Technology Forecast 2015, Military Utility of Five Technologies
- A report from seminars at the Department of Military-Technology at the Swedish Defence University

Summary

Five technology forecast reports from the Fraunhofer Institute have been reviewed by staff at the Department of Military-Technology at the Swedish Defence University. The task given by the Swedish Defence Material Administration (FMV) was to assess the military utility of the given technologies in a time frame to 2040 from a Swedish Armed Forces' (SwAF) perspective.

We assess the **military utility of a certain technology** based on its contribution to the operational capabilities of the SwAF, according to identified relevant scenarios. It should be noted that the military utility of the technology in this report is assessed solely in the presented scenario, not for the technology in any other scenarios. Since a new capability catalogue is under development at the SwAF Headquarters, we will only present general assessments of the capability impact from the technologies under study.

After the seminars, the technologies were grouped into three classes; technologies with potentially *significant*, *uncertain* or *negligible* military utility. The classification *uncertain* is given for technologies that are difficult to put into the two other classes, and not because a high technology readiness level (TRL) will not be reached by 2040.

The following technologies were assessed to have a potential for **significant** military utility;

- **3D Printers**
  Our overall assessment is that 3D printing has significant potential for military utility, possibly disruptive. Logistic concepts for both national and expeditionary missions will be affected in the 2040 time frame. The technology development will be driven by civilian industry, but a SwAF in-depth study is recommended as it could help form potential logistic concepts and determine what methods and systems are suitable for military adoption and what kind of application-specific issues have to be addressed in order to take full advantage of the new technology.

- **Deep Learning**
  The military utility for deep learning is assessed to be significant, primarily regarding SIGINT and IMINT, which is where the greatest utility can be seen. The driving force as regards research in the field is the private sector. We therefore recommend that the SwAF follow the research conducted and focus studies on how and where deep learning can be implemented within the organization.

- **Nanothermites**
  We suggest that a deeper study into the feasibility of nanothermite munitions and their possible military utility is carried out, since they are assessed to have a potential for significant military utility. Some of the remaining challenges include resolving risks and uncertainties pertaining to health, legality and material development. We also suggest that

nanothermites should be incorporated as a future area of interest within the SwAF R&D projects.

- **Unmanned Surface Vessels**
USV could be used for many tasks that are dull, difficult and dangerous. If employed to search for submarines they are expected to lower the cost of personnel, enhance the readiness level and increase the probability of finding hostile submarines. Therefore, we assess that USV have potential for significant military utility. The effectiveness of USV for the SwAF will depend greatly on how the platforms are incorporated into the organization. Research on how to use the USV tactically will likely be imperative if the technology is to reach its full potential. We recommended that the SwAF should follow the development and pursue research on USV before acquiring own platforms.

- **Structural Health Monitoring**
Structural health monitoring is a key part when utilizing kinodynamic motion planning in automated and autonomous systems; therefore it will affect the capability of all systems that rely on kinodynamic motion planning. This technology has the capacity to enhance the capabilities of automatic and autonomous systems. Therefore, our assessment is that structural health monitoring has significant potential for military utility

No technology was assessed to have **uncertain** or **negligible** military utility.

The result of our technology forecast is different from previous years since all the technologies were assessed to have *significant* potential for military utility. The reason for this is assumed to be because these technologies have been selected by a board of experts from the SwAF and the Defence Materiel Administration, (FMV), as well as from a number of interesting, potentially disruptive technologies proposed by the Fraunhofer Institute. Furthermore, the Fraunhofer Institute estimates that all technologies in this report will reach high TRL levels, mostly 8 and 9 by 2035.

The method used in this technology forecast report was to assign each Fraunhofer report to one reviewer in the working group. First, a summary of each forecast report was made. The Fraunhofer assessment of technical readiness level (TRL) in the time period to 2035 was held to be correct. The technology was then put into one scenario that was assumed to be suitable in order to assess the military utility as well as indicate possibilities and drawbacks of the technology. Based on a SWOT analysis, an assessment of the capability impact was made. An improvement this year is that the footprint table has been adjusted to the one used by NORDEFCO, presenting the assessed contribution to the factors DOTMPLFI (Doctrine, Organization, Training, Materiel, Personnel, Leadership, Facilities and Interoperability). Furthermore, the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of the technology were indicated. Finally, conclusions regarding the potential military utility of each technology were drawn. We believe that this information could be used as decision support for future R&D investments.

The chosen definition of military utility clearly affects the result of the study. The definition of **the military utility of a certain technology** is *its contribution to the operational capabilities of the SwAF within identified relevant scenarios* and is the same as used in the Technology Forecast of 2013 and 2014. This definition is believed to be good enough for this report but could be further elaborated in the future. An article that in-depth presents our concept of military utility has recently been published.[1]

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

The greatest value of the method used is its simplicity, cost effectiveness and not least the tradeoff that it promotes learning within the working group. The composition of the working group and the methodology used are believed to provide for a broad and balanced coverage of the technologies under study. This report provides executive summaries of the Fraunhofer reports and the intention is to help the SwAF Headquarters evaluate the military utility of emerging technologies within identified relevant scenarios.

Overall, the quality of the Fraunhofer reports is considered to be balanced and of a high level of critical analysis regarding technology development. However, the report on Unmanned Surface Vessels was found to have a somewhat lower quality than the other reports, for instance, some parts of the text are copied and pasted from last year's report on UCAV and some parts of the assessments are missing, e.g. in the TRL evaluation. Nonetheless, the reports are in line with our task of evaluating the military utility of the emerging technologies.

