Technology Forecast 2018 – Military Utility of Future Technologies

A report from seminars at the Swedish Defence University's (SEDU) Military Technology Division

Summary

Four technology forecast reports from the Fraunhofer Institute and two reports from the Swedish Defence Research Agency (FOI) have been reviewed by staff at the Military Technology Division at the Swedish Defence University (SEDU). The task given by the Defence Materiel Administration (FMV) was to assess the military utility of the given technologies in a timeframe up to the year 2040, from a Swedish Armed Forces (SwAF) perspective.

In the review, we assess the **military utility of certain technologies** as possible contributions to the operational capabilities of the SwAF, based on identified and relevant scenarios.

The technologies are grouped into four classes of military utility: potentially significant, moderate, negligible or uncertain.

The following technologies were assessed to have the potential for **significant** military utility:

- Rapid field identification of harmful microorganisms
- Hypersonic propulsion

The following technologies were assessed to have a potential for **moderate** military utility:

- Non-line-of-sight imaging
- Artificial intelligence for military decision support

The following technologies were assessed to have **uncertain** military utility:

- Structural energy storage
- Triboelectric nanogenerators

No technology was found to have **negligible** military utility.

The method used in this technology forecast report was to assign each report to one reviewer in the working group. Firstly, each forecast report was summarized. A new methodological step this year was for each reviewer to discuss the assigned technologies with researchers from FOI. This proved to be a valuable enhancement for understanding the technologies' present state and likely future development.

The chosen definition of military utility clearly affects the result of the study. The definition used here, 'the military utility of a certain technology is its contribution to the operational capabilities of the SwAF, within identified relevant scenarios' has been used in our Technology Forecasts since 2013.

Our evaluation of the method used shows that there is a risk that assessments can be biased by the participating experts' presumptions and experience from their own field of research. It should also be stressed that the six technologies' potential military utility was assessed within the specific presented scenarios and their possible contribution to operational capabilities within those specific scenarios, not in general. When additional results have been found in the analysis, this is mentioned.

The greatest value of the method used is its simplicity, cost effectiveness and that it promotes learning within the working group. The composition of the working group and the methodology used are believed to provide a broad and balanced coverage of the technologies being studied. This report should be seen as an executive summary of the research reports and the intention is to help the SwAF Headquarters to evaluate the military utility of emerging technologies within identified relevant scenarios.

Overall, the research reports are considered to be balanced and of high quality in terms of their level of critical analysis regarding technology development. These reports are in line with our task to evaluate the military utility of the emerging technologies.

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Introduction

Scope

This report is the result of a review of six reports from the Fraunhofer Institute and the Swedish Defence Research Agency (FOI). The task set by the Swedish Defence Materiel Administration, FMV, was to assess the military utility of the chosen technologies in a timeframe up to 2040. The review and evaluation of the technologies form one chapter each in this report.

References

The following reports from the Fraunhofer Institute and FOI are reviewed:

[1] Non-Line-of-Sight Imaging	(Fraunhofer)
[2] Rapid field identification of harmful microorganisms	(FOI)
[3] Hypersonic propulsion	(Fraunhofer)
[4] Artificial Intelligence for Military Decision support[1]	(FOI)
[5] Structural Energy Storage	(Fraunhofer)
[6] Triboelectric Nanogenerators	(Fraunhofer)

Definitions

In this report, the military utility of a certain technology is defined as the technology's contribution to the operational capabilities of the SwAF, within identified scenarios. A capability implies the ability to perform a certain task in order to produce an effect in a certain situation or environment.

If it is unlikely that Sweden will be able to use this technology by 2040, but possible or likely that potential aggressors will, a discussion of how to defend against it is needed.

Methodology

The method consists of three steps chosen both for efficiency and in order to take advantage of the professional expertise of the reviewer.

Step 1: The reports are assigned to participants in the working group based on their special expertise and interest. Each reviewer is responsible for reviewing one technology. Each reviewer discusses the technology with an assigned researcher at FOI.

The reviewer writes a summary of the report, defines one (or more) tentative military technical system, and puts it in a possible scenario for the Swedish Armed Forces in the timeframe up to 2040. The purpose of the scenario is to illustrate the utility of the technology and to put the technology described into a relevant context.

Step 2: Each review is discussed at a seminar. At the seminar, the technology is briefly introduced, and the technical system and the scenario are presented. The reviewer's role is to analyse the military utility of the specific technology in the scenario developed. The other participants' role is to support or criticize the concept.

The analyses in the report's forecasts are guided by the following logic. The quality, capacity and efficiency of a military capability in performing this task provides a certain military

[1] The report is in Swedish, Swedish title: Artificiell intelligens för militärt beslutsstöd.

utility. The quality and importance of the provided utility must always be valued against the strength of an opponent's capability. Figure 1 provides a framework for how to evaluate the analysed technologies' potential military utility. For assessing military suitability, the DOTMLPFI (Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Interoperability) framework is used. The technology assessments in the report are structured in the following sequence:

1. Description of the technology's present state and Technology Readiness Level (TRL).
2. The technology's possibilities and constraints.
3. Assumptions for the scenario.
4. Presentation of one or two scenarios (based on certain assumptions) where the technology would best or most likely be of use for the Swedish Armed Forces in the year 2040.
5. A SWOT analysis regarding the use of the technology in the assigned scenario(s).
6. The technology's capability impact.[2]
7. An assessment of the military utility.
8. The technology's affordability and effect on the suitability (based on DOTMLPFI).
9. Finally, a discussion and conclusion regarding the technology's future development, capability impact and military utility.

Each step in this sequence will have, depending on the assessed technology, different precision and impact in the respective analyses.

Step 3: The results of the seminars are documented using the Delphi method and successive brainstorming and discussion sessions among the writers of this report. Conclusions are drawn concerning the potential for military utility and capability of the technology. This was complemented with discussions with FOI experts on the specific technologies analysed in the six reports.

[2] The impact on one or several of the seven fundamental military capabilities: strike, command and control, protection, mobility, intelligence and information, sustainment and availability.

