Federal Ministry
of Defence

Military Scientific Research Annual Report 2016

Defence Research for the German Armed Forces

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Defence Research for the German Armed Forces

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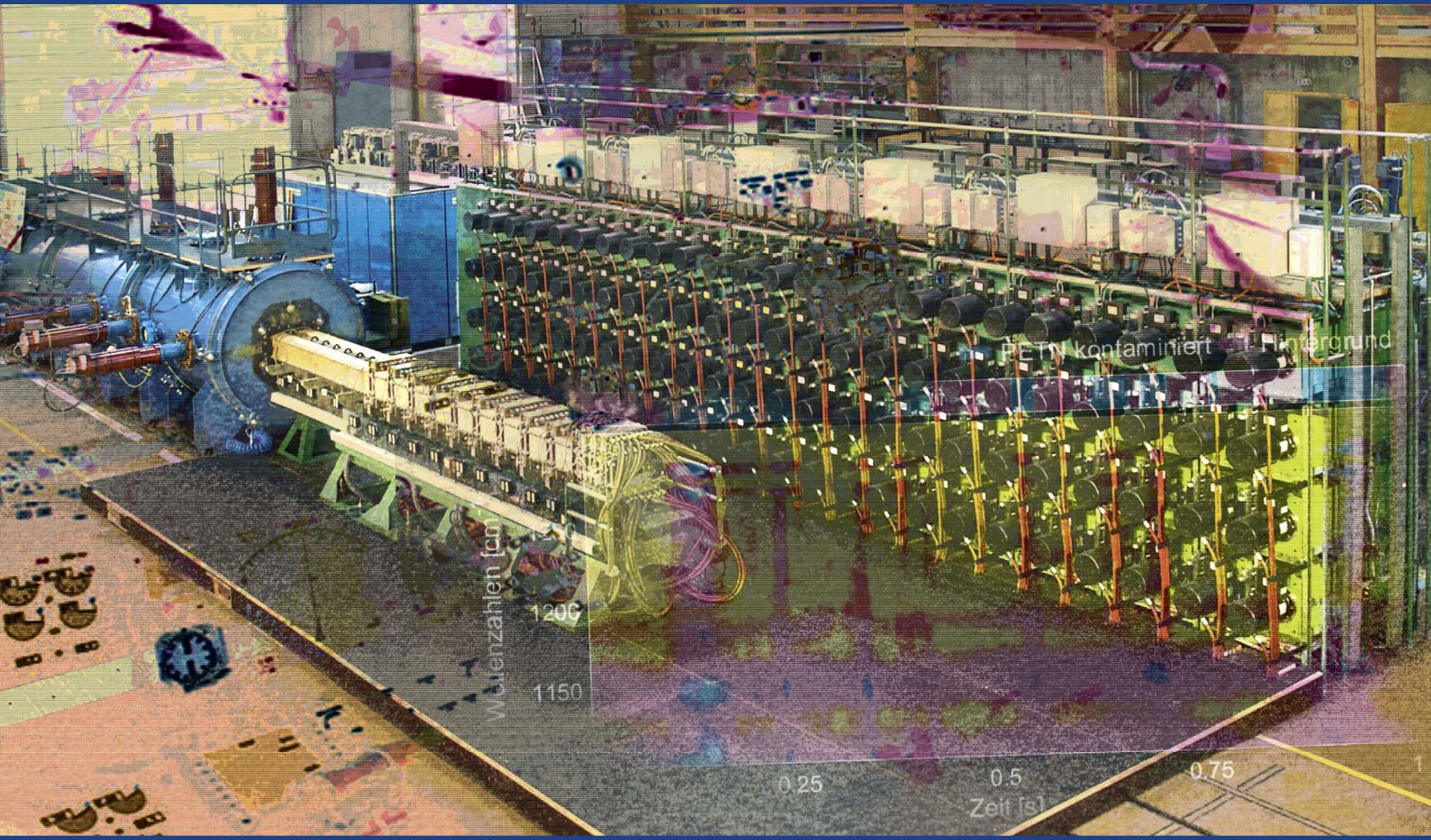
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Ministerialdirigent Ralf Schnurr

Unterabteilungsleiter A II und Forschungsbeauftragter
Bundesministerium der Verteidigung

Military Scientific Research

With Germany steadily taking on more and more responsibility internationally, the Bundeswehr has evolved over the past two decades into an army on operations.

In mid-2016 the Federal Government adopted the White Paper on German Security Policy and the Future of the Bundeswehr and, by doing so, again accorded a greater role to national and collective defence.

The Bundeswehr documents entitled “Bundeswehr Concept“ (Konzeption der Bundeswehr, KdB) and “Bundeswehr Capability Profile“ (Fähigkeitsprofil der Bundeswehr) describe how the strategic and political guidelines are implemented within Germany’s armed forces. There are plans to publish the Bundeswehr Concept and the Capability Profile as follow-up documents in the summer of 2017.

In view of the limited predictability of future challenges, it will be necessary for the Bundeswehr to continue to have a broad spectrum of capabilities at its disposal in order to adequately fulfill the tasks of national and collective defence as well as international conflict prevention and crisis management.

The strategic orientation of defence research and technology is also subject to constant review and adjustment, based on the requirements that arise.

In this issue the Federal Ministry of Defence presents selected contributions from the fields of

- defence technology research,
- military medical and military psychology research,
- military history and social science research,
- geoscientific research
  and
- cyber and information technology research.

Ralf Schnurr

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Defence Technology Research

Defence research and technology (R&T) is the first link in a value chain, at the end of which the Bundeswehr should have the best possible equipment available, on time and in compliance with mission requirements.

The broad capability spectrum of the Bundeswehr calls for intensive monitoring and development of all fields of science and engineering relevant to defence applications.

Defence R&T activities provide the analysis and assessment capability required for decision-making on equipment, i. e. they serve to analyse technological developments for their future military usefulness or their threat potential, to identify strategic fields of interest for the advancement of Bundeswehr capabilities, to take account of findings from civilian research, and to drive relevant emerging technologies forward to the stage of production readiness at the proper time.

In Germany Defence R&T activities are conducted

- at Bundeswehr-own research institutes and technical centres
- within the scope of shared government funding at the Fraunhofer Society for the Advancement of Applied Research (Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., FhG), the German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt e. V., DLR) and the French-German Research Institute of Saint-Louis (Deutsch-Französisches Forschungsinstitut Saint-Louis, ISL),

as well as

- within the framework of project-funded research through the award of R&T contracts and funding to third parties, i.e. to industry and business, universities and non-university research institutes.

The following articles present examples of Defence R&T activities conducted at these three levels in 2016.

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3D printing for defence applications: lightweight solutions through numerical design optimisation

Metal additive manufacturing, or 3D printing, allows fabrication of components with enormous freedom in regard to geometrical shape and material structuring. With precise knowledge of the load profile, it is possible with the aid of numerical optimisation methods to compute the optimum lightweight design for specific functional requirements and to manufacture high-performance components.

3D printing of metal structures and components allows full control about at which locations the starting material, such as a metal powder, is to be fused to form geometric structures. To save material, machining time and energy, structural material should be generated only where it is needed for the component – the lightweight design principle thus becoming an economic imperative for such generative manufacturing technologies. Where the material is built up in layers, similar to selective laser sintering in which a laser beam is guided across a powder bed, thereby fusing and combining the metal powder with the already generated underlying structure, this is also referred to as additive layer manufacturing.

The opposite is the case where conventional technologies are concerned, the starting point being the bulk material from which redundant material is removed using machining processes such as drilling or milling. The less material is needed to bear the expected functional loads and redundant mass were to remain in the structure, the more time and energy are expended for the removal of material. In forming processes such as casting, compression molding or forging, the starting material is shaped or formed with the aid of elaborate tooling. These forming processes are strongly directional, thus offering only very limited potential for the manufacturing of complex structures.

It is here that 3D printing technologies offer an alternative in the form of additive manufacturing. Being especially suited for lightweight designs that tend to include thin structural elements permeating the body volume, such as are familiar from lattice structures, only the material needed to fulfill the function is used in the manufacturing process and only there is energy expended to fuse the metal powder with the structure where required for the final design. Shaping and material structuring are considered optimal when material is used only in those areas and is smartly combined into a load-bearing structure where it is needed to fulfill the function of the resulting component. When the load requirements for the component design are mathematically quantifiable and good models for describing the behaviour of the construction materials in the expected load range are available, it is then possible to use numerical computer simulations to compute the optimum geometrical shape and material structure.

Design solutions arrived at in this way can now be transformed into real parts and components using the new direct metal laser sintering system at Fraunhofer EMI. At present it is capable of the additive manufacturing of large metal components within a design space of 400 x 400 x 400 mm^3.

Additional dynamic tests and diagnostic techniques enable EMI to first of all quantify the load requirements based on a starting design as a means of determining functional requirements. EMI has the expertise to realise extremely high dynamic load conditions typical of defence applications in experiments under laboratory conditions and, by doing so, to simulate material behaviour including failure in material models.

EMI is, for example, involved in establishing design rules for the utilisation of additive manufacturing processes especially in respect of the extremely dynamic load requirements in defence applications, with a view to exploiting the potential of this new technology for the Bundeswehr. It is also possible to include final design requirements extending beyond lightweight construction, such as the aspect of heat conduction in the context of thermal signature management, in the process of numerical design optimisation.

Fraunhofer EMI is working closely together with the Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) on many issues connected with 3D-printed parts for the Bundeswehr.

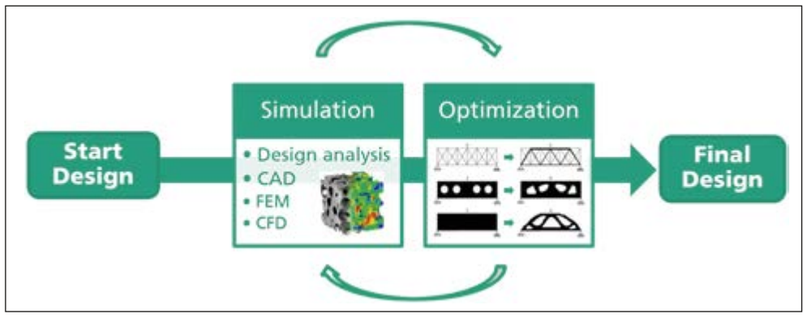

Fig. 1: Iterative process of multidisciplinary simulation and optimisation steps

Fig. 2: Numerical design optimisation for a wheel carrier, and 3D printing of the final design using the direct metal laser sintering system at Fraunhofer EMI, for testing and experimentation

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17 GHz SiGe MIMO chipset for compact 3D imaging radar modules for integration in airborne platforms and ground vehicles

In numerous scenarios in which the German armed forces operate, poor visibility conditions represent a serious problem. Missions in fog, sand and snow storms very frequently lead to dangerous situations for man and machine. With this in mind, the SiGe chipset presented here offers a compact, cost-effective and weather-independent solution for highly integrated MIMO (Multiple Input Multiple Output) radar imaging systems.

Being more or less weather-independent, imaging radar systems support visual navigation and help greatly to increase the safety of airborne and ground vehicles when compared with optical sensor technologies. Many systems currently in service, however, are either limited to measuring distances or are otherwise very space-consuming. At this point the growing possibilities offered by on-chip integration open up completely new system designs. Silicon-Germanium (SiGe) technology, which has matured over the years through its use in automotive radar, stands out not only on account of its high capacity for integration but also because of its good cost-benefit ratio, durability, and high robustness against thermal stress, making it particularly suitable for military use. The complete analog processing of radar signals from multiple channels simultaneously can nowadays be integrated onto one single chip the size of a pinhead. Entire signal chains, ranging from oscillator to coupler, amplifier and mixer, can thus be combined in one single component. Where great ranges and also high resolution are required, the lower GHz band is of major relevance and is therefore licensed for military navigation. The Ku-Band (12-18 GHz) has, for this reason, been chosen as the frequency range for the developed compact, multifunctional and 3D imaging MIMO radar. The radar ICs (integrated circuits) that have been developed combine either two transmitting channels or four receiving channels on one chip. Each transmitter chip (Fig. 1) contains a digitally controllable phase shifter and a power amplifier for each channel, and each receiving chip (Fig. 2) contains a low-noise amplifier and mixer for each of its four channels.

A multifunctional MIMO radar system combines a 3D imaging MIMO mode, where only one transmitting channel transmits per unit of time using a beamforming mode in which all transmitting channels are active at the same time. The phase shifter integrated in the transmitter path makes it possible, because of the phase-synchronous superposition of the transmitted signals, to steer the transmit beam in different directions, thereby increasing the effective transmitting power of the radar and hence also the dynamic range of the system. But even in the MIMO operating mode, the maximum transmitting power of a single transmitting channel with a differential output of 500 mW at 38 % efficiency is already very high (Fig. 3). Moreover, a low-noise amplifier and mixer with adjustable amplification on the receiver side ensure high system dynamics. The chipset developed at Fraunhofer FHR on behalf of the BAAINBw (Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support) forms the key component of the “Compact MIMO Radar” imaging system developed by Airbus Defence and Space. With 16 transmitting and 16 receiving channels and a module the size of half a shoe box (Fig. 4, top right / bottom), it is excellently suited for use in military vehicles. It is a further development of the discretely mounted MIMO radar demonstrator (Fig. 4, top left). In addition to the radar system an optical camera has been installed to combine radar images with visual information.

The high degree of miniaturisation that can be seen in Fig. 4 is attributable to the use of the newly developed SiGe chipset. This underscores the tremendous potential offered by the developed radar ICs, which can also be of great use for a multitude of other applications.

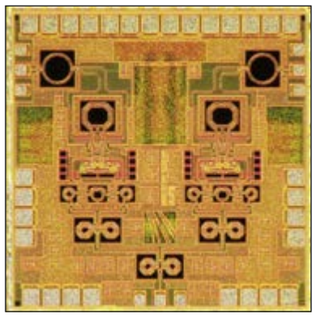

Fig. 1: Transmitter chip with two channels in SiGe technology (1,5 x 1,5 mm²)

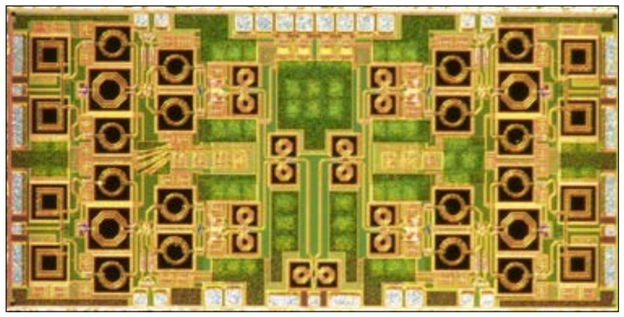

Fig. 2: Receiver chip with four channels in SiGe technology (3 x 1,5 mm²)

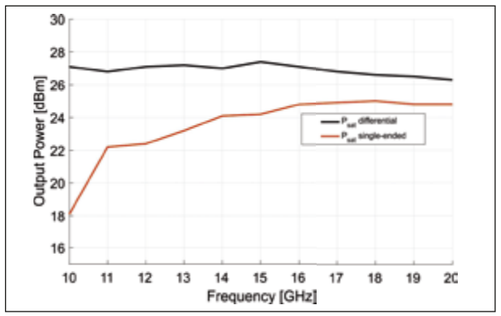

Fig. 3: Maximum transmitting power of the transmitter chip for one channel with differential (black) and single-ended (red) output

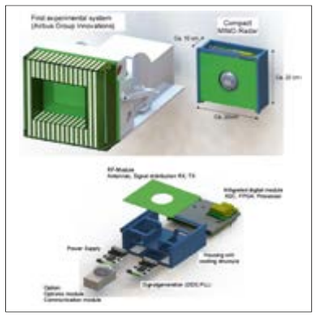

Fig. 4: MIMO Radar Demonstrator (top left) and concept of the new “Compact MIMO Radar” with SiGe chipset (top right and bottom)

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Software security: cross-platform vulnerability detection

Software vulnerabilities threaten not only desktop PCs or servers but also every area of our lives. On-board computers in cars or aircraft are just as affected as the Internet of Things (IoT), which is why high relevance is also accorded to military systems. Added to this, because of the heterogeneous nature of the hardware, the IT security industry is unable to provide standard security toolkits, making individual solutions necessary.

Minimising the threat posed by software vulnerabilities means having to adequately address different areas over the product's life cycle: prevention of vulnerabilities during software development; detection of vulnerabilities after release; and elimination of vulnerabilities after detection. This article addresses the important aspect of identifying affected devices after vulnerabilities have been newly discovered. This is no trivial challenge, as demonstrated by device manufacturers in many cases not being able to identify what other devices are affected directly after a product vulnerability has been made known.

Software security audits are ideally based on the so-called source code, which describes the program functions in an easily understandable high-level language. The source code, however, is not always accessible to the system operator, or the operator does not wish to rely on that source code being compatible with the compiled code (so-called 'executable') running on his system. It is therefore important to also be able to analyse the executable. In contrast to the source code the executable does not contain any unnecessary information

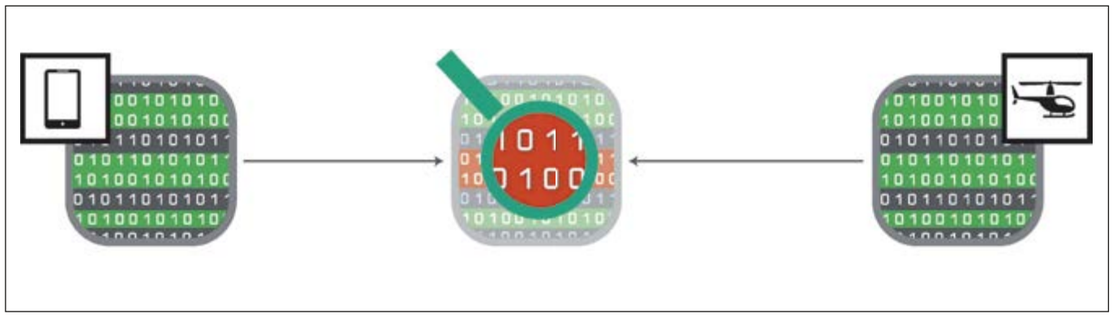

Fig. 1: discovRE has the ability to compare identical functions in executables of different platforms (e. g. between Windows, Android, and VxWorks)

such as variable names, comments or structural information, and is optimised to suit the platform in question, i. e. operating system and processor. An executable for a Windows PC with an x86 processor cannot hence be readily compared to the executable for a smartphone with an ARM or MIPS processor.

For cost and efficiency reasons, though, the same source code is frequently reused where code sharing between different systems allows manufacturers to save development time. Cryptographic code and standard device control tools are commonly shared among different systems, for example. But many other instances of such "code reuse" can be observed in practice, with the consequence that the same vulnerability may exist in a smartphone and in an aircraft onboard computer. Given the platform diversity and the highly optimised platform-dependent executables, such correlations are often impossible to spot. This problem even extends to the manufacturers as they also purchase components and do not have access to the source code for those components.

Fraunhofer FKIE has, in "discovRE", created an analysis environment with the capability to identify elements at the executable level and to spot corresponding code in other executables. For example, Fraunhofer FKIE has demonstrated in the case of the Heartbleed and POODLE vulnerabilities that they can also re-discover in Android smartphones based on Windows executables. This has been possible although the processor architectures serving as a basis are x86, ARM and MIPS and the operating systems used with Windows and Android have been very different. In the case in question the analysis took around 80ms, thus also demonstrating that the "discovRE" system is adequately scaled to analyse large data volumes.

The technology presented here is thus an important element for increasing the IT security of proprietary systems. For the first time, it is possible to search for vulnerabilities in other systems across different platforms. Particularly because of the spread of so-called 'embedded devices' (e. g. engine management systems, onboard computers, printers etc.), their voluminous software and the proprietary firmware that they use, there is a high level of uncertainty regarding the trust that can be placed in those devices. The system developed at Fraunhofer FKIE can eliminate that uncertainty by searching for known vulnerabilities in executables and by identifying devices that are infected.

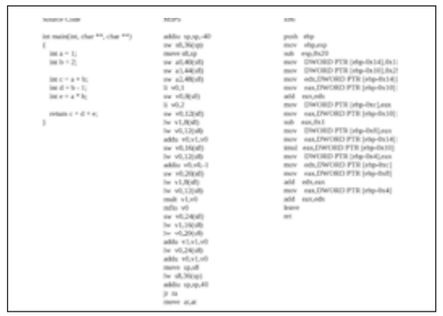

Fig. 2: Comparison of an identical function as source code and executable for MIPS and ARM

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Multiple sensor data fusion for drone defence

Drones are revolutionising the civilian world and enabling new creative applications with, as yet, unforeseeable consequences. Nevertheless, this technology is also proving to be Janus-faced: Unmanned Aerial Systems pose considerable threats. Defence research is addressing this challenge. Counter drone defence measures are not only in the interest of public security but also protect military forces.

Low-signature Unmanned Aerial Systems, whose spread is difficult to control, require particular consideration. As they are able to operate in a highly agile manner as well as at high speeds, the response times for any countermeasures are short. In order to identify any threat posed by drones, it is essential to have high-performance sensors capable of registering various characteristics of drones as they approach (Fig. 1).

Radar optimised for drone detection is of key importance because of its range and all-weather capability. Radar systems either transmit signals themselves or use existing emitters of opportunity for illumination. Echoes reflected from drones provide data concerning their position, speed and type. Passive radar uses transmissions from mobile phone base stations, for example. As permits for active radar operation are issued ever more rarely, passive radar provides the possibility for drone detection without any emissions (Figs. 2, 3).

Radar data needs to be fused with data streams from imaging sensors, typically covering several spectral regions. Although they achieve lower ranges than radar and are dependent on weather conditions and the time of day, their resolving power makes target classification easier and thus reduces false alarm rates through multiple sensor data fusion (Fig. 4).

Emissions produced by the drones themselves also make drones detectable, for example, when they are under radio remote control. Using suitable data analysis algorithms it is possible to localise a drone and its pilot. Even autonomously operating drones establish data links, however, at least intermittently. Equally important are acoustic emissions, with array signal processing being a key function for direction finding and localisation. Signal analysis makes it possible to classify drones before they appear in the field of view. Robust system solutions however also call for methods of sensor resources management, such as for coaching in laser gated viewing.

Despite their threat potential, “everyday drones” offer the advantage of having hardly any electronic self-protection. “Soft kill” measures can therefore limit their functionality. “Hard kill” measures such as projectiles, lasers or high-energy electromagnetic pulses are, in most cases, an option only in a military context as it may also have incalculable consequences (in view of possible chemical, biological, radioactive and explosive payloads). For which reason, assessing possible collateral damage must accompany any discussion of countermeasures.

In some instances it is possible to use methods of electronic warfare – for example to “hijack” a drone’s remote control, which is simple in the case of WLAN-based approaches. Where more sophisticated systems are concerned, the challenges are far greater, such that jamming of the remote control becomes an option. In cases where drones operate autonomously, jamming or deception of their satellite navigation may be appropriate. Where drones are used in spying operations, there is the possibility to jam the data downlink or their sensors through electromagnetic countermeasures. If an adversary is looking only to collect sensor data on-board a drone, it will require him to recover the drone, thereby providing the opportunity to track the drone as a counter-measure and be led directly to the ‘perpetrator’.

Where ‘kamikaze’ drones are to be expected, intercept drones would be a consideration, operating as a network to neutralise the threat. Counter drone defence would also have to be considered: what can be done to safeguard the use of one’s own drones if potential adversaries employ counter drone technologies?

Sensor data fusion, sensor management and electronic counter measures will play a key role in counter drone systems. In the context of command and control systems, the technological challenges can be met but will require close cooperation between the users (i. e. military and police forces), research institutes and industry. For the protection of stationary facilities and mobile units in urban environments or open terrain, it will be crucial to integrate drone detection / tracking / classification into command, control, information and communication systems.

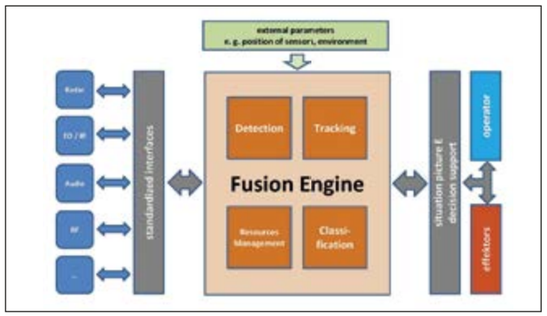

Fig. 1: Schematic view of a modular and scalable fusion architecture for a counter UAS system with standardised interfaces

Fig. 2: Experimental 16-channel passive radar system that uses mobile phone base stations (GSM broadcast signal) for drone illumination

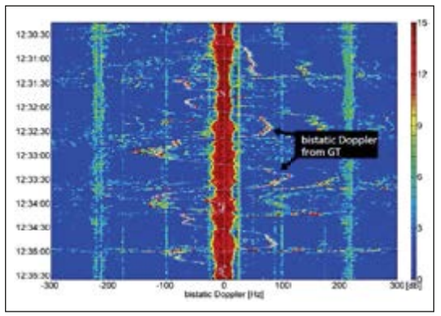

Fig. 3: Range-Doppler diagram with expected Doppler frequency as a function of time: first experimental confirmation of successful UAV detection based on GSM broadcast signals

Fig. 4: Fusion of GSM passive radar and E/O-IR sensor measurements by means of intensity filtering (iFilter), for an advanced multiple target tracker (experimental results)

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Adaptive optics for free-space communications

Laser-based free-space communications offer the potential to realise secure data transmission in the license-free wavelength range (civilian and military applications). Unfortunately, atmospheric turbulence significantly limits the use of this method. At Fraunhofer IOSB, corrective techniques are being explored with a view to making future free-space (terrestrial and space-to-ground) optical communications possible.

Free-space (i. e. non cable / fibre-dependent) communications is not a new concept. Radio and micro-waves have been used for communication since as early as experiments conducted by Heinrich Hertz in 1887. Why there is, nevertheless, such great interest in laser-based free-space communications at present can be explained with the aid of the following facts:

- Laser light is directional; thus precluding the possibility of eavesdropping on a laser channel.
- A smaller wavelength in comparison with radio- and millimetre waves is equatable to greater bandwidths and smaller antennas; smaller antennas, in turn, imply the opportunity to deploy such devices on small, possibly moving platforms.
- No license required for the use of wavelengths shorter than 1000 µm.

The technology of free-space optics (FSO) of course, as the name implies, is not reliant on cables being available between terminals. As such, it is considered to be a promising solution to the “last-mile” problem, as well as to providing broad bandwidths in rural regions and emergency services in remote areas, especially in combination with satellite links. Military applications, for example, include the transmission of intelligence, surveillance and reconnaissance (ISR) data between ships and from ship to shore.

Laser-based satellite and deep-space communications require a separate mention. Given the omnipresence of Earth-observing satellites and the amount of data their imaging sensors produce, problems may arise with the high volume of data traffic flowing back to Earth-bound terminals. An LEO (low earth orbit) satellite can produce up to 10 Tbits of data per day. A typical bandwidth of an X-band channel is currently around 800 Mbps, meaning that the satellite would have to spend at least 15 % of its time in line of sight of the ground terminal and use up all of its bandwidth just to send data back to Earth.

It should be remembered in this context that laser communications in space are also of military interest. As an example: a single Global Hawk UAV requires a data rate of hundreds of Mbps, equivalent to around 10 to 20 percent of the aperture capacity of each satellite in the US MILSATCOM constellation. With there being over 40 US Global Hawks at present, these alone would take up to 80 percent of the constellation’s total capacity. The US military currently relies on leased commercial downlinks to ground terminals to transmit ISR data from its Global Hawks.

The atmosphere can have a major impact on the performance of laser communications systems. Leaving aside disruptive phenomena such as rain, snow or fog, atmospheric turbulence affects the strength of the signal delivered to the terminal and the error rate in the transmission. Fraunhofer IOSB is addressing the problem with advanced adaptive optics (AO) technology. In its AO laboratory in Ettlingen it is exploring solutions to the most difficult challenge: laser propagation caused by strong ground-level turbulence. A holographic wavefront sensor is seen as a possible solution approach in the development, having delivered promising results (Figs. 1, 2). This approach will be integrated into a measuring setup for characterising and correcting atmospheric turbulence (Fig. 3) and then tested under real conditions.

