduce the blast, but also other types of blast deflectors can be investigated, based on the principles presented previously, that are coming from the automotive sector.

Adding baffles and dumping the recoil for the M3 machine gun is not a disadvantage. Taking in consideration the functioning principle of the weapon, damping the recoil is an added value because the system will induce less vibrations to the chassis of the vehicle.

From the numerical point of view, there are many simulations to perform in order to obtain the most appropriate setup for the cases (mesh, boundary conditions, and physics).

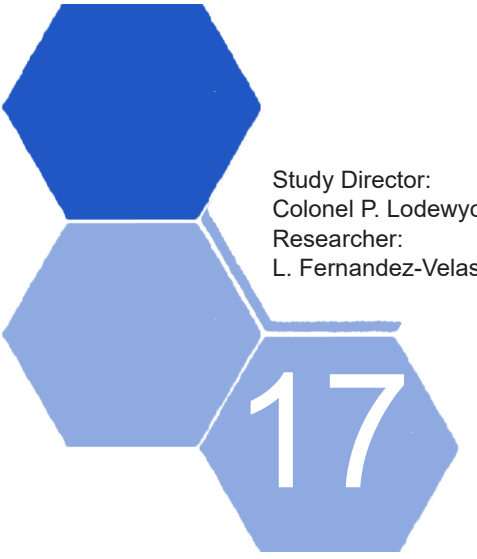
Regarding the simulations, the 2D axisymmetric approach is less favorable than the 3D periodic. The drawback of the 2D axisymmetric simulations is that the tendencies of the pressure evolution is completely different from the measurement tendency. On the other hand, the 3D periodic simulation has approximately the same tendency as the measurements, with the specification that the values are higher for the reasons exposed in the previous paragraph.

In order to state that the 3D periodic simulations provide better results than the 2D axisymmetric, more testing is required.

As iterated before, the best way to avoid the interference between the shockwave and the cockpit of the vehicle is to divert the flow towards back, and the use of baffled accessories is preferable.

The presented results can be improved if the flow due to the movement of the vehicle is considered.

This report has showed that the geometry suggested by FN is suitable to use, due to its capability to divert the flow towards back, where it cannot have a great influence on vehicle's structure.




Study Director:
Colonel P. Lodewyckx
Researcher:
L. Fernandez-Velasco

# Development of modified carbon materials for absorption of toxic gases

# Background

The JRC, the Kazakh organisation that is part of the Ministry of Education and Research (comparable to FWO/FNRS in Belgium), has granted the Kazakh Institute of Combustion Problems (ICP) this 3-year research project, with the RMA as an international partner. The ICP is a research institute, linked to the Al-Farabi National University in Almaty, the leading Kazakh university in the field of engineering.

# Objectives

The objective of this research project was the development of activated carbons from low cost local precursors. These carbons should be suited for gas phase adsorption, more specifically for use in the filters of gas masks. Both the upcoming industry and the international political situation (with Kazakhstan supporting the fight against terrorism) urge this country to develop adequate respiratory protection, in sufficient quantities, at low cost and independent from foreign suppliers.

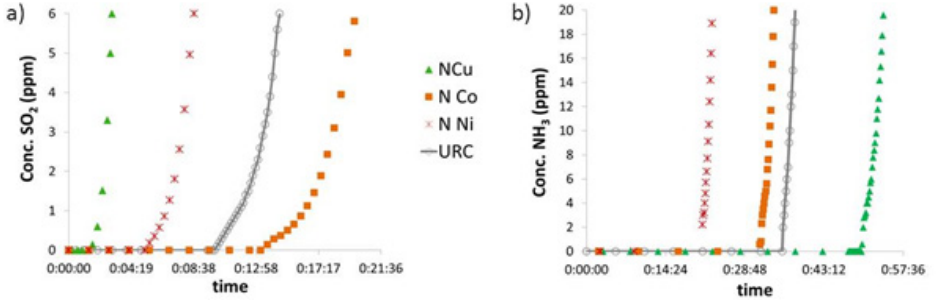
A secondary objective was the education and training of young Kazakh scientists. The history of the education system (based on the Soviet one) and the geographical and (partly) political isolation of Kazakhstan have, in the past, led to an emphasis on theoretical, rather than applied, studies. Although this accounts for students with a thorough scientific background, most of them severely lack laboratory practise. This is certainly the case when working with sophisticated, highly specialised equipment such as the different apparatus used in the characterisation of the porosity and surface status of activated carbons.