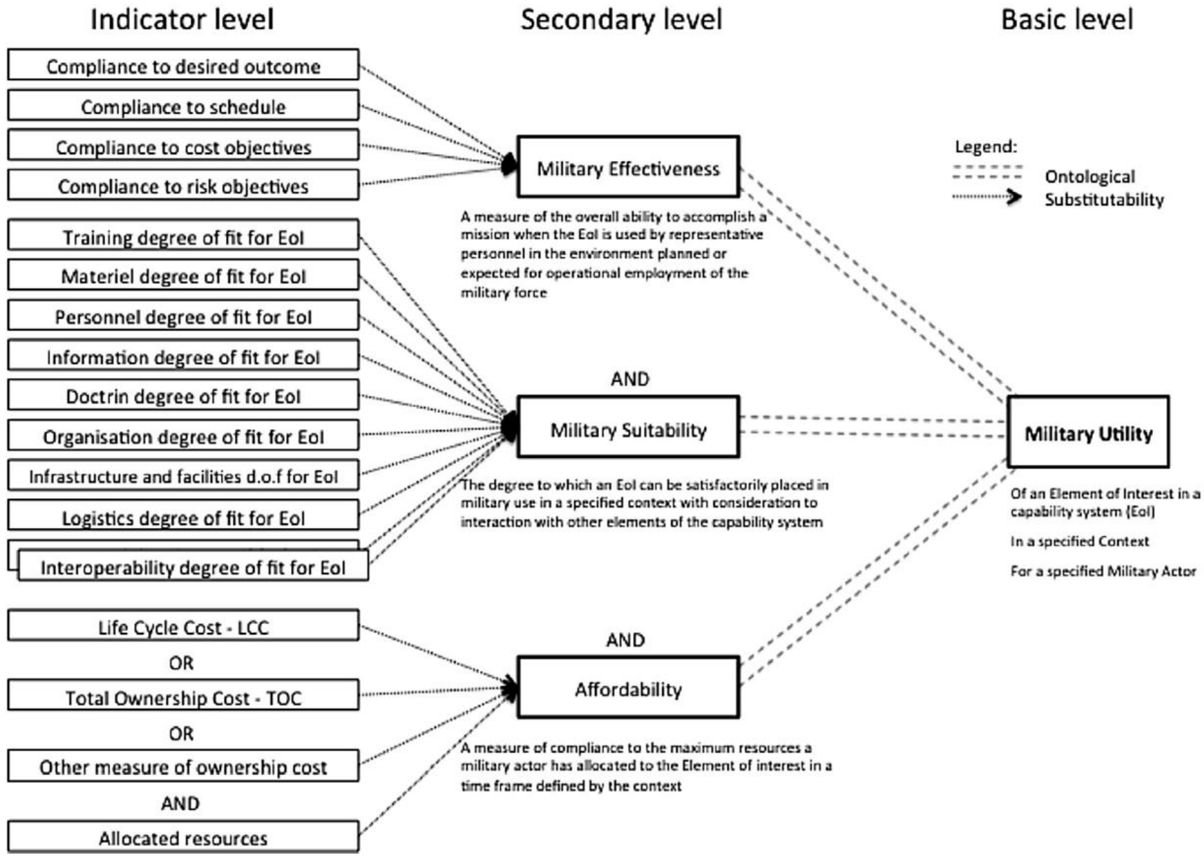

Figure 1. Military Utility consists of Military Effectiveness, Military Suitability and Affordability. Source: K. Andersson et al, Military utility: A proposed concept to support decision-making, Technology in Society 43, 2015. In this framework, the object being assessed is an element in the capability system, labelled the Element of Interest (EoI). LCC is the Life Cycle Cost. TOC is the Total Ownership Cost.

Composition of the working group

The working group consisted of experts from the Military Technology Division at SEDU:

Martin Lundmark, PhD, project manager

Gunnar Hult, Chaired Professor of Military Technology

Åke Sivertun, Professor of Military Technology

Bengt Vretblad, Professor of Military Technology

Carl von Gerber, Lt Col (Amph)

Peter Sturesson, Capt (AF), MSc, PhD student

Michael Reberg, Lt Col (A)

Marcus Dansarie, Lt (N), MSc

Lars Löfgren, MSc, PhD student

Daniel Amann, Lt Col (AF), PhD student

TECHNOLOGY FORECASTS

Non-Line-of-Sight Imaging

Ref: [1] Referee: Martin Lundmark and Peter Sturesson
Interview: Ove Steinvall, researcher, FOI

Introduction

The purpose of Non-Line-of-Sight Imaging (NLOS) technology is to generate an optical image for reconnaissance and surveillance where the terrain's geometry denies line-of-sight. The basic principle is to use Bragg reflection of dispersed radiation from structured surfaces and its time-of-flight between transmitter and receiver.

The basic components are a transmitter, typically a pulsed laser with pulse lengths of around 10^{-14} s, and a receiver/sensor, typically a camera with very short shutter time. In addition, an on-board computer for image processing is required.

Three main principles are currently considered for NLOS. The first principle uses spatial data. It is based on a 1D-detector with very high time accuracy and mechanically controlled with a 60° field of view. The detected light is categorized by a statistical model of the actual point of reflection, which provides spatial information. The second principle focuses on detecting moving objects. It is based on the emission of a specific pattern, which generates a reflected normal state. Moving objects are then detected by change detection, using the normal state as a reference. The third principle is similar to the second, but employs light intensity measurements. Objects are detected by light intensity patterns and their movement is identified by intensity changes in the normal state.

These current principles indicate a trade-off between retrieving spatial information and position change from the observed objects.

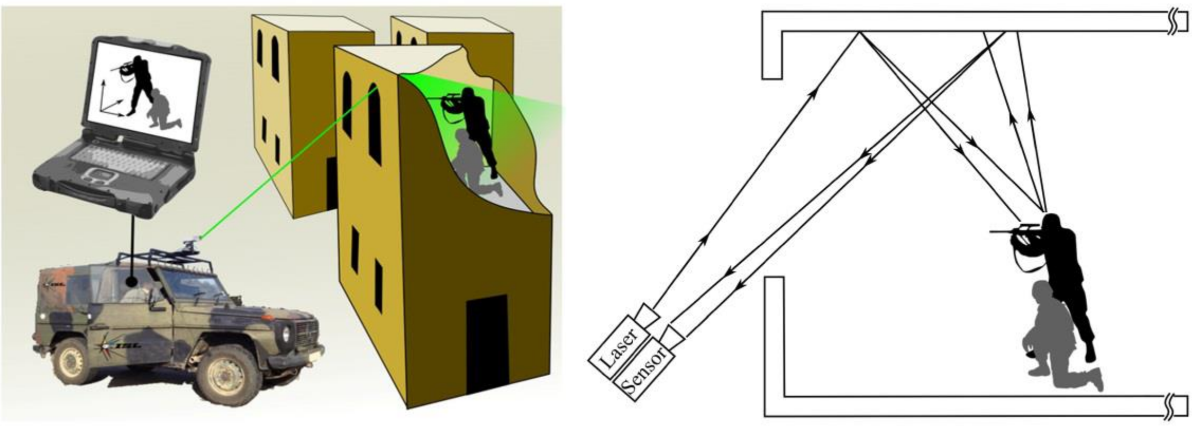

Figure 2. Military application example for NLOS imaging. Attackers hidden in a house and not directly visible to a vehicle crew could be depicted using a suitable NLOS imaging system through a window opening. [1]

There are challenges to overcome regarding NLOS. Geometric imaging requires long sampling times and movements must be put in context, which requires the geometry around the object to be known. The read range and operational distance are also limited to 10-100 m, which implies that NLOS systems should be fitted for close-range operations, i.e. carried by a soldier or a smaller platform, suggesting that the size of the system thereby matters. As high quality data presented for human intuition is relatively slowly processed, it constrains time-critical decisions. This demands high computer capacity integrated in the system. AI solutions might be an option for increased performance. The performance and outcome from a system will also vary with surface structure and surface angles. Fraunhofer (2017) states: "*Today, the* [NLOS imaging] *technology is still in a very early stage of development*".

