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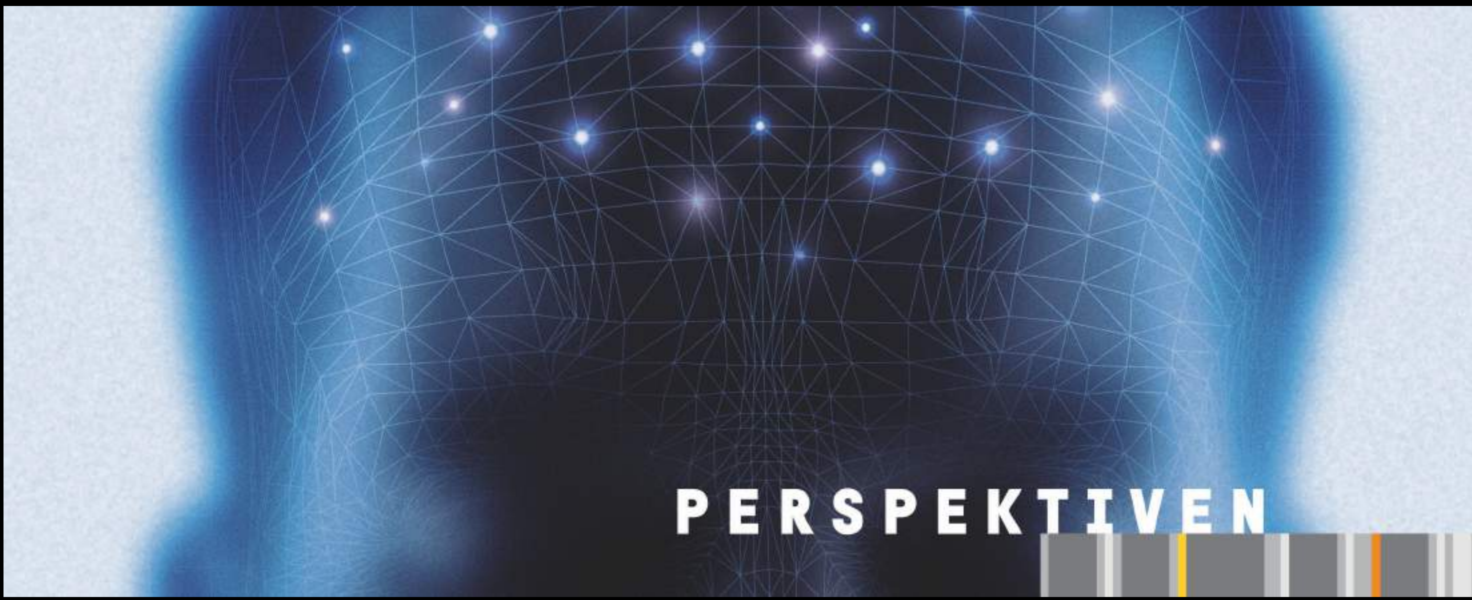

Defence Future Technologies

Emerging Technology Trends 2015

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Credits

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Front page: Emerging sun - view of the Earth from space

Foreword

As the rate of development in technology is accelerating and civil investments are pushing boundaries always closer to what was considered science-fiction until recently, the exploitation of dual-use technologies is growing in the defence & security ecosystem.

If technology is not the only driver in the evolution of warfare, it is the enabler, not to say the trigger, of most of the changes that occurred at the turning point between generations.

For a country like Switzerland, Technology Foresight is paramount to identify the opportunities and threats a technology can represent for the different military capabilities building our national armed forces.

Rather than *picking winners*, the Technology Foresight program must provide a comprehensive overview to ensure an early warning about novel relevant technological advances. Identifying potentialities provides the time to build the necessary competences, skills and expertise, in the various fields.
In that sense, Technology Foresight must be an integrated element of the doctrine, planing and procurement processes of the armed forces.

Only with this strategic futuristic vision, the Swiss armed forces are able to handle, economically and operatively, the evolutions and challenges to come.

Dr. Thomas Rothacher
Director armasuisse Science and Technology

Preface

Supported by exponential advances in technology in combination with the changes in the nature of conflicts and warfare, any fixed predictions would be illusory given the evolutionary nature the environment. The proliferation and accessibility of cutting edge military and dual-use technologies - once reserved almost exclusively to state actors - to non-state actors such as terrorist organizations makes not only the anticipation but also the detection of threats a real challenge. Falling costs and rapid changes in manufacturing (maker movement, Fablabs, etc.) also increases the availability of cheap weapons that could offset the more sophisticated systems used by militaries.

Focusing on emerging technologies and how some of them might impact the battlefield of tomorrow, the nature of this document can be considered as a continuous work-in-progress. It is the emerging part of a research program gathering information from multiple sources and structuring it in such a way it provides a strategical overview of technology horizon of the coming years.

This document structures the technologies in three main levels allowing the reader to access the technological information at a strategic, tactical or operational (detailed) level, Figure 1. The different sections are interactive between them and will be updated at regular interval with content generated from the DEFTECH (Defence Future Technologies) platform. The scope of this platform is first to centralize all the information and second to allow semantic search as well as bring to the front some hidden relationships between technologies, industrial actors and military capabilities.

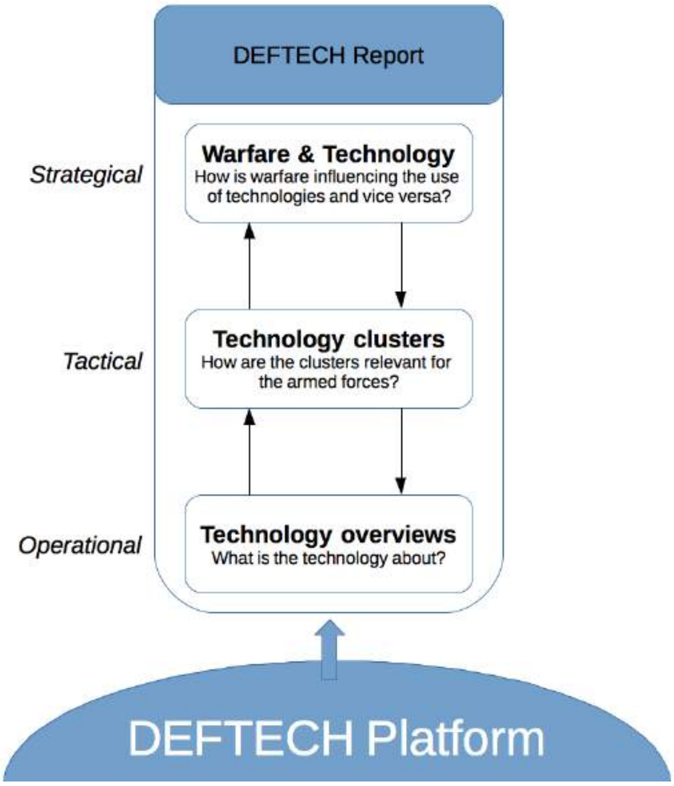
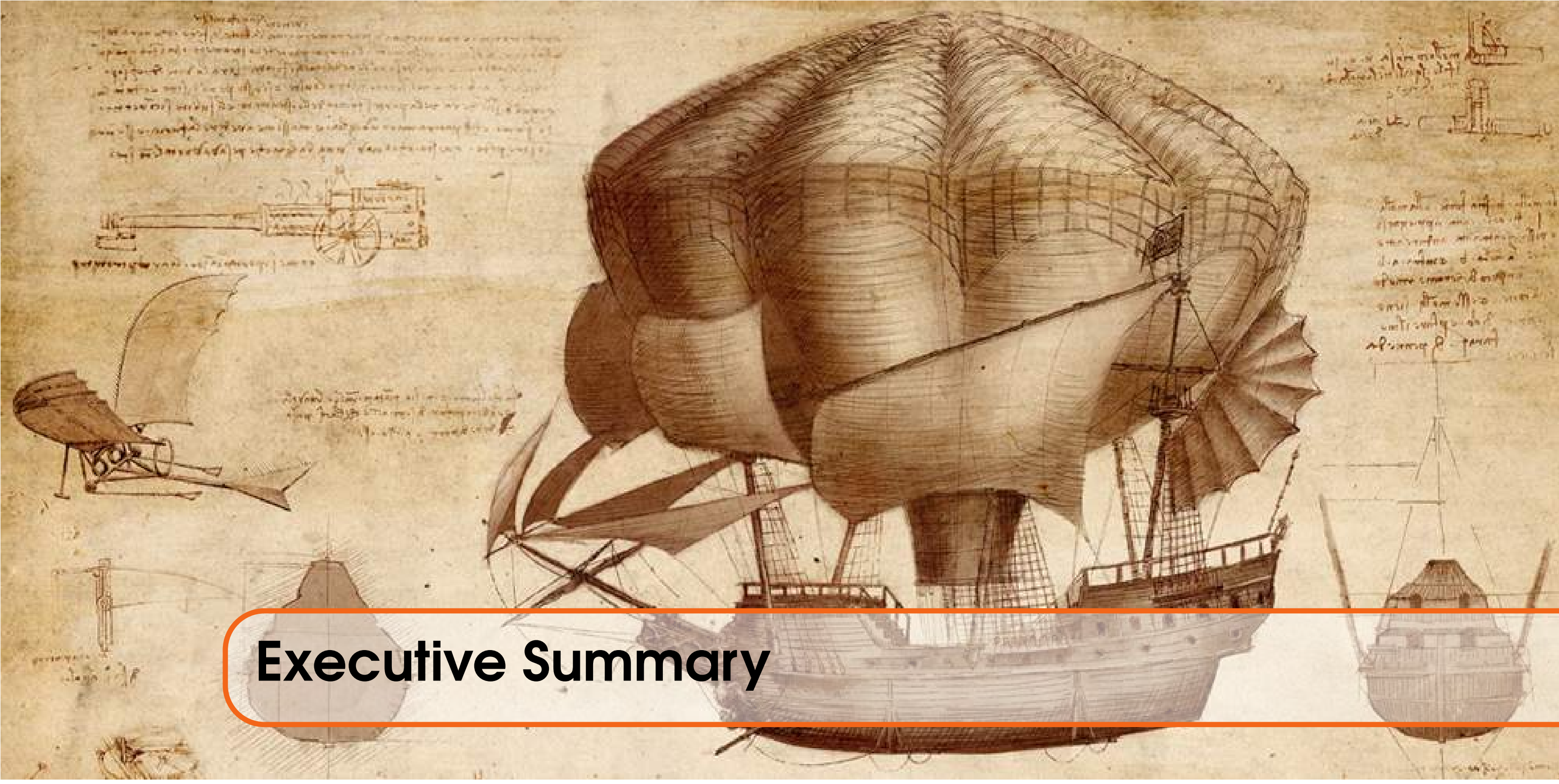


Figure 1: Philosophy of the document presenting three level of nested information, from a strategical overview to a more operational and descriptive level of information. The information is extracted automatically from the DEFTECH platform before being put into military context.



Executive Summary

Technology Foresight is an instrument for long term anticipation that aims at supporting strategic decisions.

Civilian investments and developments in technologies have overcome military resources in many research fields; this means that dual-use technologies are becoming more and more present and important on the battlefield as new combinations of existing components are used in vastly capable ways. At the same time, the evolution in warfare brings established military forces to interact with new actors using new methods of fighting. The resulting asymmetry in conflicts offers a fertile ground for the use and combination of new technologies.

The major developments support an increase in four directions; these developments affect the following four elements present in combat : Speed, Awareness & Connectivity, Precision and Distance (or Reach):

Speed Speed is increasing and it is facilitated by developments in areas from mobility to computing.

Awareness & Connectivity Awareness about multiple elements such as location, physical indicators, situation, is available anywhere at anytime thanks to communication and connected sensors.

Precision From observation to action, sensors and processing power are enabling stochastic model to guide ammunitions better or to validate decisions.

Distance Distance is not an issue anymore as systems can be operated remotely from the theatre of operations.

Illustration: Leonardo da Vinci flying machine

The four trend types, and underlying technologies, directly support and improve reliability and speed in every phase of the OODA (Observe-Orient-Decide-Act) loop; which is believed to be at the center of victory in any battle.