# Outcome

During the project, a total of 4 young Kazakh Master and PhD students spent an internship in the laboratories of the Department of Chemistry. One of them (Almagul Kerimkulova) returned to lead the laboratory of carbon nanomaterials at the ICP.

A whole array of carbons, with different porosity, surface features and metal impregnations were produced by the ICP. They were characterised by the RMA, and the most promising ones were tested in our filter test rig situated in the Defence Laboratories (DLD) in Peutie. Some of these carbons were very promising, as they showed better gas retention than a URC carbon, one of the best standard commercial carbons available. This is illustrated in Picture 1.

These preliminary results were presented at the International Carbon Conference held in Melbourne in 2017 and at the X International Symposium on The Physics and Chemistry of Carbon and Nanoenergetic Materials in Almaty in 2018. However, further research, and especially optimisation, is still required. Also, the reproducibility of the manufacturing process should be improved.




Picture 1
a) SO2 and
b) NH3 breakthrough curves obtained with the metal-impregnated carbons.

As the JRC grant ended in December 2017, both partners (ICP and RMA) looked for other (financial) means to continue this fruitful cooperation. A NATO Partnership for Science for Peace and Security Programme project proposal has been submitted to the NATO S&T board, waiting for approval.

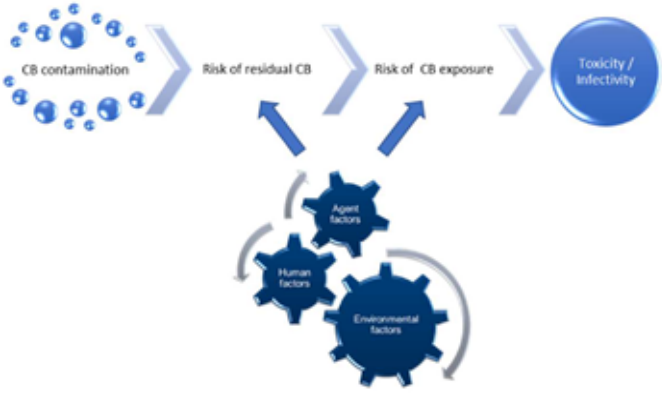
Study Director:
Med Colonel J.-L. Gala
Researcher:
M. Bentahir

18

# Risk assessment for CB exposure after decontamination

# Background

This project addressed the risk associated with exposure to residual hazards after decontamination following biological or chemical incidents. Currently fielded detection technologies are not sensitive enough to verify minimal residual agent, completely mitigating health hazards. RACED aimed to develop a risk assessment approach by integrating results of decontamination efficacy and possible exposure as a function of operational conditions, e.g. weather conditions, materials agents and decontaminants (Picture 1). In this way, decontamination efficiency and subsequent exposure can be estimated and compared to internationally or nationally safe exposure limits for chemical and biological agents, to apply for minimising the risk of exposure to CB residuals. Whilst based on a limited number of agents under a limited number of test conditions, the results from the RACED project show that, with further work, modelling of residual risk post decontamination may be possible. Still, a number of gaps exist that require attention before the model could be applied and validated for a wider range of experimental or operational conditions.




Picture 1: In order to make estimations about the risks of possible toxic effects the RACED project aimed to develop tools to make estimations of decontamination efficiency (risk of residual CB) and residual agent transfer (contact/inhalation) to persons (risk of CB exposure). Both are influenced by operational conditions (agent factors, materials, weather conditions, est).

# Objectives

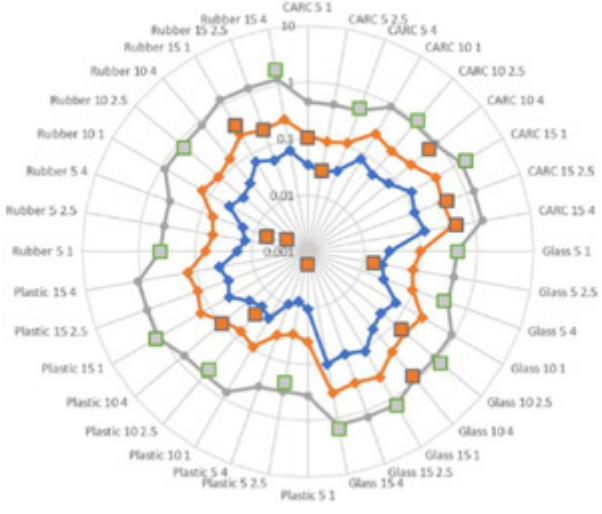
The RACED project aimed at developing a methodology for risk assessment for both chemical and biological residual contamination (after decontamination). To this end, for the chemical side, a mathematical model to estimate C-decontamination efficacy and subsequent possible exposure depending on operational circumstances was developed based on laboratory results. Assessment of inhalation risk was accomplished by using the well-known ALOHA package. For B-decontamination, residual levels of various organisms from multiple surfaces were determined experimentally and compared to pathogenicity data (ID, LD) to assess the risk of exposure by inhalation. A field test for biological decontamination revealed that outdoor weather conditions affected translation of lab results to operation. For example, sunlight led to rapid evaporation of decontaminant and wind affects efficient coverage of the subject. Several risk management strategies were suggested, and examples for B-agent as well as C-agent risk evaluations were discussed.