Table of contents

[1] K. Andersson et al, *Military utility: A proposed concept to support decision-making*, Technology in Society, No 43, pp 23-32, Elsevier Ltd, 2015.

Introduction

Scope

This report is the result of a review of five technology forecast reports from Fraunhofer Institute. The review was carried out at the Swedish Defence University (SEDU) by staff at the Department of Military-Technology, commissioned by the Swedish Defence Materiel Administration (FMV). The task was to assess the military utility of the different technologies in a time frame to 2040.

The review and evaluation of the technology forecast reports form one chapter each in this report.

References

The following reports composed at the Fraunhofer Institute for FMV were reviewed:

[1] 3D Printers – The potential of additive manufacturing, Fraunhofer INT, January 2015
[2] Deep Learning, Fraunhofer INT, January 2015
[3] Nanothermites, Fraunhofer INT, February 2015
[4] Unmanned Surface Vessels, Fraunhofer INT, January 2015
[5] Structural Health Monitoring, Fraunhofer INT, February 2015

Definitions

We define **military utility of a certain technology,** as *its contribution to the operational capabilities of the SwAF within identified relevant scenarios*.

Method

The method consists of four steps and was chosen in order to be efficient and take advantage of the professional expertise of the reviewer.

Step 1: The Fraunhofer reports were distributed among the participants of the working group, on the basis of their special interest and expertise. Each reviewer was responsible for reviewing one report. The reviewer wrote a summary of the report and defined one possible military scenario for the Swedish Armed Forces in the timeframe to 2040.
The purpose of each scenario is to illustrate the usefulness of the technology and hence, to be as convincing as possible while being in accordance with the reported technology forecast.

Step 2: Each review was discussed at a seminar. The reviewer briefly introduced the technology and presented the scenario. The reviewer's role was to be an advocate of the military utility of the specific technology in the developed scenario. The other participants' roles were to support or criticize the concept. At the seminar a SWOT analysis and an assessment of the capability impact of the technology were made. The assessed contributions to the factors DOTMPLFI (Doctrine, Organization, Training, Materiel, Personnel, Leadership, Facilities and Interoperability) were listed. Furthermore, the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of the technology were indicated.

Step 3: The result of the seminar was documented and conclusions on the potential for military utility of the technology were drawn using the Delphi method.

The composition of the working group

The working group consisted of staff members from the Department of Military-Technology at the Swedish Defence University:

Stefan Silfverskiöld, Cdr (N), PhD, project manager
Peter Bull, Associate Professor of Military-Technology
Gunnar Hult, Chaired Professor of Military-Technology
Michael Hagenbo, LtCol (AF)
Kent Andersson, Lt Col (AF), Licentiate of Technology
Björn Persson, MSc
Johan Sigholm, Capt (AF), MSc
Martin Bang, NCO, MA in Political Science

3D Printers – The potential of additive manufacturing

Ref: [1] Referee: Kent Andersson

Introduction

The Fraunhofer report states that 3D printing has become a common moniker for a wide range of additive manufacturing systems which use digital computer models (CAD files) to create real-world objects. A common denominator for all different methods is that 3D printed objects are always built up layer by layer through the successive deposition and/or fusion of suitable materials. In comparison to milling or forging, the additive process facilitates waste minimization and allows for highly complex geometries to be fabricated as single units.

Seven different 3D printing techniques are listed in the report; 1) Vat Photopolymerization, 2) Material jetting, 3) Material Extrusion, 4) Directed Energy Deposition, 5) Binder Jetting, 6) Powder Bed Fusion, 7) Sheet Lamination. The first two use liquid materials, Number three and four use materials that can be melted during deposition, and the last three use powder materials. Number one, three and six are regarded to be the most prominent techniques, where material extrusion is the technique already most commonly used in the consumer market. Common to 3D printers is that they rely on digital geometrical information, e.g. in the form of self-generated or downloaded 3D models or 3D scans. Prior to printing, the virtual models have to be pre-processed by a specific software program that optimizes build orientation, calculates necessary support structures and finally generates cross-sections of the object. The cross-section geometries (‘slices’) are then transferred to the printer, which materializes the object layer by layer.

There is a huge interest in 3D printing within the research community and the civilian industry sector. This technology has passed the hype and is now assessed to have entered a more mature phase where it is adopted by the industry. The TRL assessment for 2035 is 7-9. Industrial 3D printing is mainly driven by performance and quality requirements and is already used for medical applications and within the automotive or aerospace industries. For example “Tests …have shown that additively manufactured rocket injectors are not only up to par with traditionally fabricated parts, withstanding temperatures of more than 3000 °C, but can actually increase system performance and thus revolutionize rocket designs.” However, the techniques are continuously adapted and modified for innovative new applications, such as bio-printing of tissues and organs, contour crafting of buildings using large 3D printers extruding concrete, 3D electronics printing, food printing and more.

A trend towards an increasingly holistic approach to additive manufacturing is identified. Interdependencies between build material, fabrication methods and pre and post-processing steps are analyzed systematically, in an effort to optimize and fine tune the quality of the final product so as to meet specific application requirements. Great efforts are being put into overcoming constraints when it comes to build materials, such as polymers, pure metals, metal alloy powders and ceramics.

The overall assessment of 3D printing in the Fraunhofer report is that it “has to be regarded as **a disruptive technology**. Widespread adoption of 3D printing could have a major impact on the global economy making international supply chains obsolete, since goods are produced closer to (or even by) the end-consumer. Moreover, the ability to turn virtual models into physical objects (and vice versa) will create opportunities for innovative business models centering on the exchange and materialization of digital blueprints which will put traditional concepts to the test.” They also state that traditional manufacturing techniques will still be used for large volume production for a long time. It should be noted that localized production and consumer 3D printing will only gain prevalence if systems are affordable, easy to operate and able to produce high quality parts.