The Defence Future Technologies Foresight program deals with all observable technological trends that might have an impact on the defence landscape. Using a common taxonomy connects the technologies with the industry and the military capabilities. Using directed emergent research methods, there are five major categories which can be identified with underlying support clusters. There is significant interplay between all aspects in a constantly dynamic and morphing landscape; as technology both supports and is supported by other technologies for multiple application avenues. Regrouping the different technology fields into these categories, the following trends can be identified.

Information & Communication - *The Big Data and artificial intelligence challenge*

With increasing computing power, the variety of sources of data from sensors to social networks, the amount of information available about anything grows exponentially over time. As communications media develops in parallel, any information will be available anyplace and anytime. Network-centric warfare grows, and so does the cyber security threat.
With increased computational abilities, artificial intelligence and machine learning will help make sense out of this Big Data challenge and are enabling the prediction of future behaviors as well as the real-time presentation of scenarios that could favor a better situational awareness and better decision processes.

The clusters of technologies considered in this category are: *Communication, Computation, Cyber Security, Internet of Things (IoT), Interfaces, Monitoring, Simulations, Social Crowd*

Energy - *The efficiency and diversification focus*

The ability to acquire energy is becoming more and more compact as alternative methods in the energy fields open the way to to renewable sources such as sun, the wind, biofuels. Progress in storage, charging/generation, and weight are some of the key enablers for autonomous and remote pilot systems.
Besides renewable energies, compact nuclear fusion and micro nuclear reactor could reduce the necessity of operational logistic energy lines.
Directed-energy weapons using lasers and high-power microwave will supplement conventional means of warfare.

The clusters of technologies considered in this category are: *Efficiency, Management, Propulsion, Storage, Transformation*

Nanotechnology & Materials - *The high performance and adaptability enablers*

Nanotechnologies are enabling the manufacture of lighter, stronger, more reliable, lower cost, higher performance and more flexible electronic, magnetic, optical and mechanical devices.
Materials with new, different properties will appear; such as, self-adaptive materials responding to the environment, this includes self-healing materials.
Different type of manufacturing such as Atomically Precise Manufacturing (APM) and Additive Manufacturing (3D Printing) offers new opportunities for logistics and allow the creation and

production of new forms and shapes.

The clusters of technologies considered in this category are: *Base Compound, Biological, Construct, Devices, Materials, Reactive*

Life Science - *The genetic, synthetic revolution and the augmented soldier*

With quickly increasing capacity for the manipulation of DNA and creation of synthetic organisms, it is now possible to better understand human genetic defects or vulnerabilities and target individuals or groups specifically. Recruitment of soldiers could start before birth.
Novel chemical and biological weapons might appear more and more often; easily allowed by the inexpensive production of microorganisms.
Human enhancements span from external systems such as exoskeletons to internal systems like cognition enhancing nootropics; increasing the performance of the human brain. These aim to produce more robust and enduring soldiers where health will be permanently monitored and their capabilities improved.

The clusters of technologies considered in this category are: *Biomedical Engineering, Biotechnologies, Cognitive & Umwelt Sensing, Medical Health, Networked, Sensors, Social.*

Systems - *The robotics, autonomous systems and space endeavors*

The number of unmanned military systems is increasing. Starting with a man IN the loop (like remotely piloted drones), the trend is to have systems, and swarms of systems, able to perform without a human operator and manage extensive tasks in complicated environments for extended periods of time (man OUT of the loop). Unmanned systems will have a major impact on logistics and on how humans and machine will interact together to fight battles.
Low-cost space and above-atmosphere platforms offer new opportunities and threats for continuous observation and communication.
New precision guided weapons together with hypersonic missiles and enhanced warhead technologies will play an important role in the conduct of operations.

The clusters of technologies considered in this category are: *Flight, Infrastructure, Logistics, Robotics, Weapons*

The current and natural viewpoint on technological advances is a timeline where progress is assumed to be a linear process; when, in fact, progress can be gaining momentum stealthily before exploding out past our controls. Ideas are the name of the game and simple implementations can have massive ripple effects. This is the reason why the present ecosystem will be permanently monitored and expanded in order to anticipate the next technology wave!

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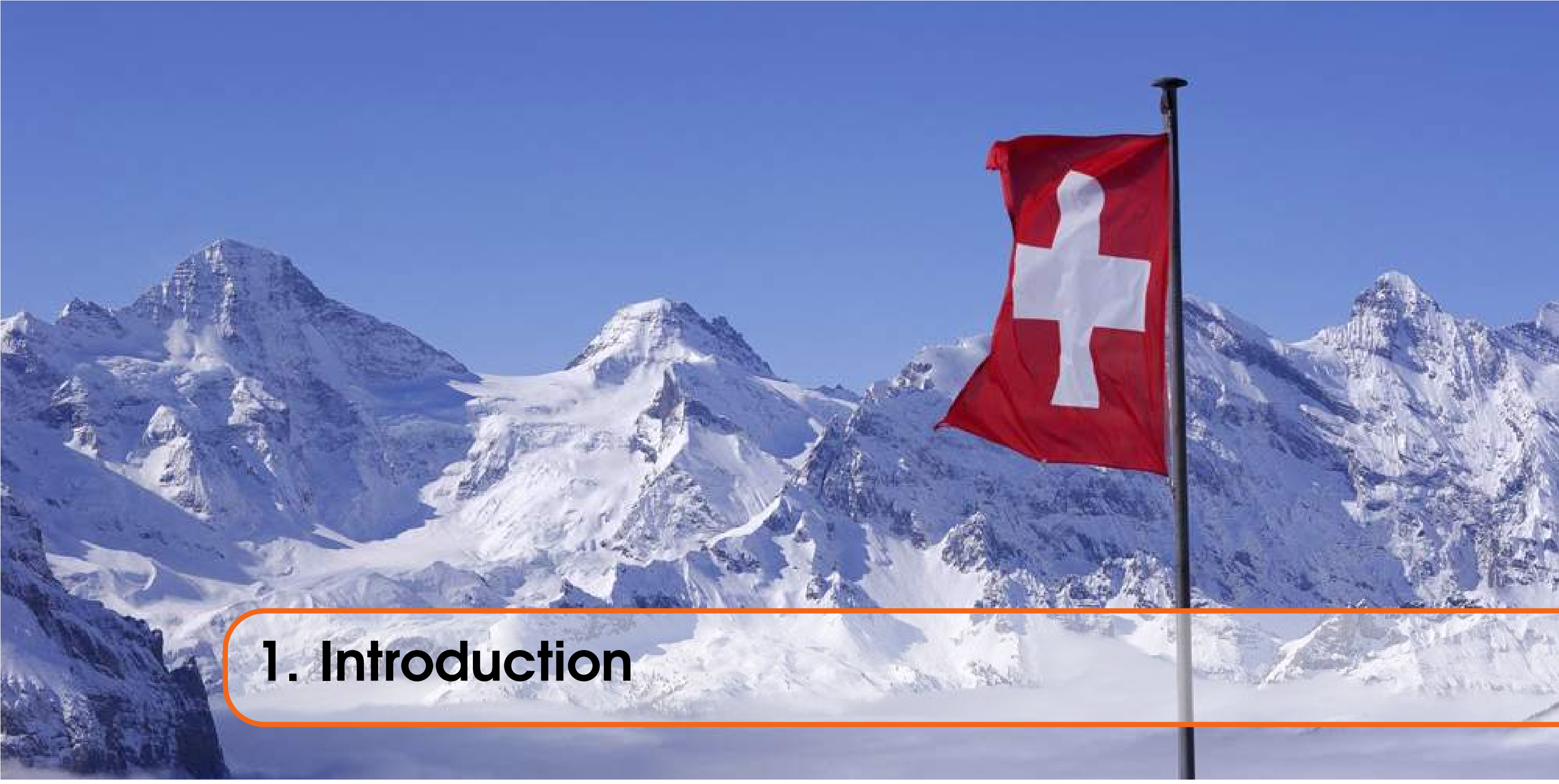
Part One



1. Introduction

In order to anticipate the future of the armed forces and their operational capabilities, it is paramount to follow the advances in the numerous civilian and military technological fields. The main reason is a reciprocal relationship between doctrine and technology. While the doctrine shows how military forces are deployed, technologies enable these possible actions, which, in their turn influence their deployments. Technological superiority does not necessarily lead to success. However successful doctrine often exploits the full technological potential available. At the same time it is important to ensure that a doctrine, through technological innovations and other developments, remains competitive against any opponent as well as any form of opposition. Unfamiliarity cannot be confused with improbability, thus there is a requirement to maintain a deeper awareness of the direction of technological advances and how they could converge to provide advantage to possible adversaries. Technology scanning and technology monitoring are central to this purpose. By taking advantage of opportunities, assessing and mitigating risks, they are both necessary for the development of the national doctrine, as well as for the continuous revision of planning scenarios [Defa].

An effective technology forecasting must draw attention to new technologies and relevant technology developments that will impact the security forces. Using technology monitoring, which has a slightly closer time horizon than technology forecasting, security forces can be advised whether they can rely on a new technology or not, if they have to adopt it (ex. replacement of a technology) and when the right time is to do it. On one hand it guarantees to invest only in mature technologies and on the other hand, it makes sure not to miss any emerging technological advances. Only this way can financial resources be efficiently invested in appropriate technologies [Defb].

To minimize the risk of bad investments, technology assessments must be included into the early stages of the military projects and procurements processes. To this purpose, the current technological trends and developments are constantly observed thanks to a comprehensive forecasting and an aligned monitoring. The focus should not be set too tightly on pure defence technologies; civilian technologies with dual-use potential play more and more an important role as development cycles tend to become shorter, alongside with military budgets for R&D.

Illustration: Swiss national flag in front of the Breithorn, Tschingelhorn and Gspaltenhorn

This broad focus is the direct consequence of a paradigm shift in technology development, which has taken place over the past two decades. While it was almost evident that both military and space research were driven by the advances in technologies for the last centuries, always looking for better equipment, the pace of technological progress today is dictated in many areas by the civilian market, and its increasing speed by the combination of different technologies, Figure 1.1.

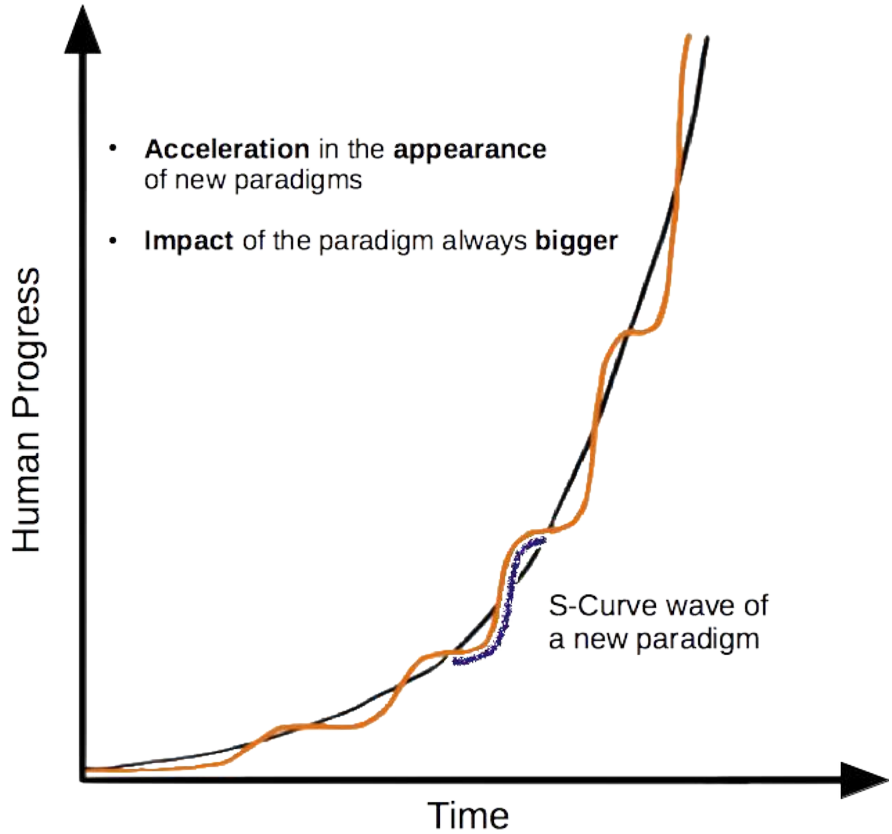


Figure 1.1: The acceleration of the Human Progress is not only, but strongly influenced by the improvements in technologies and combination of those.