The models developed are based on a number of selected decontaminants and agents, as well as parameters such as temperature, materials, timing options, severity of contamination, providing estimates of efficiency and risk. Guaranteeing that all critical parameters are tested is virtually impossible. Yet, in our opinion the outcome of this project should be an encouragement to further develop reliable tools that can support the assessment of residual CB contamination in the field/ on site.

# Outcome

1. Efficiency of decontaminants was evaluated for a number of materials, agents, and operational conditions.
2. Descriptive models based on (1) using a Design of Experiments approach (a statistical approach of experimental design, leading to descriptive models within the boundaries of the test parameters). The resulting model not only clearly displayed trends of decontamination efficacy as a function of single operational parameter values, but also revealed parameter interdependencies. Moreover, the model can be used as a MatLab routine to predict decontamination efficiencies for a given set of parameter values (e.g. material x agent).


Pictures of an indoor exercise of biological decontamination, used to validate the RACED results.




Example of presentation of experimental as well as modeled data of decontamination efficiency of three decontaminants (blue, orange & green) for various parameters (material, temperature, initial contamination level).

3. A small and hand-held detecting device was developed and tested for response and sensitivity to residual C-agents. Although agent detection was successful, the limit of detection was too high.
4. Evaporation rates of residual amounts of volatile agents were measured under various circumstances. Again, a Matlab model predicting evaporation rates as a result of parameter values was developed.
5. A method employing radioactively labelled agents proved an efficient way to measure contact transfer of agents from various surfaces to skin, using pig ears as human surrogate skin under a variety of circumstances.
6. A Matlab model developed from the results (4) revealed parameters affecting efficiency of contact transfer.
7. The Matlab models described could be coupled by using residual agent amount as input for the exposure model.
8. A small detection device was developed that successfully detected volatile chemical agents.
9. A summary of internationally published exposure values was provided, which can be helpful in the comparison between predicted exposure and health guidelines.
10. A toolbox to isolate and measure residual amounts of biological agents (spores, bacteria, viruses) was devised.
11. The toolbox was used to map the influence of decontamination parameters on the efficiency of decontamination of biological agents from various surfaces.
12. Contact transfer to skin and gloves (agent spreading) of biological agents was assessed on various parameters.
13. The risk for reaerosolisation of biological particles from surfaces was measured.
14. The RACED results used in suggested risk management approaches proved the illustrated examples to be valuable.
15. Results of the RACED project for biological contamination were validated in an in- and outside scenario. Inside, results showed predictive, whereas outside they were not, revealing some remaining gaps of this approach.
16. A well-attended symposium was organised in Portugal for dissemination of the RACED results and gathering of feedback to the RACED approach & results.


Study Director:
Prof. X. Neyt
Researchers:
Prof. X. Neyt, V. Kubica, F. Bettens *

# ESA BelSAR Campaign

* **Funding:** European Space Agency and Belspo (Stereo programme)

# Background

Airborne/spaceborne radar imaging offers the major advantage to be able to provide images of the ground regardless of the cloud cover. It is thus the ideal tool for monitoring purposes. The vast majority of the radar imaging instruments are monostatic, which means that the transmit antenna is collocated – or indeed the same – as the receive antenna. The possibility however exists to operate another receiver not collocated with the transmitter; such a configuration is called bistatic. Besides the tactical aspects (the receiver is inherently stealth), there are indications that such bistatic configuration may also provide additional benefits in terms of imagery data.

While there is some limited sample data available at C-band and X-band, there is very little if any data available at L-band. Moreover, the available data is often limited to a few acquisition and does not provide time series long enough for a meaningful exploitation.