The current state of the art includes perfecting alignment in certain field conditions through reflecting surfaces, which is conducted at FOI. Demonstrations are at the laboratory environment level, focusing on imaging miniatures to generate fundamental knowledge and understanding and to refine statistical algorithms.

Identified possibilities and constraints

The military use is primarily to search for the presence of soldier(s) or equipment in buildings or rooms in urban environments, when the operator prefers to avoid line-of-sight from the investigated space.

There are two major weaknesses with the technology, at its present state of development, when used in a hostile environment. First, the short operative range between operator and opponent increases the risk of enemy contact. Second, the long sampling time reduces the time for the operator to choose a course of action.

Assumptions

The concept scenarios are based on the following assumptions:

- A number of success factors in technology development are needed in order for this technology to provide effective military use. This includes rapid imaging, i.e. the duration of the sampling must be rapid enough in order to minimize the risk of exposure for the operator.
- The presentation must provide information that is precise and unambiguous, and above all intuitive for an operator under high pressure. This also requires precise alignment and detailed measurements to provide adequate premises for decision-making.
- Operations which require NLOS equipment are assumed to be conducted in or around buildings. These will have a large variation of surface structures and aspect angles. Moreover, opponents are assumed to have high mobility and/or low signature.

Suggested military use

- The technology can be used to minimize risk and exposure when examining concealed spaces, typically in buildings and urban environments.

Concept scenarios in 2040

Scenario 1 Soldier scenario

A soldier operates the system at close range (< 20 m) from the investigated space (likely through a doorway, window or hole in a wall). The potential threat demands a short OODA loop and there is a clear risk of casualties.

Scenario 2 Platform scenario

A surface-based or aerial vehicle (manned or unmanned) performs remote sensing (< 100 m). The measurement demands a medium OODA loop, and there is a risk of direct materiel damage and indirect casualties.

SWOT analysis

Scenario 1

Strengths	*Weaknesses*
• Early initiatives may force opponents to act under unfavourable conditions. • NLOS is less sensitive for spatial signature protection than conventional optical systems. • NLOS reduces the opponents' possibilities for concealed mobility.	• The presentation from NLOS has slow image processing. • Object analysis requires known surrounding geometry. • NLOS system performance will change with different surfaces. • Processed images from NLOS may be difficult to analyze and assess. • All NLOS systems require a transmitter, which can be tracked by adversaries.
Opportunities • An increased situational awareness from NLOS reduces own risk taking. • This increases the possibility of favorable position for the soldier. • Increases soldiers' mobility at low risk.	*Threats* • Adversaries' awareness of NLOS will lead to adapted tactics. • The characteristics of the terrain in theatre will change due to time of day, weather and season. This will change the performance of the NLOS system.

Scenario 2

Strengths	*Weaknesses*
• Aerial surveillance allows data sampling during long periods. • Aerial platforms can employ the benefits of a transparent, obstacle-free environment for their own mobility.	• Aerial platforms require relatively short sampling distances. • The mobility of a platform will be limited during sampling. • Any detection of the platform by the adversary will reveal and constrain the operation. • The stability of small aerial platforms may not be sufficient for an NLOS system.
Opportunities • The most preferred aspect angle, based upon signal strength, can be chosen from an aerial platform as long as it is outside any air defence range. • Several favorable aspect angles can be available.	*Threats* • Enemy air defence can detect and deny access to favorable airspace for operation with NLOS. • Terrain and infrastructure geometries can be less favorable from aerial altitudes than from ground. • General characteristics of any terrain change according to season, weather and time.

Assessed capability impact

The system's influence on military capabilities – DOTMLPFI.

Doctrine	None
Organization	None
Training	All users must complement battle and tactical practice based on NLOS materiel
Materiel	Complement or replacement primarily of light amplifying systems (NVG)
Leadership	Crucial risk assessment management
Personnel	For concerned military units, there must be assigned specialists
Facilities	None
Interoperability	It is likely that partner militaries will use similar techniques. Possibility to share and enhance threat libraries of identified signatures.
R&D	Driven by militaries, police and security. Terrorist threat.

Assessment of military utility

NLOS has the potential to offer a very useful capability. A rapid and precise alignment can minimize the operator's visibility and risk in urban environments. However, it has profound limitations for military use.

The technology's affordability and effect on suitability (based on DOTMLPFI)

The cost of a system that could provide military use and create capabilities is highly unclear. There are also substantial challenges to overcome regarding rapid image processing and user risk. The technology has low maturity (low TRL).

Sampling time is a major weakness, implying a high risk of being detected. Opponents can detect NLOS systems as they transmit their signal. Opponents may also have several tactical options when facing NLOS use.

Discussion and conclusions

The Swedish military R&D community has profound knowledge regarding the present state of NLOS. The military and commercial development forefront of electro-optical systems should be followed. The technology development forefront is driven by militaries. Police and security needs and terrorist threats may also require and initiate R&D/T projects. The most likely use and utility appears to be for non-line-of-sight identification of objects. For military operations, NLOS imaging will in the presence of opposing troops, be highly risky for the operator and will likely be noticed by a technically advanced adversary. Autonomous vehicles carrying NLOS equipment and sustaining higher risks will likely be developed.

If there are substantial breakthroughs in sampling time and distance to an investigated area, the military utility can be substantial. The Fraunhofer report expresses doubt that this will be reached by 2040.

Rapid Field Identification of Harmful Microorganisms

Ref: [2] Referee: Carl von Gerber and Martin Lundmark
Interviews: Per Stenberg and Per Wikström, researchers, FOI.

Introduction

Biological risks, compared to a few decades ago, have become more complex. Such risks can be described by the biological risk spectrum (Figure 3). Advances in medical and life science, globalization of concerned industries and a high increase in travel have contributed to this. Therefore, microorganisms are more accessible than ever. This also presents risks and threats. The detection of potentially harmful microorganisms needs to be identified in order to perform military operations in certain environments and situations. There is a need to develop new techniques that can identify a wider spectrum of organisms. Certain modern techniques give information concerning the organism’s characteristics e.g. if they are modified and if they are resistant to antibiotics, and/or its genetic composition. The report presents challenges in detection and different methods under development.

The reviewed report’s development outlook is from a five-to-ten-year perspective. The report does not focus on military needs and development, but rather on general societal needs for biodetectors. The more specific military challenges and development and a perspective towards the year 2040 has therefore been discussed in interviews with experts from FOI.