As more and more technologies are both usable in civilian as well as military environments, security forces are increasingly subject to adopt the technologies from the civil markets. This can be really interesting considering an economic perspective. However, very satisfying civilian technologies do not always meet the requirements of emergency services leading to expensive adjustments. As a consequence, the adoption of the latest technologies happens less rapidly than in the civilian world. If during history, security forces always used the latest available technologies, they seem today to be on the run in keeping track with them, Figure 1.2 (inspired by [FH14]).

The development of civilian technologies is carried out in some areas very dynamically, partially complementary, sometimes parallel and in great variety. This results in products, which open up new possibilities and practices, but also generate new business models and force old ones to disappear. This phenomena is called disruption. Because disruptive developments may affect the sustainability of economic, social, legal, ethical and operational environments, they must be recognized by the security forces and included in their development and planning processes. Understanding these technologies allows to better embrace them, but also to better anticipate the threat they might represent if used by the adversary.

In general technologies support military systems. To be successful, systems normally require

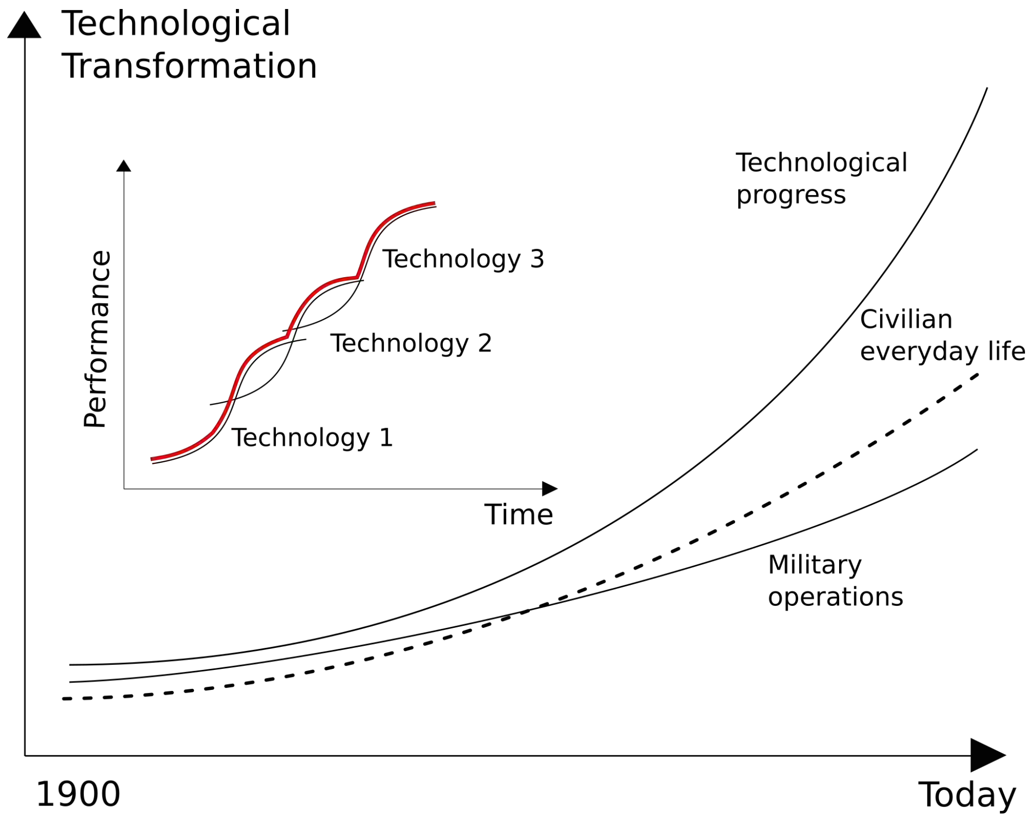


Figure 1.2: Technological progress plays an important role in everyday life. However, its adoption by society is slower than the technological progresses themselves. In the past years, military operations have always benefited from advances in technologies before the civilian did. In the recent years, a shift of paradigm occurred, resulting in having increasing civilian technologies used with military purposes (dual-use). In red you see how different technologies can be used over time to enhance the performance of a function.

several enabling or complementary technologies that must all come to fruition before the system itself becomes viable, Figure 1.3, inspired by [Grü12]. This makes the task of forecasting difficult as one must examine progress across all the supporting technology components prior to looking at the overall system [Toc14].

As partial scope of the research program "Technology Foresight", technological developments are anticipated and described with relevance to the state security forces. It is not so much about forecasting technological advances, but rather to sketch future possible scenarios using a structured and continuously-driven approach. The output will then be discussed with the interested parties and will provide an input for the development and planning processes of the military forces. The procurement agency should know in time and as accurately as possible what new technologies emerge and how relevant they may be for military equipment. They need to know with certainty if the adoption of a new technology must be dispensable, useful or absolutely necessary.

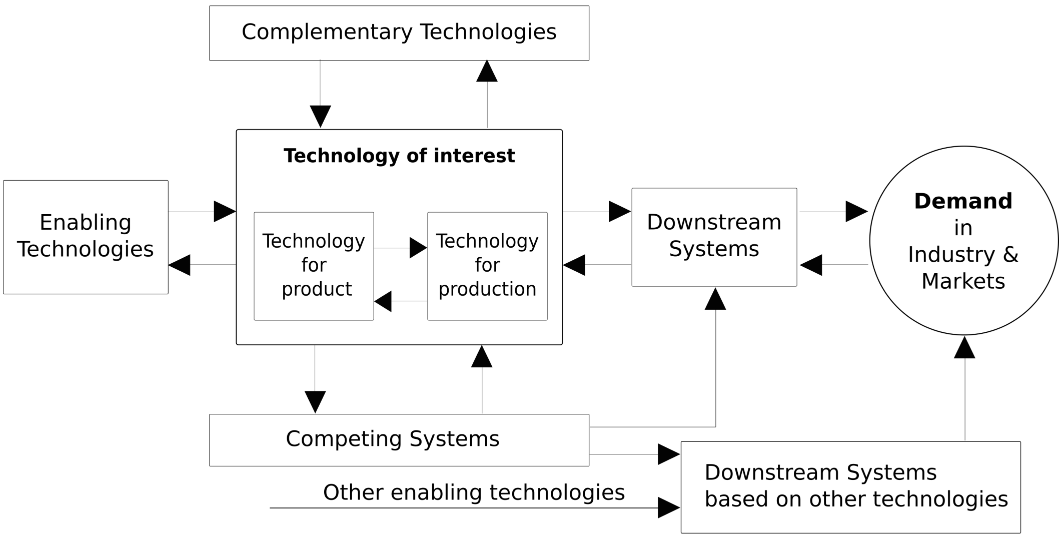


Figure 1.3: The complexity of the technology foresight exercise. To understand how a technology will evolve, it is dangerous to consider it isolated. By studying its ecosystem and the systems in which it is integrated, you get a better idea of its maturity and potential disruptive nature.

2. Technologies and the future of warfare

The assessment of the impact of technologies on future warfare cannot be done in isolation without considering both the evolution of warfare and the social and political environment within which it has evolved. *How, where* and *who* are fighting the new conflicts influence the technologies that will be used. Even if how technologies will be combined and put into action might not appear clearly, understanding the context will help identifying them and hopefully anticipate countermeasures as well as issues that will arise.
The periodization presented here is mainly to structure the context in which we will be evolving in the coming years. The attributes of the different generations are of course debatable.

2.1 The different generations of warfare

The notion of warfare, as well as victory and defeat, has evolved over the modern ages, always tightly bound with progresses and changes in technologies and strategy. It is important to notice that despite the fact that these generations appear in different period in time, they can co-exist depending on how adversaries are operating.

Illustration: Detail of the battle of Austerlitz, also known as the Battle of the Three Emperors, 1805

2.1.1 First generation warfare

Title	Massed manpower
Appearance	1648 (end of 30 Year's war)
Actors	States, small professional armies
Strategy	Destruction of the enemy's front
Method of fighting	Man-to-man
Technologies	Bore rifles
Turning point	The increased accuracy and speed of the rifled musket and breech-loaders made the concept of line fighting soldiers impracticable due to the heavy casualties caused by these new technologies.

Table 2.1: First generation warfare

2.1.2 Second generation warfare

Title	Conscription
Appearance	1793 (Napoleon)
Actors	States, armies of citizen
Strategy	Seek decisive battle in order to destroy the opponent's army and his capacity to resist.
Method of fighting	Man-to-man
Technologies	Bore rifles, artillery
Turning point	Rise of a new ideology: the nationalism. Use of the railway to move supply and soldiers.

Table 2.2: Second generation warfare

2.1.3 Third generation warfare

Title	Massed firepower
Appearance	1915
Actors	States
Strategy	Destruction of the enemy's fighting force (military and civilian if necessary).
Method of fighting	Fixed-artillery-to-men
Technologies	Breech-loaders, magazine rifle, machine gun, artillery, camouflage uniforms, radio, railway
Turning point	The use of blitzkrieg during the German invasion of France demonstrated the power of speed and maneuverability over static artillery positions and trench defences.

Table 2.3: Third generation warfare

I would like to thank Dr. Jean-Marc Rickli for the very helpful and insightful comments provided in this section.

2.1.4 Fourth generation warfare

Title	Strategic manoeuvring
Appearance	1939
Actors	States
Strategy	Destruction of the enemy's command and control
Method of fighting	Tanks/bombers-to-cities/armies
Technologies	Tank, mechanized infantry, airplanes, helicopters, missiles
Turning point	Conflicts integrating non-states actors and loss by the nation of their near-monopoly on combat forces, returning to modes of conflict common in premodern times.

Table 2.4: Fourth generation warfare

2.1.5 Fifth generation warfare

Title	Decentralized & psychological warfare
Appearance	1945
Actors	States and non-state actors
Strategy	Winning by not losing
Method of fighting	Propagandist-to-populations
Technologies	Military technologies accessible by state as well as non-state actors (drones, missiles, etc.). Simultaneous use of old and new technologies.
Turning point	Not reached.

Table 2.5: Fifth generation warfare

2.1.6 Sixth generation warfare

Title	Invisible/intellectual warfare [Dan]
Appearance	9/11 2001
Actors	States and non-state actors
Strategy	Doing such that one side doesn't know who it is fighting against, or even better, ignores that there ever was a war.
Method of fighting	Cells-to-states, cells-to-populations
Technologies	All technologies and the new possible combinations of these technologies
Turning point	Not reached.

Table 2.6: Sixth generation warfare

The evolution of technologies support a complete shift of paradigm of the conflicts as presented in Table 2.7. It does not mean that these conflicts will happen using the latest technologies, but they will be most probably supported and enabled by them (social media, satellite phone, etc.)

Traditional Conflict Paradigm	New Conflict Paradigm
Specific moment and place *Encounter on a battlefield*	Enlargement of the spatial dimension *Geographical indeterminacy of theatre of operations*
Sharply-etched sequential timeframe *Recognizable beginning and end of engagement*	Transformation of the temporal element *Simultaneous multiplicity of points of interaction; Concurrent acceleration and deceleration of engagement*
Well-defined actors *Soldiers (as state agents), civilians*	Mutation of the belligerents' identity *Obliteration of combatant/civilian categories*
Armies attacking armies *Military targets, siege warfare, proportionality*	Expansion of the nature of targets *Increasing blending of civilian and military targets*
Traditional weaponry *Targeted use of kinetic force*	Systematization of asymmetrical warfare *Amplification of the platform of combat; Weaponization of civilian assets*

Table 2.7: The evolution of the conflict paradigm after 9/11, [Moh05]

2.2 Why adopting new technologies?

The principle of adopting new technologies in modern warfare has always consisted in a temporary **advantage** for the one owning it. Technology alone, being either civilian or military, is not enough, but the evolution of the different generations of warfare, showed that it is an important driver and enabler. As the pace of technological development is growing exponentially, in order to maintain a strategic advantage, it is indispensable to stay ahead of the curve.
It is however very important to mention that technology alone is not enough. A purely technological approach is misleading because strategy is about the way you use technology: so investments in human factor and innovation in doctrine are key.