# Objectives

The BelSAR project intends to carry out an airborne campaign for SAR bistatic interferometric measurements at L-band and full polarisation, over a test site in Belgium.

The idea is to operate a flight campaign that fits as much as possible with the defunct SAOCOM/SAOCOM-CS configuration, providing the opportunity to the science community to validate the capability of active-passive satellite configuration and to validate the performances of L-band SAR bistatic imagery.

The intention is thus to assess the potential of SAR bistatic acquisitions in the particular domains of vegetation monitoring, soil moisture and change detection, by the collection, over a selected test site in Belgium, of L band full-polarimetric interferometric airborne SAR data that will be associated with simultaneous field measurements.

The acquisition schedule was driven by the applications: the campaign had to take place during the vegetation growth period, i.e. from May until September.

# Outcome

The airborne campaign was conducted over the summer of 2018 over the so-called “Hesbania” test site, located between Gembloux and Tongeren, which is one of the 3 BELAIR Belgian supersites. While the data was quality-controlled and is available, its detailed exploitation is still on-going, as part of the associated Belsar-Science project. The bistatic configurations involved successively an along-track baseline and an across-track baseline.
The campaign has already shown that some clock-synchronisation issues can be detected – and corrected – from the radar images.


Study Director:
Prof. X. Neyt *
Researcher:
M. Stasolla *

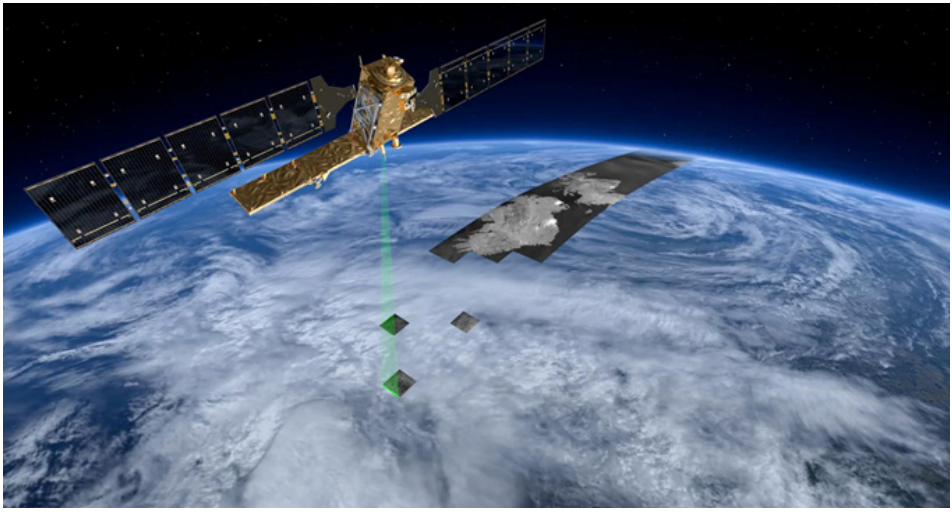
# The development of the Walloon know-how value chain for the enhancement of earth observation services in COPERNICUS and the dynamic monitoring of territories at the regional level

* **Funding:** Walloon Region (Plan Marshall 4.0) and Belspo (Stereo programme)

# Background

In the framework of the Copernicus Earth Observation programme headed by the European Commission in partnership with the European Space Agency, several Earth observation satellites were developed, launched and are operational. The Sentinel-1 and Sentinel-2 constellations of satellites are of particular interest thanks to two features: freely available data and a very high revisit time. The Sentinel-1 constellation consists of 2 radar imaging satellites with a combined revisit time of 6 days, while the Sentinel-2 constellation consists of 2 optical imaging satellites with a revisit time of 5 days, both with a spatial resolution of about 10m.

However, although the data itself is freely accessible, there remain technical and methodological barriers to fully exploit the commercial potential of these data. The technical barriers are related to the infrastructure required to process the data which, given the very high data volume, can be impressive. The methodological barriers are related, on the one hand, to the practical implementation of algorithms developed for instance by universities and, on the other hand, to the related business flow from the service-provider to the end-user, i.e. the “last mile”.



# Objectives

The EO Regions! project, headed by Spacebel in partnership with NRB, I-Mage, the University of Liège and the Royal Military Academy, aims at proposing a market place dedicated to the dissemination and commercialisation of Earth observation services.
Doing so, EO Regions! also aims at providing an environment that eases the economic valorisation of EO-related research projects and know-how. By providing a link, at technical level, in a way similar to collaborative ground segments, but also at business level, linking all actors such as the algorithm providers (universities, etc.), the operators (making sure the service is running), the integrators and the end-user, EO Regions! also aims at favoring the emergence of start-ups in the numerical economy.