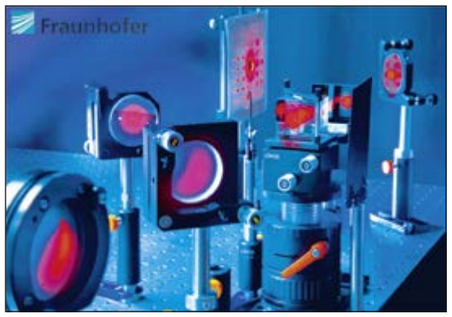

Fig. 1: Holographic wavefront sensor

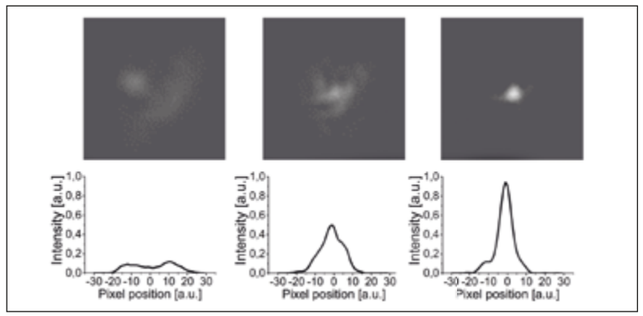

Fig. 2: Correction of a turbulence-disrupted laser beam by means of adaptive optics based on holographic wavefront sensing. Detector images (top) and their cross-sections (bottom) show that a significant improvement can be achieved after just a few correction steps. From left to right: no correction; after one iteration; and after two iterations

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Fig. 3: Transportable measuring setup for characterising and correcting atmospheric turbulence

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Certification of simulator interoperability

Simulation-based exercises have meanwhile become an indispensable tool for the German Armed Forces and for NATO for efficiently preparing joint and combined operations. A hitherto unresolved problem has been ensuring the interoperability of all the federated simulators. That said, a NATO working group under German-French leadership is currently developing a process for simulator certification.

Very many of the modern-day simulators form systems and components that are used in flexible conjunction with other simulators within complex system-of-system structures. Just like their real role models, their virtual counterparts in the simulators require the capability to form an integrated simulation system. Such a system, also referred to as a federation, defines rules or so-called ”federation agreements” for the interaction of the participants. Until now, however, it has not been possible to reliably verify whether a simulator complies with those agreements – something which often leads to very high integration costs and, unfortunately, also greatly limits system robustness as well as the reliability of the results.

As federated simulation of joint and combined exercises including expert and economic analysis has become indispensable for the German Armed Forces and their NATO partners, there has been a need to take action.

Following on from earlier work to define interoperability rules for federated simulation, NATO Working Group MSG-134, under German-French leadership, is developing a basis for introducing certificates for simulators (the name of the working group: NATO Distributed Simulation Architecture & Design, Compliance Testing and Certification).

A basic requirement for any functional interaction between simulators in a federation is agreements on interoperability, by which essentially data models and interaction processes are meant. But this can also include additional requirements relating to all levels of interoperability. The main thing is that all agreements are formulated so as to be unambiguous and verifiable.

To date, unfortunately, there has been no possibility to verify compliance with these agreements in an internationally accepted manner. Although situationally related tests have been conducted, they have always been limited in scope solely to cases in question and, as a result, also been limited in terms of their validity. What is needed are internationally agreed interoperability requirements.

MSG-134, which started its work in 2015, plans to define interoperability requirements for a selected set of federation agreements, formulate test specifications, and implement these together with a test tool by the end of 2017. An operating concept regulating the issuance of certificates will also be formulated.

This will create a quality seal for simulator interoperability that, for the first time, is uniformly defined internationally. From the perspective of the simulator manufacturer, this will provide proof of quality, and from the perspective of the user will enable a very much better assessment of simulators’ fitness for use in federated systems. The testing tool is being consciously developed as Open Source Software (OOS) so as to make it available for use without any restrictions. Any simulator developer should be able to test his product in the manner it will also be accepted and used later.

This is based on the conviction that efficient and reliable operation of simulators in federated systems is possible only through intensive compliance testing in every phase. The name of the tool under development is IVCT and stands for its three areas of application: Integration, Verification und Certification Tool.

From NATO’s perspective, the plan is for one or more accredited institutions to be responsible for conducting the certification. These will be complemented by national test institutions of the public procurement agencies that, with the aid of these instruments, will be able to define acceptance conditions and conduct compliance testing programmes.

Fig. 1: Computer-based simulation often involves many interacting systems

Fig. 2: NATO Working Group MSG-134 Distributed Simulation Architecture & Design, Compliance Testing and Certification

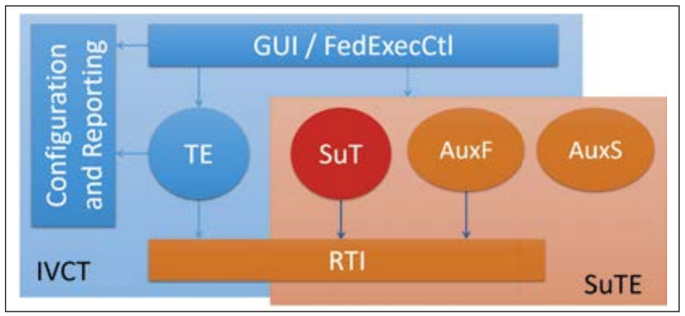

Fig. 3: Integration, Verification and Certification Tool (IVCT)

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Quantum cascade lasers for detecting hazardous and explosive substance residues

Fraunhofer IAF has developed several standoff-capable hyperspectral sensors based on active illumination by quantum cascade lasers and validated their use for the remote detection of explosive residues. The ongoing development of a rapid wavelength scanning QCL light engine will enable the realisation of compact and cost-efficient spectroscopy systems for hazardous substance detection in real time.

In the past few years Fraunhofer IAF has invested significant research effort in the development of tunable laser light sources for a broad variety of spectroscopic applications in the mid- and long-wave infrared range of the electromagnetic spectrum. Quantum cascade lasers (QCLs) are III-IV semiconductor lasers based on InGaAs/InAlAs material grown on InP substrates by means of molecular beam epitaxy. With the aid of bandstructure design it is possible to realise QCLs with centre wavelengths ranging between 3.5 µm and 12 µm and spectral tuning ranges of over 350 cm^{-1}. In the wavelength range between 7.5 µm and 10 µm, QCLs are the optimum choice for many spectroscopic applications, as many chemical compounds display a very characteristic absorption behaviour especially in spectral range (Fig. 1).

A laser illumination source named µEC-QCL which allows fast spectral tuning of the emission wavelength over a wide spectral range has been developed on the basis of QCLs at Fraunhofer IAF. The QCL chip is operated in a Littrow-type external cavity setup comprising an MOEMS (Micro-Opto-Electro-Mechanical Systems) scanner with a grating etched

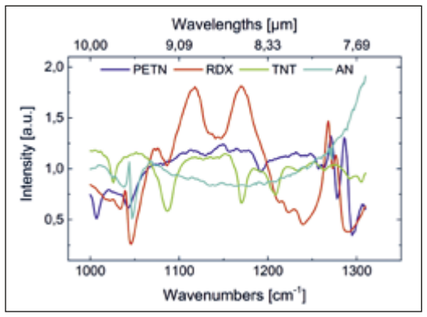

Fig. 1: The backscattering spectra of various explosives display a characteristic absorption behaviour in the considered wavelength range

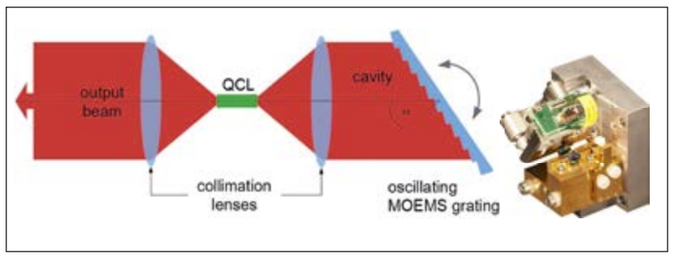

Fig. 2: Principle (left) and realisation (right) of MOEMS QCL for real time-capable spectroscopy applications (e. g. fast wavelength tuning)

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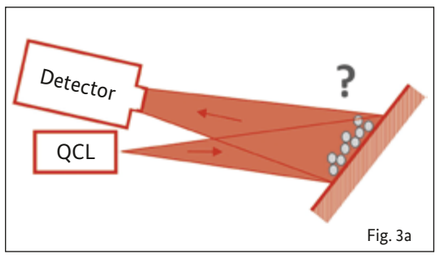
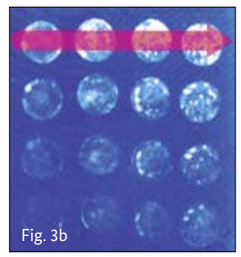
into its scannerplate as a refractive wavelength-selective element in the resonator (Fig. 2). The MOEMS grating oscillates at its resonance frequency of around 1 kHz, thus causing a rapid modulation of the emission wavelength and enabling the complete spectral tuning range of the QCL chip to be sequentially scanned in less than 1 ms.

This laser source has been used at Fraunhofer IAF to demonstrate sensor systems that allow standoff-capable detection of hazardous substance residues on arbitrary surfaces in real time using the principle of backscattering spectroscopy. The surface to be analysed is actively illuminated by the laser, and the diffusely backscattered light is registered by an infrared detector (Fig. 3a). The intensity of the backscattered signal serves as a measurable quantity which, as a function of the emission wavelength, enables the generation of a backscattering spectrum of the illuminated spot on the surface (Fig. 3b). In a final analysis step using a mathematical model, there is the possibility to identify known target substance spectra by crosschecking against a database,.

Shown in Fig. 3 is the use of this measurement principle for detecting PETN (pentrite) residues on a polyamide sample surface from a distance of around 0.5 m. The hyperspectral data along the path indicated in Fig. 3c were acquired using sequential spatial movement of the measurement spot on the surface. With the aid of customised data analysis algorithms which automatically include the spectral characteristics of the uncontaminated area in the detection process, the measured spectra were analysed for contamination with PETN, TNT, RDX and ammonium nitrate. The analysis system succeeded in distinguishing the PETN-contaminated spectra from background spectra and in identifying the target substance unequivocally.

Considering the advances made in terms of miniaturising the laser illumination source, this technology thus offers the potential to carry out contact-less and real-time chemical analysis of soil samples in mission vehicles. There is also the possibility, based on this technology, to develop a hand-held sensor for detecting hazardous substances in the field.





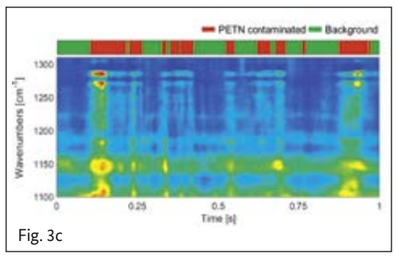


Fig. 3: Results of fast backscattering spectroscopy for the detection of PETN residues on a polyamide substrate

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Electrochemical sensor system for detecting explosives in practical sea trials

An electrochemical sensor from Fraunhofer ICT has, in cooperation with WTD 71, been integrated into an unmanned underwater vehicle and tested in multiple sea trials. The purpose of the sensor system is to detect explosives in sea water, with a view to differentiating sea mines, improvised explosive devices and unexploded ordnance legacies from harmless objects.

The Fraunhofer Institute for Chemical Technology (ICT) in Pfinztal, together with the Bundeswehr Technical Centre for Ships and Naval Weapons, Maritime Technology and Research (WTD 71) in Eckernförde, has conducted a project aimed at developing, integrating and testing a system for sensing explosives in sea water.

When an area is to be checked for the presence of mines, improvised explosive devices or unexploded ordnance legacies, the first step is to use sonar as the established method for rapid, large-scale screening. Sonar detects mostly multiple objects that cannot be clearly recognised as harmless or dangerous and thus as objects that need to be cleared. A closer inspection of such suspicious objects and the decision whether their clearance is necessary or not is currently done by divers in most cases, a process which is cost-intensive , time consuming and also dangerous .

The detection approach presented in this article is based on examining suspicious objects for the presence of any explosive charge, focusing firstly on explosive substances. This can be done using an electrochemical sensor system carried to the suspicious object by an unmanned underwater vehicle.

The developed sensor system consists of a sensor head that contains a reaction chamber including sensing electrodes and a pump. The sensor head is connected to a pressure-resistant housing containing the electronics (potentiostat, mini-computer, pump drive, power supply). Two different versions of the sensor system have been built. One has been designed for use on an AUV (autonomous underwater vehicle) and is completely autonomous as it uses its own energy supply and is controlled by a self-learning evaluation system (based on a support vector machine, or SVN), which outwardly communicates any explosive find by means of a flashing light.

The second system has been designed for use on a ROV (remotely operated vehicle); it utilises the power supply and communication system of the underwater vehicle and can be remote-controlled from onboard the consort vessel.

The sensor system is based on established electrochemical measuring methods used for detecting explosives. Measurement is done by recording the change in electric current flowing between the sensing electrodes when the target substance reacts (i. e. is oxidised or reduced) on the electrode surface. Given the fact that the target molecules have to be present on the electrode surface, it is logical that the sensor has to be manoeuvred as close as possible to the object under investigation, or the target molecules have to be transported in the direction of the sensor – similar to the process of a sniffer dog detecting an object.

The practical functionality of the sensor system has meanwhile been tested successfully on several occasions in sea trials in the North and Baltic Sea off Germany and Poland.

The measurement procedure involves an unmanned underwater vehicle moving against the water current in the direction of the suspicious object (so that the current carries the target molecules towards the sensor). As the distance to the object decreases, water samples are drawn into the reaction chamber every 5 to 30 seconds (depending on the desired sensitivity) and are directly analysed electrochemically. The registered data is then compared with baseline measurements regularly recorded between the approaches to the target and evaluated. Based on these comparison measurements it is possible to minimise the influence of changing measurement parameters (salinity, conductivity, sea water pH value, presence of other non-detection-relevant or disruptive substances).

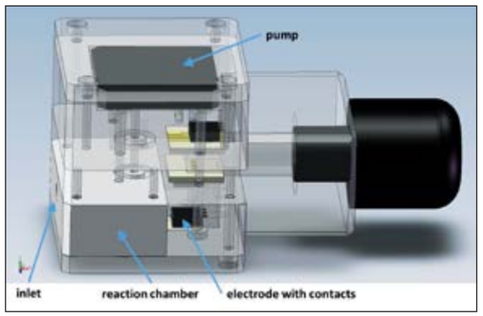

Fig. 1: Sensor head with measuring electrodes, pump and reaction chamber

Fig. 2: Pressure-resistant housing with electronics: potentiostat, mini-PC, pump driver, power supply

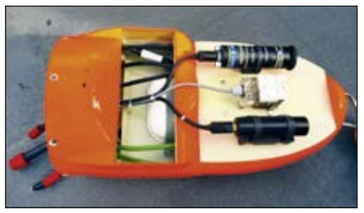

Fig. 3: Sensor system integrated inside the payload compartment of the SeaCat, of Atlas Elektronik

Fig. 4: Sensor system during practical trials in the Baltic Sea

Fig. 5: Unexploded ordnance legacies and artificial explosives-bearing objects tested for the presence of explosive substances

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Realistic MANET channel model for appraising the performance of networked radios

New network-compatible radios will need to be procured over the next few years in order to make the mobile tactical communications of the Bundeswehr fit for the future. With this in mind, Fraunhofer IIS has, in close collaboration with WTD 81, developed a realistic MANET channel model which allows an objective and sound appraisal of the performance of available systems.

Over the coming years, Germany's armed forces (Bundeswehr) are to be equipped with new, MANET (Mobile Ad-Hoc Network)-capable radios for mobile tactical communications. Compared with current tactical radios for point-to-point communications, MANET-capable radios offer numerous benefits, as they are capable of routing data over several nodes, thus allowing for larger coverage. Mobile Ad-Hoc Networks are also much more robust, as so-called 'single points of failure' are avoided and, in the event of any node failure, adapted routing algorithms provide suitable alternative routes.

Any realistic performance appraisal of the communication systems available on the market requires a sound knowledge of the mobile channel characteristics and the possibility to recreate them in the laboratory. Standardised channel models are typically used in this regard. Existing models are designed mostly for broadcasting and for mobile radio network applications and are unsuitable for the evaluation of military MANET systems due to the deviating frequency and antenna heights. Furthermore, they only allow simulation of individual, uncorrelated radio links (Fig. 1). Application scenarios typical of the Bundeswehr, such as convoy movements (Fig. 2), cannot be realistically analysed using the existing models.

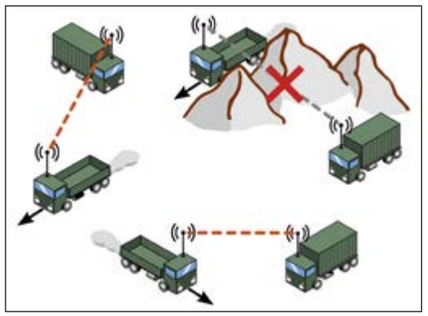

Fig. 1: Previous models assume the radio links to be completely independent. Scenarios in which the radio links are similar, for example when communicating with a convoy, cannot be simulated in a realistic manner

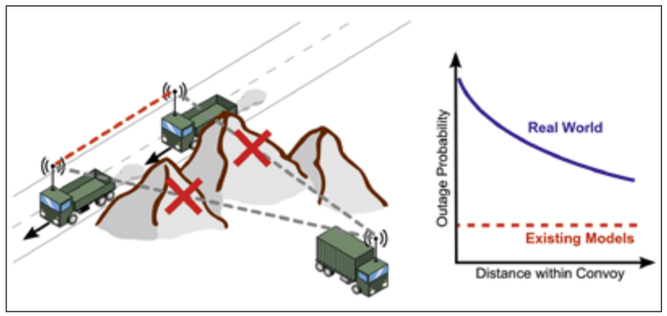

Fig. 2: Correlation of the radio links in reality: in this case the simultaneous failure of the direct links to a convoy. To avoid errors when evaluating the routing capabilities, this correlation also has to be recreated correctly in the laboratory – something which is not possible with existing models

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The goal of the research being conducted at Fraunhofer IIS is to avoid incorrect decisions in the selection of radio equipment due to improper channel modeling. For this purpose, a MANET channel model for radio links in the 30 MHZ to 400 MHz frequency range has been developed. It considers, for the first time, the correlation of the shadowing between network radio links, thus allowing a sound evaluation of routing protocols, which are crucial for the performance of Mobile Ad-Hoc Networks.

In order to create a reliable database for the model, extensive channel measurements were conducted in collaboration with WTD 81 in the VHF and UHF frequency bands relevant for military communications. Both the signal attenuation (Fig. 3) and the impulse response of the channel (Fig. 4) were recorded. The influence of the environment was also taken into account by taking measurements at eleven locations throughout Germany.

In the course of the channel model's development there was thorough analysis of the three crucial mobile channel phenomena, namely path loss, shadow fading, and multipath fading, and suitably adapted sub-models were devised. The various sub-models were then combined to form the MANET channel model, thus greatly facilitating utilisation of the models for the user. Taking solely the position of the simulated terminals over time as a basis, the MANET channel model provides the channel characteristics of all the radio links in a MANET for the chosen environment class and frequency. Complex scenarios can also be simulated without any great effort. Fraunhofer IIS has implemented the model for typical software and hardware simulators, enabling the testing and appraisal of radios that are already available as well as of systems still at the development stage.

In contrast to previous models, the new MANET channel model allows realistic recreation of the radio channel for Mobile Ad-Hoc Networks, making it possible to significantly minimise errors in radio channel prediction and to avoid incorrect decisions when selecting the optimum MANET system for the job in hand.

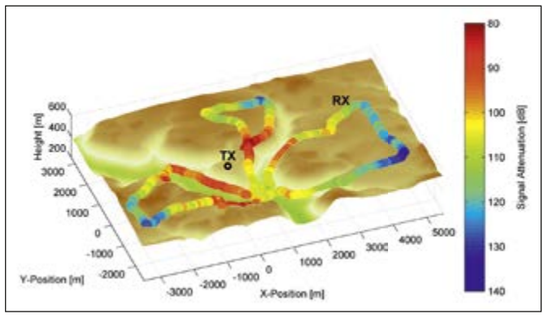

Fig. 3: Location-dependent attenuation of the transmitted test signal in a hilly environment. The influence of path loss (distance-dependent attenuation) and signal shadowing by obstacles is evident

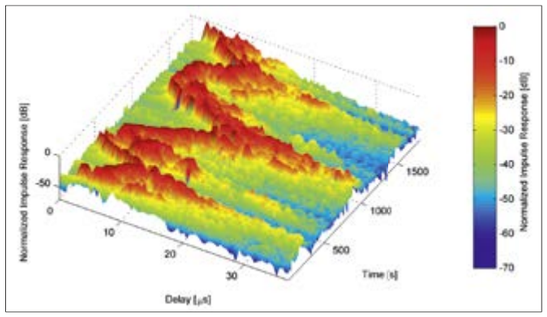

Fig. 4: Normalised time-variant impulse response of the radio channel in a hilly environment. Based on these measurement results, a realistic multipath propagation can be recreated in the channel model

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Structural modelling, dimensioning and assessment of agile military aircraft

With great probability, the next generation of military aircraft will be autonomous, highly agile unmanned combat air vehicles (UCAV) operating in units as a combat air system. The DLR is examining such a UCAV in the form of a highly swept flying wing configuration. Key aspects include control concepts, aerodynamics, aeroelasticity, as well as exploration of a structural layout using numerical methods.

Parametric modelling based on CAD / CAM / CAGD technologies is the state of the art when it comes to designing new aircraft. The DLR Institute of Aeroelasticity is providing this key capability within the scope of the MEPHISTO Project. A structural model of the DLR-F19 UCAV configuration is being set up using its in-house ModGen software. ModGen is a parameterised preprocessor for setting up finite element (FE) as well as aerodynamic and optimisation models for structural sizing, and also other simulation models (e. g. for mass modelling). The input for this parametric process is basic information such as profile data, geometrical dimensions and design parameters for the wing box (e. g. number, position and orientation of spars, ribs and stiffeners).

The coupling of the structural and aerodynamic model forms the so-called aeroelastic model. The latter is used for a compre hensive load analysis campaign. The load analyses are conducted with the aid of another in-house software, the Loads Kernel, which simulates a wide range of manoeuvre and gust load conditions while giving consideration to the flexible structure. The ascertained design loads are then used for the

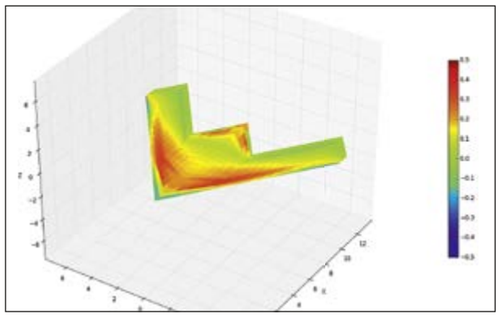

Fig. 1: Pressure distribution on the DLR-F19 during a 4.5 g pull up manoeuvre

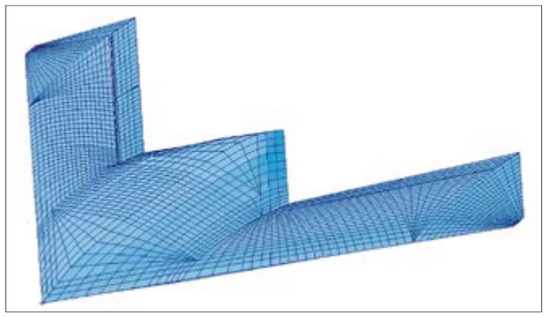

Fig. 2: Structural model of the DLR-F19

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structural sizing. As modern carbon fibre materials are used, this calls for sophisticated optimisation model techniques. The load analysis and the structural sizing are an iterative process that is repeated until convergence (e.g. in terms of structural weight) is achieved.

The resulting structural model is the basis for further aero-physical research (e. g. flight mechanics or flutter) and will help to improve the first estimate of the structural weight. It can also show the plausibility of the selected structural concept. As the structural model is used for aeroelastic analysis, the primary aim is to adequately consider the global structural dynamic characteristics.

Because the Doublet Lattice Method (DLM) is the preferred aerodynamic technique for estimating motion-induced aerodynamic forces, it is necessary to carry out an adjustment for the transonic regime. Transonic flows cause shock waves that can have a huge impact on the pressure distribution. Any shift in the centre of pressure changes the longitudinal flight characteristics. Flying wing configurations are especially sensitive in this regard due to the lack of a tail section. The DLR Institute of Aeroelasticity is studying these effects and exploring solution approaches for calculating selected aerodynamic effects in greater detail using the DLR Tau Code, an established computational fluid dynamics (CFD) method. Consideration of such aerodynamic influences in the load analysis will lead to even more reliable aeroelastic structural models.

The DLR Institute of Composite Structures and Adaptive Systems is working in close collaboration with the DLR Institute of Aeroelasticity to develop a light-weight inner structure using layers of carbon fibre fabric and so-called prepreg materials. This is based on existing knowledge with a view to creating a cost-efficient structure that also has the ability to withstand all the design loads of the aircraft. Attention is also being paid to the integration of morphing structures, such as morphing hinges for a low observable configuration, and to concepts for retractable landing gear and for closing weapons bay doors.

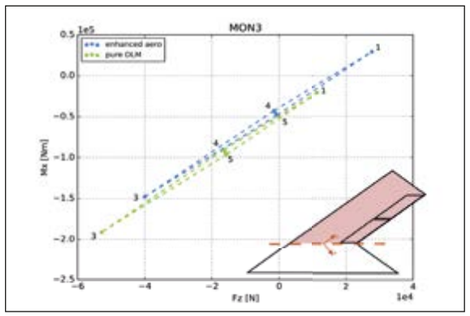

Fig. 3: Intersectional forces Fz and moments Mx at the wing root (MON3) for seven selected manoeuvre load cases

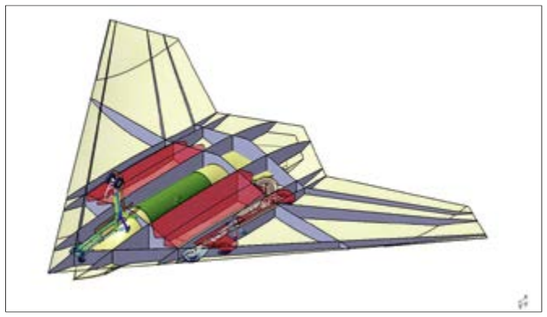

Fig. 4: Conceptual layout of the inner structure and landing gear

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Overall design of agile and low-signature military aircraft

Within the scope of MEPHISTO, an inhouse military research project, the existing overall design approach of the DLR is to be extended to include agile and low-signature military aircraft. The focus of the project is on the design of highly swept flying wing configurations. A control concept without any vertical tailplane, and also a highly integrated engine, are the development aims. The design is to be realised by using computational methods of differing fidelity level, with the **consistency of the applied methods being guaranteed through best practice approaches from previous projects.**

It is expected that the next generation of military combat aircraft will no longer comprise solely manned units. There will also be semi-autonomous unmanned and, in some cases, highly agile UAVs integrated into a so-called FCAS (Future Combat Air System). In addition to the challenges accompanying unmanned systems in regard to autonomous flight and unmanned vehicles flying together with manned systems in controlled airspace, the development of the platform itself involves very high demands in a number of aeronautical disciplines. The non-presence of a pilot offers far-reaching possibilities for system integration, which can be of benefit in terms of the requirement for a low radar, infrared and acoustics signature. On the other hand, the desired combination of low signature and high agility mostly calls for a highly sweptback planform dominated in the medium to high angle of attack range by a vortical flow topology. Managing these complex and non-linear aerodynamics poses a challenge for the aircraft's control system.

The DLR has set itself the task of contributing within the scope of defence projects to the design, analysis and assessment of highly agile UAVs. One focus of its in-house MEPHISTO Project is on developing a design environment that involves a multitude of disciplines. Besides aerodynamic design they include the structural layout and structural dynamic behaviour, the mission-specific layout of the engine, a flight mechanics assessment, development of the control system, and assessment of the radar, infrared and acoustics signature.

Particularly the aerodynamic wing design and development of a control system without a vertical tailplane represent major challenges. Yaw control in this case has to be realised by means of alternative control concepts such as adaptive structures or thrust vectoring. Also, achieving high agility through vortices providing sufficient lift in the medium to high angle of attack range cannot be allowed to reduce the efficiency of the control devices. The DLR has been able to demonstrate various solution approaches in this field in the form of innovative control devices, spoilers and morphing surfaces on its own UCAV configuration.

A further focus is on designing highly integrated air intake and nozzle geometries for the engines so as to reduce the signature and provide an inlet duct which avoids any direct view towards the rotating fan and ensures smooth flow conditions in front of the fan inlet area. Different concepts regarding the design of planar nozzles have been explored. A configuration with an internal split cooled bypass nozzle has been identified as very promising, as it permits a reduction of the temperature footprint in combination with the realisation of a mechanical thrust vector vane.

The MEPHISTO Project has already succeeded in demonstrating an enhancement of the overall design capability through a highly integrated approach to the different disciplines involved and through a high level of confidence in the methods applied, as well as in providing a valid performance prognosis for components and for the aircraft design as a whole.