Even if great progress and development has been made in recent years, it will take many years until one single technology meets all demands. The reviewed report focuses on detection techniques that are *rapid* (preferably within 60 min), *broad* (can detect many different organisms) and *fieldable* (can be carried and used outside the laboratory environment). For the near future, a combination of techniques will be required.

Figure 3. The Biological risk spectrum. [2]

NATO and EDA have adopted the DIM concept, where the primary objective of detection is to discover the presence of health-threatening levels of CBRN.

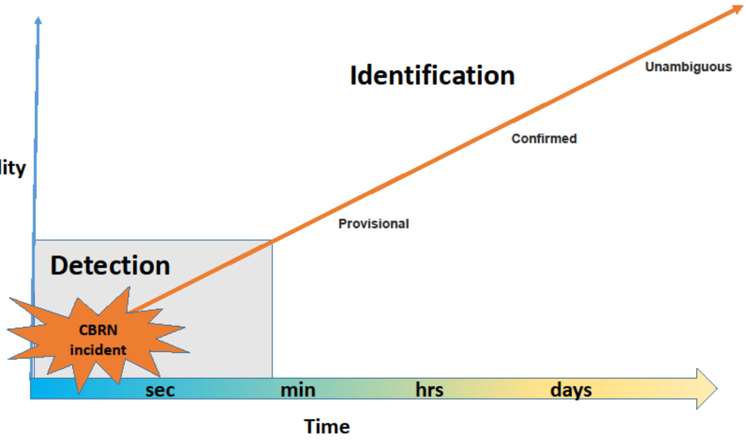

Figure 4. Detection, Identification and Monitoring, DIM, capability concept. [2]

Identified possibilities and constraints

The report describes the current biodetectors. One challenge is to have an instrument that can identify many microorganisms in one measurement. The instruments are normally set to identify defined substances or groups of substances. Therefore, unknown organisms or organisms with unusual structures may escape identification. There are biodetectors that can detect changes in the overall composition of microorganisms, thereby initiating the need for a focused analysis in this environment (instruments exist on the market that can trigger an alarm 15-30 seconds after exposure). Another challenge is that it is difficult, after having identified the presence of certain microorganisms, to determine whether it is biologically active or not.

The following applications are mentioned in the report: spectral techniques and sequencing. Advantages and limitations of present fieldable techniques are:

	Advantages	Limitations
Spectral techniques NIR, MIR, Raman spectroscopy, Portable mass spectrography	Fast, easy to use Preserves the sample	Reference data must be accumulated in advance No quantification of sample concentration of organism Sample cannot contain many different substances Devices are presently large and quite heavy
Sequencing based on analysis of DNA sequences	Many different organisms can be identified without prior knowledge of the sample The Minion device is available now and is fast, broad and fieldable	Minion has too high error rate (5-10 %) Large amounts of pure DNA required

Advantages and strengths of commercially available biodetectors are that they presently have good sensitivity, fair reliability in terms of false negative alarms and very fast operational time – often within seconds. Several can run in real time, which makes continuous surveillance possible. Apps for mobile phones already exist that can perform designated analysis for specific samples.

They presently also show limitations. There is a lack of adequate resolution and real-time systems often generate false alarms. Some applications cannot distinguish between harmful and non-harmful naturally occurring organisms, and further tests with more specific techniques are therefore required. More advanced analysis requires sending samples to a laboratory, which increases analysis time substantially, and creates a logistical challenge. Some countries (e.g. Finland) have mobile labs that can perform more advanced analysis. General problems with biodetectors are the alarming increase in antibiotics resistance, fungi in human bodies limiting remedies and the fact that designed pathogens may develop into unwanted and dangerous trajectories by mistake.

The report speculates on what techniques will be available in five to ten years. There is very rapid commercial development of biodetector technologies, which is said to be "faster than the development of computer capacity". The rapid development of computer capacity, algorithms and sequencing technologies greatly contributes to the performance of biodetection. The analytical precision, breadth and speed of biodetectors is developing rapidly, so the military establishment can reap the results of the innovation. There are also a large number of national militaries with a demand for biodetectors, so the market will present military solutions. The projected R&D focus on 5-10 years suggests that DNA-based detectors are likely to dominate the field. Sequence databases (i.e. libraries of known substances) will greatly improve. Nanopore sequencers are considered to be a disruptive sequencing technology.

Assumptions

The concept scenarios are based on the following assumptions:

- There will be a sustained, broad demand from many governments, militaries and commercial actors for continued development and perfection of biodetectors.
- There will be commercially developed products that show substantial advancements in being rapid, broad and fieldable – thereby making biodetectors not overly expensive.
- There will still be a need for analysis performed by dedicated laboratories (a 'reach-back' function).

Suggested military use

- Analysis of food, water and air in military operations for military missions in expeditionary environments in order to verify and protect the troops' general camp conditions.
- Analysis of combat arenas where biological warfare is suspected or has been indicated.
- Analysis in conflicts where terrorist groups or other asymmetric actors may be performing biological warfare or terrorist acts.

Concept scenarios in 2040

Scenario 1 Secure food and water conditions in military operation abroad

Smaller military units in an expeditionary environment with uncertain conditions for water and air (biodetectors not suitable for food, the composition is too complex). Analysis of primary water supply in order to secure that no known biological microorganisms have polluted the medium.

Scenario 2 Analyze potential antagonistic biological attack

Indications that antagonistic biological attacks might have been performed. Type of organism is not known, and might have an unknown/altered characteristic. Requires analysis of air and water.

SWOT analysis

The SWOT analysis is based upon an assessment of the military use of the technology in the scenario(s) in the year 2040, assuming a certain reached maturity of the technology.

Strengths	*Weaknesses*
• Commercially driven development will in 2040 offer sophisticated and faster equipment, meaning that a broader spectrum of organisms will be identifiable in one sample and operation time will be shorter. In Scenario 1, biodetectors will be available for rapid, precise and fieldable detection of a large spectrum of known organisms and pathogens. In Scenario 2, developments in AI, sequencing and computer capacity will offer much more sophisticated and rapid detection of dangerous organisms • Ruggedized equipment is continuously developed for military needs • Not costly	• Identifies only known and defined organisms. Analysis of complex samples with uncertain content requires transfer to centralized laboratories meaning that the response time for analysis and detection is extended. • Too high degree of uncertainty for certain techniques • False alarms • Rapid and precise identification and analysis is challenging; further tests and analyses will likely continue to be required • The aggressiveness of unknown and dangerous organisms is difficult to define
Opportunities	*Threats*
• Identification of human phenotypes (e.g. physical appearance) already available. Face reconstruction based on DNA will be highly accurate in 2040 • Digital transfer of sample data from the field to laboratories will improve, but cannot entirely replace laboratories' need for physical access to the sample in some cases	• Antagonists will develop their capabilities for attacks and contamination; knowledge is widespread and accessible • Breakthroughs in aggressors' spectrum of used microorganisms – new threats. Synthetic biology appears promising for such unwanted development. • Very rapid and precise detection is difficult, unknown and very dangerous organisms may reach quick effect • Rapidly increasing antibiotics resistance

Assessed capability impact

The system's influence on military capabilities – DOTMLPFI

Doctrine	None
Organization	Certain units must have devices
Training	Limited
Materiel	Needed in certain battle environments
Leadership	Officers must know proper action under alert
Personnel	Designated personnel in military unit must master the system
Facilities	Sophisticated laboratories with specific military competence will continue to be required
Interoperability	Likely that partner militaries will use the same or similar techniques. Possibility to share and enhance threat libraries of identified harmful organisms.
R&D	Overall commercially driven. Sophisticated, fieldable systems for military use will require military R&D involvement, but synergies with the commercially driven innovation are profound. R&D in medicine and ecology appear to be the most relevant for military applications. The development in AI will enable faster analysis in the 2040 perspective.