# Outcome

The market place was set-up with some initial services through two demonstration frameworks, one in the Walloon Region and the other in Senegal. In that framework, RMA contributed change detection algorithms mostly applied to radar imagery. These change detection algorithms were, in collaboration with ULg (University of Liège), validated over sugarcane and can be used to assess sowing and harvesting times. These algorithms are being extended to other relevant crop such as rice and sorghum.
This project lead to a related project aiming at monitoring re-development sites, where a regular assessment of the activities on a priori abandoned sites is conducted based on Sentinel-1 and Sentinel 2 satellite imagery, thus saving the effort to conduct that assessment through on-site visits.


Study Director:
Prof. X. Neyt
Researchers:
Prof. X. Neyt, M. Vandewal, V. Kubica *

# *Radar multivoie de mesure du trafic routier*

* **Funding:** Innoviris

# Background

The Macq company develops road traffic management systems. These systems require a sensing element, currently mostly based on cameras. These cameras have limitations, for instance in inclement weather, unfavorable illumination conditions (sun) of for observation at long range. Radars may provide a way to close these gaps. While there already exist some radars on the market with possibly suitable specifications, they all fail at meeting one of the requirements. In addition, existing radars may be difficult to integrate with a camera system, which is one of the main aspects of the project.

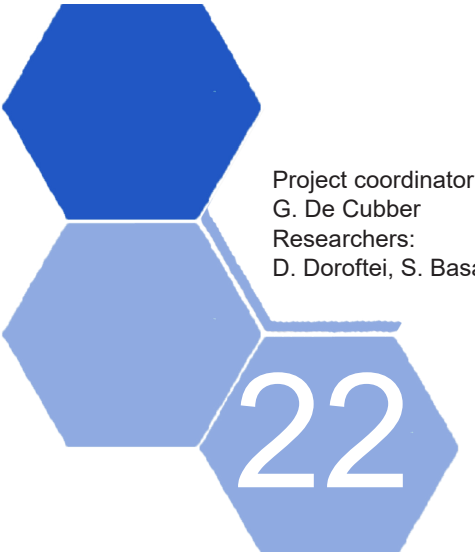
# Objectives

The aim of the project, headed by Macq in partnership with the Université libre de Bruxelles and the Royal Military Academy, is to develop a multi-beam radar together with the associated processing software. Having multiple beams make it possible to spatially (in azimuth) locate objects within the field of view of the radar, hence to manage multiple driving lanes.

# Outcome

The radar is based on the K-MD2 engineering sample, for which a dedicated processing was developed. The radar is currently being integrated with a camera head for further assessment.

Picture: One of the SafeShore detector prototypes installed on the beach in Belgium during the North Sea trials at the military base of Lombardsijde (https://tinyurl.com/y6yuul5k )




Project coordinator:
G. De Cubber
Researchers:
D. Doroftei, S. Basak, Colonel B. Scheers

# A system for the detection of threats in a maritime border environment

# Background

Recent years have seen the dramatic rise of the use of Unmanned Aerial Systems or drones by governments, consumers and – unfortunately – also by terrorists and criminals. Indeed, whereas there are a great number of very good applications for the use of drones, these new technological tools are also a threat in the hands of people with bad intentions. Terrorists and criminals are more and more using new technological tools for their activities. These include the use of unmanned aerial robotic vehicles or drones for operations such as illegal observation and surveillance, drugs trafficking, or even as attack vector. Currently, it is very difficult for law enforcement and border management authorities to deal with these new threats, as the Radar Cross Section of these drones is too small to be detected by regular radar systems, which is where the SafeShore solution comes in. Within the SafeShore project (http://safeshore.eu), twelve consortium partners from seven countries worked together, under the coordination of the Royal Military Academy, to develop an integrated system for the detection of threat agents in a maritime border environment.

# Objectives

The main objective of the SafeShore project is to cover existing gaps in coastal border surveillance, increasing internal security by preventing cross-border crime such as trafficking in human beings and smuggling of drugs. It is designed to be integrated with existing systems and create a continuous detection line along the border.