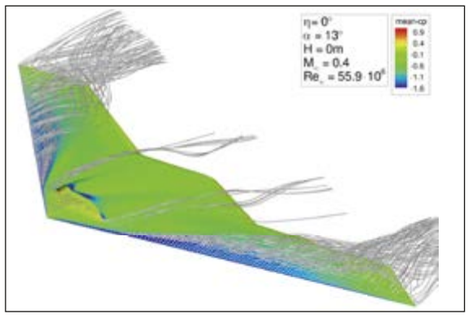

Fig. 1: MULDICON design study with highly integrated engine intake. (surface pressure distribution and vortical flow field)

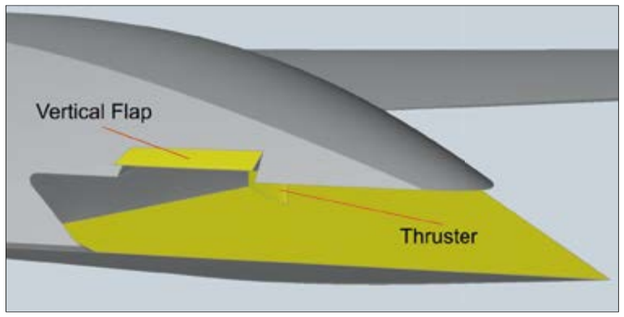

Fig. 2: Nozzle design with integrated thruster and vertical flap for yaw control

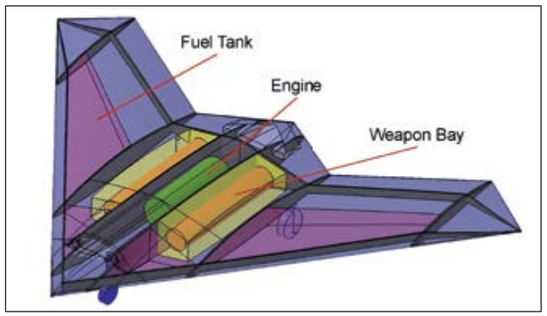

Fig. 3: MULDICON overall design study showing the basic structural layout and the location of the fuel tank, engine and weapons bay systems

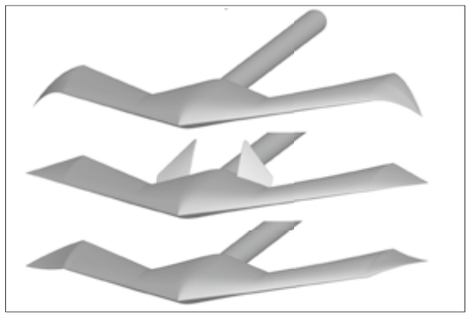

Fig. 4: Control concept design studies using spoilers and morphing surfaces for the MULDICON configuration

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Guidelines for low-noise UCAV designs

Presented is a new methodology for assessing the noise shielding potential of UCAV configurations, in particular jet engine noise through optimum engine arrangement. The aim of this contribution is to discuss new findings regarding the acoustic signature of UCAVs and to derive guidelines for low-noise UCAV designs.

The development of future UCAV (Unmanned Combat Aerial Vehicle) configurations is currently the subject of numerous research efforts. Developing such aerial vehicles poses great technical challenges with regard to their agility and the capability to fly autonomously. Both aspects impose stringent constraints on the aerodynamic design and require the use of well-established design tools and guidelines. The infrared, radar and acoustic signatures are also of major importance for the overall configuration design.

While a large body of research work has already been conducted in relation to the infrared and radar signatures of UCAVs, only little is known about their acoustic properties. Ongoing research activities at DLR on this topic are focusing on the noise shielding potential for UCAV configurations through optimal engine positioning above the aircraft wings. This work is being done within the framework of DLR's MEPHISTO Project. The activities mainly involve evaluating a UCAV configuration (SACCON) with regard to its engine noise shielding potential using a model reference sound source (Figs. 1 – 3).

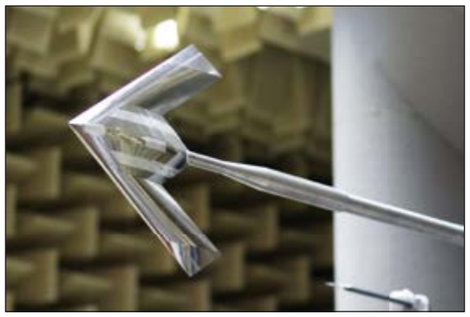

Fig. 1: SACCON UCAV configuration in the DNW-NWB wind tunnel

Fig. 2: Experimental setup in the DNW-NWB wind tunnel

Experimentally evaluating the noise shielding potential of an aircraft configuration requires a defined reference sound source with known characteristics that is suitable for use in a wind tunnel environment (Fig. 2). This requirement poses a challenge, as any spurious installation-induced effects related to flow interactions with the source should, if possible, be avoided. This is especially problematic in larger wind tunnels where structures have to be erected in-flow over large distances. DLR's strategy for circumventing such constraints is to use a laser-based non-intrusive point source. While this type of reference sound source does not aim to mimic the actual sound characteristics of UCAV engines, it provides a simple and very useful tool for wind tunnel experiments. An advantage is that it is possible to derive the source characteristics directly from a wave equation, thus permitting its exact numerical replication.

A laser-based reference sound source setup is shown in Fig. 3. It comprises a conventional PIV Nd:YAG laser with an output energy of 120 mJ in combination with two customised optical components. The emitted output laser beam is firstly expanded to a diameter of ~ 140 mm by a small diverging lens (25 mm diameter) before being focused by a large (150 mm) diameter lens at a distance of 2000 mm. This customised setup allows experiments in medium-sized wind tunnels (Fig. 2) with comparatively large wind tunnel models and correspondingly higher Reynolds numbers. The realised laser-based sound source is broadband in nature and has a uniform directivity.

An extensive noise shielding database has been compiled during the MEPHISTO Project that is to be used for the future validation of DLR's numerical simulation methods, SHADOW and FEM-BEM (Fig. 4), as well as to derive guidelines for low-noise UCAV designs. The ultimate goal of this work is to further develop DLR's aircraft predesign capabilities. The experimental work in the DNW-NWB wind tunnel was successfully completed in September and October 2016.

Being part of a cooperative arrangement with NATO Science and Technology Organization (STO) Group AVT-233, the project has benefitted greatly through a lively exchange with international partners and been able to achieve significant progress in regard to experimental methodology as well as theoretical aspects.

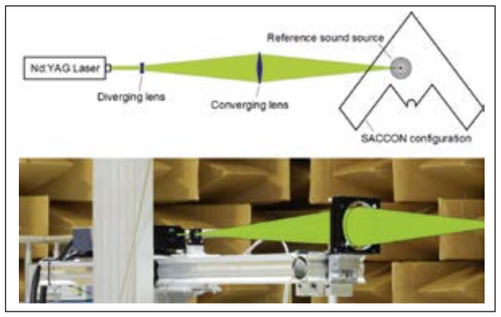

Fig. 3: Schematic view of the laser-based reference sound source

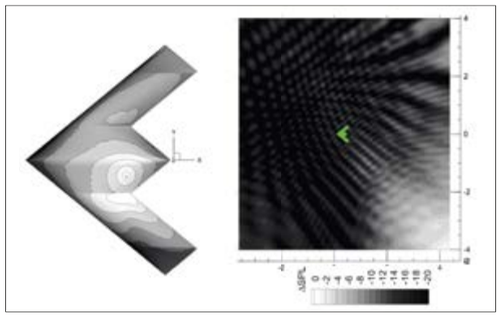

Fig. 4: Simulation of noise shielding

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Atmospheric propagation of multi-mode radiation

The German Aerospace Center has developed various numerical methods for studying atmospheric turbulence-induced propagation of high-energy lasers with regard to its effects on potential applications. The intensity distribution of such lasers has been simulated, based on decomposition into a multitude of different modes. This approach has led to recommendations for potential system designs.

Laser-based weapon systems are growing in importance for the Bundeswehr. To advance the development of such systems, it is necessary to have a profound understanding of how relevant system parameters interact. Where the performance of laser effectors is concerned, this includes the beam director, laser power, beam quality and total number of beams used. The German Aerospace Center (DLR) has developed and evaluated a general-purpose numerical algorithm for turbulent atmosphere-induced laser beam propagation to identify system design requirements.

The development of high-energy lasers has advanced significantly in recent years. Lasers with an output power of several kW and a good beam quality are available commercially. Nevertheless, for many applications including laser effectors, significantly higher laser outputs are required. This can be accomplished by combining several laser beam sources, for example. The resultant power distribution may vary considerably, however, depending on the laser system and the weather conditions at the time. To be able to compare different weapons systems with one another it is hence necessary to have a general approach available for modelling the power distribution propagation that turbulent atmosphere can cause.

The beam propagation ratio is an established concept for characterising beam quality. The beam quality generally decreases with an increasing number of modes contributing to the laser power. Any physically realistic simulation of high-power laser propagation through turbulent atmosphere thus requires knowledge of how many modes the beam profile actually contains. But since this depends on the laser design, such an approach is not generally feasible. It is, therefore, desirable to develop a universally applicable method that allows the simulation of beam characteristics without knowledge of the real mode distribution.

The concept being pursued by the DLR is based on so-called Gauss-Schell modes where the intensity is composed of a multitude of Gaussian distributions (intensity profiles) that have a smaller but identical width, and whose centre of mass has shifted, such that their incoherent superposition is identical to the original intensity. Using this approach, it is possible to freely model the beam quality irrespective of other parameters. All the relevant beam characteristics can be modelled with this algorithm, as has been demonstrated through comparisons with physically realistic methods and analytical predictions.

Alternative methods have also been tested within the study. Some have shown themselves to significantly reduce the computation time, while others have followed a complimentary approach based on raytracing. All of the developed algorithms have displayed encouraging results and will be of use with regard to potential applications in the near future.

The simulation results reveal that the laser intensity at the target is essentially dependent on all the important system parameters (beam quality, beam director size, number of coupled laser sources and their respective outputs). When comparing systems with an identical total power output, these parameters determine whether a system comprising a single laser with a high power output (but a low beam quality) or multiple coupled lasers with a weaker power output (but a higher beam quality) achieve a higher impact at the target. The knowledge acquired through this study will allow the DLR to give sound recommendations on strategic matters relating to future laser weapon system designs.

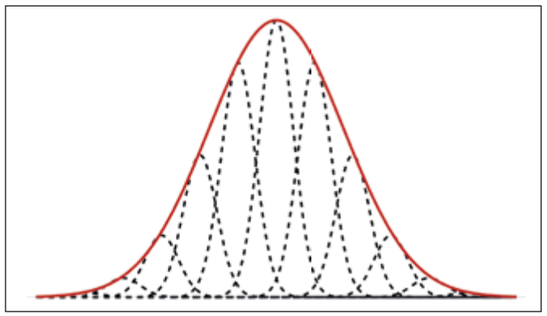

Fig. 1: Decomposition of laser intensity into Gauss-Schell modes

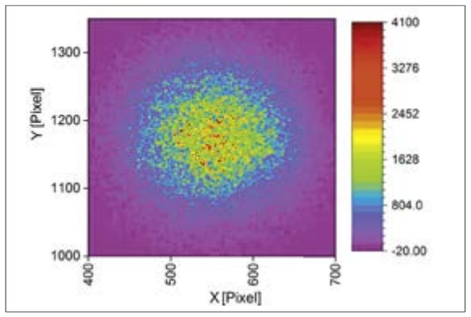

Fig. 2: Experimentally determined beam intensity

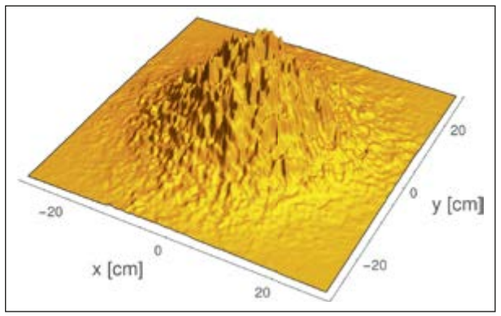

Fig. 3: Numerically simulated beam profile

Fig. 4: Beam propagation experiment on laser test range

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Laser tracking systems

Laser tracking systems are suitable for use in aerospace and defence applications as a means of object detection, position determination and identification as well as directing laser effector beams onto distant objects. Close-range use over distances of a few kilometers or for objects in Earth orbit leads to different agility and tracking accuracy requirements.

The Institute of Technical Physics of the German Aerospace Center (DLR) develops, tests and characterises laser tracking systems for various aerospace and defence applications. These systems are set up in receiver and laser transmitter configuration and operated in a laboratory as well as in an outdoor environment on atmospheric test ranges. A particular focus of the current research and development activities is on tracking and determining the position of non-cooperative targets in airspace for subsequent aim-pointing of a laser effector beam onto the target.

Tracking flying objects typically requires very agile platforms that combine high angular acceleration and velocity with accurate position determination. Standard astronomical mounts are not entirely suitable and need to be optimised in terms of their agility and real-time performance. Typical non-cooperative targets in airspace include UAVs (unmanned aerial vehicles), which particularly have a small radar signature due to the absence of metallic structures and are correspondingly difficult to locate.

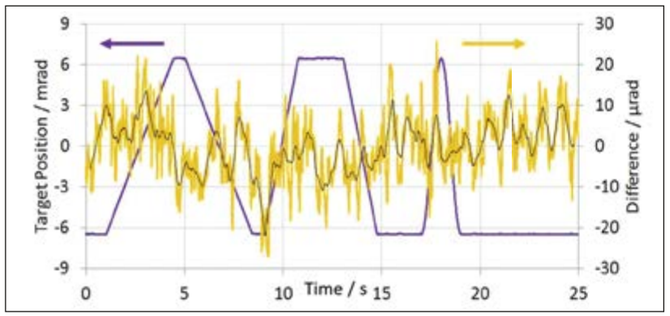

Fig. 1: Temporal motion profile of the linear stage with mounted cooperative target (purple) and corresponding measurement error of the mobile optical tracking system (yellow)

Fig. 2: Linear stage in the receiving station of the atmospheric propagation test range

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The Institute of Technical Physics has set up a mobile optical tracking system as a technology demonstrator to assess the requirements and potential for localising non-cooperative targets in airspace with laser tracking methods. This research platform allows the tracking and precise position determination of remote flying objects. Its sensor system comprises a tracking camera and a measurement camera in bistatic design. The tracking camera has a large field of view of up to 34°, while the measurement camera with its telephoto lens has only a small field of view of 0.4° to provide highly accurate angular position data on the tracked object. An in-house optimised direct-drive mount in alt-azimuth configuration serves as a pan-tilt platform. Angular velocities of 0.4 rad/s and angular acceleration values of 0.8 rad/s^2 have been routinely achieved following the optimisation. The tracking precision and the dynamic characteristics of the optical tracking system have been evaluated on the Institutes test range, which has an outdoor propagation length of 130 m between the transmitting and receiving station and permits the characterisation of optical tracking systems under atmospheric conditions. A high-precision linear stage installed in the receiving station allows assessment of typical object movements. It is equipped with high-precision optical encoders, enabling determination of the actual object position as a reference measurement. A dynamic accuracy of 10 µm or better is achievable, even for object accelerations of up to 6 g. The performance capability of the optical tracking system has been verified using a laser-illuminated target, it being possible to run different motion patterns to simulate a moving target. For angular acceleration values of up to 125 mrad/s^2, the average excursion from the real position of the object has been less than 10 µrad (RMS), this being due primarily to turbulence effects along the outdoor propagation path.

These results demonstrate the potential for determining the position of objects in airspace by means of optical measurement methods. The planned implementation of a laser-based time-of-flight sensor will complement the tracking platform and ultimately allow precise three-dimensional localisation of flying objects.

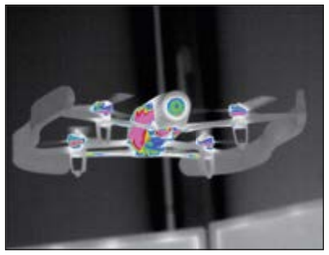

Fig. 3: Thermal signature of a flying UAV

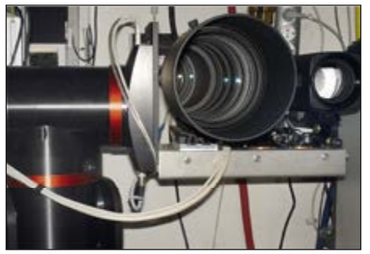

Fig. 4: Mobile optical tracking system

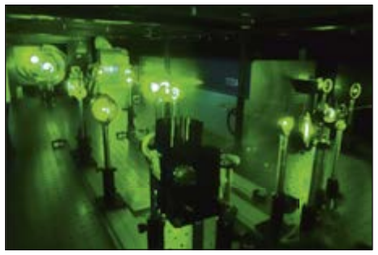

Fig. 5: Target illumination laser setup

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Metamaterials for microwave radomes

Metamaterials are seen as a promising enabling technology for a broad variety of defence and security-relevant applications. They can be used, for example, in the design of microwave radomes to improve the performance of enclosed antennas or to add new features to radomes, such as frequency- and polarisation-selective transmission.

Metamaterials (MTM) consist of a periodic array of metallic or dielectric inclusions in or on a dielectric substrate. Both the inclusions themselves and the distances between them are small compared with the wavelength of the incident electromagnetic radiation, so that the MTM acts like a homogeneous material. By suitably matching the shape and size of the inclusions, the period of the array and the substrate properties, it is possible to realise desired electromagnetic material constants that do not occur in natural materials.

Structures that are formed from only a single layer of inclusions are referred to as meta-surfaces (if impenetrable) or meta-sheets (if penetrable), (Fig. 1). In contrast to voluminous MTMs, these can be created as printed circuit boards, by etching off copper sheets laminated onto a non-conductive substrate. Despite their being thin, meta-sheets can be used to control electromagnetic fields in a great variety of ways through the choice of the inclusion shapes. Furthermore, using lumped elements, e. g. diodes, ferrite insertions and liquid crystals, leads to tunable MTM structures.

An important advantage of MTMs over frequency-selective surfaces (FSS) is the absence of side lobes in the reflected and transmitted fields.

A radome is an integral part of many antenna systems, protecting the actual antennas and their electronics from hostile exterior conditions (humidity, ice, heat, space debris, electromagnetic interference, etc.) or personnel from rotating mechanical parts. Radomes are also important for reducing the aerodynamic drag of antennas, e.g. on aircraft, or for their optical concealment. An ideal radome should be fully transparent, i. e. lossless and non-disturbing the wavefront. Real radomes, however, are only partially transparent, which negatively affects the directivity, bandwidth and gain of the enclosed antenna. In consequence, the operating range of the radar system may suffer and boresight errors arise.

Placing a specially designed meta-sheet within the radome, e. g. directly on the radome wall, can not only improve transmission through the radome but also add new features (such as polarisation and frequency selectivity; correction of phase distortions; polarisation transformations, e. g. from linear to circular or vice versa; non-reciprocal one-way transmission; the ability of the radome to be switched on/off). Such novel radome systems are referred to as “meta-radomes”. Figures 2 and 3 illustrate the use of a meta-radome in correcting the front of the wave transmitted through the radome, thus decreasing the boresight error, (Fig. 2), or in reducing electromagnetic interference (EMI) from other nearby antennas or external sources (Fig. 3).

An example of a frequency- and polarisation-selective meta-sheet and the corresponding transmission curves are shown in Figs. 4 and 5. The structure has been designed for the X-band frequencies and comprises a periodic array of copper strips (8.21 mm by 2 mm), with a unit-cell size of 14 mm, printed onto a 2 mm thick FR4 layer. The transmission of the incident wave polarised parallel to the strips (horizontal polarization) is blocked almost completely at around 10.3 GHz, while a wave polarised perpendicularly to the strips (vertical polarization) passes through the meta-sheet almost undisturbed.

The use of metamaterials in microwave radomes is a new field of research that will require extensive development work with regard to their modelling, design and fabrication for realistic antenna systems.

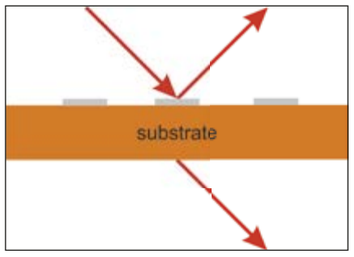

Fig. 1: Meta-sheet as a thin layer of dielectric material with a periodic array of metal inclusions on top to control reflection and transmission of microwaves

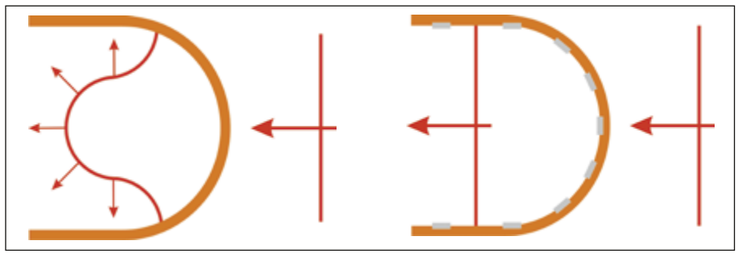

Fig. 2: Correcting the transmitted wavefront with a meta-sheet applied to the interior of the radome wall

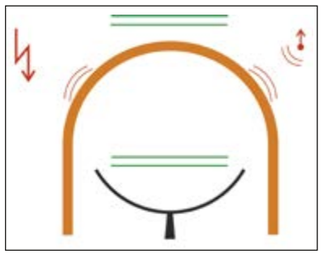

Fig. 3: Meta-radomes for reducing EMI. The radome is penetrable in the frequency band and for polarisation of the enclosed antenna but impenetrable for interfering signals from nearby antennas or other sources

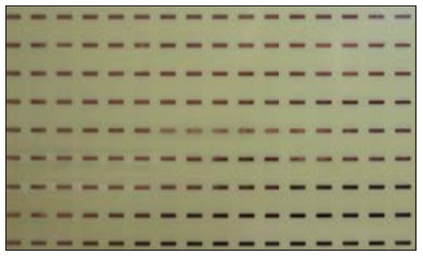

Fig. 4: A frequency- and polarisation-selective meta-sheet realised as a periodic array of copper strips printed on top of FR4 substrate

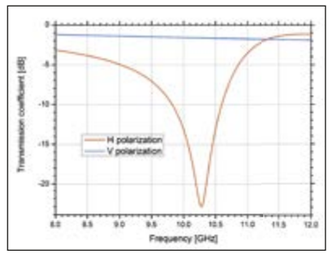

Fig. 5: Transmission coefficients of the meta-sheet shown in Fig. 4 for horizontal and vertical polarisation as a function of frequency

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Electromagnetic railgun – a future weapon system

The electromagnetic railgun will be a future weapon system with disruptive potential in terms of lethality and protection. The improvements achievable in regard to range and effect will complement and expand the capability spectrum of traditional guns considerably. A key system component in need of development because of specific requirements is the power supply.

While the successes of the US Navy in developing a demonstrator, such as generating a muzzle energy of 32 MJ, have been in the public spotlight, it is less well-known that leading-edge research in this field is also being conducted in Europe and in Germany, especially, under the responsibility of the latter's Federal Ministry of Defence (FMoD). For many years the Franco-German Research Institute of Saint-Louis (ISL) has been working on railguns and studying the "overall railgun system", ranging from operational scenarios to the power supply chain and development of projectiles. Whereas for powder guns the muzzle velocity v_0 is limited by the sound velocity of the propellants to approximately 1800 m/s, railguns can attain a muzzle velocity v_0 of more than 2300 – 3000 m/s. Current R&T activities at ISL are focusing on two important operational scenarios in the naval field where railguns will play a crucial role in future: as a long-range naval artillery system (150 km and more), and as a means of defence against already existing hypersonic anti-ship missiles – a challenge confronting current on-board defence systems. Civilian applications, such as launching microsatellites, will also gain in importance in future.

To develop a railgun, it is necessary to consider all aspects of the system, ranging from the available supply of primary energy that ultimately has to be converted into kinetic energy as part of an energy transfer chain, through to the design of guided projectiles. A compact and weight-optimised power supply is of key importance in this respect. Laboratories all over the world use capacitive energy storage devices nowadays that are available commercially (Fig. 1). ISL is therefore working on alternative storage technologies (for example, inductive storage units with, by comparison, a ten times higher energy density, Fig. 2) and on the optimisation of components, such as the design of new semiconductor switches and control electronics which, compared with conventional switches, will offer benefits relating to size, efficiency and real-time diagnostics during railgun operation.

Where the realisation of enhanced long-range naval artillery is concerned, ISL has recently achieved two extremely important breakthroughs. Firstly, the facility shown in Fig. 1 has demonstrated that the efficiency level of a railgun (ratio of kinetic energy to used electric energy) can exceed 65 %. This is a world record in internal ballistics and a factor of 2 higher than the efficiency of powder guns (ratio of kinetic energy to the energy released during the chemical reaction of the propellant). Secondly, it has been possible in Europe for the first time to use a railgun to launch 40 mm calibre projectiles with functioning sabot features (Fig. 3).

Studies conducted to realise a CIWS (Close-In Weapon System) based on a railgun have proven to be very promising. The RAFIRA (RApid FIre RAilgun) system illustrated in Fig. 4 has yielded unequalled performance data worldwide, accelerating 25 mm calibre projectiles with a mass of 100 g up to a muzzle velocity of v0 = 2400 m/s over a rail length of only 3 m, which is considerably superior to Gatling-based CIWS such as Phalanx or Goalkeeper. The RAFIRA's rate of fire can reach 75 Hz, with the possibility of delivering intelligent bursts of fire by varying the muzzle velocity v0 and the interval between two successive shots being particularly worthy of mention.

ISL intends to expand its range of research studies significantly in future. Besides internal ballistic issues such as material wear, ISL will be focusing on transitional, external and terminal ballistics aspects of projectiles launched by a railgun.

Fig. 1: 40 mm calibre ISL railgun with a 10 MJ power supply

Fig. 2: Under construction: toroidal inductive storage device with an energy capacity of 1 MJ

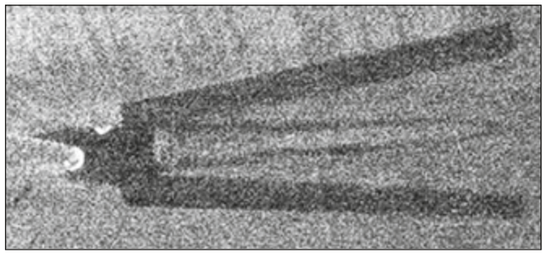

Fig. 3: Projectile with penetrator in free-flight motion and sabot opening up

Fig. 4: 25 mm calibre railgun capable of firing bursts

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Materials allowing detection of ultrafine explosive traces for the purposes of civil and military security

Detecting ultrafine explosive traces and selectively differentiating between individual explosives in the context of safeguarding security in public places and military conflict zones is a specific challenge confronting scientific research. The NS3E laboratory at ISL is working on two approaches in this regard that in future can be combined with one another – a bio-inspired concept for detecting vapours from explosives, and the nanocalorimetry method for detecting single particles of explosives.

In parallel with research on nano-based explosives, the laboratory at ISL is developing modern bio-inspired detection methods. Serving as inspiration for this are the selective and sensitive antennas of a silk moth, Bombyx Mori (Fig. 1). The male moth is able with its fine antennas to intercept pheromone molecules and thus detect female moths at a distance of up to 10 km. Based on a similar principle, ISL's NS3E Laboratory has modified the surface of sensing cantilevers of an atomic-force microscope with oxide nanotubes (Fig. 2). These bio-inspired "antennas" are capable of detecting specific molecules of diverse products, such as explosives or gas warfare agents. Detection takes place by analysing the resonance frequency variations of the sensing cantilevers, brought about by the adsorption of explosive molecules on the artificial "antennas". This measurement approach is currently able to attain a detection threshold value of a few ppt (parts-per-trillion, $1/10^{12}$). This concentration value is equivalent to one single molecule of explosive detected in a volume of a thousand billion gas molecules. The aim is to lower this threshold value even further in the near future. This technology offers the foreseeable prospect of detecting a wide variety of substances such as gas warfare agents or explosives and will thus be indispensable particularly in crisis areas. Given the small dimensions of these sensors and their possible integration in UAVs, drones or other autonomous vehicles, a multitude of other potential applications present themselves. This technology could also feasibly be used in a great many civilian applications such as for detecting and identifying ultrafine traces of hazardous substances in public rooms and buildings.

Where detection by nanocalorimetry is concerned, most technologies under development for addressing volatile chemicals permit either the detection of a large spectrum of different chemical compounds that cannot be distinguished from one another or the detection of one specific compound. It is, however, of crucial importance for innovative technologies to ensure both the detection and simultaneous identification of a few specific compounds, even when various interfering compounds are in the air. With chip calorimetry, particles of explosives can be identified and distinguished from one another in the solid state. This is done by rapidly heating single particles or a low mass of material (in the femtogramme range) deposited on a silicon nitride membrane and then heated at rates up to 10^6 K/s. The outcome is a thermal signature which is specific to each explosive. Recent research at the NS3E laboratory has shown that chip calorimetry is even suitable for identifying the nature of an explosive previously adsorbed on a porous material. For example, performing rapid heating experiments with copper oxide nanoparticles previously subjected to either hexogen (RDX, Research Department Explosive) or pentrite (PETN) vapours yielded a thermal pattern, depending on which explosive had already been adsorbed. Every explosive adsorbed on a nanomaterial has its own specific thermal signature which, when it desorbs, can then be identified. The nanocalorimetry technique thus makes it possible to discriminate between these two separately adsorbed explosives.