The adoption of new technologies is also seen as necessary to deny the adversary a unilateral military advantage. Since the creation of nuclear weapons, the potential use of such weapons being so devastating, the strategical purpose of owning such technology is for the **non-use** of the force. This can seem a paradox given the very essential purpose of the development of a technology.

2.3 Future military technology landscape

The approach considered here to anticipate the future military technology landscape is to understand the main trends and desires leading to the development of new technologies before presenting the different technologies themselves. As addressed in Section 2.1, there is an evolution in warfare supported by technologies. The future developments can be associated with the four following trends presented in table 2.8.

Putting the four trends into the context of the OODA loop (Observe-Orient-Decide-Act), Figure 2.1, we realize that the future military technology landscape contributes to the optimization of every part of the loop as well as its whole. This takes place at different levels; from improving

Speed	Speed is increasing and it is facilitated by developments in areas from mobility to computing.
Awareness & Connectivity	Awareness about multiple elements such as location, physical indicators, situation, is available anywhere at anytime thanks to communication and connected sensors.
Precision	From observation to action, sensors and processing power are enabling stochastic model to guide ammunitions better or to validate decisions.
Distance	Distance is not an issue anymore as systems can be operated remotely from the theatre of operations.

Table 2.8: The four main trends that will affect the future of warfare

the reliability of the information to the complete automation of the decision process. The value of the OODA loop is that it captured the essence of the decisional process and applies it to all the hierarchy of the armed forces; from the individual soldier facing life-threatening situations, to the general strategically leading the army. It is believe that the actor who could go through all the 4 phases (and not only the last one) as quick as possible will gain superiority and ultimately win a direct confrontation.
Under OODA loop theory every combatant observes the situation, orients himself, decides what to do and then does it. If his opponent can do this faster, however, his own actions become outdated and disconnected to the true situation, and his opponent's advantage increases geometrically. - John Boyd
The following sub-sections will try to showcase the different technology trends affecting each phase of the process. Note that the OODA is applied to the technology foresight process itself.

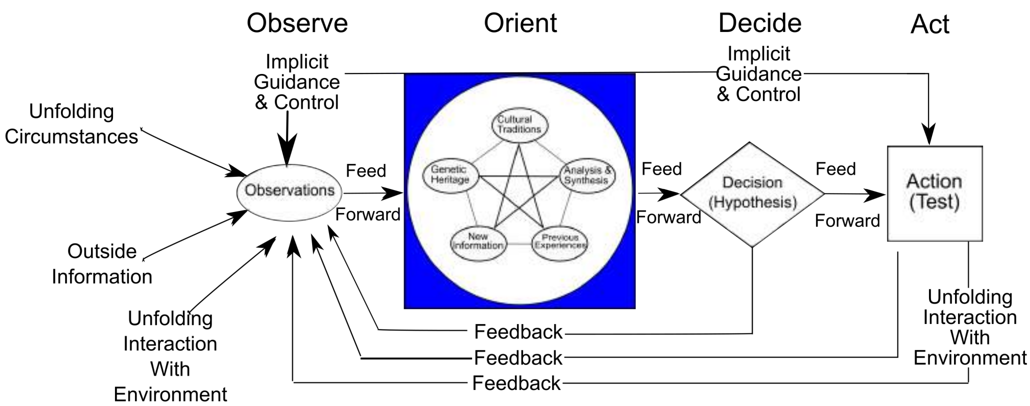


Figure 2.1: Diagram of a decision cycle known as the OODA loop (or commonly called also the Boyd cycle).
Note how orientation shapes observation, shapes decision, shapes action and in turn is shaped by other phenomena coming into our sensing or observing window.
Also note how the entire loop (not just orientation) is an ongoing many-sided implicit cross-referencing process of projection, empathy, correlation and rejection. [Boy95]

2.4 OODA - Observe

Foresight	Continuous and ubiquitous observation is made possible by a diversity of interconnected sensors operating in all the environments: sea, land, air and space. Simultaneous access to micro/detailed and macro/broad scale information is available for all type of assets (individual, environmental, contextual, political, etc.). Behaviors and patterns of physical and digital activities are available as well as the measurements of all substances of interest (chemical, biological, etc). Reliable and secure connectivity becomes a key component to maintain up-to-date situational awareness superiority. Global awareness is reached in the visible, in the measurable and in the detectable providing the necessary input for anticipation.
Speed	Time between the occurrence and the acknowledgement of an event is almost immediate.
Awareness & Connectivity	Numerous sources of different forms of information (written, vocal, images, measurable, etc.) are merged together to provide synthetic reliable content. The information is made available immediately to all interested parties, independently of their location.
Precision	From smart dust to satellites, the variety of available sensors allows a tailoring of the collected information serving the exact purpose of the needs.
Distance	The notion of physical distance is replaced here by the accessibility to the original observation/data.

Technology Trends in situation

Generated by a multitude of distributed connected sensors in/on sea, land, air and space, signals coming from detectors of different natures (labs on the chip) are processed in real-time and merged to allow a continuous flow of analysis on desired topics. On-board processing allows image, video and voice recognition directly on the sensors, which powered by self-rechargeable batteries offer autonomy to the sensor. The status of all entities such as humans (quantified self), systems, environments and processes are continuously known and monitored. Advances in observation also challenge any new stealth strategy and friend-foe identification.

Secured high-volume wireless communication enables permanent access to a growing volume of data from everywhere. Cyber security concern is growing as the access to and the reliability of the data as well as its source is paramount. Big data analysis and visualization provide the necessary support to create synthetic information and meaning out of the noise.

Semantic analysis, automatic translator and artificial intelligence applied to human interactions, from social networks to face-to-face communication, offer a better understanding and interaction capabilities between actors of different natures, origins or traditions.

The convergence of all the progresses in the different fields leads towards a more unbiased *mental model* of the reality, as changes are immediately reflected in the observations.

Related technology clusters

- Cognitive Umwelt
- Communication
- Computation
- Cyber Security
- Energy Storage
- Medical Sensors
- Monitoring
- Social

2.5 OODA - Orient

Foresight	Prevalence of data fusion and statistics to present the information and help make sense of the situation in an objective way. Direct access to world-wide knowledge in every field and previous experiences allows the validation of the assumptions and the creation of possible scenarios. The representation of the information is intuitive and where necessary integrated within a virtual environment superposed to the reality.
Speed	Intuitive representation of the information help people understand the situation more quickly and therefore minimizes the delay between the observation and its interpretation. Adaptability is improved.
Awareness & Connectivity	The fusion of previous experiences and all relevant sources of information helps building a reliable representation of the situation.
Precision	Subjective interpretations are minimized leading to a more precise assessment of the situation.
Distance/Reach	All the necessary information to proceed to the decision is delivered to the person independently of the location of this person.

Technology Trends in situation

The continuous improvement in processing power makes possible the computation of important quantity of data, Big Data. Big data visualization and analytics allows to observe trends that the human brain cannot process because of the complexity of the data. It also enables artificial intelligence (AI) to provide the analyses, anticipation and prediction of situation via possible futures and to suggest consequence-aware actions. Most of the time, considering the numerous parameters being taken into account, computational models will influence the mental model of the situation.

Augmented and virtual realities facilitate the understanding and representation of the situation. The orientation can happen directly where the observation or the action takes place even if the integration process of all various sources of information occurs elsewhere. People on the field for example are equipped with systems and displays on which synthesized information supporting the decision process appears. Man-machine interface is improved to access digital information directly. The feedback loop with the observations is shortened and new orientation, even complex ones, can happen instantaneously.

Information and knowledge are not the privileges of commanders anymore (Internet, social media, experts, etc.).

Related technology clusters

- BioMechanical Engineering
- Computation
- Networked
- Robotics
- Simulations
- Interfaces

2.6 OODA - Decide

Foresight	Decisions are supported and suggested by statistics and artificial representations. The different alternatives as well as their respective consequences are presented and the one optimizing the defined criteria is selected. In some situations, decisions are not taken by humans anymore.
Speed	Assisted (suggested) decisions are the results of algorithmic models coming directly out of the orient phase.
Awareness & Connectivity	Decisions are taken after simulation and assessment of their consequences.
Precision	The decision is considered as the most appropriate choice between multiple alternatives (ideally).
Distance/Reach	As decisions are supported by machines there is a distance in the feeling of accountability for an action.

Technology trends in situation

Because of the evolution of weapons performing at increasing speeds, decisions need to be taken always more quickly, while considering always more elements. As a consequence, suggested decisions resulting from computed scenarios and optimization functions open the way to autonomy and man out-of-the-loop systems.
A major challenge that will be faced because of the importance played by Artificial Intelligence in the future is the diffusion of decision-making towards non-human entities.

Related technology clusters

- Robotics
- Networked
- Social
- BioMechanical Engineering
- Computation
- Interfaces

2.7 OODA - Act

Foresight	Possible actions are tested simultaneously and the one offering the most satisfactory outcome is selected. The actors might be systems operating or being operated remotely with a human in-, on- or out-of-the-loop. The actors, humans and machines, are tailored and optimized for the requested actions.
Speed	Actions might happen with such a high pace that it will leave the adversary caught off guards.
Awareness & Connectivity	Simulation makes preparation and training possible for an action. People on and off the the battlefield are permanently connected improving collaboration between squad-members. Consequences of actions are directly observable, providing feedback to the first phase of the sequence.
Precision	Actions focus on selected targets only, minimizing co-lateral damages.
Distance/Reach	Actions can be performed remotely.

Technology Trends in situation

Actions in 5th and 6th generation warfare will be achieved by a variety of entities including humans, machines, programs and a combination of all of those. Interactions between humans and machines is omnipresent.

Soldiers are more and more confronted with their physical and physiological limitations. This is why the trend is to reduce their human necessities (such as eating, drinking, sleeping, pain feeling, etc.) via drugs and/or training while augmenting and enhancing their machine-like skills by the intermediary of sensors (augmented reality googles, night-vision, exoskeletons, etc.).