Assessment of military utility

Systems and equipment for biodetection will, in certain environments be both very useful and necessary. Asymmetric aggressors (military or terrorist) may develop highly specific and previously unknown harmful organisms. Under the assumption that it is likely that there will be a development of aggressors developing harmful organisms, the technology is highly useful.

The technology's affordability and effect on suitability (based on DOTMLPFI)

Equipment for biodetection will not be very costly. If the SwAF require specific systems with unique specifications, the cost will increase significantly. The recommendation is therefore to focus on acquiring off-the-shelf systems. Off-the-shelf systems will not cover, however, the military need for national laboratory resources that can analyze complicated samples with uncertain characteristics.

Discussion and conclusions

The report focuses on techniques that present rapid solutions (< 60 min). In 2040, sequencing technologies will likely have substantially reduced analysis time. Sequencing will likely be performed quickly and at low cost. Samples that are more complex require a transfer of the sample to designated laboratories. The military demand for bio-detection will include such complex analysis and was therefore outside of the reviewed report's focus.

The SwAF will from the 2040 perspective not need to finance R&D for biodetectors. Knowledge and understanding of analysis methods and a sophisticated capacity for analysis of samples and identification of harmful microorganisms is seen as needed. Specific algorithms and software will have to be developed for Swedish military purposes. In case of a severe threat situation in the Swedish geographic environment, access to such capacities outside of Sweden will likely be limited. If terrorist organizations with sophisticated resources and competence in biological warfare operations increase their activities in Europe, an increased need of capacity for biological defence may arise. R&D needs are shared with many nations that share Sweden's security priorities, so extensive international collaboration is likely for military capabilities and for national security concerns.

Hypersonic Propulsion

Ref: [3] Referee: Daniel Amann
Interview: Christer Fureby, researcher, FOI.

Introduction

Hypersonic velocity is defined as speeds faster than Mach 5 (M5). Research on air-breathing propulsion systems for enabling such speeds, hypersonic propulsion, has been ongoing for decades but is nonetheless presently considered to be at comparatively low TRL. Mature and reliable hypersonic propulsion systems are expected to take more than a decade to develop and reusable vehicles will probably not be available before 2040. Hypersonic propulsion is interesting for civil applications such as space transporters and fast long-range transport and for military applications in fast, long-range weapon systems.

Scramjet (TRL 5) is an air-breathing hypersonic propulsion system for speeds up to M12-15. Since a scramjet only operates at speeds above M5, other propulsion systems are required for bridging the gap between M0 and M5, such as, for example, solid propellant rockets, turbojets and ramjets. Another alternative to air-breathing hypersonic propulsion is detonation engines (TRL 4), which are considered to have an upper speed limit of M6-7. Due to a different thermodynamic cycle to turbojets, ramjets and scramjets, detonation engines are theoretically significantly more efficient than these systems. There are also studies on multimodal detonation engines that would enable M25.

Identified possibilities and constraints

Air-breathing hypersonic propulsion systems may allow easier and cheaper access to space, for example in launch vehicles for nanosatellites. High speed radically improves the possibilities for weapon systems to reach highly defended targets, e.g. air force bases, ballistic missile sites or ships. High speed improves the possibility to strike time sensitive targets or to win a duel, e.g. between aircraft and ground-based air defence.

High speeds in atmosphere create a very high temperature that the platform structure and fuselage have to withstand. Air breathing hypersonic engines, scramjets, only work at speeds higher than M5, which makes a combination of propulsion systems necessary.

Suggested military use

The following applications are mentioned in the report:

- Reusable space transport systems e.g. quick replacement of space systems.
- Reusable hypersonic aircraft, e.g. high altitude hypersonic reconnaissance.
- Hypersonic weapons with, for example, greater engagement range, higher hit rate, shorter flight time and enhanced effectiveness against hardened targets.

Assumptions

The concept scenario is based on the following assumption:

- Necessary missile technology for hypersonic speeds through atmosphere is developed by 2040 and available to SwAF.

Concept Scenarios in 2040

An enemy naval fleet poses a threat to friendly warships and friendly air defence fighter aircraft. To eliminate the threat, an air strike with hypersonic anti-ship missiles is launched.

SWOT analysis

The following strengths, weaknesses, opportunities and threats for hypersonic propulsion of anti-ship missiles within the scenario are identified:

Strengths • High ability to penetrate the enemy fleet's defence against anti-ship missiles. • High kinetic energy in target impact (warheads are potentially not necessary).	*Weaknesses* • High signature in the infrared and visible spectrums (high skin temperature makes the weapon glow).
Opportunities • Since saturation of the enemy fleet's defence against anti-ship missiles appears not to be necessary, a smaller number of anti-ship missiles could be launched to achieve the desired effect. That would in turn mean that the number of launch platforms might be reduced significantly, thereby reducing logistics needs and increasing availability for other tasks.	*Threats* • Hypersonic speeds will not reduce the sensitivity to many types of countermeasures, for example electronic jamming and decoys.

Assessed capability impact

Hypersonic weapon systems have the potential to increase substantially the effect of long-range engagements with air, sea or ground based targets. Such capability will impose a severe threat for many enemy systems and functions. At the same time, the number of friendly assets required to achieve a certain effect is expected to be reduced, with positive effects on logistics and availability**.**

Assessment of military utility

Within the analysed scenario, the military effectiveness is very high. The military suitability is high since an expected missile with hypersonic propulsion might, from a suitability perspective and to some extent, just be a replacement for missiles in service. Capabilities based on hypersonic propulsions might, in a wider context be affordable when the technology has matured. Even though development costs are high, unit costs and operations costs might be affordable especially when positive effects in a wider context are considered.

The technology's affordability and effect on suitability (based on DOTMLPFI)

The affordability of the technology is difficult to estimate. The development cost can be expected to be high but production costs and support costs do not necessarily need to be higher than for existing missiles. However, the lower number of missiles and missile launching platforms needed is likely to make this technology affordable in a wider context.