Identified possibilities and constraints

Advantages

- The ability to "localize" manufacturing.
- The underlying digital designs are easily modifiable, offering an unprecedented degree of customization and personalization for all kinds of products.
- The ability to realize highly complex part geometries in one piece, enabling optimized architectures for lightweight construction.

Disadvantages

- Lack of standardized guidelines and test procedures.
- Build volume is a technical limitation.
- Build time increases exponentially with the size of the object to be built.
- In some techniques, a limited resolution in build direction results in rough surfaces.
- Health hazards in manufacturing.
- Risk for uncontrolled proliferation of security-relevant objects.

Suggested military use

3D printing of military components is already a reality, Fraunhofer states, and additive manufacturing is gradually seeping into military production chains; especially for out-of-area-scenarios.

The following applications are mentioned in the report:

1. Aerospace and automotive industry use for low volume manufacturing of high performance products.
2. "ELMs (Expeditionary Lab Mobiles) – 20-foot containers equipped with 3D printers, workstations, computer-assisted milling machines etc. which allow fast on-site conception and fabrication of plastic and metal parts.
3. "upgrading warships with additive manufacturing systems and materials to turn them into mobile factories and thus reduce the length of supply chains".

Assumptions

The concept scenarios are based on the following assumptions:

- Quality control challenges solved.
- Possible 3D printing of spare parts in line with the prognosis of using polymer, metal and ceramic build materials.

Concept Scenario 3D printing for logistic support in 2040

This technology clearly has great potential for developing military logistic concepts. Logistic support for both national defence forces and expeditionary task forces can be captured in one scenario. The scenario is also subjected to a SWOT analysis.

In 2040, there will only be a few big producers of military materiel globally in each domain with headquarters and centers for research and development in their respective home states. The manufacturing of critical parts and the assembly of systems will however, be localized to the respective customer states due to the impact of national industry policies (juste retour/counter trade/offset agreements) but also owing to the potential of 3D printing technology being able to customize products to specific national requirements and cost efficient logistics.

In Sweden, for example, there is a plant for the assembly of light armored vehicles on license from a global giant manufacturer. They, and of course the strong Swedish aerospace and submarine industry represent the Swedish military industrial capacity for 3D printing. Some production, not particularly specific to the military domain, is also allocated to civilian industry. Moreover, since 3D printing technology is generic to products, a quick transformation of domestic civilian industry to support a defense effort is possible in the event of a crisis. The supply of spare parts to military systems is thereby nationally secured.

The military logistic organization has mobile facilities based on container systems. They are possible to transport using military or civilian trucks or sea vessels for enhanced operational mobility or international expeditionary expeditions. With a few different types of 3D printers, it would be possible to manufacture a vast range of spare parts locally for army, air force or naval use, provided that suitable materials and digital blue prints are available. Spare parts could be manufactured more or less on demand as the need for stocks is reduced and the availability of platforms is increased.

SWOT analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology within the scenario were identified at the seminar:

Strengths:

- Spare parts can be manufactured locally on a national scale or in theater within an international expeditionary task force.
- Production facilities can be shared between coalition partners.
- Logistic chains can be specialized in transporting and stocking build materials instead of thousands of spare parts.
- Personal customization of weapons and possibly armor etc., given that there are guidelines for what can be changed and by whom.
- Exclusive units, such as submarines can enhance their time on patrol, given that maintenance is a limiting factor.
- Flexibility in maintenance solutions. Cheaper, more available spare parts or longer MTBF and exclusive parts. Possibly better availability in materiel systems.
- Less waste material during production.
- Digital blue prints can be sent from manufacturer or national logistics center to the unit in theater, or digital blue prints can be drawn from scanning an existing spare part.

Weaknesses:

- Difficulties achieving consistent quality, testing procedures etc.
- Flexibility is a strength as long the quality of spare parts is kept at the expected level; quality deficiencies will quickly affect systems trust negatively.
- Some of the digital blue prints will possibly be confidential and require special safety measures.

Opportunities:

- New concepts for reducing maintenance costs.
- Spare parts for legacy systems can be scanned and new spare parts manufactured, thereby increasing the life cycle of these materiel systems.
- Potential for customization.
- The possibility of transforming the civilian 3D printing industry in order to support military effort in the event of a crisis.
- Scanning and copying adversaries' systems for intelligence purposes.

Threats:

- Low quality products finding their way into the supply chain.
- Manipulated digital designs or production equipment.
- Our maintenance assessments of adversaries will be less accurate, given that they have the same 3D printing opportunity.

Assessed capability impact

The impact is assessed to be great on maintenance and logistics, increasing the availability of platforms in all services.

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the use of 3D printing technology on the factors DOTMPLFI, as well as the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of this technology.

Item	**Comment**
Doctrine	An overview of logistic concepts will be necessary.
Organization	Could have great impact on logistic organization due to reduced transports and new manufacturing activities in theater.
Training	A new logistic concept and new organization might render new demands for education and training; especially for personnel in units potentially isolated and having other primary tasks.
Materiel	3D-printers are new materiel systems for the military organization.
Personnel	Manufacturing could cause health risks. New professions, a new logistic concept and new organization might render new demands for education and training.
Leadership	-
Facilities	Facilities for maintenance of 3D-printers needed. Different needs for storage of spare parts. Limited variety of items needed. More build material required. Production facilities using 3D-printing have to be modified to reduce health hazards.
Interoperability	Development of common standards for quality assessment and

	testing 3D-printed products required.
R&D	Mainly driven by civilian sector. Military R&D should focus on feasibility and logistic concept studies.