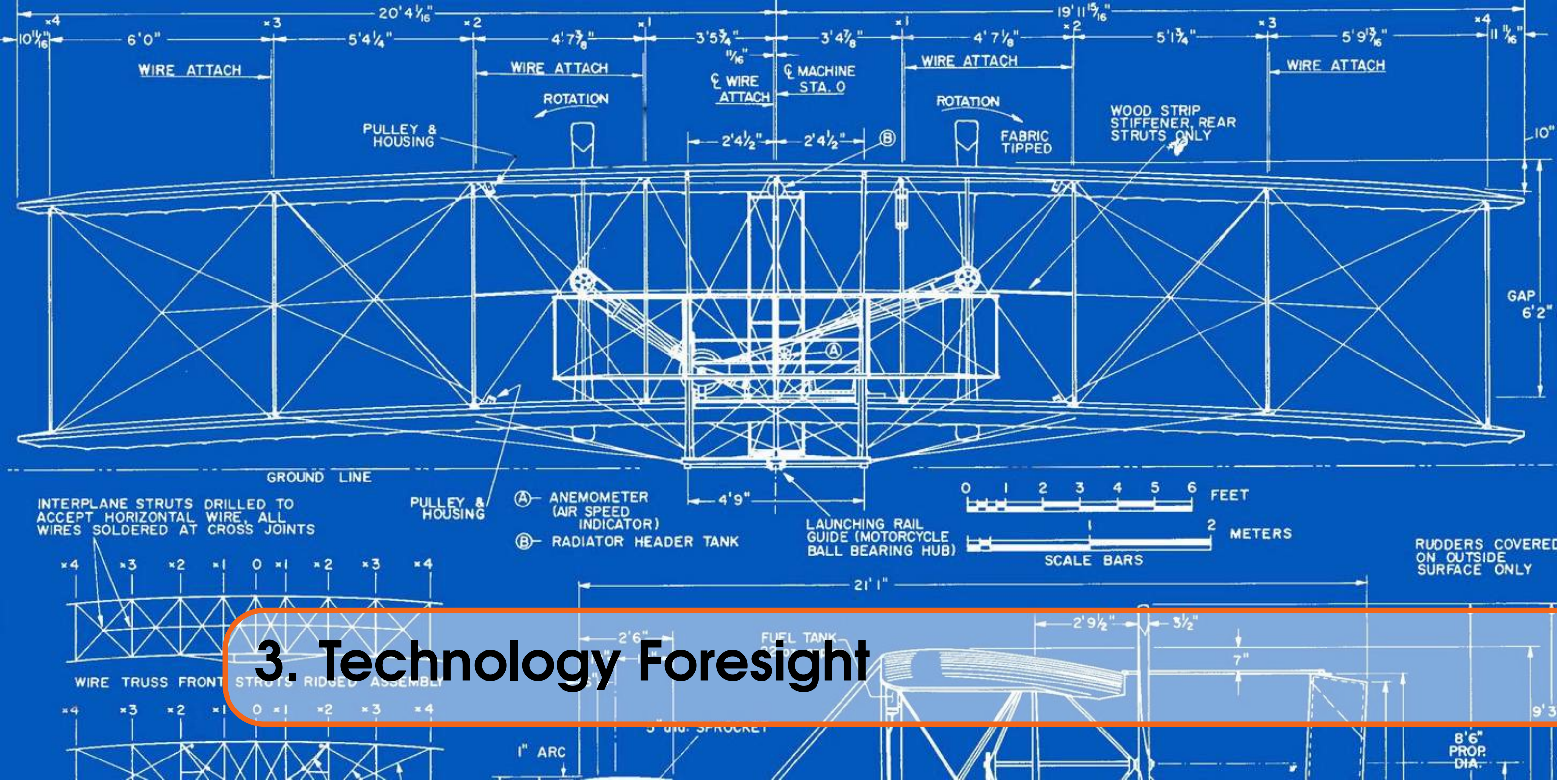
Remotely piloted, semi- and autonomous systems, hypersonic guided missiles build a growing distance between actors.

Developments in nanotechnologies, genomics and synthetic biology might also contribute to the selective targeting of individuals or group of individuals offering certain particularities. Doing so can be performed by using vectors that are easy to build, hard to monitor and almost immediately obsolete after use. Normally requiring well-equipped laboratories and skilled researchers, off-the-shelf kits will make the tools of genetic engineering accessible to many, elevating concerns on the biodefence front [DAR15].

Related technology clusters

- BioMechanical Engineering
- Biological
- Biotechnology
- Cyber Security
- Energy Propulsion
- Logistics
- Reactive Materials
- Robotics
- Weapons

As we can anticipate from the 5th and 6th generation warfare, civilian and dual-use technologies will play more and more an important role in asymmetrical conflicts involving non-state actors. An overview of these technologies and why they are relevant to military activities is presented in the following chapter.



3. Technology Foresight

As nicely stated by Alex Churchill, UK Defence Science & Technology Deputy Head Strategy, technology foresight is more about *identifying the relevant races* that defence and security organisations must address, *rather than picking the winners.* Adding to the complexity, the diversity and pace of the developments in civil technologies that may have an impact on military applications is growing rapidly and cannot be ignored. Furthermore, all the developments in the different areas happen almost simultaneously, therefore the results in one domain can quickly influence the progresses in one other domain. Figure 3.1 presents an overview of the identified relevant technologies field for the United Kingdom [PHB13].

Structuring the overview of the technology trends, the compatibility of the information with other studies and the evolution of its content plead for the adoption of the classification in 5 main domains adapted from the BRINES American National Defense University [Toc14]: Energy & Resources, Information & Communication, Nanotechnology and Materials, Life Sciences, and Systems.

3.1 Energy & Resources

Energy security is paramount and the intrinsic condition for all military operations. Security will come from interdependence that could be pursued in four strands:

1. Energy efficiency
2. Diversity of supply
3. Development of supply/demand partnership
4. Increasing renewable supplies

The enormous amount of energy used by the military means that efficiency, in and of itself, will have a very short payback period. From an operational point of view, energy lines of communication are vulnerable and expensive to maintain so shifting focus from supply side to demand side is logical from both fiscal and operational perspective.

Illustration: Wright Brothers - Measured drawings of the 1903 Wright Flyer, Plate 2

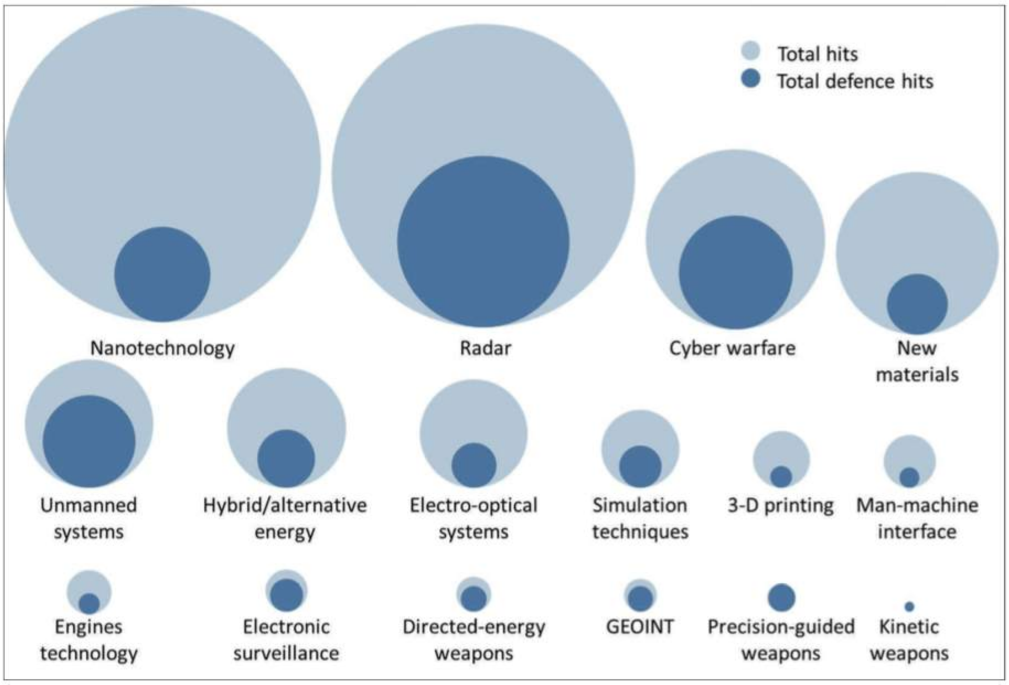


Figure 3.1: 16 emerging cross-sector technologies with particular relevance for defence; The total publication activity by technology area and the split between overall hits and defence-specific hits is presented.

3.1.1 Efficiency

The capacity for being fast and efficient can mean success or failure in the field. With more resources requiring electricity to operate escalating demands should be quelled. Acquiring energy, transmitting energy, and effectively using energy gives an edge in deployed assets for their ability to remain self-sufficient and reduce expenditures on unnecessary losses.

Trends

- E-Mili
- Energy Intelligent Buildings
- Fast Charging Batteries
- Portable solar
- Ultra-Efficient Solar Power

Applications

Advancements in the length of asset deployments and working capacities for these assets is growing. The capability to use energy in the field leads to extended uses of current, possibly energy conservative, technologies.

Military Relevance

The enormous amount of energy used by the military means that efficiency, in and of itself, will have a very short payback period. From an operational point of view, energy lines of communication are vulnerable and expensive to maintain so shifting focus from supply side to demand side is logical from both fiscal and operational perspective. More efficient and diversified means of generating energy will increase resilience within the network as individual islands would not be caught up within cascading failures and would be harder to target. Transport of the energy over long distance will also be minimized.

3.1.2 Management

Currently energy infrastructure is experiencing vulnerability due to its highly localized and outdated methodologies. The systems are vulnerable to cyber-penetration attacks and system fluctuations. As the global energy demands rises, so does the need for dynamic and effective energy management solutions.

Trends

- Distributed power generation
- First-generation smart grid
- Long-range wireless charging
- Small modular nuclear reactors
- Smart energy network
- Smart wind and solar power
- Supergrids

Applications

Defense against new threats towards civilian energy infrastructure. Dynamic deployment of energy supplies to assets. Awareness of emerging weaknesses and threats.

Military Relevance

Having the capability to create and connect to heterogeneous electricity grid networks benefits the flexible deployment and the repair of damaged grids. Smart energy management is important at any level and for any type of devices. Being able to remotely provide power to elements could support advances in man-operated and autonomous systems.

3.1.3 Propulsion

Moving assets from one location to another is a vital component in any operation; whether it's for surveillance, reconnaissance or for deployment. Advancements in other energy areas can lead to sudden improvements in this sector.

Trends

- Electric vehicles
- EM Drive
- Pulse detonation engine
- Solar sail

Applications

Transportation, Travel, Surveillance, Exploration.

Military Relevance

The focus on speed and endurance has a direct influence on maneuverability, but also on the generation of noise, pollution and heat. New vehicles and assets may develop new stealth capabilities being more silent and with less heat signatures. High speed capabilities might also decrease reaction time and make some defense systems obsolete. Consequently, the adoption of a certain type of propulsion could completely modify the military logistics and supply chain.

3.1.4 Storage

Energy storage and transport has had very little innovation for quite some time; this opportunity has been recognized by large commercial players as well as research institutes. Renewed interest has spurred innovation and incentives for transforming the sector. Recent developments show large promise for noticeable increases in performance.

Trends

- Air and water fuel
- Artificial photosynthesis
- Biological Batteries
- Hydrogen Energy
- Lithium-air batteries
- Printed batteries
- Second-generation biofuels
- Solid State Batteries
- Wearable batteries
- Zinc Poly

Applications

Infrastructure; asset deployment; remote systems; batteries; portable power; fuels.

Military Relevance

Improving energy storage on the soldier can highly reduce the weight and the necessary logistics to operate modern warfare equipments. As energy storage is vital for autonomous systems to operate, any reduction in weight will improve the duration of their mission.

3.1.5 Transformation

The energy transformation ecosystem is growing into a more diversified pool of technological advancements as more and more elements are potential generator of energy.

Trends

- Airborne Wind Energy Systems
- Fusion
- Low Energy Nuclear Reactions (LENR)
- Micro nuclear reactors
- Perovskite-based Solar Cells
- Piezoelectric power
- Sewage
- Solar Panel Windows
- Tidal Power
- Transparent Photovoltaic Glass

Applications

Dual-use infrastructure, Asset supply, Independent power generators.

Military Relevance

More efficient and diversified means of generating energy increase the resilience within the network and the possibility of creating local grids. Independent and mobile power generators would be more difficult to target. The transport of the energy over long distance can also be minimized.

3.2 Information & Communication

The volume and diversity of information shared every day around the globe, by wire or over the air; the apparition of new ways of performing tasks, of representing global and individual, real, virtual and augmented reality (or realities!) are supported by the combination of enabling technologies. They have already changed our everyday lives and will completely change military operations.

3.2.1 Communications

Bottlenecks in communicative infrastructures can cause catastrophic failures. Data is growing exponentially; and, it must be transmitted between multitudes of new devices. There are several methods being explored and built to handle the new loads.

Trends

- 5G mobile network
- Aerial wireless network
- Cloud communications
- Faster Internet
- Hidden / DarkNet / Deep Web
- Laser communications
- Software-Defined Radio (SDR)

Applications

Everything to Everything communication, Transport, Logistics, Simulated Environments, Information

Military Relevance

Military Command and Control (C2) will use space-based system coupled with meshed networks systems to support deployed operations and allow data exchange in austere environments wherein units will join ad hoc networks built upon the devices belonging to the friendly forces. Mobile communication devices (MCD) will share intelligence, translate languages, provide navigation, targeting data and blue force position while maintaining visual contact with the surrounding environment.