Based on an assessment relative DOTMLPFI and R&D (below) the suitability of the technology within the Swedish Armed Forces is expected to be high.

Item	Comment
Doctrine	Little or none
Organization	Little or none
Training	Little
Materiel	Little
Leadership	Little or none
Personnel	Little or none
Facilities	Little or none
Interoperability	Little or none
R&D	Requires R&D for lifting several technologies from TRL 4-5

Discussion and conclusions

The review group unanimously believe that future hypersonic missiles can increase mission effectiveness. This analysis is shared by, e.g. the commander of U.S Strategic Command, who has stated that even the United States has no defence against such weapons[3]. The importance of this technology is stressed by the US Undersecretary of Defense for Research and Engineering, holding hypersonic technology as the number one priority[4]. Development is now ongoing, e.g. in April 2018 Lockheed Martin was awarded a contract to build hypersonic conventional strike weapons for the US Air Force[5]. Other countries in the forefront of research on hypersonic propulsion are China, India and Russia.

Hypersonic weapon systems, in an adversary's possession, might be a substantial game changer for a defender. Naval bases, air bases and ships are examples of military units that in the future might be even more challenging to defend.

Highly effective weapons, which consider hypersonic missiles to be, might be expensive but affordable, since a lower number of missiles is needed, thereby requiring fewer missile-launching platforms, and less logistics. However, it is debateable whether high supersonic speed achieved by ramjet engines, potentially M5, would not be sufficient for penetrating dense air defences. Ramjet engines are already operational, for example as the propulsion system in the Meteor air-to-air missile.

[3] https://www.cnbc.com/2018/04/18/lockheed-martin-just-got-one-step-closer-to-handling-hypersonic-weapons-to-the-us-air-force.html
[4] Air Force Magazine August 2018
[5] https://www.cnbc.com/2018/04/18/lockheed-martin-just-got-one-step-closer-to-handling-hypersonic-weapons-to-the-us-air-force.html

Artificial Intelligence for Military Decision Support

Ref: [4] Referee: Marcus Dansarie

Introduction

The report describes current and possible future applications of artificial intelligence (AI) for military problems. In general, the uses of AI are in *decision support* and *automation* applications. Decision support refers to the use of AI to aid humans in various stages of their decision-making processes. Automation refers to the replacement of human decision-making with a machine-controlled process. The reviewed report focuses on the specific use of AI for military decision support, and not the entire development of AI.

Artificial general intelligence (AGI), i.e. machines that think and reason the way higher order animals do, will not be realized in the foreseeable future. Therefore, the term AI could be considered a misnomer. Machine learning (ML) is probably a better term that holds higher descriptive value.

For implementing artificial intelligence systems, a range of underlying methods and technologies may be used. They range from the trivial, such as simple linear algebra methods, to the advanced, like *deep learning*. A common property for all these technologies is that solutions to problems are created as a result of of training, rather than of programming. In fact, the challenge often lies in designing the training algorithms and creating training sets.

Some military systems manufacturers presently claim to use AI in their products. The apparent uses are for descriptive decision support, generally classification of sensor data. The training is normally done at the R&D level and the AI system in the final product is static, i.e. no new learning is performed. Other military uses of AI for descriptive decision support may be sensor fusion, situational awareness, event identification and information extraction for intelligence analysis.

Prescriptive decision support presents considerable military potential, provided that it can be realized. For example, it could be used for operational planning, courses of action (COA) evaluation, and opposing force estimation and prediction. There are no known offered or fielded systems that include AI technology for predictive or prescriptive decision support. The report mentions a number of research projects in, among others, the United States, Canada and Australia. In one case, a COA evaluation system is described as having TRL level six.

A common efficient training method for machine learning systems is so called adversarial training. In that method, a separate machine learning system is created as an adversary to the system being trained. During training, the adversary system continuously creates training data for the principal system intended to make it fail in its task, i.e. misclassify or make bad decisions. During training, the results are used to improve both the principal and adversary systems. The result is thus two systems: one trained for the task and one trained to mislead the first.

Identified possibilities and constraints

Decision support systems may be able to provide descriptive, predictive and prescriptive aids to humans. Descriptive decision support aims to describe the current state of a situation or system. Predictive decision support helps in answering questions about how situations or systems are likely to change in the near or far future. Prescriptive decision support synthesises or identifies possible courses of action and assesses their suitability.

Machine learning systems in general are constrained by availability and quality of input data.

Assumptions

The concept scenario is based on the following assumption:

- Working decision support systems for staff use have been developed by 2040.

Suggested military use

- Staff members at all levels could use decision support systems as a natural part of the planning process. The systems could automatically wargame and rate plans generated by human staff as well as synthesise plans autonomously.
- Machine learning technology could be used in training systems that detect adversary units faster and with better accuracy than human operators. The systems could use information from several different sensors concurrently.
- Machine learning systems could be used against an adversary's machine learning systems in the same way as conventional electronic warfare systems are presently used against adversary sensors.

Concept scenarios in 2040

The staff in support of a tactical or operational commander uses machine learning systems to synthesise and assess courses of action.

SWOT analysis

Strengths • Performance limited by computer, rather than human speed. • Potential to perform tasks with higher success rate than humans.	*Weaknesses* • Verifiability problems. • Dependent on good input and training data. • Uncertain performance in higher level tasks (military planning etc.)
Opportunities • Counter-AI capabilities.	*Threats* • AI deception/counter-AI.

A clear potential with investment in AI technology research is that a major by-product is counter-AI capabilities. In the event that AI technology is widely fielded, such capabilities will quickly become important. They will likely come to be included in the information warfare/electronic warfare (EW) field and used in similar ways. In addition, in common with EW, the same sort of ongoing battle between sensor and EW capabilities will likely ensue. This will raise the requirements for verifiability and general system safety even further, especially in cases where systems incorporate decision making AI technology, even if such decisions are relatively low-level.

Assessed capability impact

Doctrine	Introduction of capable decision support systems will likely drive doctrinal changes
Organization	None
Training	Little
Materiel	AI/ML systems will likely require integration and/or specialized hardware
Leadership	Little or none. The fact that machines have synthesized plans may cause leadership challenges.
Personnel	None
Facilities	None
Interoperability	Little or none. Information interchange may require standardization
R&D	While general AI/ML technology development is commercially driven, militarization will be necessary

The technology's affordability and effect on the suitability (based on DOTMLPFI)

The majority of the cost of ML systems is assessed to lie in development. Fielded systems will likely consist of mostly standard COTS computer hardware. Any hardware customization will probably be due to standard military requirements for ruggedization and fieldability. After technology development, the cost is therefore expected to be comparable to other military computer hardware.