Discussion and conclusions

3D printing has the potential of having a great impact on logistics and the supply chain, given that the technology matures as predicted by Fraunhofer. Their assessment is that the technology is disruptive since it could render transportation of goods unnecessary.

It is however unclear how large a part of the logistics volume will be affected. There will still be a requirement for transportation of some goods, and of course fuel. However, undoubtedly in some situations the downtime due to waiting for critical spare parts could be shortened. The impact of these situations should be assessed in a study calculating MTBF using simulations.

In summary, our overall assessment is that 3D printing has significant potential for military utility, possibly disruptive. Logistic concepts for both national and expeditionary missions will be affected in the 2040 time frame. This technology development will be driven by the civilian industry, however, a SwAF in-depth study is recommended as it could help to form potential logistic concepts, and determine what methods and systems are suitable for military adoption, as well as what kind of application-specific issues have to be addressed in order to fully exploit the new technology.

Deep Learning
Ref: [2] Referee: Martin Bang

Introduction
Deep learning is an approach within machine learning. Simplified; machine learning is when computers learn from, and make predictions from data. Deep learning is based on biological neural networks and is an algorithm, which in its structure is inspired by how the human brain operates. It is characterized by the fact that it uses learning in several layers, hierarchically organized. The higher layers in this hierarchy have an increasingly abstract concept or feature. The Fraunhofer report exemplifies this in the case of facial recognition. What in lower layers can only be recognized as two separate eyes, could at the higher layers possibly be recognized as an image of a face and it might be realized that two eyes are often present in a human face.

In general, what deep learning excels at is pattern recognition connected to speech and visual recognition tasks; it has also shown great potential in information retrieval. One area in which the report sees a potential is connected to the dependence on future engineering, compared to some of the other available machine learning algorithms. The required features are learned automatically from the raw data with what is called unsupervised learning. The Fraunhofer report concludes that deep learning can be a key enabler for many both future and current military applications. However, a limiting factor today is computer power.

Although deep learning could be described as a hype during the last years, recent studies from 2014 have shown some of the vulnerabilities of deep learning. Christian Szegedy et.al. write that; *"deep neural networks have counter-intuitive properties both with respect to the semantic meaning of individual units and with respect to their discontinuities."*[2] This means that one can subtly alter an image to trick a neural network into making a misclassification of it. Another article shows the other side of the same problem; the simplicity of producing an image that is unrecognizable to humans, but which can trick the algorithm into believing it has 99.99% confidence in detecting a specific object.[3] Worth mentioning is that this problem is not unique for deep learning but applies to most machine learning algorithms.

Deep learning and its development is connected to artificial intelligence (AI). However, development in deep learning can only solve part of the challenge of creating intelligent machines. In this report, the contribution of deep learning to AI is excluded from the rest of the analysis. AI as such has been analysed by FOI[4] and its military utility was assessed by SNDC[5] in 2014.

Identified possibilities and constraints
Advantages

- Increased capability regarding pattern recognition and pattern analysis compared to some other machine learning algorithms.
- Increased capability regarding smart search engines analysis compared to some other machine learning algorithms.
- Does not need to be programmed explicitly for a certain task.

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[2] http://cs.nyu.edu/~zaremba/docs/understanding.pdf
[3] http://arxiv.org/pdf/1412.1897v2.pdf
[4] http://foi.se/ReportFiles/foir_3919.pdf
[5] FHS Ö 149/2014, *Bedömning av den potentiella militära nyttan av Neurovetenskap, Artificiell Intelligens och Kvantinformatik*, FHS, 2014.

Disadvantages

- High energy consumption compared to the human brain.

Assumptions

The concept scenarios are based on the following assumptions:

- Computer power will continue to evolve.
- Optical sensors will evolve to allow higher resolution.

Suggested military use

The suggested military use in the Fraunhofer report is mainly connected to information analysis concerning intelligence, surveillance and reconnaissance (ISR). Another area to which deep learning opens up new possibilities for military use is natural language processing and speech recognition. This area provides the capability of automated translation from the spoken word to the written, as well as translation from one language to another, both of which can be seen to have great utility within the military context.

The following applications are mentioned in the report:

1. Speech recognition (transcription from the spoken word to written).
2. Image recognition.
3. Natural language processing (language translation).
4. As part of human-computer interfaces based on voice command.
5. Information retrieval.

Concept scenario IMINT in 2040

Pattern recognition is a vital part of intelligence analysis, not least regarding the huge amounts of collected sensor data. Deep learning has, and will continue to have a role to play in analysing signal intelligence (SIGINT) and imaged intelligence (IMINT) within the military intelligence services. The utility of deep learning will probably be the most for IMINT, regarding increased opportunities to analyse great amounts of satellite footage and "near-real time" analyses of UAV footage and deliver this directly to the soldiers in the field.

Within intelligence analysis the recurring problem is finding the signal in the noise. Deep learning will possibly also have a role to play regarding the problems connected to Big Data and the issue of sifting through data to find patterns of relevance.

The ever increasing volumes of collected data, which have been seen since the beginning of 2000, have not diminished. In 2040, the amount of information collected will still overwhelm the analysis systems, however, developments in machine learning should help to mitigate the problems. In 2040, deep learning and machine learning will be an integrated part of the daily work. The constant collection of data from satellites, UAV and other optical sensors will be processed to deliver decision support on both tactical and operational levels.