The research results presented here demonstrate that the NS3E Laboratory at ISL is close to perfecting this technology for industry.

Fig. 1: Male Bombyx Mori silk moth with antennas (photo: Scienceimage CSIRO).

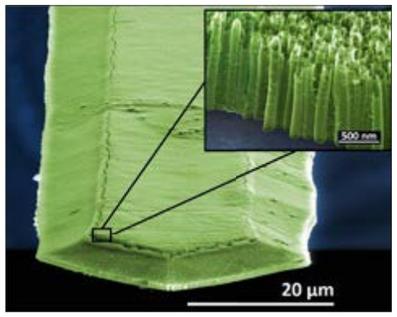

Fig. 2: Tip of a cantilever modified with metal-oxide nanotubes for the detection of explosives

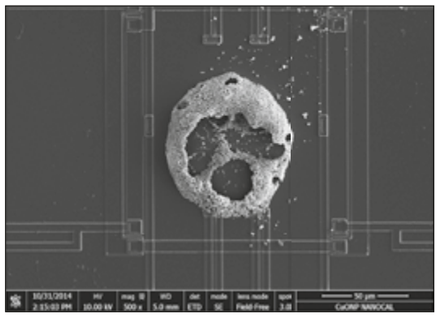

Fig. 3: CuO copper oxide material on the nanocalorimeter sensor after RDX decomposition inside the CuO matrix. The holes are created by the highly energetic dissipation of RDX molecules outside the matrix during rapid heating

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Multi-camera system for fire safety in military vehicles

The fire suppression systems currently in service in Bundeswehr vehicles will have difficulty in meeting future requirements. One reason for this is the sensors they use, because they provide only minimum information about the fire. A new approach will now make it possible to detect fires in vehicles quickly, reliably and more accurately than before.

The Bundeswehr is being confronted with ever more complex hazard situations on its deployments abroad. Its vehicles are equipped with a multitude of safety systems to protect its servicemen and women. One of them is a fire suppression system, which serves to extinguish static as well as highly dynamic fires (such as deflagration) in time and thus avoid greater personal injury and material damage.

Although the sensor systems used nowadays to detect highly dynamic combustion processes are very fast to respond (< 15 ms), they do not provide any additional information about the fire, such as its location, size and direction of propagation. Given that halon cannot be used as an extinguishing agent anymore and the fact that no adequate and environmentally compatible substitute has as yet been found, future extinguishing agents (such as water mist) will have to be used more effectively, i. e. as directly as possible at the location of the fire, making further information about the fire indispensable.

The requirement of detecting fires within only a few milliseconds of them occurring will pose a special challenge to any future sensor system. They should be very sensitive when it comes to detecting fires, yet also not generate any false alarms, if possible.

An approach being pursued at Helmut Schmidt University / University of the Federal Armed Forces Hamburg (UniBw H), together with the Bundeswehr Research Institute for Protective Technologies and CBRN Protection (WIS) aimed at detecting highly dynamic combustion processes consists in monitoring the vehicle crew compartment with several distributed cameras, thus allowing the possibility not only to detect whether there is a fire inside the vehicle but also to determine its position and size. As the system is based on cameras which operate in the visible spectrum of light, the hardware costs are manageable, although special capabilities are required where the image processing is concerned.

To keep the latter as simple as possible and thus fast, consideration has been given to a suitable detection algorithm designed in an already completed research project whose results were already very promising but the processing time too long at 54 ms per camera frame. There were also very frequent false alarms, triggered for example by incident light from a flashlight, culminating in a false alarm rate of around 20 %.

By parallelising and optimising the algorithm in an ongoing research project at the UniBw H, it has been possible to reduce the processing time to less than 4 ms per camera frame, thereby fulfilling the real-time requirements. Further enhancements which ensure more reliable and accurate fire detection as well as exclusion of sources of interference that may lead to false alarms, such as flashlights, rotating lights, fire-coloured moving objects, etc, have also been explored and implemented. The false alarm rate has been reduced to less than 3 %, which is a significant improvement but still too high for any future application. The recently implemented parallel analysis of the image data from the distributed cameras now makes it additionally possible to determine the location of a fire within the required 15 ms. A first fire volume estimation has also been achieved, based on which the necessary amount of extinguishing agent can be calculated.

As the research results to date have been promising, the UniBw H and the WIS intend to continue their research into new kinds of sensor systems for preventing and tackling fires in military vehicles.

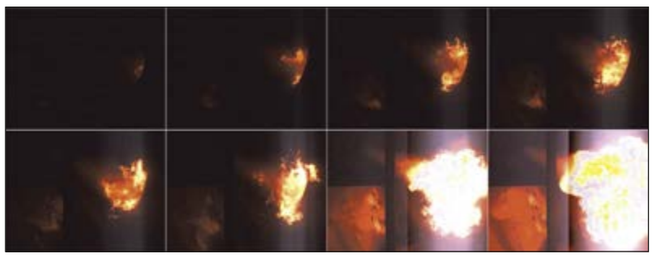

Fig. 1: Images of a diesel deflagration inside a test vehicle at intervals of around 28 ms (development of the deflagration line by line, from top left to bottom right)

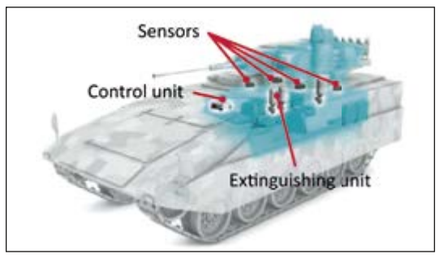

Fig. 2: Fire suppression system in a tank

Fig. 3: Functional principle of a fire suppression system

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Study on “Applied Knowledge Management in the Federal Armed Forces”

The implementation of a socio-technical knowledge management approach is currently being tested as part of a study on ”Applied Knowledge Management in the Federal Armed Forces”. The concept includes the design of virtual spaces for interaction to support asynchronous cooperation between separately located actors in project- and process-oriented work within the Federal Armed Forces.

The restructuring of the Federal Armed Forces has been shaped by, among other things, the centralisation of specialised capabilities, permitting streamlining of the Armed Forces as well as extensive cost savings. Specialised knowledge bearers for central supporting functions (e. g. logistics, Medical Service) are, however, no longer equally distributed across the different capability areas of the Federal Armed Forces, and the size and diversity of the Armed Forces’ tasks have also greatly increased. These factors are today adding to the complexity and dynamics of internal processes and projects in the Armed Forces (e. g. procurement processes, planning and implementation of exercises, missions). Knowledge and expertise bearers from across the Federal Armed Forces work in many cases at different locations for limited time periods on specific activities and projects in asynchronous cooperation processes. Efficient identification, sharing and retention of knowledge is becoming a key factor in the accomplishment of missions.

Since 2013, the Laboratory of Production Engineering at Helmut Schmidt University; Hamburg, has been conducting a study on ”Applied Knowledge Management in the Federal Armed Forces“ under the direction of Prof. Dr.-Ing. Jens Wulfsberg. The aim of this study is to explore the potentials of modern ICT technologies for promoting an efficient transfer of knowledge across departmental and organisational boundaries in know-how-intensive processes and projects in the Federal Armed Forces. There are diverse potentials for safeguarding the transparency of missions, roles, tasks and objectives for all involved in such complex and dynamic projects and processes throughout the work cycle as a whole and for ensuring the retention and availability of knowledge over the long term.

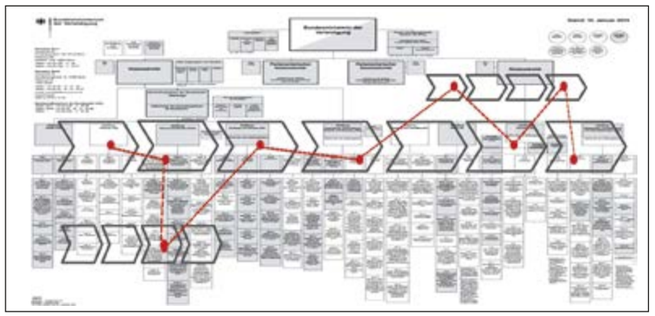

Fig. 1: Highly complex cross-functional processes and projects in the Federal Armed Forces

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Groupware and social software offer an IT solution in this regard, enabling the creation of virtual interaction spaces within which decentralised actors have extensive possibilities to interact and communicate (e. g. through web meetings, video chats, instant messaging, blogs) as well as coordinate their activities (e. g. through collaborative document processing, activities, wikis). The personnel of the Federal Armed Forces already have access to an efficient collaboration tool in the form of IBM Connections, which offers diverse potentials for designing virtual interaction spaces. Also, a procurement process called “Groupware Bw” has been initiated with a view to servicing prospective requirements. Collaboration tools are becoming more and more relevant in the daily working routine of the Armed Forces personnel. To date, however, the potentials offered by the IBM Connections application have been used only to a limited extent.

In the study four central fields of action have been identified for increasing productivity (and transparency) by using this software in the Federal Armed Forces:

- standardisation of knowledge work processes,
- development and establishment of new roles,
- modifiable functional project-specific design of the virtual interaction spaces,
- reduction of knowledge barriers and of barriers in implementation processes.

Consideration of these fields of action as well as implementation of the technical requirements (groupware, social software) are crucial for the integration of a process-oriented, socio-technological knowledge management approach. In particular, training will be necessary for those actors who will be responsible for the operational side of the project and process work. The Laboratory of Production Engineering team is working closely together with the branch of the Federal Ministry of Defence responsible for management development and is currently supporting the implementation of IBM Connections in the Executive Group Information Centre of the Federal Ministry of Defence.

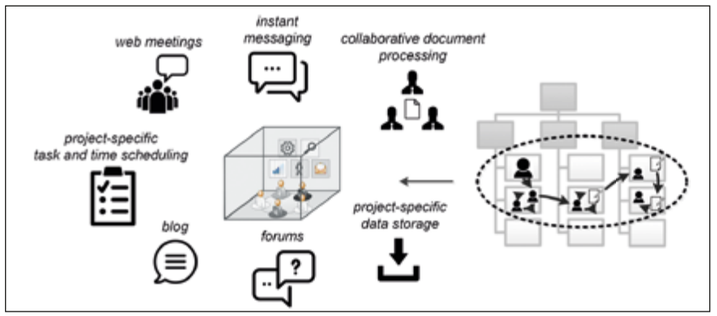

Fig. 2: Demand-oriented cross-functional pooling of decentralised actors in virtual interaction spaces

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Dynamic micro actuator system based on electrorheological fluids

Installation space is nowadays an important commodity, which is why components are being scaled down and decentralised. This results in weight savings and additional installation space, which can be used for other components. The use of 'smart' fluids such as electrorheological fluids can, moreover, reduce the number of components and, thus, susceptibility to malfunction.

Electrorheological fluids (ERF) are suspensions, e. g. of silicone oil and polyurethane (PUR) particles, whose flow behaviour can be rapidly and reversibly changed. This change, also known as the ER effect, can be brought about with the aid of an applied electric field. The PUR particles, because of their polarity, form chains along the field lines of the electric field. This leads to a viscosity increase, which can be used, for example, in valves or dampers. Such an increase will almost block the flow channel of a valve and generate a pressure difference.

The goal of the ongoing project is to develop a micro actuator system with micro ER valves and mobile supply unit. The micro ER valve is characterised by a higher force density compared with conventional valves, which is achieved by self-amplifying and realised through a change in the cross-section of the flow channel. The valve is part of a micro actuator system which boasts a high degree of integration. The small distance between the valve and actuator makes shorter response times possible.

The lower hydraulic volume requirement means a reduced hydraulic capacity and inductance. Several of these actuator

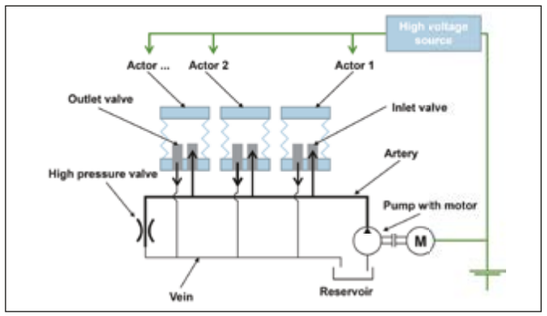

Fig. 1: Schematic diagram of the micro actuator system

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systems incorporating ER valves are designed for mobile operation using a central supply unit, which provides the requisite high voltage as well as ER fluid.

Possible applications include systems that require compact actuators with a high positioning force and high travel distances as well as a wide frequency range extending from a few hertz to around 500 hertz. Hydraulic systems with a high power density and central power supply are needed in missile control systems, for instance. A micro actuator system offers weight and dimensional advantages over hitherto used systems. Improvements are, furthermore, possible in closed- and open-loop controls through high actuating frequencies. The system might be useful in supporting locomotion, for example in exoskeletons for soldier mobility augmentation. Light and compact systems with a central power supply are vital for such exoskeletons. By supporting and reinforcing the lifting or transporting of loads, long distances can be overcome without great fatigue. Another field of application is that of sound generation. The possible frequency range is suitable for many applications aimed at actively reducing air- or structure-borne sound. In this regard, conventional electromagnetic loudspeakers would have to be large and heavy in order to produce low-pitched sounds. For sound reduction in aircraft cabins, for instance, a large number of actuators is required, something which can be realised with small actuators with a high power density and a central power supply.

The ongoing project can serve to shed light on how to improve the design with regard to the pressure difference that is achievable as well as suitability for production. The components need to be coordinated better when linked together in order to achieve a higher performance. Research with regard to the use of other ER fluids is also imaginable.

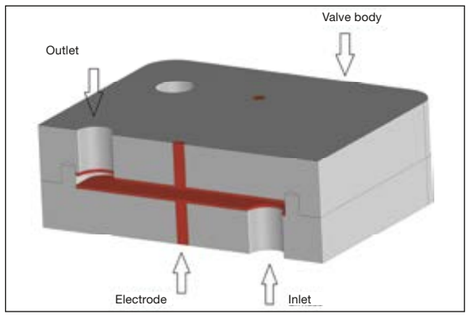

Fig. 2: Micro ER valve

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Highly Automated Driver Assistance Systems for Offroad Scenarios

Unmanned ground vehicles (UGVs) offer the opportunity to reduce the risks and cognitive burdens confronting military personnel. The Military European Land Robot Trial (M-ELROB) is organised every two years to evaluate the state of the art. Bundeswehr University, Munich (UniBw Munich) took part in M-ELROB 2016 with the robotic vehicles TULF and MuCAR-3 in the Convoy and Mule scenarios.

The M-ELROB scenarios are motivated from the perspective of military and civilian disaster control. They include unmanned reconnaissance in damaged buildings, the recovery of injured persons, and the driverless transportation of goods in a convoy or along trained routes (Mule). In comparing robotic platforms' capabilities, however, the organisers are less intent on electing a winner than on demonstrating the platforms' current possibilities and limits in real scenarios.

At M-ELROB 2016, held at the Tritolwerk CBRNE training facility in Austria, only the two mentioned transport scenarios were suitable for larger test vehicles.

The Institute for Autonomous Systems Technology of UniBw Munich was represented by its MuCAR-3 robotic vehicle in both scenarios. It additionally took part with the TULF vehicle in the convoy scenario as a member of the Smart Military Vehicles (SMV) team together with Diehl Defence and Hentschel System. Large parts of the algorithms in use were developed within the scope of BAAINBw (Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support) financed studies.

Fig. 1: Convoy scenario of M-ELROB 2016: aerial image of the competition area showing the path driven (blue), waypoints in a pregiven order (yellow) and mapped warning signs (orange)

Fig. 2: TULF ("Technologieträger unbemanntes Landfahrzeug", or Unmanned Land Vehicle Technology Demonstrator) stops in front of a dynamic obstacle during the convoy scenario. The sensors used for automated following are labeled

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In the first scenario a convoy had to complete a course over grasslands, field and gravel roads (Fig. 1). The driver of the guidance vehicle was given a map with waypoints that had to be passed in the correct order. The autonomous vehicles are equipped with various sensors (Figs. 2, 4), which are used in the algorithms for tracking the guidance vehicle. A model-based tracking algorithm matches previously learned 3D feature models to camera and LiDAR (light detection and ranging) data. Another algorithm works on 3D point clouds. Automotive radar and LiDAR sensors additionally provide several object hypotheses. To increase robustness, all information is processed by a downstream object-based data fusion algorithm (OBDF) (Fig. 3). Based on the OBDF results, a trajectory for automated lateral and longitudinal vehicle control is generated which is then followed using a drive-by-wire system.

The TULF (Fig. 2) uses the same software modules for vehicle tracking as well as the OBDF. Positional information from vehicle-to-vehicle communication is also used, this being of great advantage particularly if the leading vehicle leaves the field of view.

MuCAR-3 took first place in the convoy competition without any manual interventions, and the TULF achieved second place. The evaluation was based on the distance driven autonomously as well as on a subordinate reconnaissance task ("find orange signs marking hazardous materials, then map them and provide pictures").

The second scenario, Mule, is divided into two Teach-And-Repeat phases. In the first phase an autonomous vehicle learns and maps a path between two camps (teach-In, Fig. 4). In the second phase the vehicle repeatedly shuttles autonomously between the camps. For the teach-in phase, the LiDAR tracking version was optimised to detect and track persons (the guide). While the vehicle shuttles between the camps, the organisers repeatedly block individual parts of the route, making the implemented behaviour more complex since the vehicle has then to find alternative routes autonomously. The challenge in the Mule scenario thus lies mainly in the (re-)planning and navigation algorithms and in finding suitable paths and drivable terrain. The evaluation criteria were similar to those for the convoy scenario. MuCAR-3 shuttled more often than all the other teams and achieved first place, ahead of the SMV team in second.

To support the LiDAR technology in future, the use of stereo cameras in combination with hyperspectral cameras will be explored to a greater degree, possibly allowing identification of the material properties of recognised obstacles.

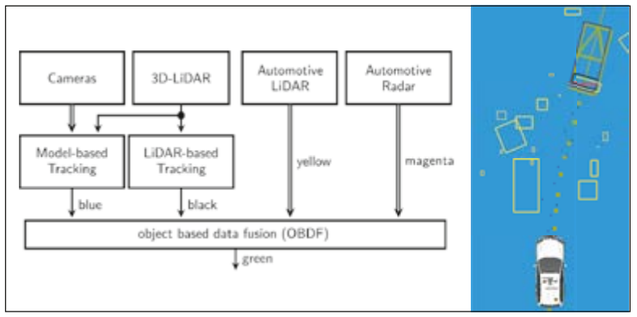

Fig. 3: Object-based data fusion in the convoy scenario: schematic overview of the data flow (left) and a typical scene with visualisation of the tracking results, including path driven by the guidance vehicle (right)

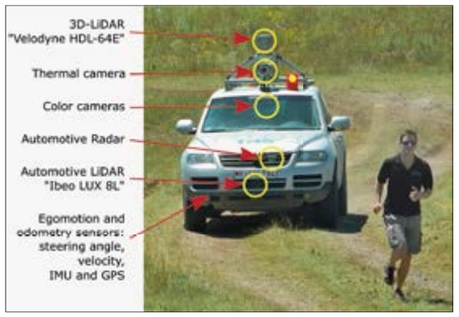

Fig. 4: Teach-in phase of the Mule scenario: MuCAR-3 automatically follows a person. The sensors used in the scenarios are labeled

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Thermal analysis of toxic chemicals and compounds typically found in explosives

Toxic chemicals and compounds typically found in explosives pose a high potential danger. To characterise them, it is crucial to have a sound knowledge of their thermodynamic properties, especially volatility. Experimental determination, in this regard using simultaneous thermal analysis, is thus essential for carrying out risk assessments.

The Chemical Weapons Convention prohibits the production, stockpiling and use of chemical weapons. Not all states have ratified the Convention; however (or ignore their commitments). Recent events such as the use of sarin, a nerve agent, in the Syrian civil war show that chemical warfare agents continue to pose a threat. It is one reason why there is increased demand for the further development of capabilities to defend against hazardous chemical agents as well as for the improvement of relevant analytical techniques.

Vapour pressure is an important parameter in predicting vapour concentration dynamics following the release of chemical warfare agents. The data gleaned as a result helps to arrive at a risk assessment for defining the safeguards needed to protect deployed military personnel and materiel. The functionality of vacuum-based decontamination techniques as well as the calibration of detection devices rely, furthermore, on having the appropriate thermodynamic data available.

Most explosives and some chemical warfare agents are low-volatile, meaning that they are difficult to detect in the gas phase. A crucial factor for reliable identification is, therefore, proper calibration of the detection device, as well as the availability of a suitable compound database. In the case of biosensors, such as explosive-detector dogs, this takes the form of training and conditioning. False alarms may arise as a result of batch-related composition variations, impurities stemming from production, contamination due to handling, or also through the ageing and decomposition of explosive agents. To take account of these limiting factors, the associated chemical signatures and volatility characteristics have to be known in advance.

In the chemical laboratories of the Bundeswehr Research Institute for Protective Technologies and CBRN Protection (WIS), a simultaneous thermal analysis (STA) device has been adapted to determine basic thermodynamic parameters of toxic chemicals and compounds typically found in explosives (Fig. 1). Analysis is based on differential scanning calorimetry (DSC), which records the difference in the amount of heat required to increase the temperature of a sample in relation to a reference. The change in mass of the sample is simultaneously monitored as a function of temperature and / or time through thermogravimetry (TG).

STA measurements of compounds typically found in explosives have been carried out to develop a reference database. A typical thermogram reveals the characteristic phase transitions, thermal stability and decomposition behaviour at ambient pressure, shown for trinitrotoluene in Fig. 2. The vapour pressure for low-volatile explosive compounds is measured indirectly by monitoring the mass loss as a function of time under isothermal conditions.

Where more volatile chemical warfare agents are concerned, direct measurement of vapour pressures is possible by means of isobaric DSC (Fig. 3). The vapour pressures of the sulphur mustard (HD) blister agent, the photocatalytic degradation product HD disulfide and the hydrolysis product thiodiglycol (TDG) have been determined within the scope of a research study. The corresponding pressure-temperature diagram is shown in Fig. 4. The two HD degradation products display significantly lower vapour pressures than the actual warfare agent and are therefore more persistent.

Future research activities will focus on the effects of additives and impurities on the vapour pressure of toxic chemicals and explosive agents. Augmentation of the STA apparatus to include emission gas analysis capabilities is additionally planned, with a view to collecting further information on decomposition behaviour through the detection of thermal degradation products.

Fig. 1: Simultaneous thermal analysis (STA) apparatus for performing TG-DSC measurements

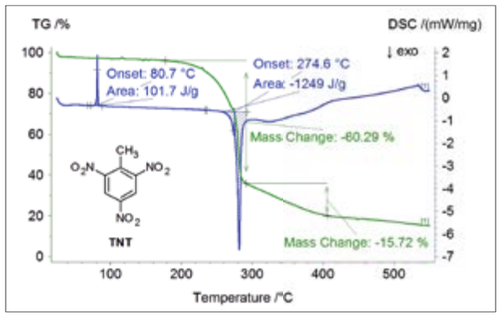

Fig. 2: Simultaneous TG-DSC measurement of trinitrotoluene (TNT). The thermogram shows endothermal melting (positive DSC peak, blue curve) and exothermal decomposition (negative DSC peak, blue curve) accompanied by mass loss (TG signal, green curve)

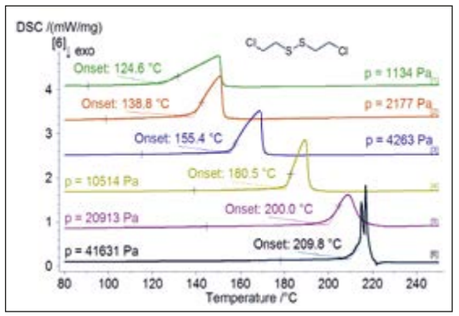

Fig. 3: Isobaric DSC measurements of HD disulfide at varied pressures showing endothermal peaks due to boiling. At the point of boiling, the vapour pressure equals the applied pressure

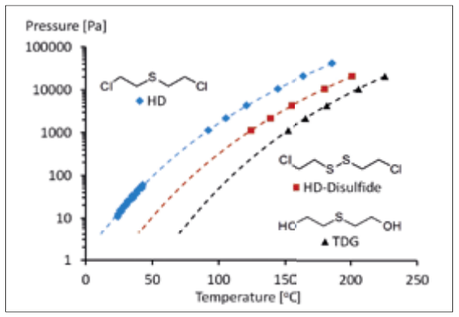

Fig. 4: Pressure-temperature diagram of liquid samples of sulphur mustard (HD), HD disulfide and thiodiglycol (TDG), showing the respectively measured data points and Antoine fit (dashed line)

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Analysis of HPEM disturbance effects on computer networks in a realistic environment

The susceptibility of computer networks to IEMI (Intentional Electromagnetic Interference) has been a well-known phenomenon for some time. Research on the effect mechanisms and assessment of the actual risk potential emanating from marketavailable sources for generating high-power electromagnetic radiation can lead to effective protection measures in future.

Modern civil and military infrastructures would be inconceivable today without the use of digital information technology. Electronic systems no longer perform just simple control functions but link sensors and actors with the aid of suitable software algorithms to form complex systems of systems. Such a high dependence on computer systems, however, also gives rise to new threats for systems and facilities.

Intentional interference by means of high-power electromagnetic radiation – so-called HPEM (High-Power Electromagnetics) – in networked systems within critical infrastructures can influence digital systems so that they no longer function normally (mission kill) or even fail permanently. Civilian interests are, at the same time, driving developments in the field of information technology to such an extent that there are often no special hardening measures beyond the typical safety standards for EMC (Electromagnetic Compatibility) to counter such an HPEM influence.

According to experience the possible impacts of HPEM interference are very wide-ranging. Obvious effects such as flickering screens or frozen computers directly indicate a potential HPEM attack. More problematic, however, are concealed effects, such as data corruption or limited data communication, which are not noticed immediately. These effects apply particularly to networked systems and are hard to localise, yet can nevertheless affect operation quite considerably. Aside from unspecific interference thresholds determined within defined laboratory environments, very little information is available about the behaviour of networked systems within realistic HPEM environments.

To explore possible effects generated by HPEM interference, an Electromagnetic Office Module (EMOM) has been set up as a representative environment at the Bundeswehr Research Institute for Protective Technologies and CBRN Protection (WIS). The module is an office container built of steel-reinforced concrete and is mounted on a heavy-duty trailer. The entire EM Office Module is equipped electrically to VDE (Association for Electrical, Electronic & Information Technologies) standards and prepped, for example, to accommodate a typical office network or also a networked operations centre.

Within the scope of a measurement campaign, a data network consisting of several computers and network components was installed inside the EMOM and exposed to a market-available HPEM source. At the same time the computers were monitored for interference effects, with special attention being paid to data communication within the system network. Used for this purpose was a new test method developed as part of this research project which runs as application software on the computers and also provides precise information about physical interactions of the network with the interfering signals.

Coupling measurements served to verify that the test set-up as a whole is a suitable environment for such experiments.

The results of the experiments showed what threat potential commercial HPEM sources pose to networked computer systems. The findings also apply to military data networks used by the Bundeswehr. No direct visible interference or even damage to the hardware was observed. However, the employed test method did make it possible to observe concealed adverse effects on data communication and identify critical components that, in terms of overall function, can be considered as uncritical. This opens up the possibility for inexpensive, software-based detection of HPEM attacks even before serious consequences arise. In view of the constant further development of HPEM technology, a multilevel protection concept in combination with suitable shielding measures is conceivable.

Fig. 1: EM office module exposed to an HPEM interference source

Fig. 2: Network installation used as a test device inside the office module

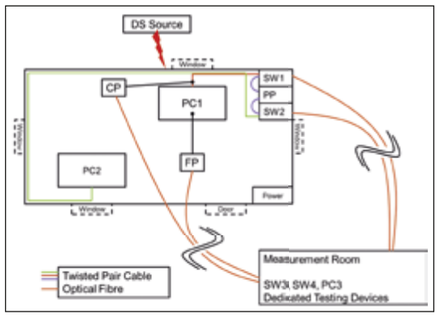

Fig. 3: Schematic view of the network topology and measurement set-up for HPEM susceptibility tests

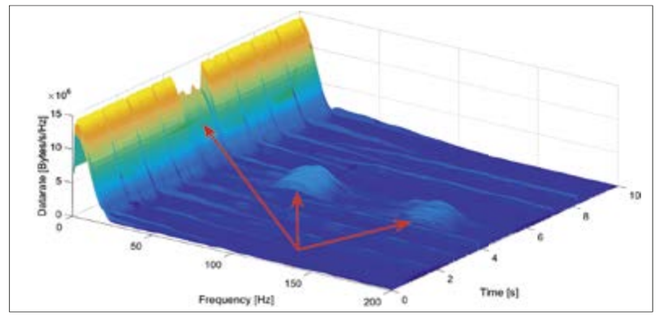

Fig. 4: Spectral analysis of a data transmission as a basis for HPEM detection. Spectral changes during the HPEM exposure are clearly evident

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Future methods for condition monitoring on vessels of the Navy

Worldwide and long-enduring missions are necessitating a change in the utilisation concept for seagoing vessels of the German Navy. It has led to vibration analysis already being performed on selected systems onboard vessels with a view to monitoring their condition. The analysis of vibration data serves the aim of increasing the operational availability of the units and of simultaneously reducing maintenance costs. Overall, 240 systems on six vessels are being constantly monitored.