3.2.2 Computation

Computational abilities are affected by several underlying technologies and innovations; and, is one of the largest sectors in the market. The implications for breakthroughs can mean drastic shifts in short amounts of time. Moore's Law continues to be relevant.

Trends

- 3D Holographic Data Storage
- 3D Memory Chips
- Context-aware computing
- Memristor
- Quantum computing
- Speckled Computing

Applications

Design, Logistics, Pattern Recognition, Scenario Modeling, Real Time Intelligence

Military Relevance

The importance of computational speed is paramount for military systems as it must allow to go through the OODA loop quicker than the opponent. Computational speed is also the enabler or the prohibitor for various applications such as Big Data analysis and cryptography.

3.2.3 Internet of Things

Combining sensor technology with increased efficiencies is allowing for an explosion of new information available for monitoring and interacting with. From infrastructural and machine parts, to innumerable real world contexts like pedestrian flow to anything you might be holding right now.

Trends

- Big Data
- Smart Dust
- Ubiquitous Computing
- Wifi for things

Applications

Monitoring and Interacting with Everything

Military Relevance

The Internet of Things and its "connected everything" offers direct inputs and feedback opportunities to the OODA loop. Inventory and logistics can be optimized thanks to traceability as already performed in the commercial industry. Friend-foe identification, perimeter access control, presence of explosive and hazardous gases are examples of applications that IoT will facilitate. Coping with Big Data, fusing all the information will provide a zoomable, multi-scale quantitative representation of the battlefield.

3.2.4 Cyber Security

Cybersecurity protocols must be implemented by hand, and diagnosed with teams; giant leaps are being made in algorithmic modeling in several applicable areas from genomics to auto-deploy machine learning attack and defense systems.

Trends

- BioAuthentication
- Computer Vision
- Cyber hardening
- Deep learning
- Infrastructure Security
- Machine Learning
- Risk Analysis & Decision Making
- Self-configuring/healing/optimizing/etc

Applications

Defense, Infrastructure, Data, Intellectual Property, Private Information, Operational Controls, Authentication

Military Relevance

Considering cyber attack (and not only), the overall security of any network is only as strong as the weakest link connected to it. Given the importance of communication (voice & data) in the military applications of tomorrow, centralized network management systems will not be able to cope with the new challenges. To enhance capability, dynamic planning mechanisms based on artificial intelligence and learning systems will assist in the pro-active provision of service delivery at the right time, at the right place. Systems that will have enhanced self-diagnosis/self-adaptive/healing platforms and network capabilities will be developed.

3.2.5 Interfaces

Interfaces increase the speed and effective manipulation of digital tools for more depth of control. Creating a connection with a person through a captured medium, creating new real spaces and interlaying new information through the senses.

Trends

- Annotated-reality Glasses
- Augmented Reality
- Gesture Based Interactions
- Holographic technologies
- Immersive Spatial Interfaces
- Metaverse
- Virtual Reality Accessories
- Wearable Computing

Applications

Data Input, Information Delivery, Strategic Support, Training

Military Relevance

Military systems will provide continuously updated status and holistic knowledge bases to the soldiers in the field. As more and more information is available, the five senses will be used to interpret it and to interact with it. Interfaces directly connected to the brain will allow to blend information and reality together while simultaneously enhancing man-machine interface and speed.

3.2.6 Simulations

Understanding the human form to greater degrees allows for faster information delivery and uptake by individuals; resulting in better training and conditioning programs taking less time with more effective results through the use of feedback simulations and new haptic technologies.

Trends

- Biofeedback Video Game
- Holoroom
- Immersive Virtual Reality

Applications

HR, Recuitment, Troop Training, Education, Scenarios, Design

Military Relevance

By having access in real time to risk analysis, advanced simulation outcome and subject matter expertise, artificial intelligence will transform the decision-making process on the battlefield by making prediction and bringing the entire military wisdom and lessons learned to the soldier in mission. Simulations also offer lower training costs and the exposure to mission critical scenarios.

3.2.7 Social Crowd

Gathering information has always been subject to a certain cost and availability. Individuals' abilities to connect and coordinate with large groups revolutionize how quickly ideologies can be spread and actions instigated. The ability to monitor social sentiments has never been so expansive or so inexpensive; and, neither has the ability to manipulate emotions and perspectives.

Trends

- Biohacking
- Emotion Tracking
- Empathic Things
- Quantified self

Applications

Sentiment Monitoring, Social Influence, Decision Herding

Military Relevance

Analytical tools that visualize and fuse data from different sources will interpret data and search for patterns. These algorithms will monitor the battlefields and autonomously move supplies and forces based on demand indicators and signals received and computed from the battlefield. The openness of information brings visibility and will make military leaders to be more accountable for their actions. The military will need to be adaptive to these issues in its recruiting, training and operations.

3.2.8 Monitoring

From the hunting plains of the desert thousands of years ago to the ability to scan uncountable numbers of images digitally, and search through semantic contexts, modern day monitoring systems have transformed our basic abilities to see and notice things into very large-scale acquisition through innumerable means. Surveillance and monitoring provides invaluable information to strategic decisions.

Trends

- Environment Mapping
- Microelectromechanical Systems (MEMS)
- Sequentially Timed All-optical Mapping Photography (STAMP)
- Video & Image Recognition

Applications

Surveillance, Movements, Threat Detections, Opportunity Finding

Military Relevance

Continuous real-time monitoring from Earth and Space is the ultimate goal allowing an up-to-date situational awareness picture of the battlefield. Monitoring is key for all information services as well as the necessary enabler for future autonomous systems.

3.3 Life Sciences

Rapid advances primarily driven by commercial research and applications have made biotechnology and genetic engineering able to alter genes and combine them with one another. Human enhancements, going from external systems such as exoskeletons to cognition enhancers that increase the performance of the human brain, aim at producing more robust and enduring soldiers. The soldiers' health will be permanently monitored and their capabilities improved.

3.3.1 BioMechanical Engineering

The technologies in this cluster center around the synthesis of mechanical engineering and knowledge of biological function, with the intent to yield an increase in efficiency in the areas where the two overlap. From the increasing efficacy of prosthetics and exoskeletal wearables, to tools, vehicles and weapons that are easier and more efficient to operate, Biomechanical Engineering is making its way into every facet of human life.

Trends

- 3D Printed / Advanced Prosthetics
- Bionic implants
- Powered Exosuits
- Pulse Oximetry (Blood O2)

Applications

Imaging, Skeletal Motion Mechanics, Cardiovascular, Soft Tissue, Cell,

Military Relevance

The integration of prosthetics and digital equipment with the human body, growth of replacement organs and other human enhancements will increase the ability of soldiers to act on the battlefield with greater resilience, speed, reaction and endurance. Recruitment process and parameters might evolve as capabilities can be adapted and tailored for individuals. What happens with the *enhancements* when the soldiers retire from the military forces?

3.3.2 Cognitive & Umwelt Sensing

One of the easiest things to take for granted are the senses we use on a daily basis to interpret the surroundings we live in. Brain mapping technologies and new understandings in neuro cognition have opened vast new fields in breaking the human experience out past the natural physical limitations into new realms of discovery and experience. Allowing for new ways to, directly, integrate information into, and control external devices with, the brain.

Trends

- Biologically Extended Senses
- Brain Computer Interface
- Brain Mapping
- EEG Brain Recording
- Human Sense Hacking
- NeuroProsthetics
- Nootropics
- Ocular Resampling
- TransCranial Direct Stimulation

Applications

Cognitive Modeling, Brain Interaction, Extension of Senses, Extension of Control, New Methods for Experiencing 'new realities'.

Military Relevance

Cognition enhancers that increase the performance for the human brain, such as improving short-term memory, increasing speed of thought and reducing fear, will become available. The ability to read someone's mind could prove very useful in many aspects of training and operations as well as for a better interaction between the different team/squad members.

3.3.3 Biotechnology

The Biotechnology cluster is home to technologies that seek to alter genetic structures, either to improve or harm an organism. Advances in computing resources and algorithm design lead to applications in immunology for increased resistance as well as biological weapons and genetic therapies capable of rewriting DNA in an existing organism.

Trends

- Genome Editing
- Full Genome Mapping
- Internet of DNA
- Liquid Biopsy
- Prenatal DNA Sequencing
- Scientific Invention of Ideas by A.I.
- Supercharged Photosynthesis
- Synthetic Biology
- Transgenic Organisms

Applications

Interspecies transgenics, Immunology, Gene Therapy, Designer Genes

Military Relevance

For the military, knowledge of specific human genetic defects or vulnerabilities, and of ways to create such defects take on added concern simultaneously to the ability to modify microorganisms or toxins that would increase pathogenicity. Biotechnology theoretically provides opportunities for adversaries to modify existing organisms with specific characteristics, such as increased virulence, infectivity or stability. There is the hidden scope to target individuals or specific group of people sharing similar genetic characteristics.
Modern advances also allow for the inexpensive production of large quantities of replicating microorganisms for weaponization through recombinant methodologies, and the possibility to create new agents for future warfare that bypass current preventive or therapeutic interventions. Naturally occurring infectious agents could be used to generate epidemics among susceptible troops. This could lead to confusing disease situations on the battlefield as environmental detectors may not necessarily be able to differentiate between natural and man-generated contamination. Biological agents can escape detection and can be used to aim for specific genetic targets.

3.3.4 Medical Health

The study and application of Medical Science in order to diagnose, treat or prevent adverse conditions, diseases and injuries. Many new areas and advancements currently in development have made leaps forward in treating some of the most tenacious and devastating ailments known to man.

Trends

- 3D organ printing
- Brain Organoids
- Extrauterine Fetal Incubation
- Genetic Therapy
- Medical Nanobots
- Personalized Medicine
- Robotic surgery

Applications

Vaccines, surgical procedures, epidemiology, diagnostics

Military Relevance

In the area of bio-defence, advances in technologies will allow for more directed and coordinated approaches in the development of vaccines against biological warfare agents and endemic diseases. In parallel, the creation of new biological agents will be made possible. The development of combination vaccines, eliminating the need for multiple vaccinations, is of practical importance for the military.

3.3.5 Networked

Networks can be viewed as a means for individual systems to communicate and function as a collaborative whole. As the efficiency and speed of networks increases, so do the ways, quality and depth in which information passes along them. Diagnostics that were only accessible after medical consultation are now reliably possible on the field.

Trends

- AI Doctor
- Crowdsourced medicine
- Internet of healthy things
- Telehealth
- Universal Medical Repository

Applications

Crowd Sourcing, Universal Medical Knowledge Repository, AI Doctors

Military Relevance

Medical diagnostics can be performed on the field and assessments of situations can be challenged or validated by the wisdom of people having experienced similar situations.
Remote systems coupled with robotic surgery could be used to provide care to wounded soldiers directly in the field, increasing the likelihood that this the treatment would be delivered within the *golden hour* without exposing medical personnel to increased danger.

3.3.6 Sensors

The use of sensors to monitor infantry health while in the field can allow for improved strategic decision making and targeted medical response to realtime situations. Sensors may also serve to detect infection; allowing for rapid containment and minimization of effects of harmful agents. Monitoring blood chemistry levels of infantry allows insight into many performance dependant factors, like stress and energy levels.

Trends

- Auditory
- BioMetrics
- Cosmetic Stickers
- Ingestible Sensors
- Labs-On-Chips
- Molecular Sensor

Applications

Unit Health, Cardiovascular, Motion, Chemical, Neuro / Hormone, Biological Agent Detection, Discovery & Research, Troop & Resource Monitoring

Military Relevance

The use of sensors to monitor soldier health while in the field can allow for improved strategic decision making and targeted medical response to realtime situations. Sensors may also serve to detect infection; allowing for rapid containment and minimization of effects of harmful agents. Monitoring blood chemistry levels of infantry allows insight into many performance dependent factors, like stress and energy levels.
Biometrics technologies allowing identifications or people will be particularly important in military operations in highly populated areas to have a mechanism to catalog and track information about residents. This will also be the future of friend-foe identification.

3.3.7 Social

Social analytics allow for the widespread analysis and influence of population sentiments. Understanding emotional consensus of a group opens the door to not only accurate identification of emotional perspectives surrounding topics, but also the ability to steer the perceptions and opinions of a population in order to, for example, create or quell unrest.