The data collected by tactical UAV ahead of the units on patrol as well as helmet cameras will be analysed in near-real time. Searches in real time for small changes in the images will help to detect relevant information. The UAV will spot tracks on the ground, the images will be automatically analysed and give the squad leader the information e.g. *an Armata T-15 or T-14 has recently passed the area with a given probability*. The squad leader will then be able to react according to that given information and redirect the UAV to gather more information. The same information can be sent to brigade level, where it will be incorporated into the common operating picture of the theatre.

The increased reliance on machine learning systems also has the consequence that both sides of a conflict put greater effort into deception as well as protecting their own algorithms from falling into the hands of the enemy.

SWOT analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology within the scenario described were identified at the seminar:

Strengths:

- Time effective analysis of image data.
- Possibility of analysing large volumes of data.
- Cost effective analysis of raw image data.
- Possibility of creating a faster decision cycle (OODA Loop).
- Opportunities to increase situational awareness.

Weaknesses:

- High cost for storage of data.
- High energy consumption compared to the human brain.
- If the algorithm is known, it can easily be tricked.
- Requires large volumes of data to operate.

Opportunities:

- Developments in computer power will enable better capacity.

Threats:

- If the algorithm is known, it can be tricked.
- Lack of data to learn from or lack of reliable data.
- Can create an overreliance on sensor data.

Assessed capability impact

The assessed impact is primarily on Intelligence.

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the use of deep learning on the factors DOTMPLFI, as well as the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of this technology.

Item	**Comment**
Doctrine	The fast information rate forces the military into a more adaptive intelligence process, which imposes changes in the doctrine.
Organization	Could have impact on the requirements for operators and image analysts on tactical level.
Training	New requirements for officers to understand how deep learning affects planning and the usage of IMINT.
Materiel	The capability of deep learning is connected to computer power as well as data storage.

Personnel	Deep learning algorithms will not take work away from image analysts, however, the work of the analysts will be “to train” the algorithm rather than conduct the analysis.
Leadership	-
Facilities	Storing the amount of data considered useful, as a consequence of enhanced capability based on deep learning.
Interoperability	Need for common networking architecture for intelligence analysts to be able to harness the data.
R&D	The private sector will take the lead in research and development.

Discussion and conclusions

Deep learning is used in a plethora of ways today; e.g. iPhone, Facebook and Google image searching. The military and commercial need for sorting and finding relevant information in an increasing volume of available data will continue and it is therefore assessed that the military utility is particularly significant. This is primarily because of its potential of being a part of the solution for one of the major intelligence problems in today’s military; sifting through large quantities of collected data. However, whether or not it is deep learning which will be used in 25 years from now is hard to say, however, it is likely that some form of machine learning algorithm that is kindred to deep learning will play a vital role.

The private sector will continue to take the lead regarding research and development, therefore the SwAF should follow the research conducted and should focus on how and where deep learning can be implemented within the organization.

Nanothermites

Ref: [3] Referee: Johan Sigholm

Introduction

Nanothermites are described in the Fraunhofer report as a class of energetic materials that may lead to new applications. Nanothermites have been made possible by the leap forward in nanotechnology during the last 15 years, allowing for synthesis of nanoparticles and compounds of high quality with well-defined combustion properties.

Current research on nanothermites is still at an early stage, and the fundamental principles for mass transport and reaction propagation are still not well understood. Moreover, there seems to be some uncertainty regarding the stability and sensitivity of different nanothermite compounds towards thermal, mechanical and electric shock ignition during handling and transport. Nevertheless, experimental field tests have already been performed, demonstrating the superior combustion properties of nanothermites.

Although there may be civilian applications of nanothermites, such as a small but powerful energy source or for controlled demolition, they are almost exclusively studied for military use. One of the main benefits of nanothermites is that the energy release time may be adjusted and controlled as needed, resulting in an abrupt or rather slow process. This allows for effects ranging from explosives to that of thermobaric munitions.

Given that the potential for nanothermite-enhanced warheads to generate blast effects up to tenfold of those of conventional weapons in 15-20 years, and assuming that protective measures are not developed at the same rate, there is a possibility that nanothermites may provide significant battlefield impact.

Identified possibilities and constraints

Advantages

- Enhancement of the blast effect of warheads, up to ten-fold compared to traditional warheads.
- Less collateral damage.
- Improved safety during transport and handling may be achieved with proper compound design.
- Enhanced long-time stability of ammunition (40-50 years).
- Higher flexibility in terms of effect, weight and size of ammunition systems.
- Non-toxic, widely available elements, requiring no special disposal processes.
- May be used to replace toxic materials in fuzes for conventional energetics.

Disadvantages

- Relatively expensive to produce in contrast to conventional thermites.
- Reacts at very high temperatures and is difficult to extinguish.
- Produces large amounts of light in the visible and ultraviolet spectrum that might lead to blinding if the reaction is observed directly without special eye protection.
- Some compounds may be very sensitive to electrostatic discharge (ESD) and to mechanical shock ignition.
- Finding the right combination of materials, and fully understanding combustion mechanisms and reaction propagation require further research.

Suggested military use

As research on nanothermites continues during the coming years, Fraunhofer expects that several applications of military use will be developed.

The following applications are mentioned in the report:

- Enhancing the effect of conventional explosives or kinetic energy weapons.
- Allowing for shaped-charge warheads that react with low pressure after hitting a target.
- Underwater torpedo warheads, using the surrounding water for the reaction.
- Micro-thrusters for altitude stabilization in small satellites.