Through the introduction of vibration monitoring and data analysis, the Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) provides an important service for the Navy in terms of in-service support. Further activities of WIWeB in this field include the identification of future methods for monitoring the condition of lubricated onboard systems. The objective in this regard is to optimise utilisation of the monitored systems based on their actual state, have the ability to initiate overhauls when necessary, reduce maintenance costs, and increase the operational availability of the individual platforms.

Forming the basis for this is a transmission test bench offering the possibility to selectively age different oils in long-term experiments. The test bench parameters have been recorded continuously for later data evaluation. A sensor network based on commercially available, robust online sensors has been set up as a means of monitoring the condition of transmission systems and their oil content.

Fig. 1: F 220 Hamburg, A 1411 Berlin und F 221 Hessen (Source: © 2008 Bundeswehr / Ricarda Schönbrodt)

Fig. 2: FZG test stand with sensor field

Fig. 3: FZG test gear unit

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Through constructional and conceptual modifications to the existing transmission test bench it has been demonstrated in near-realistic conditions that controlled aging of the system is possible within reduced inspection intervals. The online measured data has helped to determine the current condition of the oil and gear unit with a higher resolution and transparency than has been the case by taking samples and analysing them in a laboratory. The large abundance of data has also made it possible to generate a trend forecast for the oil aging progress through linear regression analysis. Based on all the online measured data, the system condition has then been determined by means of multivariate analysis and verified with the aid of diagnostic findings for individual system components.

In addition to a sensor system for recording the operating parameters of the monitored test stand, such as pressure and temperature, three oil sensors have been identified for further use in a future multi-sensor platform. They include an inductive particle counter, a sensor for determining viscosity, and a dispersive infrared spectrometer. This sensor network has permitted the constant measurement of the following state variables:

- water content
- particle concentration (size class)
- oxidation progress
- additive degradation (here: only zinc dithiophosphate)
- base oil viscosity
- alkaline reserve and acid number (Total Base / Acid Number)

As a continuation of the study, the sensors listed above are to be combined in a multi-sensor platform and tested both in the laboratory and on board platforms. It has to be borne in mind, however, that the models for oil and system aging are device-specific, meaning that when new systems are installed with such a monitoring system, the aging models stored to predict the oil and system condition have to be recreated. The use of self-learning algorithms would make it possible to shorten and optimise the adaptation process for a specific system significantly.

The use of a coordinated sensor combination in conjunction with multivariate data evaluation will enable oil and system conditions to already be identified during operation. Unfavourable operating conditions adversely affecting overall service life will thus be recognisable and avoidable, with the expectation of there being increased reliability when predicting the remaining service life.

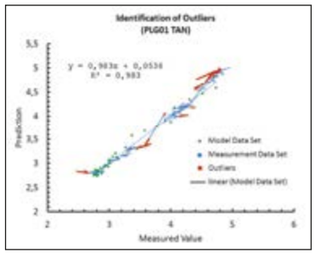

Fig. 4: Truth table for determining outliers, using the example of TAN prediction

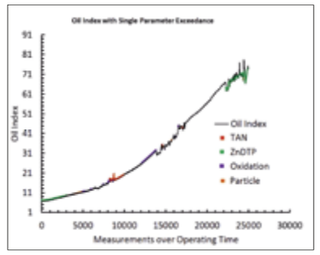

Fig. 5: Oil index and factors influencing system aging

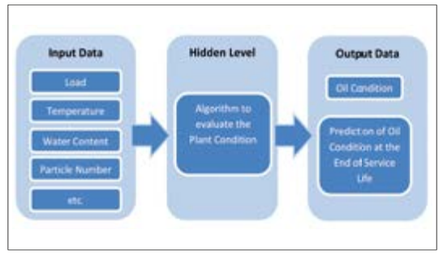

Fig. 6: Functional diagram of the multi-sensor platform for early damage detection

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Dynamic track tensioner

A dynamic track tensioner has been used for the first time on the "Weasel DIOK" chassis demonstrator vehicle available at WTD 41 and is to be tested and optimised in driving trials

Innovative chassis designs for tracked vehicles are being developed in the context of an R&T project titled "Chassis Concepts of the Future". The aim is to enhance the mobility features of existing systems, to ensure that a minimum degree of mobility is preserved in case a track is lost, to facilitate adaptation to different driving conditions – for instance, by adjusting the control parameters for springs and dampers – and to reduce the mass of all the parts to a minimum. The results and lessons learned from the project may provide major impetus for service life extensions as well as for planned follow-on generations.

In the context of the "Dynamic Track Tensioner" subproject undertaken collaboratively by Bundeswehr Technical Centre 41 (WTD 41) , enterprise DST, the Fraunhofer Institute for Production Technology (Fraunhofer IPT) and Bundeswehr University, Munich, a dynamic track tensioner has been developed on the Weasel DIOK demonstrator vehicle available at WTD 41 (effectively an extended Weasel chassis with an additional road wheel; Fig. 1), with this basic solution also intended for application on other tracked vehicles.

Fig. 1: DIOK demonstrator vehicle made available by Bundeswehr Technical Centre 41 (WTD 41)

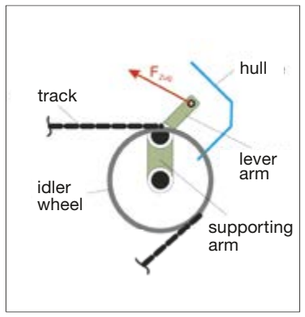

Fig. 2: Functional principle of the track tensioner

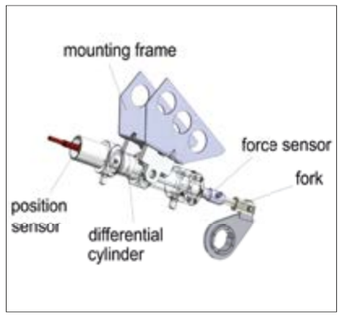

Fig. 3: Configuration of the track tensioner concept

The primary function of the track tensioner is to avoid track loss in the following driving situations:

- driving on sloping roads
- turning manoeuvres
- negotiation of obstacles

Track tension has an influence on:

- loss of track parts
- chassis operability
- meshing with the drive sprocket
- cross-country mobility and grip
- wear and tear of the track and suspension components
- vibrational load within the vehicle

The aim is to achieve optimum track tension, because if the initial tension is too low there is a higher probability of the track disengaging from its guide. If the initial tension is too high, on the other hand, there will be increased traction resistance and greater chassis wear and tear.

Concept methodology:
When the concept was drawn up and kinematic analyses were carried out, pivotable and translational options were compared. Ultimately, the pivotable approach was adopted.
Advantages:

- series-produced parts are available (cylinder, accumulator etc.)
- available installation space remains unchanged
- little design and manufacturing effort involved
- fully active and quasi-stationary operational modes possible
- flexible adjustment of tension and compression spring levels
- hydraulic coupling to additional tensioners possible / retrofittable

Disadvantages:

- loss of contact with track support rollers if chassis is completely lowered (only relevant for ride height control option)
- performance of the hydropneumatic spring suspension is temperature-dependent

The overall dynamic track tensioner system comprises an actuator, sensors and information processing unit. It is thus a mechatronic system structured according to the principle shown in Fig. 2.

The track tension is adjusted via the hydraulic differential cylinders, which are powered by the compact decentralised motor-pump units and adjustable servo valves, and is monitored by force sensors as well as, alternatively, by pressure sensors attached directly to the cylinder chambers. Additional pressure sensors monitor the condition in the hydraulic accumulators.

After its assembly and installation in the vehicle at WTD 41, the system as a whole was subjected to a basic functional test. During this testing the initial track tension showed itself to be continuously adjustable within the predetermined range between 8 and 16 kN. Initial driving trials (obstacle course, steady-state circular test, zigzag driving trial) were conducted on WTD 41's test tracks.

The activities scheduled for 2017 include, among others: optimisation of the control device parameters during test drives; possible adaptations of the user interface with regard to ease of use; and testing of a fully active mode for the implemented system.

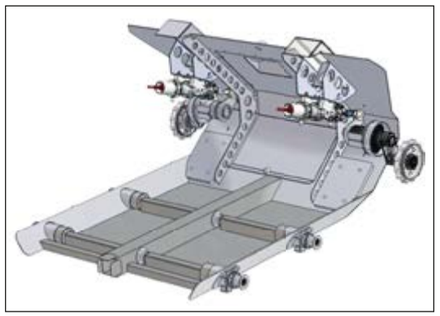

Fig. 4: Integration into the hull

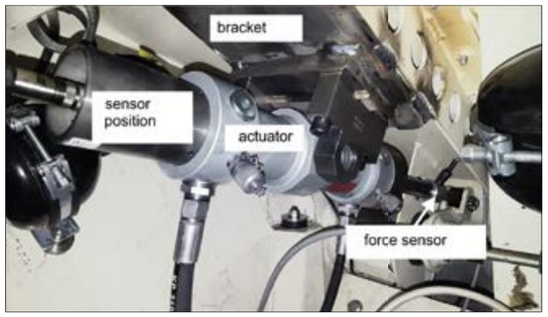

Fig. 5: Installation in the vehicle

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Analysing ammunition storage risks

When ammunition is stored during routine duty and operational deployments, it is not always possible to comply with the mandatory quantity-safety distances because of local conditions and complex constraints. A means is needed to be able to specifically analyse such special circumstances with respect to the increased danger and risk posed to personnel and materiel.

An important aspect of risk management in the Bundeswehr in future will be to establish a systematic, quantitative risk analysis approach for special instances of ammunition storage during routine duty and operational deployments. R&T activities in this field will serve as a basis for maintaining a focused assessment capability.

The explosion of ammunition during an accident can generate a blast wave and flying fragments which sometimes require very large safety distances and are crucial parameters to be taken into account when determining such distances. The integrated compliance demonstration with regard to safety and operating requirements is a responsibility of the Bundeswehr Technical Centre for Protective and Special Technologies (WTD 52) and its partners. These carry out numerical simulations and real tests as a basis for the creation of models and their integration into software-supported solutions used to compute the potential hazards.

The ESQRA-GE (Explosive Safety Quantitative Risk Analysis – Germany; developed by Fraunhofer-Institut für Kurzzeitdynamik, Ernst-Mach-Institut (EMI)) risk analysis tool covers many parameters that are absolutely essential for a transparent presentation of results.

Fig. 1: On-site inspection of the ammunition storage site in Mali

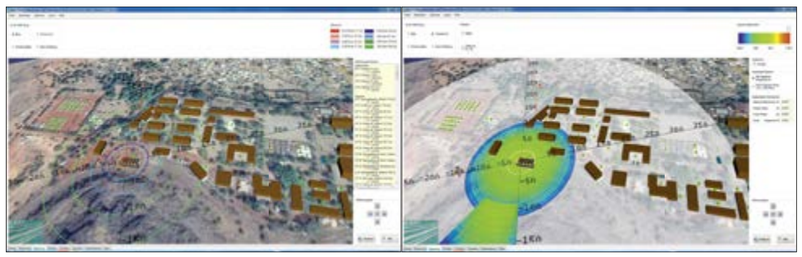

Fig. 2: Analyses by means of ESQRA-GE for different load cases

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Using the European Training Mission in Mali (EUTM Mali) as an example, such a standardised procedure has been implemented for the first time for training and security ammunition in an ammunition store (EUTM MAO) built by the French armed forces. Based on clear structures and responsibilities and using the risk analyses carried out with the aid of ESQRA-GE (Figs. 1 and 2), a team of experts from the Bundeswehr Territorial Tasks Command (“Ammunition Safety/Firing Safety” Section), the Federal Office of Bundeswehr Infrastructure, Environmental Protection and Services (BAIUDBw) Infra II 2, and WTD 52 have developed a joint reporting system as part of the future risk management approach for providing support on special problems for, among others, the Bundeswehr Joint Forces Operations Command.

Joint analyses are absolutely essential for routine duty, too. This is illustrated by the example of an explosives workshop at the ammunition storage site in Köppern. The quantity-safety distances between the explosives workshop and other buildings located within the safety area were less than the safety distances required in relevant directives. It was possible to use the workshop only to a limited extent or subject to exemption permits. An analysis was performed in this connection for the ‘explosion’ load case, giving consideration to all the scenarios relevant for the explosives workshop.
The extant hazards were presented transparently and systematically (Figs. 3 and 4). From this it was possible to derive recommendations regarding further use and it was ultimately demonstrated that, by building a safety barricade, the explosives workshop can be used further, subject to certain conditions, to meet the increased material maintenance and repair requirements.

Also where future R&T activities are concerned, the primary goal remains an integrative, holistic and Bundeswehr-wide approach which combines the requirements on ammunition safety and reflects them in a coordinated, uniform analysis process for all involved. The focus in this respect is on operational relevance and on optimising the protection and safety concept for handling ammunition during routine duty.

Fig. 3: On-site inspection of the explosives workshop in Köppern

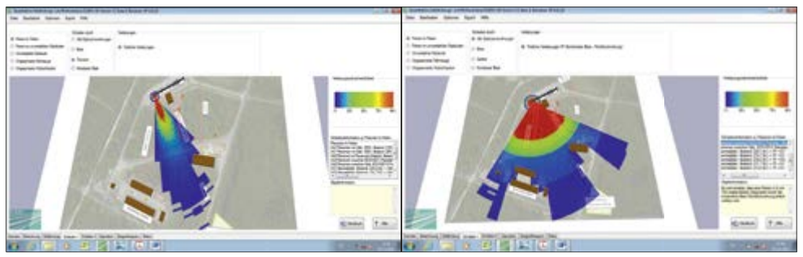

Fig. 4: Analyses by means of ESQRA-GE for different load cases

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Investigating specific flow phenomena in modern engine inlet systems

Highly integrated propulsion systems are a necessity for minimising the radar signature of military aircraft. Accurately predicting the flow in complex serpentine inlet systems is a major challenge, even using state-of-the-art simulation software. The Institute of Jet Propulsion has, for this reason, designed and developed an engine inlet research duct for in-depth experimental testing.

Future military aircraft will have to fulfill high expectations in terms of propulsive performance and minimum radar signature, making integration of the propulsion system into the fuselage indispensable. The main benefits of a compact integrated propulsion system are a shorter overall aircraft length (and thus also a weight saving), a reduction of aerodynamic drag, and enhanced stealth characteristics due to decreased visibility of rotating compressor components.

Major contour variations in complex serpentine inlet systems, however, typically cause highly distorted flow conditions at the engine inlet plane, significantly influencing the stability and performance capability of the propulsion system. It is therefore important to know the flow conditions in such inlet systems precisely. An accurate flow prediction is extremely challenging, though, even with state-of-the-art flow simulation software. Such simulations are nevertheless being used more and more frequently in the design of inlet systems. WTD 61, in cooperation with the Institute of Jet Propulsion, has initiated a research project with the specific objective of broadening its

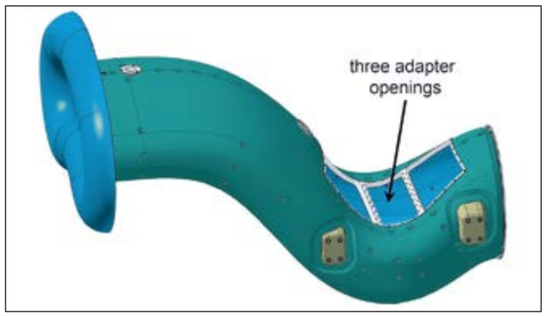

Fig. 1: CAD model of the MEIRD inlet system with three large openings for removable inserts in the area of a large-scale flow separation (thus enabling an adaptable test set-up)

Fig. 2: The MEIRD research duct installed upstream of a Larzac 04 turbofan engine in the engine test facility at the Institute of Jet Propulsion

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knowledge and experience in both the design and simulation of complex inlet systems.

An engine inlet system typifying military applications has been developed and built specially for experimental testing with the Larzac 04 turbofan engine at the Institute's engine test facility. The so-called Military Engine Inlet Research Duct (MEIRD, Fig. 1) has been designed to induce a combined pressure-swirl distortion, which typically occurs in complexly shaped military engine inlet systems. The distortions are large enough to be able to measure aerodynamic interactions between the inlet and compressor flow. The flow distortion is also within the operability limits defined by the engine manufacturer so that the Larzac 04 turbofan engine can be used for experiments within its entire operating range. Extensive instrumentation (installed in three adapter openings) in the region of the flow separation (Fig. 1) enable detailed measurement of complex flow phenomena and their interaction with the compressor system.

The results from the experiments also provide a valuable database for the validation of computational fluid dynamics (CFD) solvers. The duct system is, moreover, adaptable for future studies, such as for optimising the flow conditions in engine inlets.

The MEIRD research duct has already been installed (see Fig. 2), with visualisation of the flow separation in the upper part of the duct being the main aim of the research to date. This flow separation is visualised in Fig. 3 by means of a static wall pressure plot. Narrow lines on the left-hand side represent high-pressure gradients slightly upstream of the region of flow separation. The red area denotes a plateau of constant pressure occurring within the flow recirculation area. The pressure gradients on the right-hand side of the plot indicate the re-attachment of the flow.

The first experimental tests with the MEIRD research duct at the engine test facility have fulfilled all expectations, providing an extensive database for general s-duct flow analyses and for the validation of CFD simulations. The adaptability of the inlet system will permit further comprehensive research on flow stabilisation measures aiming at minimising flow distortions and thus optimising engine performance and stability.

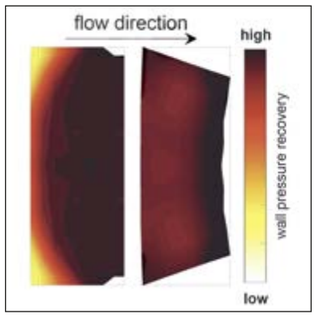

Fig. 3: Static wall pressure plot visualising the flow separation within the second bend of the duct

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Advanced signal design for diver detection

Reliable and earliest possible detection is necessary to protect ships or harbour installations from attacks. Active high-frequency sonars are used to locate threats such as divers. When looking to expand the use of sensors to include the MIMO (Multiple Input Multiple Output) type, the choice of transmitting pulses is crucial for detection quality.

Protecting ships and harbour installations from underwater attacks calls for constant surveillance of such areas with one or more detection sensors. Since a largest possible detection range has to be achieved, active acoustic sensors are the means of choice. Use of active acoustic techniques is necessary especially for targets with weak signatures (such as divers or military AUVs).

Where diver detection is concerned, primarily high-frequency active sonars in horizontal orientation are employed to be able to observe as large an area as possible. Automatic track extraction is used to decrease the number of false alarms. A typical scenario is depicted in Fig. 1.

When designing a sonar sensor, the sensor size, transmission loss and radial resolution rival one another as design parameters. Mostly used to date have been SIMO (Single Input Multiple Output) sensors, whereby the whole surveillance area is insonified by the same transmission pulse. Such a sonar will be utilised on the Type F125 frigates for self-protection and is also planned for the upcoming MKS 180. This sonar, named Cerberus, is shown in Fig. 2.

Expanding the use of detection sensors to include full MIMO (Multiple Input Multiple Output) leads to the possibility of transmitting different – mostly non-interfering (orthogonal) – pulses and thus of increasing the detection performance through a beamforming gain on the transmitter side, as well as of taking account of different backscattering characteristics in the surveillance area (by adapting the transmission signal). The properties of the different transmission signals are described by the broadband cross-ambiguity function.

The investigation of transmission signals and their properties for improving the detection performance for SIMO sonars is also possible with a broadband ambiguity function applied to a single transmission signal. This requires use of the more elaborate broadband ambiguity function if the ratio of propagation speed to object speed is not much greater than the product of time and bandwidth. The latter is the case when it comes to underwater detection.

Ideally a transmission signal produces no ambiguities in the time and frequency domain, such that a unique delay (i. e. radial range) and a unique Doppler shift (i.e. radial velocity) can be measured.

In the case of classical sonar detection transmission signals such as CW (Continuous Wave) bursts or chirps (frequency-modulated pulses) it is generally possible to measure either the velocity or the range.

The use of coded signals in which the information is spread over the complete time-frequency plane and with which a thumbtack-shaded ambiguity function is realisable (Fig. 3) is meanwhile possible thanks to acoustic transducers with a broader bandwidth being available and to the signal processing software being capable of significantly improved performance. Coded transmission signals such as pseudo-noise pulses (PN-pulses) can be processed as a means of detection only with the aid of a Doppler filter bank, which multiplies the required computational effort by the number of Doppler channels.

The advantage of such transmission signals lies in the simultaneous measurement of range and speed, which in combination with a tracking system can reduce the number of false tracks. Shown in Fig. 4 are the tracks of a target approaching the sonar, generated with coded transmission signals.

The presented transmitter signal design approach offers the possibility not only to measure range and speed simultaneously but also to operate multiple sonars in parallel through the use of different codes.

Fig. 1: Surveillance area scenario

Fig. 2: High-frequency sonar Cerberus (F125)

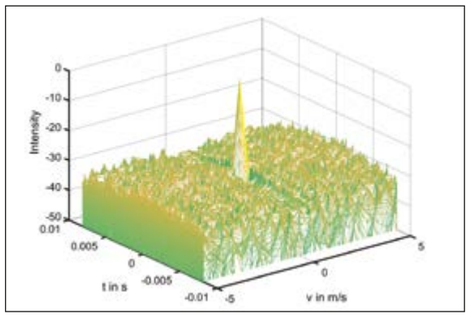

Fig. 3: Ambiguity function of a coded pulse

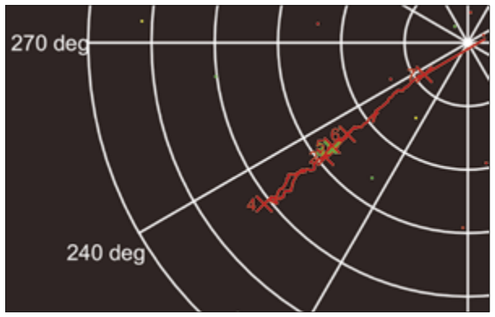

Fig. 4: Target tracks of an artificial target generated with coded pulses

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MiDNet – Communicating without a connection

In IP-based tactical radio networks, the agility of network nodes and coinciding distortions and disruptions lead to a low probability of reliable end-to-end connectivity between user systems. Disruption Tolerant Networking (DTN) supports the exchange of information between communication partners even when they currently do not have a viable connection via the mobile network.

Various measures can be taken to augment the variable quality of a mobile networking node radio connection. Adaptive waveforms can react to varying channel noise when a networking node in a tactical vehicle approaches the radio range limits of its neighbouring node. The more favourable proximity to an alternative neighbour is detected by routing protocols (MANET – Mobile Adhoc-NETworking) that periodically send and receive topology information through the network.

This also includes selection of other radio communication systems, if available. However, all of these measures have their physical limitations. If connectivity gaps occur too often or for too long, no stable route can be established.

From 2013 to 2016, the multinational study MiDNet – Military Disruption Tolerant Networks – was conducted to explore disruption-tolerant networking technologies capable of signaling a reliable transmission option to communicating applications without any continuously stable end-to-end connection between the communication partners.

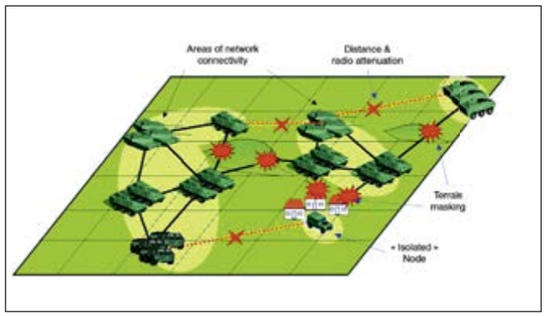

Fig. 1: Mobile tactical communication – the challenge (Source: BAAINBw I1.1 as member of the Programme Arrangement Management Group (PAMG) for the MiDNet EDA study)

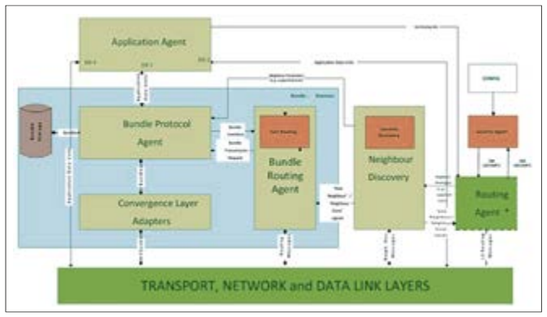

Fig. 2: Architecture of a networking node with DTN bundle layer and geo-routing (Source: BAAINBw I1.1 as member of the Programme Arrangement Management Group (PAMG) for the MiDNet EDA study)

MiDNet implemented a ”bundle layer“ between the network / transport layer and the application layer, which builds upon a performant MANET protocol and is additionally fed with geo information, with geo information by piggybacking GPS information on each topology update transmitted by the routing protocol instance of the individual node. Even if some of this information is / gets lost, it is possible for all the other nodes to extrapolate the most probable position of a node by means of past positional information. If there is a need to exchange information, the sender can identify the physical transmission direction towards the recipient as well as the next hop network neighbour in that direction. The information is sent via IP multicast to all those nodes that apply the same forwarding mechanism. If a forwarding node receives information bundles multiple times from various neighbours, its intelligent data storage function makes sure that duplicate information is deleted or updated with more recent information (e. g. blue force tracking information). This function also serves as a buffer in case there is no immediate opportunity for forwarding towards the recipient.

This feature can also be used for ”data muling“: a command post and a subordinate unit might not have a robust network connection, yet orders and situational awareness reports can be exchanged by means of a drone that transports the information between their individual non-overlapping radio ranges.

Based on a military patrol scenario, these DTN functionalities were successfully presented to an audience of international experts during a field test in May 2016 at the Bundeswehr Technical Centre for Information Technology and Electronics (WTD 81). From a technological perspective, DTN currently imposes higher bandwidth requirements than can be met by legacy radio systems currently in service in the Bundeswehr due to the MANET protocol’s exchange of topology information. At present, the current current implementation does not provide any significant advantage yet in the case of an unfavourable proportion of information exchange need and bandwidth availability, since causes of connectivity impairment cannot be differentiated in terms of exceeding channel access versus physical transmission disruptions. With respect to the technical capabilities of current and upcoming V/UHF radio systems, non-realtime information exchange of voice and text chat services as well as between entities of service-oriented architectures is reliably supported by DTN in a disrupted communication environment.

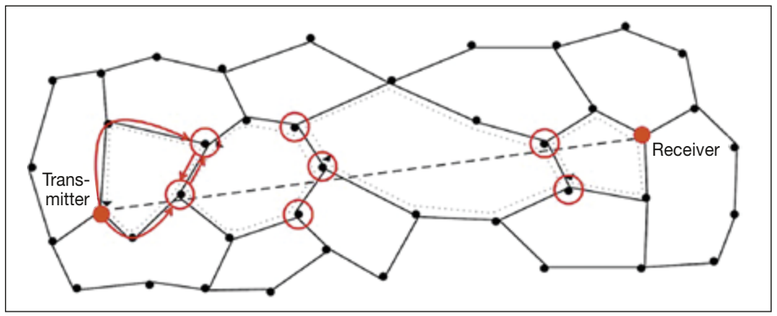

Fig. 3: Directed multicast in a DTN network. Forwarding nodes may receive information multiple times on its way to the receiver (Source: BAAINBw I1.1 as member of the Programme Arrangement Management Group (PAMG) for the MiDNet EDA study)

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Improvement of crew protection for vehicle crashes

Bundeswehr vehicles are generally equipped with highly developed protection systems to withstand highly dynamic loads, the main focus being on protection against mine and IED (Improvised Explosive Device) threats. The use of active crew protection systems (e.g. airbags) is not conducive in this regard due to the systems' inherent latency. They do, however, offer promising potential for crash scenarios.

The tactical vehicles in use with Germany's armed forces offer a defined level of protection against mines, IEDs and ballistic threats. What these threats have in common is their comparatively short load exposure duration (about 3 – 10 ms). In contrast, crash scenarios such as "ordinary" vehicle accidents have load exposure durations > 20 ms. Crew protection systems to date have generally employed passive measures to safeguard military personnel. Such passive measures characteristically do not have any inherent latency and are therefore instantly operative and effective – where applicable, after a built-in threshold has been exceeded. Active crew protection systems, on the other hand, enable a functional analysis of input signals (e.g. from sensors) and consequently a more informed decision as to when to activate the protection system or not.