Discussion and conclusions

Descriptive decision support systems based on AI/ML technology will probably become increasingly common in the near future. Initially, training will likely be performed by industry. However, the need to adapt to new threats or changing tactics will probably drive a need for training closer to the end users. This will in turn create further verifiability and system safety issues.

The immediate potential for decision support systems is high. It is very likely that they quickly will become better than human operators in detecting, tracking and classifying sensor targets as well as merging data from multiple sources.

Counter-AI technologies will very likely emerge as soon as AI and machine learning for descriptive decision support is widely fielded. It is analogous to traditional deception and electronic warfare technologies. The potential of counter-AI will grow as users depend more on their decision support systems. While such technologies will likely be classified, it should be noted all developers of AI/ML systems would, as a by-product, gain some expertise in the counter-AI field.

The applicability of predictive and prescriptive decision support systems is uncertain. Such systems have been shown to outperform humans in highly complex and intellectually challenging tasks. Examples of this include beating the world's best human players of games such as chess, go and poker. Games are however, characterized by the fact that all rules, circumstances and possible outcomes are completely and unambiguously described. This cannot be said to be the case for military decision making, which is characterized by uncertainty and risk management. Any prescriptive military decision support systems in the near to medium future will likely be very sensitive to small changes in input. It can be questioned whether they will have any advantage over more traditional operations research methods.

Structural Energy Storage
Ref: [5] Referee: Lars Löfgren
Interviews: Hanna Ellis and Martin Skarstind, researchers, FOI

Introduction

The report deals with future lightweight materials with an ability to store electrical energy at a low level of technology readiness (TRL) that is assessed to be developed to TRL 9 by around 2030. The basic principle is that electrical energy can be stored in the structural material itself, rather than in batteries or capacitators. In the report, several potential uses for military equipment systems using structural energy storage (SES) are mentioned, including components in armour systems, combat aircraft and underwater platforms. Basic assessed TRL is also presented in order to give an overview of if, and when, any such technology can be ready for later implementation.

SES is assessed to mainly contribute to weight and volume savings when electrical energy can be stored in the structure itself rather than in batteries or capacitators. An example of technology that can be boosted by SES is smaller unmanned flying vehicles, where weight saving is of the essence. The structure of such vehicles could store energy in the vehicle structure and not only in batteries. However, combining SES with structural design will probably not optimize both energy storage capability and structural design, which means that SES will not be the best technology for storing energy, and the structure where the electrical energy is stored will not have the best material properties.

Cost efficiency for such materials is believed to be realistic only for large production volumes.

As presented in the Fraunhofer report, SES is exemplified to be used in vehicle structures for very light vehicles where battery weight can be a problem. The new technology can perhaps be most effective in smaller applications, such as automated sensor systems, making the sensor systems more independent from a constant power supply, according to interview. The nature of military reality will probably mean that SES will contribute little to daily military use. SES will complement other existing technologies for each potential area where it can be used. SES will also compete with other technologies, which makes it difficult to know if it will make any significant impact. Volume can be minimized for many applications, but will provide limited benefit to the overall military capacity. Concerning weight savings, improvements can probably be reached in some applications but will be limited to parts of the structure, according to interviews. Such applications should be compared to the alternative of more effective generators in aircraft. Unless very high production volumes of military systems are at hand, the real contribution of SES to military applications appears to be limited.

The technology is not yet ready for use and aims at general functionality: to store energy for smaller applications with the capability to store energy in the structure and not only in batteries. SES will develop incrementally and probably not result in any revolutionary impact. Therefore, SES will probably have limited impact on military applications.

Identified possibilities and constraints

Potential to store energy in smaller applications and reduce weight and volume for use in, e.g. automated sensor systems and potentially make vehicles more energy saving.

Potentially highly complicated systems providing little energy. Capacitors of this kind are mainly used in military applications. Civilian research will thus provide limited contribution to the general development.

Cost effective only with very large production volumes.

Assumption

The concept scenario is based on the following assumption:

- SES will exist and can be used in military applications in 2040.

Suggested military use

- The report suggests that the potential for SES is storage of energy in the material itself as in different pieces of structure. The structure of smaller flying unmanned vehicles can be an example of use due to high demands on weight savings.

Concept scenario in 2040

An automated networked system for soldiers can use SES in order to save energy by storing energy in the material structure itself, thereby increasing the time of use without any change of batteries.

SES development is not described as a rapid technology revolution in the report, but rather as a component of an iterative and uncertain future development. This implies that the technology development of SES and triboelectric nanogenerators (discussed in the following technology review in this report) should be followed. The application is probably best for storing and generating enough electrical power for normal operations, but is restricted to being a complement to already existing electrical power generation and energy storage within the application structure itself.

SWOT analysis

During the seminar, the following strengths, weaknesses, opportunities and threats for the proposed technology within the scenario were identified:

Strengths	*Weaknesses*
• To save energy for smaller applications and increase operating time by using stored energy, for instance to increase stand-by time and thereby increase endurance of technology applications.	• The technology is at low TRL in 2018, but it may result in an increased cost of structures if implemented in larger structures, such as different kinds of vehicles, if developed by 2040.
Opportunities	*Threats*
• If applied in automated sensor systems, it can result in higher endurance. Together with batteries, the system becomes more independent from other kinds of power generation.	• If structures contain SES, damaged structures may lead to degradation of other functions in a vehicle than just the structure, including the power storage capability. • Repair of damaged structures can also become more difficult due to the complicated technology. The structure does not only have the function of a structure, but is also to store energy.

Assessed capability impact

SES has a potential to store electrical energy in hardware and structures to complement already existing batteries in applications. It concerns smaller amounts of energy and the majority of operations will still rely upon standard batteries. If for instance SES is used in satellites to save weight and volume, it is still possible to construct normal satellites using traditional technology. However, the main gain of using SES can potentially be where weight and volume can be lowered in combination with a principal need for energy. The capability impact will still likely be limited.

Footprint/cost 2040

The following list is a compilation of possible footprints created by the use of SES according to factors included in DOTMLPFI and the expected demands on the Swedish Armed Forces R&D to facilitate the introduction of the technology.

Factor	Comment
Doctrine	Little to none
Organisation	Little to none
Training	Little to none
Materiel	Requires development
Leadership	Little to none
Personnel	Little to none
Facilities	Little to none
Interoperability	Little to none
Research & Development	Likely limited impact in military environments. Research and development should be followed.

The technology's affordability and effect on suitability

The technology is considered affordable only if very large volumes are produced. This would make this technology dependent on the kind of SES that is developed by the non-military community. A further related concern about cost is that a break-even point is required for SES in order to become affordable in military applications since other cheaper solutions for storing electrical power can prove to be more effective than SES.

Discussion and conclusions

The storage of energy in hardware structures can be an attractive solution if enough energy is stored for a specific application. However, there are presently and probably in the future better ways to store energy than in structures. Different kinds of battery technologies are constantly developing and becoming more effective. For smaller applications, this kind of technology can be effective if weight saving is critically important.