Apart from the applications mentioned above, the review group could envision the following:

- A bunker-buster with a nanothermite explosive charge could be able to maintain a high pressure and temperature for a longer time than a conventional thermobaric charge, which could be effective in targets with complex internal structures.
- Nanothermite shrapnel shells could possibly be used to defeat hard-kill Active Protection Systems (APS) for armored vehicles or to destroy incoming cruise missiles by high temperature reaction after impact.
- Nanothermites might be used in the casing of fragmentation grenades in order to limit the risk for collateral damage since the shrapnel would burn and consume itself.

Concept scenario Nanothermites in 2040

Nanothermite-enhanced APFSDS[6] projectiles, where the last section of the projectile is made from nanothermites, could give enhanced effect inside a target as the nanothermite would catch fire and cause high pressure and temperature. In a future combat scenario between tanks and Infantry Fighting Vehicles (IFV), such as the Swedish CV90, using such ammunition could increase the chance of defeating a traditional tank, if the latter was hit from a favorable angle.

SWOT analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology within the scenario were identified at the seminar:

<u>Strengths:</u>

- Nanothermite weapons could be used to efficiently destroy specific difficult targets, such as depots for biological or chemical warfare agents, as they do not generate large amounts of gas that would disseminate the agents.
- Sweden has a competent weapons industry that may be able to invest substantial resources in necessary research and development of nanothermites.
- If nanothermites are designed properly, they have a low tendency of shock ignition. This could reduce the risk of ammunition fire onboard ships or other contained areas.

<u>Weaknesses:</u>

- Research and development costs are high.
- May cause eyesight damage as a result of UV light emission.

[6] Armor Piercing Fin Stabilised Discarding Sabot

Opportunities:

- Nanothermites can be designed with different properties depending on what materials are used. The logistics chain could be made more efficient by letting the weapons be customized at the end of the chain, instead of carrying several different ammunition types.
- An opportunity for the Swedish defense industry to gain a competitive edge by being at the forefront of munitions development.
- Well-functioning nanothermite weapons may generate a threshold effect against antagonistic attacks.

Threats:

- An adversary may develop countermeasures that prevent the effectiveness of nanothermite weapons, or may use nanothermite weapons against us.
- An Electrostatic Discharge may cause a nanothermite ignition.
- The legal status of nanothermite weapons is unclear and they may be banned as a result of a future international treaty.

Assessed capability impact

Nanothermites will affect the basic capabilities of *effect*. A higher degree of effect is assumed to be achieved by supplementing conventional weapons with nanothermite components.

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the use of nanothermites on the factors DOTMPLFI, as well as the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of this technology.

Item	**Comment**
Doctrine	New use of current forces as effects can be achieved against tanks, and better protection against incoming missiles. Our doctrine must be revised if the adversary acquires this weapon. How nanothermites are used may be regulated by International Law, requiring doctrinal revision.
Organization	-
Training	Nanothermites will require new training for soldiers, commanders, and logistics personnel, but the cost will likely not be extreme.
Materiel	Nanothermites will be a new materiel system requiring separate routines.
Personnel	Reductions in personnel may be possible through the use of nanothermites, as more effect can be generated by an individual system or soldier.
Leadership	-
Facilities	Bunkers may be penetrated as a result of nanothermite weapons, reducing their protective capabilities.

Interoperability	-
R&D	SwAF should support research into nanothermites in collaboration with the Swedish defense industry.

Discussion and conclusions

Based on the current and assessed Technology Readiness Level of nanothermites, the SwAF is presumed to be able to make use of them after 2040, given that investments are made in R&D. Initially, we suggest that a deeper study into the feasibility of nanothermite munitions and their possible military utility is carried out, since they are assessed to have a potential for significant military utility. Some of the remaining challenges include resolving risks and uncertainties pertaining to health, legality and material development. We suggest that nanothermites should be incorporated as a future area of interest within the SwAF R&D-project.

Unmanned Surface Vessels

Ref: [4] Referee: Björn Persson

Introduction

The development and operation of unmanned aerial vehicles (UAV) for both military and civilian application has experienced a breakthrough in the twenty-first century. Still, Unmanned Surface Vessels (USV) have yet to reveal their full potential. USVs have been in active service in a number of armed forces for a long time. However, these vessels are usually tele-operated from a mother ship which the USVs stay relatively close to. Most aspects of the technology required for armed forces to operate USVs are mature and often commercially available.

The recent general trend for unmanned vehicles aiming for more autonomy in operations, also applies to USVs, which enables new types of missions to be undertaken. The US navy program called Swarm demonstrates how small fast boats can navigate and “swarm” an adversary. Another example of the progress in USV technology is the DARPA “Anti-Submarine Warfare Continuous Trail Unmanned Vessel”, which is designed to find and track hostile submarines over great distances.

Identified possibilities and constraints

Advantages

- Reduce the risk for loss of own personnel.
- Better endurance.
- Lower signatures.
- The weight of the platform may be reduced.
- Continuous tracking of submarines.
- Reduced cost for each platform.
- Less personnel required to operate the platform.

Disadvantages

- When something unexpected happens, there is no one present who can fix the problem.
- Hard to communicate with human actors in the area of operation.

Assumptions

The concept scenario is based on the following assumption:

- The methods for hunting submarines are essentially the same as today. However, sensors are likely to be more sensitive and accurate, whereas threat submarines have lower acoustic signatures.