The goal of one conducted research study has been to determine to what extent crew protection in tactical vehicles can be improved in crash scenarios through the use of airbag systems. As there had been no systematic analysis in this regard in the past, coordinated work steps were defined before commencing the study.

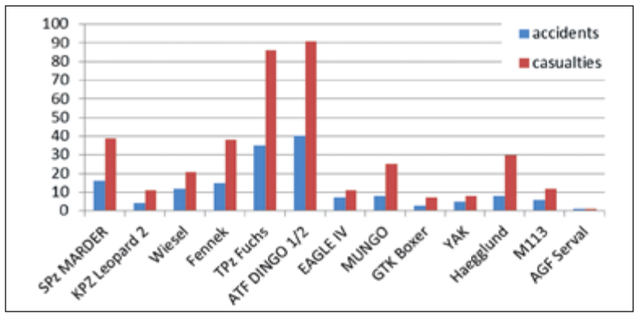

Fig. 1: Accident statistics (years 2005 – 2013)

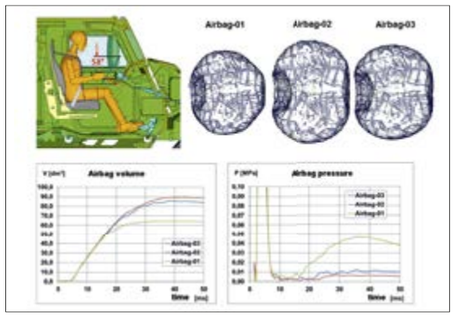

Fig. 2: Conceptual design of an airbag system by means of numerical simulation

The research started with a statistical analysis of accident data from the years 2005 to 2013. In total, 1349 vehicle accidents had been recorded: 4 with fatal injuries, 15 with serious injuries, and 412 with light injuries. Per year there are some 90 to 140 accidents involving protected vehicles, with around 50 persons Injured. The use of airbags and other (active) protection systems can be considered as very sensible in light of this statistical analysis.

The subsequent work steps concentrated on determining what loads the vehicle structures were exposed to and on analysing the load profiles. For a comparative examination, data from mine and IED protection research experiments was used. As no experimental data concerning vehicle crashes was available, numerical simulations were conducted for the APC FUCHS 1A7 and GFF 2 EAGLE V vehicles as examples. It was found that, as load cases, blasts (from a mine or IED) and accidents generally differed, with blast loads being characterised by short load times and extremely high accelerations, while accident loads had medium acceleration but longer load times. In theoretical extreme crash scenarios, however, such as a head-on crash with an APC FUCHS 1 A7 against a non-deformable barrier, the same acceleration amplitudes can be attained as in a mine or IED attack. Furthermore, in crash scenarios the risk of injury can be reduced by an – albeit stiff – crumple zone. This applies especially to vehicles with engine compartments in front of the crew compartment, e. g. EAGLE IV, EAGLE V, DINGO 1 or DINGO 2.

Based on this numerical analysis, an algorithm was created as an activation trigger for a control unit of an active protection system.

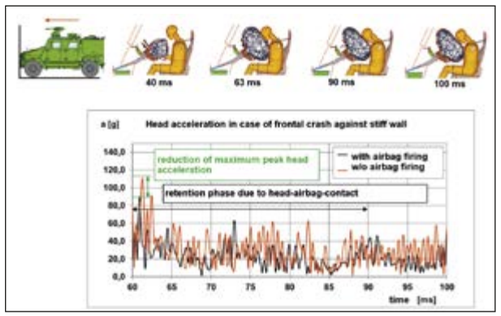

Fig. 3: Crash simulation to demonstrate the improvement in protection provided by airbag systems

Fig. 4: Crash test with a GFF 2 vehicle

In November 2016 a crash test involving an instrumented GFF 2 EAGLE V was carried out for the first time in the Bundeswehr within the scope of a demonstrator experiment. This experiment served, on the one hand, to validate the results previously determined by numerical simulation and, on the other hand, to demonstrate the efficacy of an incorporated active protection system. Human-related efficacy was measured through the use of anthropomorphic test devices – or "crash test dummies". Further crash tests involving military vehicles are planned for 2017.

Future work will also include defining suitable airbag systems for protected vehicles, such as steering wheel airbags, curtain airbags or skull / head airbags. This will be followed in a second step by optimisation of the geometry and characteristics of those defined systems in cooperation with an airbag system manufacturer. A market analysis to determine if suitable COTS airbag systems might be conducive to improving protection will round off the present task package.

2

Military Medical and Military Psychology Research

The Bundeswehr Medical Service has a timeless commitment to protecting and restoring the health of the servicemen and women entrusted to its care. Meeting this commitment calls for constant innovation – to which the scientists working in military medical research at the departmental research and health care facilities of the Bundeswehr Medical Service make a vital contribution. Some of this work is described in the following.

The Bundeswehr Institute of Radiobiology presents current research activities aimed at providing efficient clinical triage in case of exposure to ionising radiation and at implementing lifesaving measures as purposefully and effectively as possible.

The Bundeswehr Institute of Microbiology reports on fluorescence in-situ hybridisation (FISH) and on portable full genome sequencing (MinION) – two methods for rapidly and reliably diagnosing biological outbreak events.

The Bundeswehr Institute of Pharmacology and Toxicology has a new test system, based on “precision long cut slices“, for developing antidotes to life-threatening respiratory paralysis caused by nerve agents.

Insulating protective clothing that saves lives and is indispensable in CBRN scenarios also induces intensive heat stress. The Central Institute of the Bundeswehr Medical Service, Koblenz, presents an effective way of reducing such stress with its “Dry Air Comfort“ system.

The Naval Institute of Maritime Medicine of the German Navy reports on its studies concerning the rescue and safe movement of sick and injured persons under maritime conditions.

Laser attacks can pose a danger to the safety of pilots, crews and passengers. The Centre for Aerospace Medicine describes this growing threat and the first steps towards effective countermeasures.

Active promotion of healthy behaviour is also gaining in importance for the Bundeswehr Medical Service for the long-term effectiveness of the armed forces and for the health of all their personnel. The Federal Ministry of Defence has initiated trendsetting measures in this field with the widespread introduction of an occupational health management concept (Betriebliches Gesundheitsmanagement, or BGM). The BGM Task Force at the Bundeswehr Medical Service Headquarters reports on the promotion of healthy nutrition as a specific aspect of occupational health management.

The Armed Forces Office of the Bundeswehr is responsible for the conceptual development, implementation and support of research conducted in the fields of defence and military psychology. It reports on a completed study concerning vocational mobility in the Bundeswehr.

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In the midst of an outbreak: sequencing in field

Unambiguous identification of the causative agent is of highest priority for reconnaissance of unusual disease outbreaks. Here, whole genome sequencing can yield important information. Using one of the first portable miniature sequencing devices, possibilities and limitations were investigated for use in field missions.

Usually, whole genome sequencers used for identification of unknown pathogens are housed in a stationary laboratory not only due to their sizes and weights. Conversely, a backpack-sized portable whole-genome sequencer with a laptop would enlarge its utility. This device might become very handy in close vicinity to an unclear outbreak event and thus improve hypothesis-free reconnaissance.

In spring of 2014, the first market-ready "sequencer on a USB flash drive" was available for limited number of expert laboratories (beta testers) in a worldwide competitive bidding. The Department of Microbial Genomics and Bioinformatics of the Bundeswehr Institute for Microbiology (BwIM) applied for this opportunity and was selected as partner to evaluate the new devices within a period of two years.

It was initially necessary, however, to evaluate the sequencer device under the controlled conditions of a stationary laboratory before moving on to a field setting. In cooperation with the Department of Biomedical Reconnaissance and Verification, the system was then tested for the first time in the context of an insect vector surveillance exercise at the military training area in Heuberg, for which purpose the "whole genome sequencing" workstation was packed up in tropicalised transport boxes together with other devices used by the rapidly deployable diagnostic unit of the BwIM. Using a "metagenomic profiling" approach it was possible to identify the potentially human pathogenic bacteria present in the microbiome of collected ticks with the aid of a universal bacterial marker, the 16S-rRNA gene. The first useful sequence data was already available 15 minutes after the start of sequencing run and allowed thus a "more or less real-time" analysis. The collected data was analyzed and evaluated in a reach-back laboratory. Sequencing was also repeated under optimal laboratory conditions at the stationary laboratory. Finally, discrepancies were analyzed, error rates determined, and the analysis algorithms optimized in-house with regard to performance, accuracy and quantitative data output for further processing.

The next test was performed in February 2016 as part of a bi-national exercise at winter temperatures. For the first time, the entire DNA obtained from a contaminated blood sample was sequenced and evaluated without any species-specific enrichment steps in order to test the teams' ability to identify the "unknown" pathogen.

The final test phase for this system commenced in July 2016. Equipped with updated software for autonomous sequencing and evaluation, the whole genome sequencer was implemented as a now permanent component of the rapidly deployable laboratory for the NATO exercise "Precise Response", staged in Suffield (Canada). With the laboratory technicians specially trained for the evaluation work in attendance, it was now possible to carry out the first DNA sequencing and subsequent data analyses independently of on-site bioinformatics specialists' support or sophisticated add-on IT infrastructure. Local databases were also brought along which even allowed initial molecular typing based on the identified bacterial DNA sequences. For validation and deeper analysis, a compressed data set was transmitted in parallel via an Internet connection to the reach-back laboratory in Munich. Through this approach, decision-relevant information based on multifaceted expertise was generated and directly available in the field.

In the near future, further advances in this technology, as well as in the field of bioinformatics needed for the data analysis, can be expected to enable the routine use of "on-site" whole genome sequencing in the context of outbreak investigation, both for identifying the causative agent and for possibly retracing the likely infection sources. This will be especially valuable in cases where initially conducted species-specific tests have not produced reliable results or the starting scenario is medically unclear.

Fig. 1: Camouflaged rapidly deployable laboratory at exercise "Precise Response"

Fig. 2: "MinION™" whole genome sequencer manufactured by Oxford Nanopore Ltd.

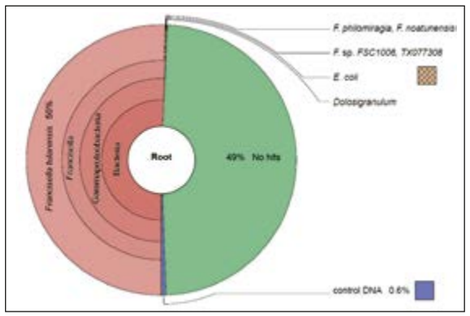

Fig. 3: Example of results displayed for detected sequences

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Fluorescence in-situ hybridisation (FISH) as a means of identifying highly pathogenic bacteria

One of the major challenges facing medical biodefence is how to diagnose highly pathogenic bacteria rapidly and reliably in the field. Fluorescence in-situ hybridisation may represent a valuable addition to the classical molecular biology-based diagnostic techniques.

Molecular biology-based methods such as real-time polymerase chain reaction (PCR) currently represent the gold standard for the detection of biological agents where diagnostic sensitivity and specificity are concerned, but are also very demanding in terms of logistics, laboratory facilities and personnel training. These methods also have limitations when it comes to differentiating in the context of assessing the risk whether the pathogens are live or dead, or whether one or more bacterial species are involved. For the so-called “confirmed identification” of biological agents, it is furthermore necessary to apply at least two independent diagnostic methods.

Fluorescence in-situ hybridisation (FISH) offers a complementary alternative to the classical portfolio of molecular biology-based methods for diagnosing bacterial pathogens. With this approach, bacteria are incubated with short fluorescently-labelled DNA sequences (gene probes) which are able to bind to the ribosomal RNA of their respective target organisms. The hybridisation conditions are adjusted so that the probes are only able to bind specifically to those organisms (Fig. 1). Following a washing step, the hybridisations are evaluated under a fluorescence microscope, thereby exciting the fluorescence dyes and lighting up the cells in which binding has taken place (Fig. 2). Since the target molecule for the gene probes – the ribosomal RNA – is present only in viable cells, only such are also detected and stained. By simultaneously applying DNA-binding dyes which stain all cells equally in the analysed sample, information is gained whether the target organism consists of one or several bacterial species. One particular advantage offered by the method is also its extensive robustness when compared with other, more sample matrix-influenced methods (such as PCR).

The aim of the research project at the Bundeswehr Institute of Microbiology (BwIM) has been to adapt this method for use under field conditions and to develop a diagnostic algorithm that allows FISH identification of various bacterial pathogen species of relevance for medical biodefence. As there is no stationary laboratory infrastructure with chemical exhaust hoods available under field conditions, it was necessary as a first step to find an alternative, non-toxic component for the toxic formamide compound used to facilitate the specific binding of probes to their respective target sequences. After several experiments and protocol optimisations, urea was found to fulfil all the essential criteria as a non-toxic replacement. Public databases were subsequently searched to determine whether specific FISH probes already exist for the relevant target organisms. Where that was not the case, a set of gene probes was newly developed on the basis of phylogenetic sequence information and their hybridisation conditions were experimentally optimised. By using multiple fluorescent dyes per gene probe and combining differentially labelled probes, it has been possible to develop an algorithm which enables the identification of thirteen pathogens highly relevant for medical biodefence at species level in just two hybridisation steps. This involves the use of group-specific probes in the first hybridisation step, and the pathogen type in question is then detected in a further hybridisation step by means of species-specific probes (Fig. 3). To ensure cold chain-independent implementation of this method, all the required components were combined into a ready-to-use mixture and freeze-dried.

The new FISH-based diagnostic algorithm has already been used successfully several times under stationary laboratory conditions at the IMB to diagnose highly pathogenic bacteria in clinical samples. The next step will be to test the new method under field conditions. A further important method for both stationary and field-based diagnostics thus looks set to be available for medical biodefence purposes.

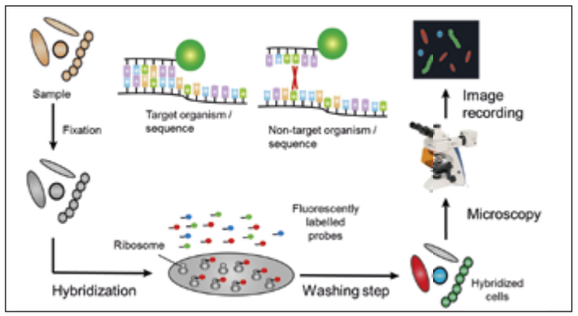

Fig. 1: Principle and steps involved in fluorescence in-situ hybridisation: After fixation of the bacteria, they are hybridised with specific, fluorescently-labelled gene probes. Based on sequence information, these probes are designed to ensure a perfect match with the gene sequence of the target organism, whereas they display mismatches with non-target organisms and cannot therefore bind there. After a washing step the hybridisation is evaluated using a fluorescence microscope. Cells in which probes have bound to their target sequences will light up

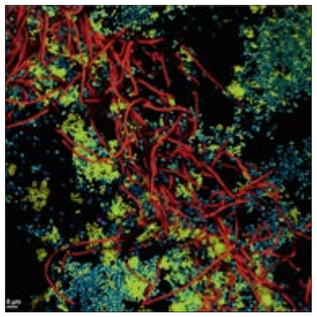

Fig. 2: Example of a hybridisation with differentially labelled gene probes. Under a fluorescence microscope the target organisms of a bacterial species light up in different colours (here red, yellow and turquoise) and can thus be clearly identified

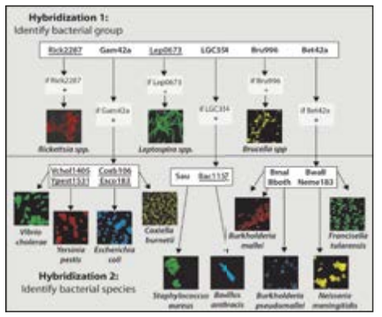

Fig. 3: The diagnostic algorithm. Thirteen pathogenic bacteria highly relevant for medical biodefence can be specifically detected in two subsequent hybridisation steps. ”Rick2287“, ”Gam42a“, etc. refer to the probes in use

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Precision-cut lung slices as a test system for candidate therapeutics in organophosphate poisoning

Intoxication with organophosphorus compounds such as nerve agents and pesticides poses a danger to the lives of soldiers and civilians. The standard therapy in some instances to date has lacked effectiveness. The present research project features a model, based on precision-cut lung slices, for testing new therapeutic substances to treat organophosphate poisoning in lung tissue.

Servicemen and women on military operations are under constant threat from a wide range of munitions and weapons systems, as is the civilian population from increasing terrorist activities. A part of this threat concerns the use of chemical warfare agents, which include organophosphorus (OP) compounds such as nerve agents (e. g. VX, sarin). Incorporation of OP leads to an irreversible inhibition of the acetylcholinesterase (AChE) enzyme, which physiologically catalyses the degradation of the messenger substance acetylcholine (ACh). The resulting accumulation of ACh in the body triggers severe respiratory symptoms (paralysis of airway muscles, narrowing of airways, increased production of mucus, and impaired respiratory control in the brain) that can eventually cause death.

The standard therapy for OP poisoning comprises the combined administration of an oxime (to reactivate the inhibited AChE) and atropine (to counteract cholinergic symptoms). However, due to the various characteristics of the different OP, this therapeutic approach lacks effectiveness in some instances. Alternative treatment options are rare, especially regarding the respiratory symptoms of OP intoxication. The aim of the research project presented here is to investigate the exact pathophysiological effects in the lung, with a view to evaluating new candidate therapeutics and thus optimise the protection of soldiers and civilians alike.

Precision-cut lung slices (PCLS), already established in research, were used as a test system for new therapeutic substances. These thinly cut lung sections (Fig. 1) allow the examination of pathophysiological pulmonary processes while representing all the functional and anatomical features of the lung on a small scale. The lung tissue used for the PCLS can be of human or animal origin, with a key advantage of the method being that a small amount of tissue is sufficient to produce a large number of PCLS. The use of this method consequently helps to reduce the need for animal experiments.

In this study, mainly microscopic analysis of selected airways (Fig. 2) was conducted to assess changes in airway area following Ach stimulation. In control groups, ACh induced an airway contraction that was spontaneously reversible (Fig. 3), as indicated by an initial decrease of the airway area to around 30 ± 5 % (mean ± SEM) compared with the initial area (defined as 100 %), followed by a spontaneous increase to around 60 ± 6 %. The reason for the reversibility of the contraction is the degradation of the applied ACh by the AChE of the lung tissue. In PCLS poisoned with cyclosarin (GF), the ACh-induced airway contraction was irreversible, as shown by a constant decrease of the airway area to around 7 ± 2 % of the initial area (Fig. 3).

Trials were conducted to examine the effects of atropine as the standard therapeutic, and of HI-6, an oxime currently awaiting clinical approval, on PCLS poisoned with cyclosarin. It was found that atropine rapidly antagonised the ACh-induced irreversible contraction (Fig. 4), while even unphysiologically high concentrations of HI-6 brought about no significant reversal of the ACh-induced airway contraction within the 66-min. test period (Fig. 5). This underscores the need for new therapy options whose effects on the airways can now be tested in PCLS.

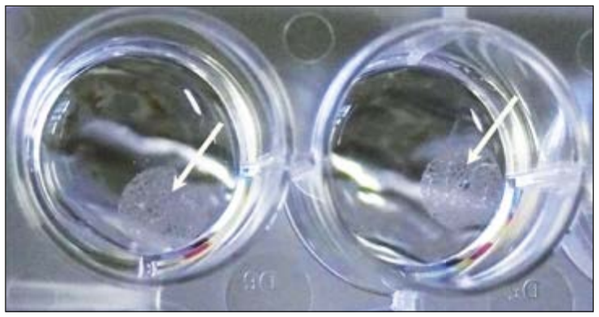

Fig. 1: Precision-cut lung slices in cell culture media

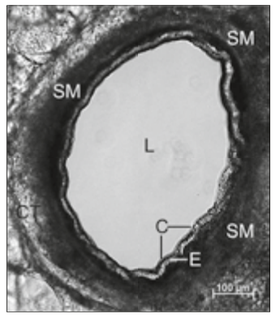

Fig. 2: Microscopic view of precision-cut lung slices, airway cross-section.
L = luminal area, E = bronchial epithel with cilia (C), SM = smooth muscle, CT = connective tissue

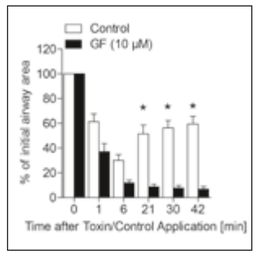

Fig. 3: Stimulation of precision-cut lung slices (PCLS) with acetylcholine induced a spontaneously reversible airway contraction in the control group. In PCLS poisoned with cyclosarin (GF), the ACh-induced airway contraction was irreversible. The initial airway area was defined as 100 %. The columns show the mean + SEM of n = 15 (control) and n = 10 (GF) PCLS.
* p < 0.05 (GF vs. control)

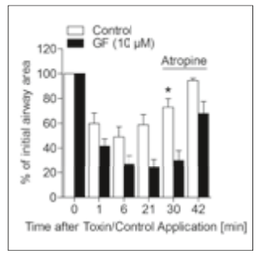

Fig. 4: In precision-cut lung slices (PCLS) poisoned with cyclosarin (GF) the application of atropine rapidly antagonised the acetylcholine-induced airway contraction. The initial airway area was defined as 100 %. The columns show the mean + SEM of n = 9 (control) and n = 8 (GF) PCLS.
* p < 0.05 (GF vs. control)

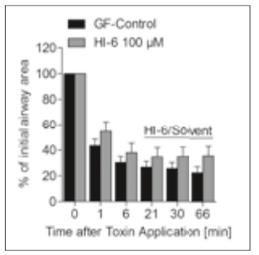

Fig. 5: In precision cut lung slices (PCLS) poisoned with cyclosarin (GF), even unphysiologically high concentrations of the oxime HI-6 brought about no significant reversal of the acetylcholine-induced airway contraction. The initial airway area was defined as 100 %. The columns show the mean + SEM of n = 8 (GF-control) and n = 6 (HI-6 100 µM) PCLS

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Current research on the improvement of clinical triage after damaging radiological and nuclear events

Nuclear events, terrorist attacks with radioactive material and similar circumstances have the potential to cause mass-casualty scenarios. To optimise the radiobiological triage of patients, the Bundeswehr Institute of Radiobiology has developed the 'H-Module'. This software tool has been successfully tested during a NATO-wide exercise and is to be introduced to physicians from various nations in the near future.

In 2009, former US President Barack Obama initiated the Nuclear Security Summit. His statement that nuclear terrorism is one of the greatest threats to global security underscores the relevance of this topic. The spectrum of terrorist risks ranges from the use of improvised nuclear devices to "dirty bombs" (improvised explosive devices comprising radionuclides). Yet also nuclear events such as the reactor disasters in Chernobyl and Fukushima, and radiological events like the 1987 Goiânia incident (Brazil), affect the lives of hundreds of thousands of people. Especially in such mass-casualty scenarios, it is essential to decide through clinical triage (selection) which people have actually been exposed to radiation and which of those patients require intensive medical attention. The aim is to prevent overloading of the medical infrastructure and thereby ensure a high quality of patient care. As a basis for this, the absorbed radiation dose is estimated so as then, in a second step, to predict the radiation-induced damage (effect). Besides this retrospective and enormously time- and effort-intensive biodosimetry approach, concepts are becoming established that directly diagnose acute radiation syndrome on the basis of clinical signs and symptoms (Fig. 1).

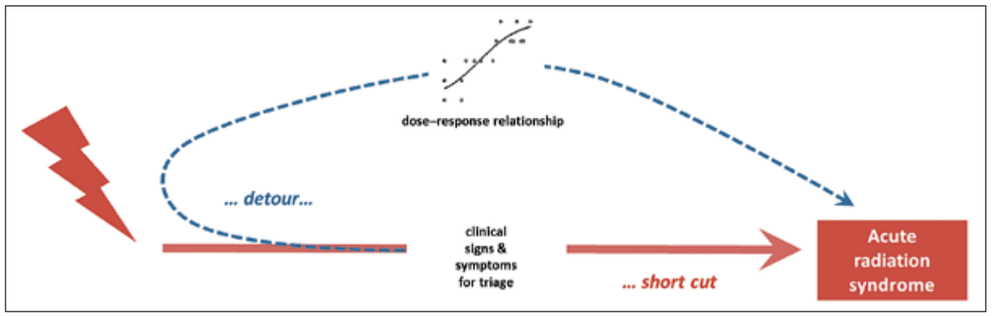

Fig. 1: Concept for diagnosing acute radiation syndrome. It is possible, on the one hand, to perform the diagnostics based on a time-consuming dose reconstruction approach (clinical signs and symptoms – dose reconstruction – radiation damage).
Or it is possible to estimate the radiation damage directly based on clinical signs and symptoms (radiation-induced clinical signs and symptoms – radiation damage) (Source: InstRadBioBw)

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The Bundeswehr Institute of Radiobiology (InstRadBioBw) has developed an IT-based tool (H-Module) for rapid clinical triage (Fig. 2). Using simple blood cell counts from the first, second and third day after radiation exposure, the H-Module is able to predict the hematological radiation damage and its expected grading (severity). It also recommends therapeutic options. Its calculation algorithm is based on changes in the blood cell counts of real-life radiation casualties. The use of biological material and data from radiation-exposed collectives is a key quality feature of the tool.

The H-Module has demonstrated its practical relevance during a NATO-wide exercise hosted by the InstRadBioBw. In a tabletop exercise, a terrorist radiological scenario involving a hidden radiation source on a train was simulated (Fig. 3). After only three hours it was possible, with a high accuracy of 90% on average, to predict the severity of the acute radiation syndrome to be expected as well as give a recommendation for hospitalisation for the 191 patients. One of the eight participating teams used the H-Module and achieved up to 19 % better predictions of the patients' sickness severity in comparison with other teams.

The H-Module is an easy-to-handle tool. Students of the "Radiation Biology" masters programme at the Technical University of Munich were given a few hours of instruction and afterwards were able to achieve prediction results with the tool on a level comparable to that of recognised radiation biology experts.

There are plans to make the H-Module available to physicians within the framework of NATO teaching classes as an introduction to the medical management of radionuclear (RN) scenarios. In the event of a nuclear or radiological mass-casualty scenario, early and high-throughput diagnostics methods will inevitably be required. The H-Module, given its high practical relevance, can thus play an important role in such a scenario.

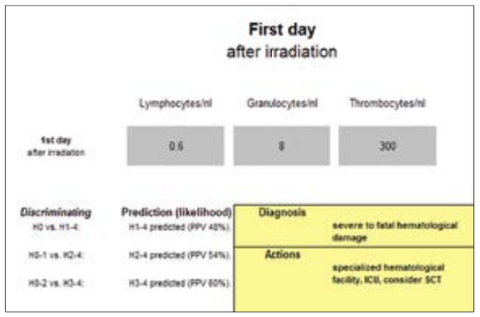

Fig. 2: H-Module for predicting hematological radiation damage. H0-4: the severity of the hematological acute radiation syndrome is given in grades ranging from 0 (unexposed) and 1 (mild) to 4 (severe); PPV: positive predictive value; ICU: Intensive care unit; SCT: Stem cell transplant (Source: InstRadBioBw)

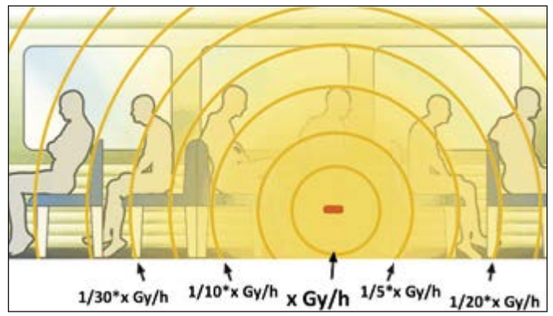

Fig. 3: Scenario of a radiation exposure device deposited on a train.
Dose rate: Gy/h (Gray per hour)
(Modified from: https://www.remm.nlm.gov/red.htm (19 .12. 2016))

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“Dry Air Comfort” (DAC) – Development of a “physiological” microclimate cooling method to reduce heat stress under thermally insulating protective clothing

Heat stress caused by thermally insulating protective clothing (CBRN, barrier nursing etc.) limits wear and thus work time in such attire. The new “Dry Air Comfort” (DAC) method provides, for the first time, effective microclimate cooling, adapting the most effective physiological cooling mechanism, sweat evaporation. The innovative approach is based on inventions of the Institute’s employees and is now patent-pending.

In training as well as on operations, German servicemen and women are also required to wear thermally insulating protective clothing (CBRN, barrier nursing etc., Figs. 1, 2). The equipment’s weight as well as movement restrictions increase metabolic rate and, consequently, body heat production. The thermal insulation of such clothing also limits heat dissipation, such that the resulting heat stress reduces physical performance and can pose a significant risk to health, especially in hot environments (i. e. hyperthermia).