Trends

- Brain-to-Brain Interface
- Emotion Hacking
- Human-Robots Relationship
- NeuroInfluencer
- Personalized Predictive Analytics
- Predictive crime prevention
- Propaganda Advancement

Applications

Propaganda, advertising, sentiment manipulation, perception monitoring, target tracking.

Military Relevance

Anticipating and/or suggesting intentions and motions of the adversary is an obvious advantage for the actor mastering it. Having predictive models implemented in robots may facilitate the interaction not only between machines and militaries, but also between machines and civilians.

3.4 Nanotechnology and Material Science

Fabrication of structures at the nano scale will enable manufacturing of lighter, stronger, more reliable, lower cost, higher performance and more flexible electronic, magnetic, optical and mechanical devices.

3.4.1 Base Compound

Ongoing research in compounds has led to interesting discoveries in molecular synthetics with properties that exceed any conventional and traditional 'structures' by far. As there are more and more fields of research and new-comers to the fields, expect that the influx and cross connections of ideas will spur chaos, in turn revealing previously unknown potential properties.

Trends

- 3D Printed Materials
- Aerogel
- Carbon Nanotube
- Carbyne
- Graphene
- Metamaterials & Dynamic Camouflage

Applications

Computing, Infrastructure & Construction, Armor, Biology, Weapons, Chemistry,

Military Relevance

Compound construction using molecular building blocks provides enhanced property attributes like strength, weight, and conductivity; compared to existing methodologies, superiority in adoption should be expected.
While conceptual technologies may be around for quite some time, even decades, before they converge with other notions for an accelerating effect on operational friction reduction, we could call them *Dormant Multipliers*, an example of this is JIT, Just-In-Time, manufacturing with the emerging diffusion of distributed, compact, additive manufacturing. The observed direction with this field indicates fewer requirements to maintain inventories of spare parts; as, only a stock of material and a 3D design to print *on demand* are necessary [Pao+15].
At the same time, this also includes the potential opportunities and threats of *sharing* the designs of weapons including, for example, items such as triggers or fuses for Improvised Explosives Devices (IEDs) or even the actual IEDs themselves.

3.4.2 Biological

Nano & micro scale applications of technology are integrating bio-compatibility; allowing for highly specific and targeted uses. This ranges from new methods for fighting viruses by passing through the Blood Brain Barrier, protein based molecular machines, to bacteria resistant surfaces. Threats and opportunities could arise overnight.

Trends

- Antimicrobial Nanocoatings
- Nanobiotechnology
- Nano Food
- Nanotechnology Cosmetics
- Vector Control

Applications

Viral, Health Recovery & Maintenance, Strength & Endurance Conditioning, Immunoresistance, Defect Reversal

Military Relevance

Applications range from the utilization of inherent, natural, properties of nucleic acids to create and manipulate larger scaled structures; to synthetic nano-agents directed to specific tasks, like tumor removal; nanotechnology in the biological field has many applications. Despite its benefits, it has also important threats. For example, improvements of the human immune system which make it more resistant to viruses; if this is implemented as a threat, it could be manipulated to lower an organism's resistance to pathogens. The generation of taste and odorless substances created with specificity for a desired lethal, or nonlethal, effect that can be transmitted by ambient contact absorption, or inhalation.
Other uses can be seen in protective creams against heat, sun, mosquitoes or used as agent detectors in specific circumstances.

3.4.3 Construct

This cluster contains Nanotechnology focused on building at the particulate scale. Assembly and construction technologies from widespread 3D printing, molecular self-assembly and protein chain alteration to the use of passive and inherent energy properties for macro-scale construction, as well as dynamic infrastructural support.

Trends

- 4D Printing
- Controlled self-assembly
- Microscale 3D Printing
- Nano-Architecture
- Nanofactories

Applications

Computing, Self-Assembly, Shape & Property Change, Construction, Manufacturing, Infrastructure

Military Relevance

Methods and technologies for construction applications have a broad scope; from micro and nano scale replications, to self-assembly, and fourth dimension manufacturing. The ability for manifesting greater controls in respect to real world creation of conceptualized structures have strong potential impacts for a large, unknown, number of different fields and applications. This includes the ability to construct tube structures which would be able to change morphology to aid the transmission of fluids, by calculated expansion and contraction, over long distances; also, increased manufacturing precision advances self-healing properties currently seen with thermo-reactive metals and kinetic absorption.
This cluster's advancements show promise and feasibility in construction of, seemingly, science fiction creations. These *enablers* will give birth to new products or to new generations of products which continue to accelerate the, ever changing, landscape of humanity's horizons.

3.4.4 Devices

New methods and materials are giving rise to micro-scale architectures, which are capable of creating vast improvements to systems of measurement, in packages a fraction of the size of their predecessors.

Trends

- Cathodes Fabricated from Nanomaterials
- Nano ElectroMechanical Systems
- Nanoelectronics
- NanoGenerator

Applications

Biological and Chemical Agent Detection, Information Supply, Data Processing

Military Relevance

The ever increasing capacity for compact design and miniaturization from engineering methodologies and material innovation leads to the ability of comprehensive portable devices. Allowing systems to move from the laboratory onto the field; or even in the pockets of the individuals in deployed units; reducing the time, cost, and associated risk of sample analysis, broadening the spectrum of battlefield situational awareness.
Imagine a chemical spectrography lab which can be carried in a pocket and synced to a super computer, with its data displayed on a wristwatch; alerting to pathogens in the area.

3.4.5 Materials

Creating properties never before seen in nature, as well as the restructuring of existing materials, are among the most exciting prospects in this cluster. Subtopics from metamaterials with optical plasmonic properties to foam metals, are paving the way for lightspeed computing, subatomic microscopes, self assembling structures with increased durability and light weight hull designs.

Trends

- Auxetic Materials
- Biomaterials
- Invisibility Cloaks
- Morphing Materials
- Nano Glass
- Nano Textiles
- Nanocomposite Plastics
- Nanoengineered Copper
- Nanophase Titanium Alloys
- Nanotechnology Solar Cells
- Negative Index Material
- Self-healing Materials
- Superomniphobic Materials

Applications

Structural Design of Vehicles and Buildings, Thermal Resistance, Photo-optics, Radio Communications

Military Relevance

More complex combinations of Base Compounds yield opportunities for new nanomaterials to be fabricated with complex properties. Foam metal alloys show promise for incredible strength and thermo diffusion coupled at a nominal fraction of the normal weight; and, nanoengineered antennas for increased RF capacities, help to exemplify the diverse fields of applications.
New smart materials will also allow the self-adaptation of the equipment and of the systems to their environment and to the specificity of the battlefield (day, night, warm, cold, color, etc.). This will give birth to new stealth strategy.

3.4.6 Reactive

Reactive Nanotechnology provides new ways of thinking about how objects interact with the environment. Thermal, chemical, and other contextual reactive properties can be programmed as composites in deeper layers of substances.

Trends

- Colloid Camouflage
- Designer Carbon
- Green Concrete
- Nano Catalysts
- Nanomaterial-Based Photocatalyst
- Nanoremediation and Water Treatment
- Smart & Interactive Textiles
- Thermo-Bimetals

Applications

Armor & Weapons, Environmental Context Adaptations, Thermal, Photo-reactive, Chemical Sensing, Synthesis

Military Relevance

The ability to create and produce materials with specific and desired properties such as mutations in color, appearance, and strength when exposed to different temperatures, changes in humidity, and photon reactivity lead to novel applications in many fields. The use of reactive nanotechnology has applications in thermite disbursement in heavily armored bunkers; delivered in layered composites to a target's interior. Once this warhead penetrates the last barrier, the alternate reaction releases the nano thermites as a dust into the atmosphere. This stimulus triggers a combustive explosion, which lethality can be increased by magnitudes of 500% compared to non stimulated ones.

3.5 Systems

The combination of the advancements in technologies in the different previous fields allow improvements and birth of various systems having an impact in military operations.

3.5.1 Flight

For the last century the sky has been an expansive playground of imagination and opportunity; NGAD, Next Generation Air Dominance, is still on everyone's mind. From SCRAMJets to UAV's and communications logistics. There is increasing amounts of interest in the field as a whole from commercial capitalization to hobbyist experimenters.

Trends

- Electric Airplanes Recharged by Drones
- High Altitude Platforms
- Hover Bike
- Long Distance UAV
- Pocket Drone
- ReLaunchable Above Atmosphere Transportation
- SCRAMJet

Applications

Transportation, Weapons, Logistics

Military Relevance

The growing reliance on space-borne systems for communications, navigation, intelligence and weather observation could create critical vulnerabilities if these systems were lost. Backwards compatibility to pre-GPS generational equipment, including back-up systems for precise munitions, and retaining core skills in this area will facilitate future regeneration. Alternative use to space, like stratosphere, are being investigated for cost and operational opportunities.
Operating remotely from the air, instead of sending troops on the grounds, might be a strategy for the first phases of future operations.

3.5.2 Logistics

Complicated activities coordinated with consumption requirements as well as delivery modes can be looked at as flow management and ability between any given types of nodes. Logistical systems are the infrastructure which keep everything moving and supported.

Trends

- Autonomous Vehicles
- Deliverbots
- Modular Hardware
- Payload Drones
- Robotic Mule
- Smart Structures
- Intelligent autonomous swarms
- Telepresence Robots
- UAV Supply Delivery
- Vehicle-to-Vehicle Communication

Applications

Support, Maintenance, Delivery, Infrastructure

Military Relevance

Logistics convoys will be using autonomous or remotely piloted vehicles to reduce human casualties and have precise delivery of goods where and when required.
Modularity and exchangeability of hardware parts will facilitate interactions between the different actors within a coalition while simultaneously augmenting the life-time of the systems themselves.
Anticipation and auto-organization of the maintenance of the different assets in the field. Prepositioning of assets which remain in a *silent-state* until its content or function is required. Once activated, they could autonomously navigate to the requested place of operation.
Pack mules will also reduce the equipment burden on individual soldiers.

3.5.3 Robotics

From fully autonomous surgical aides to responsive personal assistants, the Precision Robotics field is advancing through improvements in algorithimic software and sensory equipment that allows for high dexterity, contextually adaptive, robots; able to carry out routine tasks.

Trends

- Advanced Navigation Systems
- Agile Robots
- BioRobotics
- Insect Drones
- Minibuilders
- Personal Robotics
- Robonauts
- Service Robots
- Soft Robotics

Applications

Manufacturing, Assistance, Maintenance, Routine Tasks

Military Relevance

Robots are particularly well suited for surveillance function as they do not get tired and lose concentration.
Robotic systems have the attractive feature that they can be stored indefinitely until they are needed, thus reducing their overall operations, maintenance and other lifecycle costs. This might however not be proven. Deployment times could be significantly reduced as robotic systems could be pre-positioned in various depots around the globe until they are activated and given a mission. Robots aim to be cheaper to manufacture than manned systems and leveraging the growing commercial investment in robots, future opportunities could include consumable robotic systems that are cheap and disposable.
Used within the Explosive Ordnance Disposal (EOD) community, robots allow to detect, identify, access and mitigate hazards from explosives. Autonomous systems might also be engage primarily to secure sensitive infrastructures in areas where the presence of a human would be already suspect per se [Boi15].
Integrating semi-autonomous or fully autonomous system on the battlefield rises however a lot of unknowns as technology is advancing faster than the development of associated policy, legal and ethical considerations. As all possible environments in which autonomous robots could be employed and all possible circumstances in which these robots may find themselves could never be modeled in a laboratory or developed into computer code, developing autonomous systems will not be a simple programming problem. The software programs to support these types of systems will be extremely complex and lead to unforeseen emergent behaviors. This is part of what is termed a *first generation problem* where one will not know what type of mistakes autonomous systems could commit until they have already committed them.
It would not be difficult to imagine many paradoxical situations where robots would come up against contradictory information where even humans would have difficulty making an appropriate decision.
In operations, robotic systems will be unaffected by emotions, adrenaline and stress, and thus less susceptible to conditions that may have driven human soldiers to over or under-react. So there may be more motivation to develop these types of systems. Lastly, the human-robotic interface and team dynamics will have to be carefully examined. How will human soldiers react to monitoring by robotic systems?