Suggested military use

The following applications are mentioned in the report:

1. Defense against mines, especially mine-hunting, with deployment and coordination from outside the danger zone posed by mines or enemy fire.
2. ISR (Intelligence, Surveillance, Reconnaissance) of own or hostile coastal areas by small craft, again with deployment/guidance and coordination from a safe distance, as well as persistent electronic warfare activities (electronic intelligence, respectively deceptive measures).

3. Capabilities for coast protection against all kinds of smuggling, or also counter action, which in part is police duty as well.
4. Spotting submarines as soon as they leave their home waters and the continuous tracking of their activities.
5. Armed protection of own manned ships.
6. Improved means for civilian duties of hydrographic surveillance in national and international waters by a more tight-knit net of persistently working survey stations/measuring platforms.

Concept scenario USVs for anti-submarine warfare in 2040

The difficulties of detecting foreign submarines in Swedish waters remains in 2040 and the number of dubious sightings of suspected submarines by the public is steadily increasing. The SwAF lack the resources to investigate all the reports and have therefore invested in small USVs with the purpose of hunting submarines in group. The USVs do not require any human interaction once they have left harbor and can be equipped with the same kind of sensors that manned platforms use for anti-submarine warfare. The USVs are to be used for both investigations of sightings and continuous surveillance.

The platforms will not likely require to be armed in order to be useful for anti-submarine warfare; however, from a technical perspective, it is straightforward to develop armed USVs.

SWOT analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology within the scenario were identified at the seminar:

Strengths:

- Lower risk for own personnel.
- Lower cost per search hour.
- Reduced need for training and maintenance of a crew.
- Longer time on station than manned or flying alternatives.
- Higher readiness level.
- The increased number of platforms can enable a tracking capability where an established track can be handed over to another platform.
- Increased detection probability.

Weaknesses:

- Possibly reduced situational awareness, since it might be harder for a remote operator to understand what is happening around the vessel.
- If the number of platforms increases and each platform operates longer; maintenance will have to increase as well.
- The ability for ”field repairs” is lost, if the operator is removed from the platform.

Opportunities:

- Possibly improved group combat effectiveness, because of advancement of artificial intelligence.
- Can be sacrificed to achieve other mission objectives.
- Increased survivability due to platform designs, which have lower signatures than the manned alternative.

Threats:

- Easier to tamper with than a manned alternative.
- It may be hard for a remote operator to interact with humans encountered during the mission.
- USVs will have to share the water with civilian actors; social acceptance for the technology could threaten the operations of USVs.
- Unmanned platforms are not as flexible in terms of improvisation as the manned alternatives.

Assessed capability impact

Unmanned surface vessels will contribute to the ISR capabilities in coastal areas and will in the presented scenario contribute to the anti-submarine warfare capability.

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the use of technology USV in the scenario above on the factors DOTMPLFI, as well as the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of this technology.

Item	**Comment**
Doctrine	Small adjustments.
Organization	Fewer personnel required to operate USVs.
Training	Required for operators and decision makers.
Materiel	Communications systems.
Personnel	Different competences required.
Leadership	Low effect.
Facilities	Harbor and command facilities.
Interoperability	Low effect.
R&D	Artificial intelligence for the purpose of anti-submarine warfare is required.

Discussion and conclusions

USVs face many of the traditional difficulties that all unmanned vehicles do, even though the operational environment is likely to be easier to cope with than for ground and aerial vehicles. Still, problems concerning certification, legal aspects, and artificial intelligence apply to all unmanned vehicles. However, the traditional advantages of unmanned vehicles also apply to USVs.

Democratic countries are often reluctant to expose own personnel to different kinds of risk, which in turn can result in the inability to act in certain situations. Unmanned vehicles in general can solve this problem since the acceptable risk they can be exposed to is higher.

The effectiveness of USVs for the SwAF will depend greatly on how the platforms are incorporated into the organization. Research on tactics on how to use the USVs will likely be imperative, if the technology is to reach its full potential. We recommended that the SwAF should follow the development and pursue research on USVs before acquiring own platforms.

USVs could be used for many tasks that are dull, difficult and dangerous. If employed to search for submarines, they are expected to lower the cost for personnel, increase the readiness level and increase the probability of finding hostile submarines. Therefore, we assess that USVs have potential for significant military utility.

Structural Health Monitoring

Ref: [5] Referee: Peter Bull

Introduction

Structural health monitoring (SHM) is a method for keeping track of the physical state of a system consisting of mechanically loaded parts, by using different types of sensors. Sensors can be added to the surface of parts in the system or they can be embedded into parts. Both passive and active sensors can be used for the task. Sensor technologies mentioned in the report are strain measurement, acoustic emission, ultrasound, fiber optics, and eddy current tests. These sensors can be used to monitor deformation, temperature, development of damages, and occurrence of events such as impacts in the parts they are added to. By keeping track of how signals from the sensors develop over time, and comparing them to reference values, it is possible to monitor the health of a system. This makes it possible to get a better understanding of what kinds of loads each part of a structure is subjected to. Such statistics can be used for better service scheduling or as input for design of upgrades. In addition, it is a requirement for automatic or autonomous systems utilizing kinodynamic motion planning, a technology which was discussed in the previous technology forecast.

Identified possibilities and constraints

Advantages

- Extending intervals between maintenance.
- Optimizing the service life of structures.
- Manufacturer can gain information on how parts wear out.
- Possible to predict failure of mechanical parts.
- Possible to fix mechanical parts before failure.

Disadvantages

- Yet another system that might fail.
- Misplaced faith in predictions made using data from SHM system.
- Sensors and cables might add weight to the system.
- SHM can interfere with other wireless systems, if wireless communication is used.
- Sensors need power.