SES competes with other already existing technologies like lithium-ion batteries and emerging technologies that can prove to be more effective. This makes it difficult to assess if SES will become useful enough to be important for the armed forces. SES could be used in, e.g. sensor systems in order to extend the endurance of automated sensor systems. Such systems can be placed in potential areas of interest and be operative over long periods without the need to charge or replace the batteries. Systems with this kind of technology can have a greater endurance if standby mode is used over longer periods without being connected or having to use the power grid or batteries.

This can limit the relevance of SES to a small number of applications under circumstances when systems need to be independent. Nonetheless, it is claimed in the Fraunhofer report that SES needs to be mass-produced in order to become economically affordable. If SES is integrated only in small volumes of applications and is relatively expensive to produce, any breakthrough for SES for military applications is unlikely occur unless civilian development becomes the main driver for development of the technology.

Triboelectric Nanogenerators
Ref: [6] Referee: Lars Löfgren
Interview: Hanna Ellis, researcher, FOI

Introduction

The report discusses triboelectric nanogenerators (TENG), which were reviewed in Technology Forecast 2012. Although the performance of triboelectric nanogenerators has increased since 2012, it is still at low TRL. TENG is assessed to reach TRL level 7-9 around 2035 to 2045. TENG concerns harvesting electrical energy from mechanical movements of different kinds. The evaluation is based on the fact that the development of triboelectric nanogenerators has developed significantly since the previous evaluation was made. No research in this field is known to exist in Sweden.

Typical applications of special use can be automated sensor systems or surveillance and security systems that may need to generate their own energy. Systems that use triboelectric nanogenerators could possibly be developed with to meet some of the electricity needs of soldier carried equipment. Another future use for triboelectric nanogenerators can be to give robots the ability to feel, using an electric skin, like humans. One more future application, strongly developed by market driving forces, is in the Internet of Things (IoT), when wireless small items can be connected to the Internet and the potential massive use of batteries will be cumbersome. Triboelectric nanogenerators could then be an alternative.

Triboelectric nanogenerators are not assessed as the sole energy supplier to any system in the short term or even medium term period (Ellis, 2018). Instead, hybrid systems using triboelectric nanogenerators could combine energy-harvesting components with traditional electrical energy sources e.g. piezoelectric components to increase the endurance of the system in question.

Triboelectric nanogenerators are, according to the Fraunhofer report, assessed as potentially used as sensor system automated systems or as an energy harvester for soldiers. There are however already existing sensor systems that could be applied to automated systems, or energy storage such as batteries for soldiers. Due to the competing alternatives and already existing technologies that solve all tasks that triboelectric nanogenerators potentially can be used for, the technology will probably have little impact on military and defence applications.

Identified possibilities and constraints

Possible generation of energy in smaller applications, instead of or complementing batteries.

Use in sensor systems might have potential since it would not necessarily require any cables for power supply.

Overly complicated systems providing limited gain of energy.

Assumptions

It is unlikely that triboelectric nanogenerators will be affordable for military use by 2040. However, the concept scenario is based on the following assumption:

- Triboelectric nanogenerators exist and are economically viable for use in 2040.

Suggested military use

- No specific military applications are mentioned other than for application as technology for different kinds of sensor technologies and electric power source.

Concept scenario in 2040

Underwater application on submarines to create pressure sensors along the hull in order to replace conventional sonar arrays. Attached along the hull of a submarine, a pressure sensor can sense hydroacoustic signals (sound) to detect, track and identify other ships or submarines.

SWOT analysis

During the seminar, the following strengths, weaknesses, opportunities and threats for the proposed technology within the scenario were identified:

<table>
<tr>
<td>Strengths
Used as sensor on the hull of a submarine the application could potentially become an efficient sensor complement for submarines.
Possibly increased endurance for systems with little energy consumption.</td>
<td>Weaknesses
Immature technology and limited capability to create electrical energy for other applications than when small amounts of electrical energy is needed.</td>
</tr>
<tr>
<td>Opportunities
In the scenario, the capability to detect other ships could potentially increase considerably if a layer of TENG is attached to the submarine hull.
Bearing accuracy and signal-to-noise ratio could increase by using the entire hull’s surface as a sensor.</td>
<td>Threats
An enemy with TENG attached to its hull would have increased accuracy and sensitivity in its sonar systems against our platforms.</td>
</tr>
</table>

Footprint/cost 2040

The following list is a compilation of possible footprints created by the use of triboelectric nanogenerators on the factors DOTMLPFI and also the expected demands for the Swedish Armed Forces R&D to facilitate the introduction of the technology.

Item	**Comment**
Doctrine	Little to none
Organisation	Little to none
Training	Little to none
Material	Requires development
Leadership	Little to none
Personnel	Little to none
Facilities	Little to none
Interoperability	Little to none
Research & Development	With little likely impact in military environments, R&D should best be followed.

The technology's affordability and effect on suitability

If the technology is fielded in 2040 and is affordable with relatively cheap production cost, it can contribute to military effectiveness in smaller applications.

Discussion and conclusions

Triboelectric nanogenerators do not yet exist and will generate little electrical power. Several other sources of electrical power available today can be more effective. In falling order, hybrid engines, batteries and solar cells can potentially be used in military applications but are presently not sufficiently developed. Triboelectric nanogenerators have a potential for use in military applications using low electrical power consumption, such as in sensor networks and perhaps in automated systems set in standby mode to save energy.

As sensors, triboelectric nanogenerators can perhaps be useful. They could be used to build small pressure sensors for different kinds of applications, including on vehicles and clothes. This could contribute to sensors for automated systems and thus give automated systems the sense of touch and pressure. However, little is currently known about any real future military applications according to the reviewed report. However, other technologies such as small radars, lasers, signal and infrared sensors may be better for sensor applications.

It can be questioned whether triboelectric nanogenerators will have more than limited impact in military applications. In 2018 but also in 2040 there will be applications generating considerably more energy, making such energy sources more tempting.

Reflections on the method

Our evaluation of the method used shows that there is a risk the assessment is biased by the participating experts' presumptions and experiences from their own field of research. The scenarios that were chosen do not cover all aspects of the technology and their possible contribution to operational capabilities. It should be stressed that we have assessed the six technologies' potential military utility in the presented scenarios, not the technology itself.

The chosen definition of military utility clearly affects the result of the study. The definition is the same that has been used in the Technology Forecast since 2013. It is seen as being sufficient for this report, but could be further elaborated in the future.

The greatest value of the method used is its simplicity, cost effectiveness and the trade-off that it promotes learning within the working group. The composition of the working group and the methodology used is believed to provide for a broad and balanced coverage of the technologies under study.

This report provides an assessment of the military utility of some emerging technologies within identified relevant scenarios. It is intended to contribute to the SwAF Headquarters' evaluation of emerging technologies.