One preventive measure consists in limiting the wear time. In hot climates, however, work times are reduced to less than 30 minutes, meaning that effective job performance is hardly possible. Microclimate cooling devices may provide a remedy. Traditional approaches have so far failed to extend the tolerance times to any lengthy degree when wearing insulating protective clothing. This is due to the fact that sweat evaporation, as the most effective heat dissipation mechanism for anyone doing hard physical work, is not supported, or only insufficiently so.

Fig. 1: Examples of different forms of thermally insulating protective clothing

Fig. 2: Patient care exercise under barrier nursing conditions

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As a solution, the Koblenz research and development department, has developed a new microclimate cooling method called “Dry Air Comfort” (DAC). It is an innovative air-diffusing garment (DAC suit, DAC-S) that can be worn by personnel beneath their protective clothing. The DAC-S is insufflated with a steady flow of dry air (<< 5 % rel. humidity) via a flexible tube, thus enhancing sweat evaporation.

The air flow (600 l/min) and air temperature (max. 33 – 34 °C) are adjusted to sweat production and regulation of skin perfusion. The method is based on employee inventions and is patent pending. The undergarment cooling suit has been developed in cooperation with the Bundeswehr Research Institute for Materials, Fuels and Lubricants.

The ventilation multiplies the sweat evaporation rate and significantly reduces heat stress when compared with unventilated control conditions, thereby lowering heart rates as well as body core and skin surface temperatures. In laboratory trials the method has proven to be so effective that time schedules for CBRN decontamination work or immediate medical care of CBRN casualties can be extended as long as such tasks can be carried out at fixed (stationary) locations where continuous ventilation is provided (Fig. 3).

The length of the flexible tubing connecting personnel in their DAC-S to a stationary compressor currently restricts freedom of movement. One potential approach for tasks requiring full mobility is interval cooling, where personnel work without any cooling, unrestrained by any tubing, and take regular breaks to cool down, reconnecting to a stationary compressor for air supply.

The aim of an ongoing study (Fig. 4) is to test the efficacy of such a strategy using a suitable work/rest interval regime. If successful, the DAC method could also extend the time periods for wearing thermally insulating protective clothing during mobile tasks. Interval cooling, in particular, could eliminate the time and effort involved in donning and removing the protective suits, allowing work to be continued after a cool-off period as well as relief personnel to be relieved in turn. Alternating between actively working and resting (cooling) personnel would permit an overall reduction in personnel resources.

Fig. 3: Soldier of CBRN Defence Regiment 750 “Baden“ with portable measuring equipment during an on-site analysis

Fig. 4: Volunteer in thermally insulating protective clothing in a climatic chamber

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Scientific findings concerning a healthy target group-oriented diet in the German Armed Forces in the context of occupational health management

A healthy diet as part of occupational health management is an essential component for fit and capable armed forces. Two scientific projects have identified possibilities for optimising the nutritional composition of troop meals as well as for increasing the selection of healthy foods and beverages in the short-to-medium term through "choice architecture".

After a trial phase and the subsequent launch of an occupational health management scheme within the area of responsibility of Germany's Federal Ministry of Defence (FMoD), measures are being implemented for "systematic, target-oriented and continuous management of all occupational processes, with the goal of preserving and promoting health, performance and success for the organisation and all of its personnel".

Whether on routine duty in Germany or on operations, personnel within the area of responsibility of the FMoD should have optimum possibilities for a healthy diet as part of occupational health management. A balanced diet is fundamental for health promotion and illness prevention and has a positive influence on fitness for work and life expectancy. The provided catering is of the utmost importance in this context. Troop meals and the food on offer have been analysed in a research sub-project accompanying the occupational health management drive, and recommendations for improvements made.

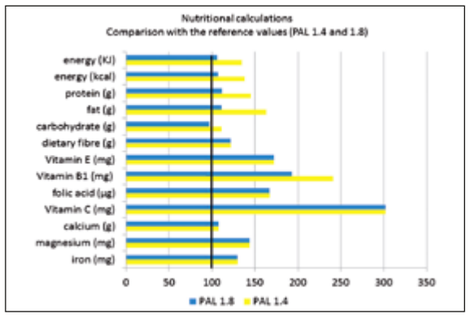

Fig. 1: Comparison of nutritional calculations for lunchtime meals with the D-A-CH reference values for specific nutrients

Fig. 2: Example of a simple nudging measure: sliced fruit as a dessert in attractive glasses, and assorted fruits on green trays (Picture: KErn)

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Over a period of 20 catering days, troop meals (mainly lunch) were assessed, taking as a basis the quality standards for workplace canteens drawn up by the German Nutrition Society (Qualitätsstandards für die Betriebsverpflegung der Deutschen Gesellschaft für Ernährung). Analysed were the frequency of the foods served and the nutritional value based on nutrient calculations from recipes. The findings were compared with "D-A-CH" reference values, using the "Physical Activity Level" (PAL) as a measure of physical activity: 1.4 (predominantly seated activity), and 1.8 (heavy physical or athletic activity). These analyses served to determine that, assuming a PAL of 1.4, current troop meals contain a significant surplus of calories and macronutrients (proteins, fats and carbohydrates), with essential vitamins, mineral nutrients and fibres being supplied in adequate amounts (Fig. 1).

Apart from the sheer supply of meals, choice architecture influences the choice of the food on offer in mess halls. Classical, mostly informative measures aimed at improving eating habits have only a limited effect on the whole. Choice architectures are used to induce positive behavioural changes in people.

Within the scope of a second sub-project, nudging measures were tested in the mess hall of KAUFBEUREN Air Force base to examine how they affect the numbers of healthy meals and beverages that are choosen. Simple changes (e. g. improved handling at the salad bar; broader variety of fruit desserts; additional selection of mineral water in eye-catching green containers (Figs. 2 and 3)) led to a significantly higher demand for salad as a side dish, for fresh fruit as a dessert and for a higher amount of mineral water as a beverage in the short- and medium term (Fig. 4).

In summary, it is found that there is room for optimisation where troop meals are concerned. The findings from these sub-projects will lead to changes in canteens in 2017/2018 as a result of positive experiences with nudging measures and modifying basic recipes. In addition, at least one lunchtime meal menu based on a PAL of 1.4 will be offered even at facilities where physical activities are high on the agenda to cater for personnel employed mostly in desk-bound work.

Fig. 3: Example of a simple nudging measure: additional 500 ml mineral water bottles in green containers available at multiple locations (Picture: KErn)

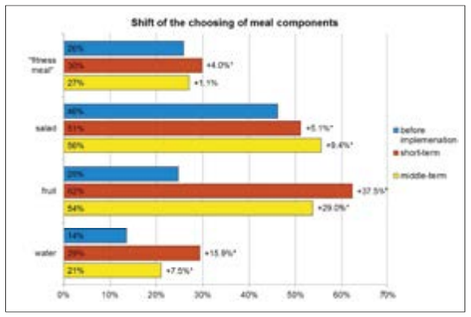

Fig. 4: Percentage of mess hall patrons who chose fitness meals, side-salads and fruit desserts shortly (3 months) after, and in the medium term (6 months) after the introduction of nudging measures, as well as percentage of water as a beverage, * $p < 0.001$

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Cave Lucem – Laser Attacks on Aircraft

Laser attacks on aircraft through the misuse of laser pointers are increasingly becoming a problem affecting flight safety. The German Air Force Centre of Aerospace Medicine and its cooperation partners have made it their task of analysing the background issues and risks posed by this trend and of providing suitable measures to protect both pilots and the public from the effects of such attacks.

Since their development, lasers have become the epitome of technological progress. The acronym based on Einstein's prediction of amplifying coherent light is still a source of fascination. However, this light is dangerous if abused or misused without the necessary precautions. Multiple case reports refer to children and adolescents causing themselves irreversible retinal injury by looking directly into a laser pointer and thus damaging their sight.

Given the increasing incidence of laser attacks, the question whether or not an aviator's eyesight might also be injured is certainly justified. Although according to the current knowledge, this question has to be answered in the affirmative in principle, this may reflect only a sub-aspect of the problems posed by lasers. Considered much more likely and, hence, more dangerous, is how flight performance is affected in the critical phases of flight when maximum concentration and faultless flight are expected from the pilots. It is in those flight-phases that 60 – 80 % of laser attacks occur, i. e., the slower and lower the aircraft flies, the more likely confrontation with a laser becomes statistically.

To be able to better simulate the interference potential in this situation, a descriptive model has been developed which takes account of all suggested in-flight laser incapacitation possibilities. In this model, distinct levels of mental (1), visual (2) and physical (3) interference are defined. How the respective interferences of levels 1 and 2 (distraction and glare) affect a pilot's performance is not known so far. Within the framework of NATO SET-198, a computer simulation of the effect of glare and flash-blindness on the human eye has been rendered which documented that depending on the device's light energy, the central field of vision might be eliminated completely by a laser pointer. A follow-up project (SET-249) will now investigate the extent to which individual handling assurance is impaired by varying laser exposure patterns.

The call for protective measures gives rise to considerable concerns in this context. If flying under visual conditions is to be retained, then an a-priori decision has to be made regarding which wavelengths in which transmissions should be blocked, resulting in two problems. Firstly, there is no or only insufficient protection against the wavelengths that remain and, secondly, filtering out an individual wavelength from the visible spectrum leads to a clinically apparent disturbance of colour vision. Research into suitable protective goggles has shown that such colour vision disturbances, in their extreme, may make it impossible to correctly read the digital displays in modern glass cockpits.

In order to facilitate the necessary compromise between blocked and transmitted light beams, a working paper has been issued in cooperation with the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support and the Federal Office of Bundeswehr Infrastructure, Environmental Protection and Services in which the potential beam-specific glare and incapacitation levels of available laser pointers have been calculated as a function of their ranges, energies and wavelengths. The first protective goggles selected on the basis of these calculations are currently being tested at Bundeswehr Technical Centre WTD 61 in Manching, near Munich. In addition, LED panels will be applied to the flight simulators of operational flying units that can be used in training for unforeseen coherent light exposure. The pilot project is to take place in Fritzlar.

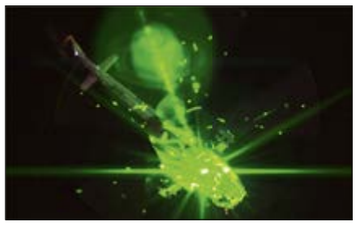

Fig. 1: AH-64 Apache helicopter targeted by multiple laser pointers during public unrest in Cairo in 2013 (Courtesy of David Cenciotti, 2017)

Fig. 2: In-line (frontal) laser dazzling on the ground during a taxiing manoeuvre, as seen from the perspective of the pilot (FAA public release, 2008)

Fig. 3: Inundation of the cockpit and pilot with light from a 5 mW laser beam scattered by the aircraft's front canopy (FAA public release, 2008)

Fig. 4: Global display of aviation-related laser incidents, 2005 – 2009.
Source: http://aviation.globalincidentmap.com
(© OpenStreetMap)

Fig. 5: Global display of aviation-related laser incidents, 2010 – 2014.
Source: http://aviation.globalincidentmap.com
(© OpenStreetMap)

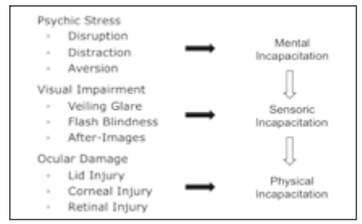

Fig. 6: Model of ocular laser in-flight incapacitation as suggested by the author
(© FMJakobs, 2012)

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Expert medical evacuation on board German Navy vessels

An interdisciplinary working group at the Naval Institute of Maritime Medicine is intensively addressing the challenges of transporting sick and wounded on board naval vessels. A standardised and reproducible research methodology has been developed with the aim of analysing and further evolving rescue and recovery procedures medically, ergonomically and with regard to safety.

The standard procedure for evacuating sick, injured or wounded persons on board seagoing German Navy vessels is in need of review.

Tried and proven equipment that has now become outdated has to be adapted, upgraded or replaced in line with the technical and practical advances that have been made. The steady professionalisation of civilian emergency rescue services has an additional influence on the military medical service, of course. Current regulations and policy from the fields of occupational safety and occupational medicine need to be given greater consideration where the movement of patients is concerned. Lessons learned from armed conflicts have led to NATO armed forces upgrading their first aid and medical care concepts. Humanitarian military missions are confronting medical aid personnel with having to transport patients of all age groups.

The working group is conducting strictly practice oriented evaluations in cooperation with the medical aid personnel from various naval vessels. The aim is to accumulate information and to document possible deficiencies as well as particular challenges directly on site.

Fig. 1: Inspection for patient transport on board a naval vessel

Fig. 2: Laboratory evaluation

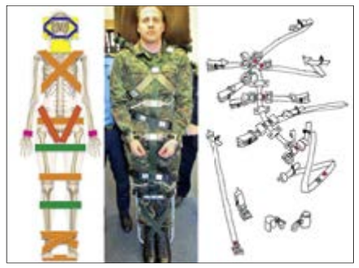

Fig. 3: Prototype of a universal patient restraint system

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Special „laboratory equipment", comprising mainly various medical transport devices and accessories, mannequins of various sizes and weight categories, as well as load lifting gear, is used for this purpose.

The results obtained so far have led to a catalogue of standardised test scenarios that allow comparison of patient transport equipment and, in particular, methods for transferring patients.

It has proven imperative to take into account not only the equipment in use but also the best possible synthesis of medical requirements, the expertise of the responding personnel, and the possible methods of transport. Compatibility between the various items of equipment plays a vital role in helping to largely avoid the time-consuming, and potentially harmful, transfer of patients between transport devices. The findings of the evaluations include recommendations for procurement projects as well as for providing support in resolving specific transport problems on site.

Existing restraining material is often inadequate for securely immobilising patients on transport devices when moving them on board. Unusual body positions, including vertical transport, are therefore not possible without endangering the patient. The development of an optimised universal restraint system for the immobilisation of patients has, as a result, become a separate project.

Because vertical transport of patients on board is unavoidable, special attention is being paid to the development of concepts for "vertical rescue and retrieval", for which purpose intensive cooperation with marine engineers and shipbuilders has been initiated. The aim is to use modern lifting gear and vertical rescue techniques on board to a greater extent.

In a further research project the working group has begun the development of a patient protection bag that meets the medical requirements for patient transport at or over sea. This increases the chances of survival in case of accidentally falling into the water.

Fig. 4: Roping technique to improve the ergonomics

Fig. 5: Roping technique used to rescue patients in distress situations at sea

Fig. 6: Patient protection bag

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Survey on job mobility in the German Armed Forces

A representative survey has been conducted to empirically study the full scope of job mobility in the German Armed Forces, yielding information on its distribution, causes and consequences. Initial approaches to reducing or mitigating the stress that accompany the job mobility very broadly expected of members of the German Armed Forces have been identified.

Employees in today's working world are required not only to be flexible but also mobile to an ever greater degree. The German Armed Forces, being a nationwide organisation, is particularly reliant on the professional, i. e. regional mobility of its personnel.

There are multiple possibilities to be occupationally mobile, ranging from daily commuting, to lengthy absences from home and family, to moving house.

Job mobility offers diverse benefits and opportunities. For the German Armed Forces as an employer, the benefit consists in adequately filling vacant posts or flexibly managing training and qualification courses. For the occupationally mobile member of the German Armed Forces, more career options and opportunities for advancement can open up. However, occupational mobility in many cases comes with personal as well as family-related disadvantages for the persons concerned and their dependents, for example in the form of frequent time constraints or the lack of opportunities to spend adequate time with the family and lead a social life.

Previously there had been no extensive reliable data available to the German Armed Forces on the extent of occupational mobility, its causes and consequences, or on possible optimisation measures from the viewpoint of those concerned.

Given this lack of empirical data, a representative survey of military and civilian personnel (N = 15.082) including their partners has been conducted. The response rate for those sampled within the German Armed Forces was sufficient with almost 30 %. Partners of those respondents living in a partnership provided a 77 % response rate. This substantial percentage gave a first indication of how important this topic is for the relatives and dependents.

Employees of the German Armed Forces show a high rate of mobility, with 60 % of respondents being occupationally mobile, this figure lying well (19 %) above that for gainfully employed German adults.

Respondents primarily specified job-related reasons for being mobile, such as training and qualification courses (22 %), effects of in-house reorganisations (15 %), or better career opportunities for the future (14 %), and the occupational activity of both partners (10 %).

The benefits of occupational mobility are most commonly seen in the learning of new things, the broadening of personal horizons and the establishing of new contacts. The disadvantages for those facing occupational mobility however, are considered to be greater, namely effects on family life (less time to spend with children and partner, difficulties in providing care for relatives), high financial costs, and personal constraints such as pressure of time and exhaustion. Those concerned and their partners consequently experience occupational mobility basically as stressful (60 % – 92 %, depending on the form of job mobility).

Only a minority of the respondents (29 %) regard job mobility as a personal opportunity, while 73 % of respondents see it as a necessity, and 54 % even as a constraint. Just under one third of the sample (27 %) expressed their readiness to be occupationally mobile also in future, while 44 % are unwilling in that respect.

For the German Armed Forces to remain a competitive and attractive organisation and employer, and given the additional stresses placed on its members through further absences as a result of deployments abroad, the survey findings show that it will be necessary and desirable to further reduce and moderate the negative effects associated with job mobility. From the viewpoint of those who are affected, long-term assignment planning and lengthier assignment durations, consideration of the family situation where reassignments are concerned, flexible working-time models and financial support are most important.

Fig. 1: Commuting by train (© 2016 Bundeswehr/Dinnebier)

Fig. 2: Commuting by car (© 2016 Bundeswehr/Dinnebier)

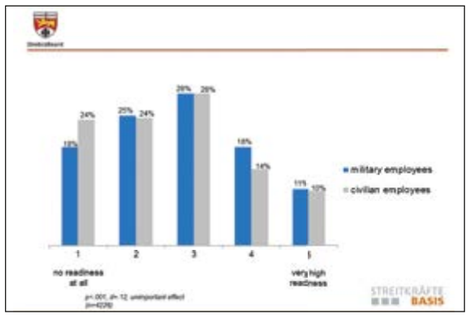

Fig. 3: Extent of readiness for future job mobility, by status (military vs. civilian personnel)

3

Military History and Social Science Research

The Bundeswehr Centre of Military History and Social Sciences (ZMSBw) undertakes military historical and socio-scientific research on behalf of the Federal Ministry of Defence with a view to actively shaping the public debate about military and security issues in Germany through its academic findings.

The ZMSBw researches German military history in accordance with the generally accepted methods and standards applied in the science of history, taking into account the interrelationships between the military, politics, economy, society and culture.

Through its social science research the ZMSBw contributes to the continued development of the social sciences as well as to academically based political consultations. The intertwined nature of the science of history and the social sciences broadens the range of opportunities in the field of research and in the application of its findings in history education.

The contribution made by the ZMSBw helps to better understand the role of armed forces in a pluralistic society. The social sciences, being thematically interlinked with military history, feed into the research on, and interpretation of, new conflicts and special operational scenarios of the Bundeswehr.

Through their work the researchers at the ZMSBw are members of the academic community. They foster and maintain contacts with organisations, institutions and agencies at home and abroad as well as with university and non-university research facilities.

Of increasing importance is cooperation with other Bundeswehr institutions engaged in training, research and education. The ZMSBw supports Bundeswehr missions through historical and social science analyses.

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57th International Conference of Military History (ICMH) “The Grand Battles 1916“

The Bundeswehr Centre of Military History and Social Sciences (ZMSBw) annually organises an International Conference of Military History. To mark the centenary of the Battle of Verdun, numerous historians met in April 2016 in Trier where they discussed questions of warfare and of everyday life in World War I as well as commemorative culture.

The 57th ICMH, which took place in Trier from 18 to 21 April 2016, was very much dominated by the battles of 1916, because 2016 marked the centenary of no fewer than four important major battles of World War I: the Battles of Verdun and of the Somme River in France, the attack by Austria-Hungary in Tyrol on the southern front towards Italy, and the offensive of Russian General Brusilov in the east. The three-day conference, organised in cooperation between the ZMSBw and the French Service Historique de la Défense (SHD, Vincennes), offered insights for more than 150 international researchers and an interested audience from the military and civilian sectors into current military history research on the Battle of Verdun, on the other major battles of 1916, and their commemoration in the states involved in the war.

In his words of welcome, the Vice Chief of the German Joint Support Service (SKB), Lieutenant General Peter Bohrer, also emphasised the significance of places of remembrance, such as Verdun, for how our military personnel perceive themselves in present-day Europe. Historical education as an element of political education is one of the keystones of the Bundeswehr concept of ‘Innere Führung’ (leadership development and civic education) and its guiding principle of the ‘citizen in uniform’. Military history is an integral part of training in Germany’s armed forces.

Prof. Dr. Gerd Krumeich (Freiburg) outlined aspects of war strategy, soldiers’ battlefield experiences and commemorative culture in his keynote introductory evening lecture on the first day, entitled “Verdun 1916. The Battle and its Myth”. He impressively demonstrated the repercussions of the Verdun event beyond the borders of nations, generations and individual fields of research, thus moving into focus the wide range of possibilities for conducting military history research on world war. The presentation of this range was unquestionably an important cornerstone of this year’s ICMH as a means of illustrating the new methodological openness and multiperspectivity of world war research in general.

The participants included this innovative approach in their presentations and lively discussions. Totally in keeping with a broader approach to military history, the presentations of the five sections covered not only modern operational history with the topic “Learning in war”, but there were also presentations on religion, “trench art” or medical ethics to turn the audience’s attention to commemorative culture and to the history of art or medicine. Looking beyond national perspectives underscored the great relevance of international comparison.

A one-day excursion to the battlefield of Verdun on the fourth day concluded the event. In the presence of the Chief of the Joint Support Service, Lieutenant General Martin Schelleis, the Commandant of the Leadership Development and Civic Education Centre, Major General Jürgen Weigt, and the German Defence Attaché in Paris, Brigadier General Hans-Dieter Poth, the participants visited key historical sites on the battlefield. The forts at Douaumont and Vaux, as well as the Ossuary, vividly evoked the horrors of the three-hundred day battle and the memory of this widely defining major historical event one hundred years ago. The visit to the renovated and recently reopened Mémorial de Verdun, in particular, was an excellent example of the modern approach to commemorative culture and the teaching of history. Senior representatives of the ZMSBw and SHD commemorated those who fell in the battle in a low-key wreath-laying ceremony.

A conference volume documenting the research has meanwhile been published.

Fig. 1: Words of welcome from the Deputy Chief of the Joint Support Service, Lieutenant General Peter Bohrer, April 18, 2016

Fig. 2: Opening presentation of Prof. (ret.) Dr. Gerd Krumeich, April 18, 2016

Fig. 3: Military-historical excursion, Ossuary Verdun, April 21, 2016

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Military sociology research on recruitment and retention

Studies on personnel recruitment and retention in armed forces form a core element of international military sociology. Germany's Federal Ministry of Defence has often expressed a need for socio-scientific research on personnel topics – and not just since the suspension of universal conscription in 2011. That being the case, corresponding assignments issued by the Ministry were again the focus of project work undertaken by the Military Sociology Research Branch at the ZMSBw in 2016, the year under review.

The general topic of current research projects is how the Bundeswehr can improve its position as an attractive employer. At the centre of attention in the year under review was the "Personnel Survey 2016" project, the aim of which was to measure the effect of the attractiveness agenda entitled "Bundeswehr in the lead – an active and attractive alternative", launched in 2014 by Federal Minister of Defence Dr. Ursula von der Leyen. For this purpose, 10,000 Bundeswehr members (military and civilian personnel) were contacted by mail in the period from 13 June to 19 July 2016. The results are meanwhile available as a research report on the ZMSBw homepage.

The study's findings are pleasing. Positive impacts on employer attractiveness are noted both for the measures under delegated legislation regarding the agenda and for the Act on Enhancing the Attractiveness of Service in the Bundeswehr, i. e. Bundeswehr members who already notice effects of measures initiated as part of the agenda, either personally or in the area where they work, rate the attractiveness of the Bundeswehr as an employer more highly. In response to the question whether they would again decide in favour of the Bundeswehr as an employer, 56 percent answered with a "yes" – representing an increase of 13 percentage points compared with a reference survey conducted in 2013. Satisfaction with service conditions, at 62 percent, is significantly higher in 2016 than it was four years previously, when 49 percent responded as being more or less satisfied, satisfied, or very satisfied. The study indicates, however, that there is a need for adjustments in the communication work surrounding the attractiveness agenda. While the majority of the Bundeswehr members stated that they were familiar with the agenda and knew the key facts and reasons for it, 29 percent of them had neither heard nor read anything about the attractiveness campaign.

Two research projects that have looked at specific target groups in terms of personnel work were completed in 2016. These were long-term projects on "Recruitment and retention in the Bundeswehr Medical Service" (in progress since 2012) and on "Navy officer candidates in the first year of training" (in progress since 2013). Relevant research reports and journal articles have already been published or are planned for publication in 2017.

Further target group analyses will be undertaken in 2017. A project entitled "Motivation of military personnel in the Bundeswehr" is being undertaken to identify the reasons why military personnel are willing to re-enlist, and to deliver proposals for the future organisation of careers. Another project, "Careers of former temporary-career volunteers in the private sector: experiences, success factors, and prospects for cooperation", has also been launched. It will study the careers of that target group as well as examine the prospects for closer cooperation between Germany's armed forces and the civilian labour market. The ZMSBw also plans to hold a conference in 2017 which will put the military-sociological findings on recruitment and retention into a broader scientific context.

The academic and scientific work of the Military Sociology Research Branch is characterised by a consistent combination of basic and commissioned research. The Branch again succeeded in 2016 in meeting the needs of the Federal Ministry of Defence for specific knowledge by conducting various research projects and providing reliable scientific findings – sometimes at very short notice. It also arranged the studies so that they provided added scientific value and their findings could be shared in academic exchanges and used for publications and presentations.

Fig. 1: Agenda „Bundeswehr in the lead – an active and attractive alternative"

Fig. 2: ZMSBw research report on the personnel survey conducted in 2016

To what extent do the following statements apply to you? (Figures given in percent)	not true	not quite true	partly / partly	rather true	true
I consider the Bundeswehr an attractive employer.					
2013	7	15	39	25	14
2016	3	8	30	35	24

Fig. 3: Assessment of the Bundeswehr's attractiveness as an employer. Database: the ZMSBw personnel surveys conducted in 2013 and 2016

Fig. 4: A recent Military Sociology Research Branch publication

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Geoscientific Research

The Bundeswehr Geoinformation Centre, or BGIC, is the central agency of the Bundeswehr Geoinformation Service (BGIS). With its Applied Geosciences Directorate, the BGIC is the executive body for geoscientific research in the Bundeswehr. Geoscientific research is a sub-process of the "Ensuring Work in the Geospatial Field" performance process of the Federal Ministry of Defence (FMoD). Invariably, the research and development (R&D) activities of the BGIC are geared, by virtue of the FMoD's research plan, to the immediate needs of Germany's armed forces and to the missions they undertake. The global orientation of the Bundeswehr has for years required the BGIS to provide all-round geospatial support in an interdisciplinary approach through close cooperation of the 18 geoscientific disciplines represented in the Service. This involves routinely handling topical and short-term as well as medium- and long-term tasks and problems.

The goals of the geoscientific R&D are directly contingent on the current and evolving mission of the Bundeswehr and the BGIS. Accordingly, research activities are conducted whose results are immediately needed to meet the requirement for quality-assured geospatial information. Moreover, it is important to bring methods and procedures already in use into line with the constantly advancing state of research. It is necessary to be able to identify relevant geospatial factors and environmental influences at all times and in all circumstances, to assess their impacts on military operations and tactics, to provide up-to-date and quality-assured low- as well as highly dynamic geospatial information worldwide for exercises, operations preparation and deployments, as well as to brief operational forces on geoscientific aspects and raise awareness for the importance of political processes including geospatial factors. The results of the geoscientific R&D serve in total to assure the military core capability for geoinformation support. They help the BGIS to accomplish its mission of providing, at all times, the latest science- and technology-based information on operationally relevant geofactors for all tasks of the FMoD and the Bundeswehr that relate to a specific geographic area. Geoscientific R&D data also find use in planning and decision-making processes of the FMoD and the Bundeswehr. The BGIC participates in both national and multinational R&D projects and programmes.

The geoscientific R&D activities build upon the current state of external research and technology, provide analyses of pertinent scientific assignment-related findings and make use of the services offered by research institutes of other federal ministries as well as military and civilian science and research organisations. Geoscientific R&D projects are conducted in cooperation with suitable partners from other departmental research institutions, universities, universities of applied sciences, non-university research facilities and commercial enterprises. The geoscientific research not only focuses on steadily improving the ongoing geoinformation support provided to the Bundeswehr, but is also perspectively geared to addressing problems and questions for which there is as yet no apparent need for action or regulation. It thus helps to identify and take account of new developments at an early stage and to ensure that the appropriate advisory services can be rendered in advance.

The following pages of the Military Scientific Research Annual Report 2016 feature selected examples of such applied geoscientific research work.