Assumptions

The concept scenarios are based on the following assumptions.

- Kinodynamic motion planning is available.
- Computing power is not a bottleneck.
- Small and cheap sensors of adequate quality are available.

Suggested military use

The following applications are mentioned in the report:

- Civil engineering applications such as bridges, tunnels and dams.
- Mobile structures such as vehicles, seagoing vessels and aircraft.

Concept scenario structural health monitoring in 2040

Assume that an enemy has taken control over a strategically important island and located a highly capable medium to long-range anti-aircraft missile system there. Efficient short-range anti-aircraft gun systems are located in the vicinity for protection of the missile system.

A possible way of taking back control over the island and the airspace is to use cruise missiles to defeat the anti-aircraft missile system. To achieve delivery of weapons effect, the cruise missiles would have to get past the anti-aircraft gun system. Every anti-aircraft system has a saturation point; therefore, sending an adequate amount of cruise missiles into the airspace protected by the anti-aircraft gun systems will saturate its control system and allow some cruise missiles to pass. Depending on the efficiency of the anti-aircraft system, this approach might turn out to be prohibitively expensive.

By designing a small, highly agile subsonic cruise missile that is reasonably cheap, it could be possible to exploit the terrain surrounding the protected area, and in that way reduce the amount of missiles required to penetrate the anti-aircraft gun system. A subsonic design will make it possible to design a relatively small missile with reasonably good endurance. Even if the missile is physically small, its shape has to be designed for low radar and IR signature. Preferably, it should have only passive sensors such as EO and IR cameras for navigation, terrain following and targeting, and signal intelligence antennas to keep track of opposing radars. With access to a good terrain database of the target area, it might be possible to navigate using only the cameras and the terrain database.

In the Technology Forecast report of 2014, systems utilizing kinodynamic motion planning were covered. It was concluded that in order to exploit the full potential of such systems, some kind of structural health monitoring system would be needed. By combining kinodynamic motion planning and structural health monitoring in the proposed cruise missile, it would be possible to achieve a highly agile missile that could fly along roads, maybe even paths, behind hedges, and between trees. A structural health monitoring system keeps track of current health and load on parts and subassemblies of the cruise missile. This will allow the control system to subject parts to loads very close to their breaking point. Which in turn would make it possible to maneuver the missile very close to its structural limits. The resulting agility would make it capable of avoiding unforeseen obstacles at very short notice.

Equipped with a short range communications system, it would be possible to fly a group of missiles in close formation during parts of the route towards the target. If the missiles were also equipped with an active radar reflector, a formation of missiles could give the appearance of being a formation of large aircraft. The radar reflectors could be turned off after a while to give the impression that the aircraft disappeared, or they could be kept on in order to draw attention from other missiles with the reflectors turned off.

The missiles should preferably be transported on a modular mobile launcher system so that the system can be moved by different kinds of vehicles making it difficult for an enemy to find and engage.

SWOT analysis

The following strengths, weaknesses, opportunities and threats with the proposed technology within the scenario were identified at the seminar:

Strengths:

- Increased maneuverability of cruise missiles thanks to improved structural health awareness.
- Increased probability of penetrating even highly protected targets because of reduced probability of detection and interception.
- Reduced risk exposure for own forces.

Weaknesses:

- System might fail during operation with resulting collateral damage.
- Increased system complexity, weight and power consumption.

Opportunities:

- An enemy might be reluctant to occupy the island in the first place, given knowledge of the cruise missile systems' capabilities.

Threats:

- Increased systems complexity might lead to reduced performance.
- New tactics, techniques, and procedures for protection of ground based air defence.
- If the adversary really wants to capture the island, they might employ a significantly larger force.

Assessed capability impact

Structural health monitoring is a key part of utilizing kinodynamic motion planning in automated and autonomous systems; therefore it will affect the capability of all systems which rely on kinodynamic motion planning.

Footprint/cost 2040

The following list is a compilation of anticipated footprints created by the use of technology SHM on the factors DOTMPLFI, as well as the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of this technology.

Item	**Comment**
Doctrine	Increased systems capability would have to be taken into account in doctrines.
Organization	Minor changes in order to take systems usage history into account.
Training	Operators and maintenance personnel need training to take information into account.
Materiel	Systems to download and analyze usage history.
Personnel	Systems can be taken care of by existing personnel categories.
Leadership	Nil
Facilities	Nil
Interoperability	A standard for usage history is needed.
R&D	An investigation of which platforms were to gain from this technology would be beneficial. Connection or cooperation between SHM and kinodynamic motion planning needs to be developed by defense research establishments.

Discussion and conclusions

Structural health monitoring is a key part for utilizing kinodynamic motion planning in automated and autonomous systems; therefore it will affect the capability of all systems that rely on kinodynamic motion planning. This technology has the capacity to enhance the capabilities of automatic and autonomous systems.

It can also deliver usage history with a very detailed resolution making it possible to find couplings between different maneuvers and the strain to which they subject a system. This can be used for increased detail in planning of maintenance, but also as input for systems development and upgrades.

Logistic services can benefit from the usage history of this technology, in order to help choose systems that are most fit for a certain operation. In combination with 3D printing, this could make logistics capable of adapting to new circumstances very quickly.

Our assessment is that structural health monitoring has significant potential for military utility.

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 five 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 was used in the Technology Forecast 2013 and 2014. It is believed to be good enough 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 tradeoff 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 executive summaries of the Fraunhofer reports which are believed to help the SwAF Headquarters to evaluate the military utility of emerging technologies within identified relevant scenarios.