The SafeShore core solution for targets that are flying in low attitude is to use a 3D LIDAR that scans the sky and creates above the protected area a virtual dome shield. In order to improve the detection, SafeShore integrates the 3D LIDAR with passive acoustic sensors, passive radio detection and video analytics. The boats and humans on shore are detected by a 2D LIDAR integrated with video analytics. Those technologies can be considered as low cost and “green” technologies. It is expected that a combination of orthogonal technologies such as LIDAR, passive radio and acoustic and video analytics will become mandatory for future border control systems in environmentally sensitive areas.

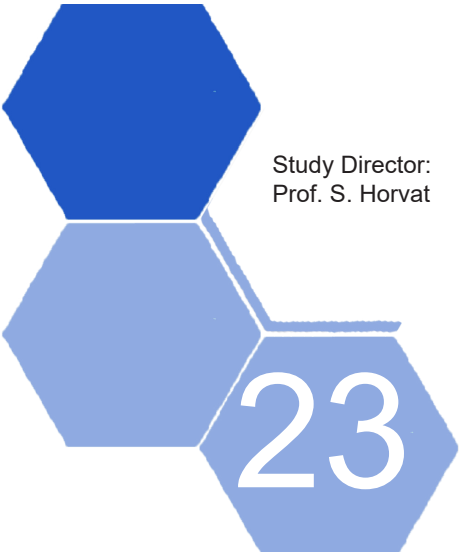
# Outcome

The SafeShore project developed three well-equipped, mobile detection platform prototypes. Each one of those platforms covers itself with a virtual detection shield, in a dome shape with a radius of about 250 to 300 meters. Overlapping the detection domes of multiple platforms creates a continuous virtual detection shield along the shore. Any attempt to penetrate this virtual shield leads to an intruder alarm in the main control room.

The SafeShore system has been put to the test in a series of trials on costs of Belgium, Israel and Romania. The results of these trials showed great potential for the developed technology and its further exploitation and commercialisation.

The foremost potential impact of the project is in improving the security level of the shorelines of the European continent. In the future, the SafeShore detection mechanism will be able to provide answers to the problems related to the economics of securing coastal borders. Indeed, protecting whole shorelines with expensive RADAR technology may not be economically viable. The project has developed potentially more affordable methods and mechanisms for securing maritime borders that are user-friendly for the operators and easy to maintain.

Beyond the scope of pure maritime border security, a second impact of the SafeShore project is that it provides a means to fill the gap still to be closed between regulation and law enforcement capacity. Indeed, everywhere in Europe, regulations are now put into place to give drones access to airspace and the police forces are requested to regulate this access to airspace. However, the police forces do not have the means to detect illegal activities. The SafeShore system could provide a solution by enabling the detection of illegal operations.




Study Director:
Prof. S. Horvat

# Belgian soldiers executed by firing squads in 1914-1918 – Procedural regularity before Belgian courts-martial

# Background

During the Great War eleven Belgian soldiers (some corporals) were shot after being condemned to death by courts-martial. Since then myths and reality about the functioning of Belgian field courts-martial during the war regularly emerge. In 2013, in prospect of the commemoration of the Great War, MPs and relatives of executed soldiers requested the rehabilitation of those soldiers and solemn apologies to these by the Belgian government. They alleged that breaches of the regular procedure had led to the judgments and that the soldiers had been shot "as an example". The government asked a scientific committee of historians to provide an expert opinion. Following this, the Royal Military Academy provided the abovementioned scientific committee with a detailed expert report.

# Objectives

The research by the Royal Military Academy aimed at analysing the legal and historic circumstances of the offenses committed by the said soldiers, as well as the regularity of the procedural conduct by the military and judicial authorities and the legal basis of the sentences.

# Outcome

The research resulted in a detailed and comprehensive report, showing the discrepancy between long-lasting myths (i.e. the alleged breaches of procedure, the alleged innocence of the shot soldiers, the alleged shootings "as examples") and reality. If occasional errors occurred during some procedures as a result of lacking detailed war legislation or earlier jurisprudence, in only two cases was the underlying cause of the prosecution disputable – even if legally correct –, in two other cases it is not excluded nor proven that some of the offences resulted from emotional distress. However, there was neither a "policy" of groundless convicting and condemning soldiers nor a "will" of shooting personnel "as an example". Strict prosecution and severe judgments were the result of severe wartime regulation.

# SCIENTIFIC RESEARCH
## IN THE BELGIAN DEFENCE FORCES
# Report 2018


Royal Higher Institute for Defence
Department Scientific and Technological Research of Defence

Responsible editor: Director-general Filip BORREMANS (MSc Eng), Air Force Colonel GS