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The Ebola epidemic in West Africa

From 2014 to 2015 Sierra Leone, Guinea and Liberia battled an Ebola epidemic. The development, from initial infection to full-blown epidemic, has made the entire issue relevant for geopolitical consideration. The Federal Republic of Germany sought to improve the situation at source, showing its commitment through, among other things, financial donations and dispatching the Bundeswehr.

The aim of the study has been to analyse the reasons for the outbreak and the consequences of the Ebola epidemic. A weakening of the economy and negative developments in the United States could have had an impact on international security policy. Pursued approaches such as "scenario planning" are possible ways of discussing situation developments for the future.

Where Ebola is concerned, it is assumed that particularly bats serve as microbial reservoirs for the virus. The animals' enormous adaptability to changing habitats, such as cleared forest areas, and the option to make residual trees or even houses their home have increased the risk of zoonosis, i.e. the spread of a pathogen from an animal to a human. In the countries under review, there is no consistent reutilisation or total clearance of the areas formerly definable as primeval forests but, instead, a fragmentation of the existing forest sections, thereby greatly expanding the contact area for man and nature.

To understand how the virus was initially able to spread unnoticed and nearly uncontainably, it has been necessary to consider the history of the region. It has subsequently become clear that the epidemic was by no means a spontaneous and spatially arbitrary event. The sluggish development of the region can be traced back to the negative predisposition of the affected countries to civil wars, ubiquitous nepotism and corruption. The fragile statehood of the affected countries is an unfavourable condition for avoiding or containing epidemics.

In early 2014 the World Health Organization declared the Ebola epidemic to be a global health emergency. This development was due to the fact that the virus was occurring in densely populated areas. An important aspect was that medical staff in those countries' clinics and hospitals had failed to identify the virus as the Ebola virus. The widespread habit of the population of consulting witch doctors was an additional hindrance to curbing the epidemic. People in city slums were particularly at risk as they live in a very confined space, have to make do with miserable sanitation and lack clean (drinking) water.

The direct costs of the epidemic, for example as a result of deaths and the loss of earnings caused by sick members of the workforce, has to be quantified well below the costs incurred through aversive behaviour of the population within the countries affected as well as of institutions and industries from outside.

The "Humanitäre Hilfe Westafrika" (Humanitarian Assistance for West Africa) support mission, comprising the German Red Cross, the Bundeswehr und Liberian healthcare personnel, made a vital contribution in combating the Ebola virus, even if it has to be conceded that the focus was not so much on specifically treating Ebola patients. In helping to adapt the national crisis concept and provide sustainable training to native specialist personnel, they managed however to offer substantial input.

The Ebola epidemic, as it has become clear, is a developmental crisis that manifested itself in medical aspects and led to an exacerbation of the economic situation in the countries concerned. Overcoming the epidemic does not mean that the danger has been averted or that further commitment is unnecessary. The contrary is the case. The epidemic has shown how important international commitment is for sustainable development aid in countries that are historically predisposed and incapable of changing that status on their own.

Fig. 1: Distances between selected towns and airports, and direct flight connections, as well as relative probability of any import of Ebola, and selected transit connections (Brockmann 2014)

Fig. 2: Relative probability of Ebola transmission through wild animals and forest loss in 2000-2013

Fig. 3.: Donning of full-body protective suit for staff attending at the Severe Infections Temporary Treatment Unit (SITTU) in Monrovia on 26 January 2015 (Source: Bundeswehr/Wilke 2015)

Fig. 4: A staff sergeant trains with Liberian nurses at the Severe Infections Temporary Treatment Unit in Monrovia on 21 January 2015 (Source: Bundeswehr/Wilke 2015)

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Mineral dust forecasts for Bundeswehr deployment areas

Over the past few years, advances have been made in regard to the preparation and continuous improvement of mineral dust forecasts on the basis of numerical weather predictions for Bundeswehr deployment areas. This information is often requested in addition to the general meteorological forecast for arid mission areas and is highly beneficial for all services.

The COSMO-ART model system (Bundeswehr nomenclature: RLMD, or Relocatable Local Model Dust) is notable for coupling the numerical weather prediction (NWP) models of the German MET Service (DWD) and the Bundeswehr online with the ART modules developed at the Institute of Meteorology and Climate Research of the Karlsruhe Institute of Technology (KIT) for the treatment of Aerosols and Reactive Trace gases in the atmosphere.

The NWP simulations are augmented by the forecasting of concentrations of particular aerosol particles and, if required, also of gaseous components with every time step and at all points of the computational grid. The advantage of online coupling is that the meteorologically relevant parameters of the additional processes can be used synchronously for the numerical weather prediction in high frequency. Moreover, the same algorithms are used as for the NWP model itself in this case, such as for the description of scale (advection) and subscale (convection, diffusion) transport processes. Specific processes such as the parametrisation of emissions, sedimentation, wet and dry deposition on the ground, or conversion processes e.g. owing to chemical reactions, are provided by the ART modules.

If there are interdependencies between meteorological processes and the additional parameters, this can also be basically considered in the online coupling (aerosol-radiation interaction or cloud interaction). These computation-intensive interaction processes are not as yet implemented in the operational model calculations currently undertaken for the Bundeswehr.

In recent years, mineral dust amounts have been forecast for, among other purposes, flight weather briefings or because of the dust susceptibility of measuring instruments on vessels operating in various areas (e.g. Afghanistan). Operational forecasts are prepared twice a day (00 / 12UTC) for the ATALANTA area including Syria / Turkey / Iraq (forecast up to day 3) and for the West Africa region including the mission area of Mali (up to day 2). The Bundeswehr thus covers almost the entire Sahara and the Arabian Peninsula with its computations. Since there is no transfer of the mineral dust at the boundaries of the models, it makes sense for the model area to cover all dust sources from which emitted dust is transported into the target / mission area.

Scientific findings led to improvements in the dust forecasts for theatres of operations in 2016. A useful mineral dust forecast requires a soil dataset which is as accurate as possible. The emission of varyingly sized sand grains depends strongly on the category of land use and the grain size distributions. For that reason the system has been equipped with a soil dataset that has a ten times higher spatial resolution (~ 1 km). Furthermore, it is now possible to operate worldwide with this dataset. To refine the prediction for the first (up to 12) forecast hours in which, for a cold start (dust-free atmosphere) of the model, emitted dust is accumulated gradually, a dust concentration is included in the system for initialisation as a starting analysis. It comprises a 12-h forecast from the preceding model run. This change in the forecast leads to, among other things, an improvement in the prediction of gradual obscuration, which may build up over days. The research topic of computing visibility with the aid of the predicted mineral dust concentration is currently the focus of academic activities. Any evaluation is difficult on account of there having been very few measurements of the visibility / mineral dust content in the mission areas. A case example in Fig. 3 shows a good-quality dust concentration prediction in comparison with satellite soundings.

Fig. 1: Dust wave with ensuing obscuration of less than 100 m
(Camp Mazar-e Sharif / Afghanistan)

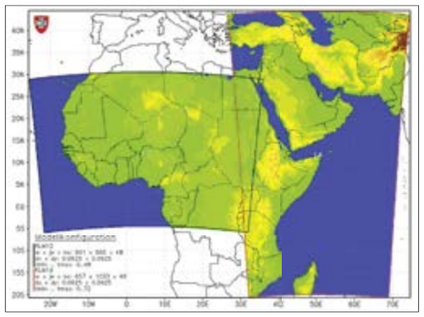

Fig. 2: Operational model areas for mineral dust forecasts,
status: 18 January 2017

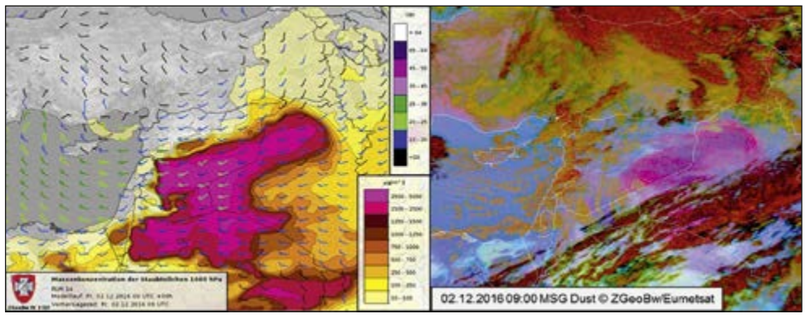

Fig. 3: Comparison of numerical dust prediction with satellite observation on 2 December 2016 09UTC in the area of Syria.
Left: Projected concentration of dust particles + wind arrows, Right: Meteosat RGB Composite Dust © Eumetsat, dust represented in purple

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Cavity detection using methods of applied geophysics

Methods of ground-based applied geophysics are being tested for their suitability to detect cavities. New subsoil imaging techniques are also being developed in this regard.

The Earth is studied by measuring its physical parameters with methods of applied geophysics. These can be categorised into passive measuring methods, such as the measurement of the Earth's magnetic field or the Earth's gravity, and active methods, such as seismics whereby acoustic waves are transmitted into the subsoil and received back. Both method categories are non-destructive. The Bundeswehr Geoinformation Centre (BGIC) is exploring methods suitable for detecting underground cavities. To be at all able to identify cavities in subsoil, there has to be a sufficiently high contrast of the cavities' physical parameters (air) and the surrounding soil or rock. Among the strongly contrasting parameters are density, electrical permittivity and electrical conductivity. These, or parameters resulting from them (propagation time of acoustic or electromagnetic waves, voltage) are measured using the methods of microgravimetry, seismics, ground-penetrating radar and electrical impedance tomography.

To test the mentioned methods for their suitability for the BGIC to detect underground cavities, terrain measurements are being conducted at various sites in Germany and abroad.

The selected locations differ in their geology and in the nature of the cavities that are present. Being measured, for instance, are historic mining tunnels or mining galleries from World War I whose dimensions are equivalent to those of tunnels dug by irregular forces. Prior to the actual measurement, the most true-to-life modelling of the measurement as possible is performed on a computer which includes the input of the physical soil and rock parameters in the measurement area and the dimensions and depth of the cavities. Such an approach delivers optimum measurement configurations for the measuring instruments in use (such as measuring point distance, signal recording period, etc.) which are indispensable for detecting cavities in the terrain. The task becomes a real challenge if the exact location of the cavity in the measurement area is unknown, as the measured data then has to be interpreted all the more carefully. What is just noise, and which is the signal?

After the measurement the data is processed, evaluated and interpreted. Following a detailed error analysis of the measured data, a simulated measurement of a so-called starting model is matched on the computer with the real measured data. The discrepancy between synthetic and real measured data is ascertained, and the starting model is adjusted slightly. Another model measurement is subsequently computed and matched with real measured data. This iterative process (inversion) is repeated until a model of the subsoil is found that accounts for the measured data within the limits of its errors. It is an imaging process that is used not only in geophysics but also in medicine, where it figures prominently. The result is an image of the subsoil obtained either as a depth section or as a three-dimensional model in space.

The BGIC's geophysical research in the field of cavity detection has multiple goals:
Firstly, GeoInfo experts are to be provided with practical instructions and recommendations for measurements in-theatre, enabling them to decide what measuring method and what configuration are best to be used for a given subsoil geology. Secondly, evaluation routines with regard to lateral inhomogeneities (cavities) are to be optimised and, if required, expanded. The ultimate goal is to develop a computer programme that allows joint evaluation of different geophysical methods and thus combines the advantages they offer to provide a better image of the subsoil.

Fig. 1: Entrance area of a military mining gallery at La Boisselle, France – an ideal measuring object

Fig. 2: Geoelectricity measurement in the La Boisselle measuring area, France. The exact location of the mining galleries was unknown in this case

Fig. 3: Ground-penetrating radar measurement with a 200-MHz antenna (red box) near Breitenbenden (Eifel hills). The underground Roman aqueduct (which is now dry) was looked for and found in this forest area

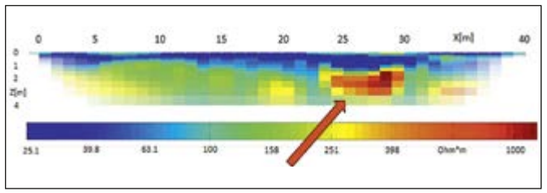

Fig. 4: Result of a geoelectricity measurement at La Boisselle, France. A profile section through the subsoil shows the apparent resistivity. A military mining gallery can be clearly recognised as a high-resistivity anomaly (red colours)

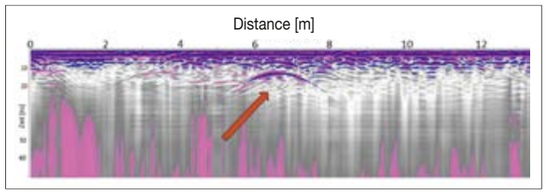

Fig. 5: Raw data with mere start time correction of a ground-penetrating radar measurement using a 400-MHz antenna to measure the Roman aqueduct near Breitenbenden (Eifel hills). Although the data has not yet been processed, the Roman aqueduct can be easily identified in the middle of the profile

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Cyber and Information Technology Research

Defence research in the field of cyber and information technologies has been strengthened by the establishment of the Cyber / Information Technology (CIT) Directorate General within the German Ministry of Defence. This also reflects the importance of these technologies for society. We appreciate the benefits that increasing digitisation in a highly interconnected world offers and, that said, are reliant on secure networks, on information confidentiality, and on having the relevant information available where and when required, reliably processed, for making the appropriate decisions.

Unlike civilian enterprises or other government departments, the Bundeswehr must be able to use and make available cyber and information technologies quickly and reliably, even under extreme environmental as well as field and combat conditions.

Both the wide range of mission requirements and the demands regarding interoperability with national and international partners or supranational organisations are challenges to which the best possible solutions are constantly sought. This makes it important for the innovations that appear on the market to become available as quickly as possible for the Bundeswehr's information and communications network.

The primary areas of research where cyber and information technologies are concerned are, therefore, cyber security, communication within networks and also via radio, hardware and software platforms and the applications that run on them.

The research can range from abstract questions such as the search for possibilities to integrate architectures into requirements management within the procurement process and the use of radio services via satellite to control unmanned aerial systems. But tangible solution approaches are also explored, such as creating a role-based cyber operational picture suited to the level of need, or a public key infrastructure (PKI) in mission areas.

Ultimately, the aim of any research is to identify in good time the significance of new technologies in terms of threats to, and capabilities for, the Bundeswehr, and to make the necessary scientific and technological findings and skills available for reaching suitable economic decisions regarding equipment.

In what follows, three examples of defence R&T activities relating to cyber and information technologies are presented in greater detail.

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Results of the LTE over Satellite system study

Global missions of the Bundeswehr call for highly mobile, tactical communication networks which can be seamlessly integrated into long-haul communication links over satellite. Under the lead management of Bundeswehr University, Munich, the "LTE over Satellite" system study has practically demonstrated the strengths and weaknesses of the commercial LTE communications standard, giving particular consideration to satellite links.

Initiated by the Department for Satellite Communications of the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support, the "LTE over Satellite" system study was concluded in November 2016 with a broad-based system capability demonstration in front of invited guests. The study was conducted under the lead management of the Chair of Signal Processing at Universität der Bundeswehr München together with the Fraunhofer Institute for Integrated Circuits and Dresden-based SME INRADIOS integrated radio solutions GmbH.

This two-year study focused mainly on the question whether and how the indispensable management components of an LTE core network can be thoughtfully distributed over hybrid networks comprising terrestrial components and geostationary satellite transmission links and be operated securely and resiliently. Several, in some cases very complex, network structures were designed on the basis of typical military requirements, such as central user management and allocation of privileges. These structures were analysed theoretically and practically for their feasibility under the technical constraints of the Long Term Evolution (LTE) commercial standard and tested in multiple laboratory sessions. The core success criteria were the reliability, security and performance of the network. The highlight of the study was a practical live demonstration using satellite transmission capacities of the Bundeswehr. Around 40 visitors from industry, the scientific community and the Bundeswehr gathered hands-on experience over two days in the University's laboratories and acquired a realistic impression of the performance capability of LTE over Satellite.

The baseline for this demonstration was a typical operational scenario comprising a patrol, a stationary checkpoint, and an operations and control centre as a strategic component. The mobile cell of the patrol was connected via a SATCOM on-the-Move (SOTM) terminal provided by U.S. enterprise L3-Com. Apart from the typical signal delay when using the geostationary satellite connections, such a scenario posed particular challenges due to the mobility of the LTE base station and the periodic shadowing of the SOTM vehicle. A special highlight of the demonstration was the integration of legacy communications equipment such as the field telephone commonly known in the Bundeswehr by the abbreviation "FFOBZB". This was possible by means of a uniformly harmonised quality-of-service concept encompassing satellite, LTE and terrestrial network technologies.

The SATCOM infrastructure required for the demonstration was provided by the University's unique test and reference SatCERTBw facility, which has been set up and is being operated there by the Chair of Signal Processing. Where the LTE core network was concerned, after a review of offers received from different vendors, Bavarian enterprise blackned GmbH was selected, which had proposed the most flexible and scalable solution.

The results of this study demonstrate the potential as well as limits of using the commercial mobile LTE over satellite networks wireless standard in a military context. The findings provide a cross-system contribution toward regenerating the mobile tactical communications infrastructure and will help the Bundeswehr to develop informative selection criteria for its procurement decisions and to design suitable test scenarios.

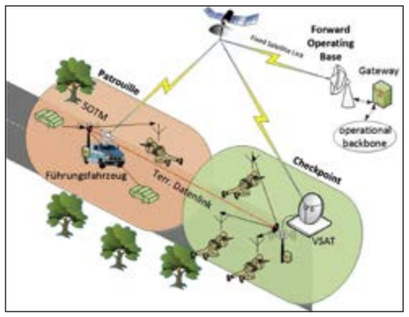

Fig. 1: Typical military operations scenario as a baseline for the demonstration of LTE over Satellite conducted at Bundeswehr University, Munich, in November 2016. It involved setting up and operating mobile and fixed LTE cells connected via satellite to a headquarters using a star network topology

Fig. 2: Hub station (4.6 m) as part of the SatCERTBw reference facility in operation during the demonstration of LTE over Satellite

Fig. 3: Successful integration of legacy communication equipment into the modern LTE over Satellite network. VoIP connectivity was reliably established between a field telephone (FFOBZB), manufactured in 1956, and the modern LTE user equipment running on the Android operating system

Fig. 4: Integration of a Sina Box into the network during the demonstration at Universität der Bundeswehr München. Left: Sina Box with SECRET classified tunnel and live video transmission via satellite; centre: LTE core network components installed in a commercial laptop; right: LTE base station (eNodeB)

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Rapid prototyping with flexible IP waveforms for SDRs

A software-based radio (Software Defined Radio, SDR) has been developed for the German Armed Forces. The performance capability of this technology is substantially influenced by waveforms. FLIP, a Research & Technology (R&T) project, is exploring the waveform development platform as well as the prototype realisation of a flexible, scalable and modular Internet Protocol (IP) waveform based on rapid prototyping.

A cutting-edge level of innovation has been reached in military radio communication with the introduction of software-based secure radios (Software Defined Radios). The complete radio functionality is realised by loading and running standardised software (waveform application) on a generic radio platform (similar to a PC). By having several waveforms available in the memory of an SDR it is possible to respond in an agile manner to changes without having to alter the radio in terms of hardware. Modularity, flexibility and reduction of logistical effort are just some of the advantages of this technology. An SDR derives its enormous effectiveness through the use of modern IP-capable waveforms. However, the conservative development of an SCA (Software Communications Architecture)-compliant waveform application is time-consuming and cost-intensive. The fast prototype realisation of capabilities is more conducive for evaluating and assessing the added value of modern radio technologies.

The FLIP (Flexible IP) waveform R&T project follows this premise. It creates the possibility to quickly implement technology approaches to test their performance in an application-specific manner. Through close research cooperation between Fraunhofer Institutes IIS (Erlangen) and FKIE (Wachtberg), the Bundeswehr Technical Centre for Information Technology and Electronics (WTD81) in Greding and the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw I1.1) in Koblenz, it was possible over the space of one year to produce the first increment of a “Flexible IP Waveform” with modern capabilities (routing, prioritisation, simultaneous voice and data transmission (push-to-talk), IP capability, MANET capability, cross-layer optimisation), and a prototype was demonstrated as part of a NATO exercise. It provides a cost-effective, manufacturer-independent and scientifically sound basis for evaluating the effectiveness of modern signal processing algorithms, protocols, routing mechanisms and modulation methods and also for realising a demonstrator that makes these capabilities visible and testable for the user.

The “Advanced Test Device” of Fraunhofer IIS from the SVFuA (German SDR) project, which can control the transceiver modules via the same interface as the basic SVFuA device, serves in the FLIP R&T project as a demonstrator as well as test and development platform for the rapid prototyping of the modern waveforms. The use of different high-level languages and the support provided by powerful General Purpose Processors (GPP) shorten the programming times.

This prototype implementation enables the public contracting authority to identify and evaluate new protocols, solution approaches and algorithms at an early stage. It also provides an insight into the effort with which a waveform can be ported to the target platform of an SDR. Rapid prototyping offers the user the opportunity to reflect his expectations where the modern, technical added value of an SDR is concerned and, if necessary, to identify operational and organisational structures and procedures in good time. Such feedback will have a positive and risk-reducing impact on future developments and make an essential contribution to mobile tactical communication.

FLIP is a technology demonstrator for a modern, high-performance and IP-capable waveform for SDRs which defines open standards and transitions between the different layers of the ISO/OSI model and thus promotes competition for future waveform developments.

A wealth of experience gained from national and international studies and projects as well as operational requirements (from various Integrated Planning Teams) are reflected in the FLIP project. The resultant data can be seamlessly made available, such as for the Mobile Tactical Communication project. Through this industry-independent knowledge structure, public contracting authorities will have a new quality of assessment capacity at their disposal.

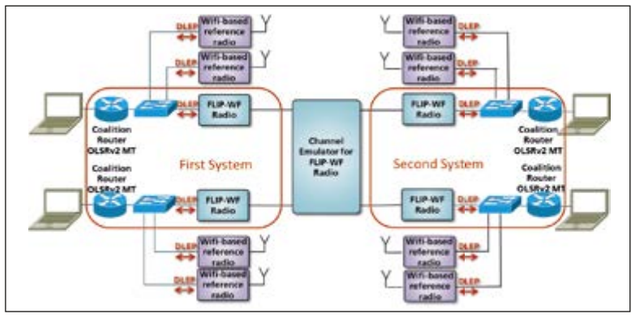

Fig. 1: Test set-up comprising four FLIP radios connected via a channel emulator (schematic); (Source: Fraunhofer FKIE)

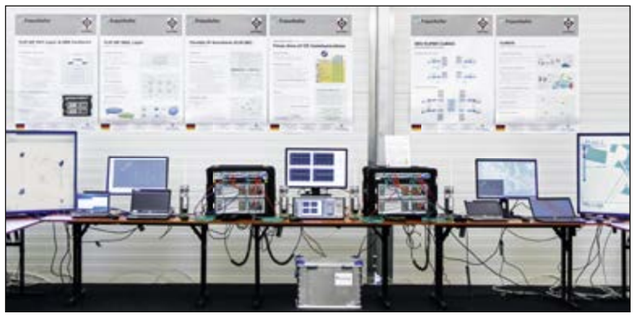

Fig. 2: Diagram of the CWIX 2016 test set-up comprising the two test systems (black cubes) and the channel emulator (centre); (Source: Joint Force Training Centre (JFTC) Bydgoszcz)

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Secure navigation using the Enhanced Location Service for Smart Devices

An important feature of "smart devices" is the information they provide about their own location. Approved mobile devices whose location services have been removed for security reasons are impractical for military use. A secure high-precision option has been created in the form of the Enhanced Location Service, which has additional features such as authenticity, indoor navigation and fusion of sources.

While everyday life is no longer imaginable without "smart devices", military users of approved mobile devices have to face unexpected limitations. Often their mobile devices consist of the same hardware as commercial devices, but important functions are missing. For security reasons, use of the internal Global Positioning System (GPS) hardware as well as of the software for generating and providing unified positioning information is limited or deactivated. One of the main functions whereby mobile devices could become an indispensable aid during operations, however, is position determination. Most applications (apps) reveal their strong points and direct additional value by knowing the device's own position and displaying information and features adapted to the location and current situation. What is the use of a navigational app that is unable to determine the current location?

To make mobile devices fit for use for the "last mile", Bundeswehr Technical Centre (WTD) 81 has examined a secure implementation of the Location Manager service using the example of the Android Framework. Not only did the prototype implementation include the existing functionalities, but it was also augmented to meet military requirements, including indoor navigation, information regarding the position's authenticity, high-precision military satellite navigation (GNSS), fusion of various position sources, a unified programming interface (API), growth capability to incorporate future sources, and open implementation.

Analysing the platform requires an equivalent substitute for the Google location service API, thus meeting the architectural requirements with regard to API and the consolidated interface and achieving flexibility for incorporating different and future sources. At the same time, applications only need to perform their core functions and are "standardised", since only unique, secure and reliable position information is provided. It has been possible to draw upon extensive work from previous open source activities within the "µG GMSCore" framework. Fig. 1 shows the basic system architecture, taking the example of adding a WLAN back-end module for indoor navigation and using a radio beacon database that can contain either public sources or WLAN relay military networks, such as from the "ad-hoc mesh networks" survey or LTE nodes from "MAN Bw". The route illustrated in Fig. 2, originating from radio beacon indoor navigation, allows not only conclusions as to the room and floor layout of a building.

In another step, further sources such as acceleration sensors, a pedometer, compass or barometer were used with a Pedestrian Dead Reckoning Location Provider. A fusion back-end was additionally implemented for the aggregation of various location providers, the result of which is shown as an example in Fig. 3. GNSS receivers, such as "DAGR" or "RSR", were connected by means of a prototype implementation of a background service that monitors the interface, communicates with the GNSS receiver via a standardised protocol, ensures settings and operation, and notifies the Network Location Provider. It was hence possible to demonstrate not only the connection of military GNSS receivers (Figs. 4 and 5), but also the growth capability by using the modular design of the system architecture.

All in all, the more comprehensive architectural approach has proven effective in implementing the individual functions relating to sensor and GNSS connection and the fusion of sources. The growth capability and open implementation will ensure future use in "smart devices" so that the coming generations of approvable mobile devices from the "MoTaKo" (mobile tactical communication) or "MoTIV" (mobile tactical information processing) projects can also be furnished with secure and reliable position information for military use.

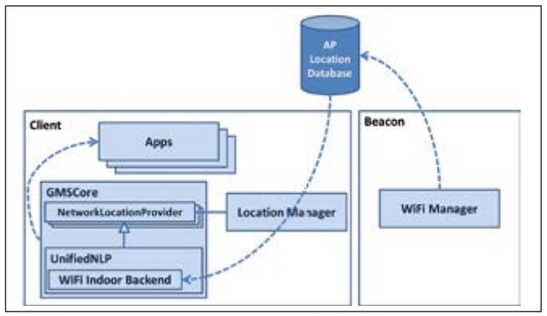

Fig. 1: System architecture including indoor navigation elements

Fig. 2: Indoor navigation (orange colour: actual route; blue colour: localisations) (Source: Fraunhofer AISEC)

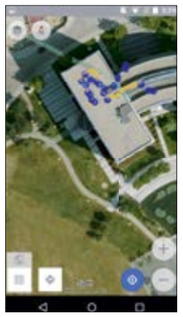

Fig. 3: Fusion of various sensors for indoor navigation (Source: Fraunhofer AISEC)

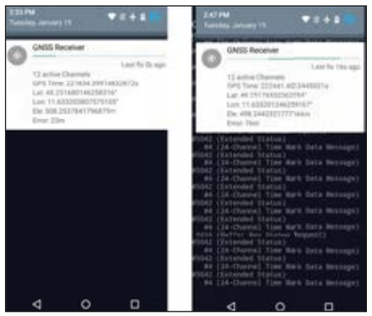

Fig. 4: Status report of connected GNSS receiver with current fix (left) and obsolete, inaccurate fix (right) (Source: Fraunhofer AISEC)

Fig. 5: Map presentation of own position from the military GNSS receiver with high and low accuracy (size of the blue circle) (Source: Fraunhofer AISEC)


ARCTIC CIRCLE
Siberia
ASIA
North
Atlantic
Ocean
EUROPE
NORTH
AMERICA
Gobi
Sahara
Arabian
Peninsula
AFRICA
EQUATOR
Congo
Basin
Indonesia
Indian
Ocean
SOUTH
AMERICA
South
Atlantic
Ocean
AUSTRALIA
35n
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25n
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15n
50
100
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200
250
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350
400
-5n
-100

6

Appendix

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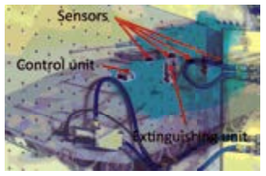

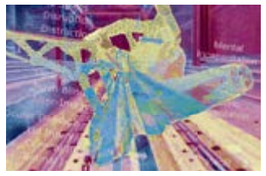

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