3.5.4 Weapons

Anti-matter devices, self guided munitions and electromagnetic rail guns are the tip of the spear when it comes to next generation weapons systems. As advancements in these fields continue, so must the ways we find to defend against them. The Weapons cluster is among the most diverse, as well as hypothetical, with many of the developing categories shockingly futuristic.

Trends

- Antimatter Weapon
- Automatic Target Recognition
- Directed Energy Weapon
- Electrolaser
- Electromagnetic Rail Gun
- Electrothermal-chemical Technology
- Explosive Reactive Armor
- High-altitude Electromagnetic Pulse
- Hypersonic Missiles
- Modular Armor
- NanoEnergetics
- Self-guided bullets
- Sonic Weapons & Long-range Acoustic Devices

Applications

War, Immobilization, Demoralization, Intimidation

Military Relevance

Precision guided munitions will help to perform selective attack with proportionate and adaptable hard-kill effect, while at the same time increasing the lethality and flexibility of use. Increase in speed and changes in the actuators might also make obsolete most of the anti-missile strategies and systems.

Non-Lethal Weapons have two principal roles: anti-personnel (crowd control, incapacitating individuals, area denial, clearing of facilities) and anti-material or infrastructure (area denial, disabling or neutralizing vehicles, vessels aircraft of equipment and electromagnetic devices).

4. Conclusion

The present document highlighted what we pretend to be today the main technological trends that will shape the future of warfare in the coming years. However, the permanent evolution of warfare together with the high development rate of the various civilian and dual-use technologies makes a prediction almost obsolete at the date of its publication. The work of technology **foresight** is therefore **continuous** and the different trends presented here will be regularly updated as well as completed by new trends rising over time.

The increasing developments taking place at the border and the **intersection and convergences** of various technology areas create new opportunities but at the same time rise the awareness on potential security implications of these emerging technologies.
The selected approach starts with the basic sciences and related technologies and projects them into the future to see what synergies and occur and which new capabilities will be possible. At the same time we access the list of future needs for the military capabilities and provide the basis to infer from each what technologies and underlying basic scientific advances would be required.

With accelerating speed of development, we must be aware not only of growing gap between technology and **law**, but also between technology and **ethics**. We do not often benefit from the necessary step back to assess the real opportunities or hidden threats of a technology and this element might reserve some unexpected surprise.

By connecting the various technology **trends** to the Swiss armed forces capabilities as well as to the Swiss **industry**, we believe that this contribution will provide some new information and indicators to stimulate discussions and decisions for the benefit of **national security**.

Illustration: Green plant sprouting from the asphalt of the street

Part Two

5. Methodology

5.1 Introduction

Performing technology foresight at 360° is an intensive and continuous challenge. Fortunately, several military and civilian international organisations are pursuing the same goal. Rather than re-inventing the wheel, we are taking advantage of the different reports to support this research and provide the description of some technologies as well as their maturity. This offers us the opportunity to focus mainly on the organisation of the information, on the importance of the technologies for the military and for the Swiss context in particular.

Technology foresight needs to remain as broad as possible in order to avoid any technology surprise (see Figure 5.1).

The methodology applied to survey the numerous technologies places the scalability at the centre of its challenge as this one should survive major variability in budget and human resources. A graphical representation is displayed in Figure 5.2.

The main steps of the process can be summarized into

1. The **collection** of the information
2. The **storage, classification and representation** of the information
3. The **transmission & dissemination** of the information

5.2 Collection of the information

The collection of the information first goal is to have an overview at 360° of all technologies that can have an impact on warfare. This task is performed by involving different private and governmental entities, which are in charge of detecting the early trends and weak signals in the academy & research community (publications), the industry (patents) and the society (products). To overcome any bias in perception, an effort has been made to get information from entities geographically spread around the world (Figure 5.3) as well as some kind of*crowd sourcing* brain power.

Illustration: Detail of a visualisation realized by Envisioning Ltd

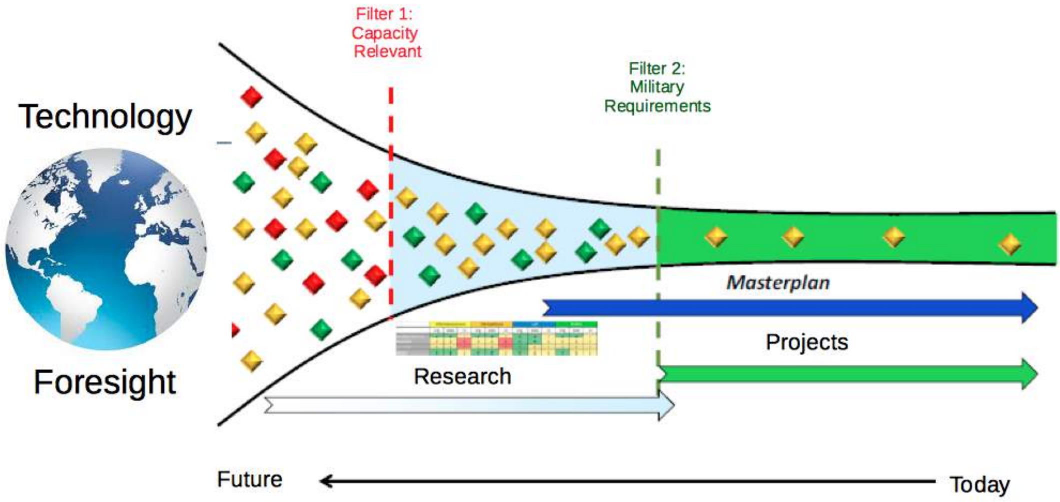


Figure 5.1: From technology foresight to the concrete use of the technology within military project. At the beginning, an inventory of all technologies is necessary to determine their potential use in military applications.

The output is a list of technologies containing structured information that will serve as basis for future deeper investigation according to the needs and interests. As an example, the collection of the information is performed by the company Envisioning Ltd observing the following procedure:

1. Overview
   (a) Scoping
      i. Analysis of existing public resources
      ii. Futures studies
      iii. Books
      iv. Articles
      v. Patents
   (b) Identify experts
      i. Academics
      ii. Engineers
      iii. Journalists / authors
      iv. Founders
      v. Users
2. Experts (Primary research)
   (a) Conduct in-depth interviews with experts in the field
   (b) Identify key technologies used today
   (c) Derive / interpret key technologies being researched in the field
   (d) Develop timeline of possibilities
3. Immersion (Secondary research)
   (a) Look outside boundaries of current research
   (b) Analyse industry / sector for emerging technology initiatives
   (c) Map and tag technology news (Wired, Engadget, Techcrunch)
   (d) Map crowdfunding initiatives (Kickstarter, startup events)
   (e) Map and tag public disclosures of private research & development initiatives
4. Analysis

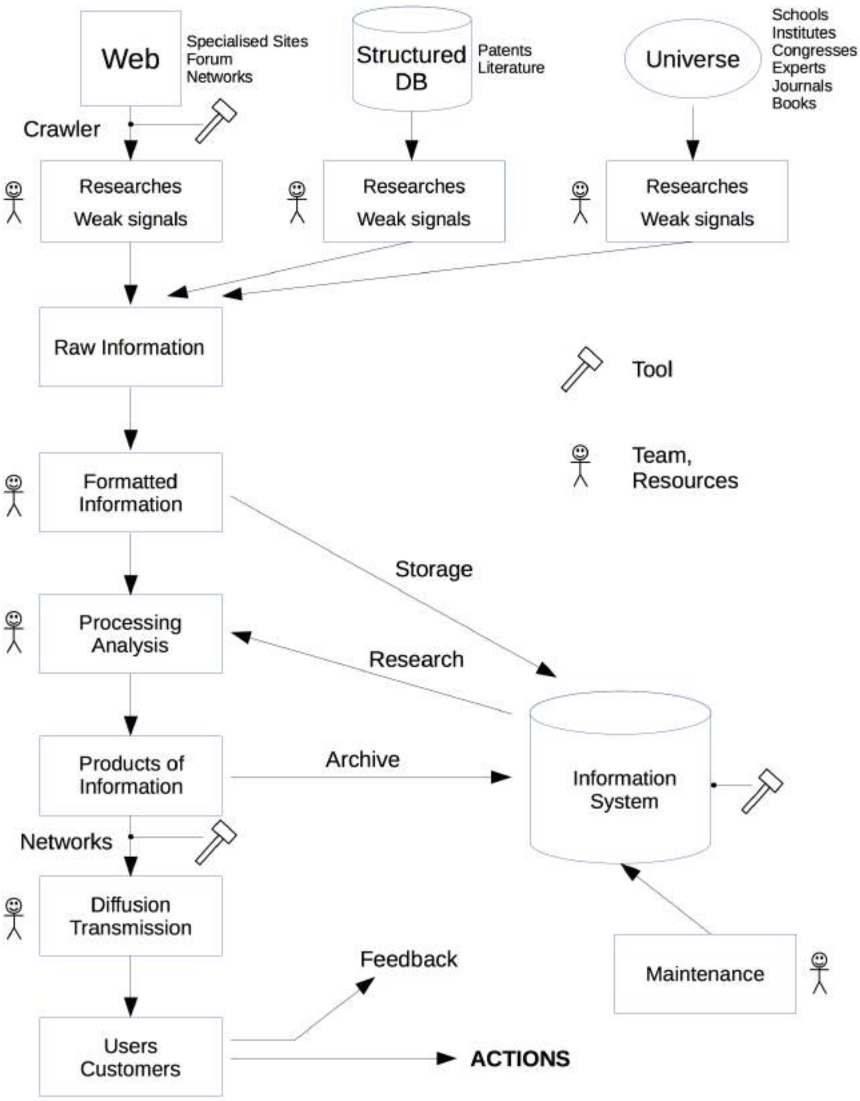


Figure 5.2: Representation of the adopted process for the technology forsesigh, from the monitoring of weak signals to the diffusion of the information and resulting actions.

(a) Identify unique technologies
(b) Describe technologies
(c) Clustering (identify connectivity for macro & micro technologies)
(d) Readiness
(e) Impact

This is of course an on-going activity, which can be performed externally or internally according to the time pressure and the level of information required. In order to ease the comprehension as well as the search through the different documents, the information is structured as much as possible, as input first, as well as in the resulting documents (see chapter 6).

5.3 Platform of Information

To support and assist in the interpretation of the information, it is necessary to have a platform, which main purpose is to

Figure 5.3: Distribution of the Swissnex network around the world - www.swissnex.org

1. **Store** and **index** the information for an optimal **search** including **semantic** analysis.
2. **Enable** a comprehensive **visualisation** of the information (relationships, indicators, etc.).
3. **Generate** outputs for diffusion and support for further actions.

One of the main important added value provided by the platform is also the possibility to connect the technologies with other environments. The link between the technologies and the capacities of the armed forces is possible thanks to the use of a common taxonomy. By discovering which technologies affect which capacities, the importance and relevance of each of them are directly visualisable. Priorities as well as scenarios can be built based on these different correlations. To close the loop, as presented in Figure 5.4, the same taxonomy is also used to classify the national companies with strategical military relevance in the diverse industries (STIB - Sicherheitsrelevante Technologie- und Industriebasis der Schweiz). Given this common language, we are therefore able to answer to strategic questions like:

1. Which technology affects which military capability and is there a Swiss based company active in this field, Figure 5.5?
2. Which present and future military key technologies are not being covered by the national industry?
3. In which technologies will I have to build competences if the capability X is becoming of major importance?

5.4 Readiness

Rather than debating for the most disruptive technology in an area, we have reversed the question. We sequentially consider all the new interesting developments and try to understand how and under which conditions these technologies are emerging, evolutionary, revolutionary or disruptive in a military and civilian environment. The definition of the used terminology is presented here [Toc14].

- **Emerging** Technology is a technology which is not yet commonly perceived in the Defence and Security community and which has the potential to turn out to be evolutionary, revolutionary or disruptive.
- **Evolutionary** Technology is an incrementally developed technology that gradually improves its role in a component, a sub-system or a system without a significant impact on a system

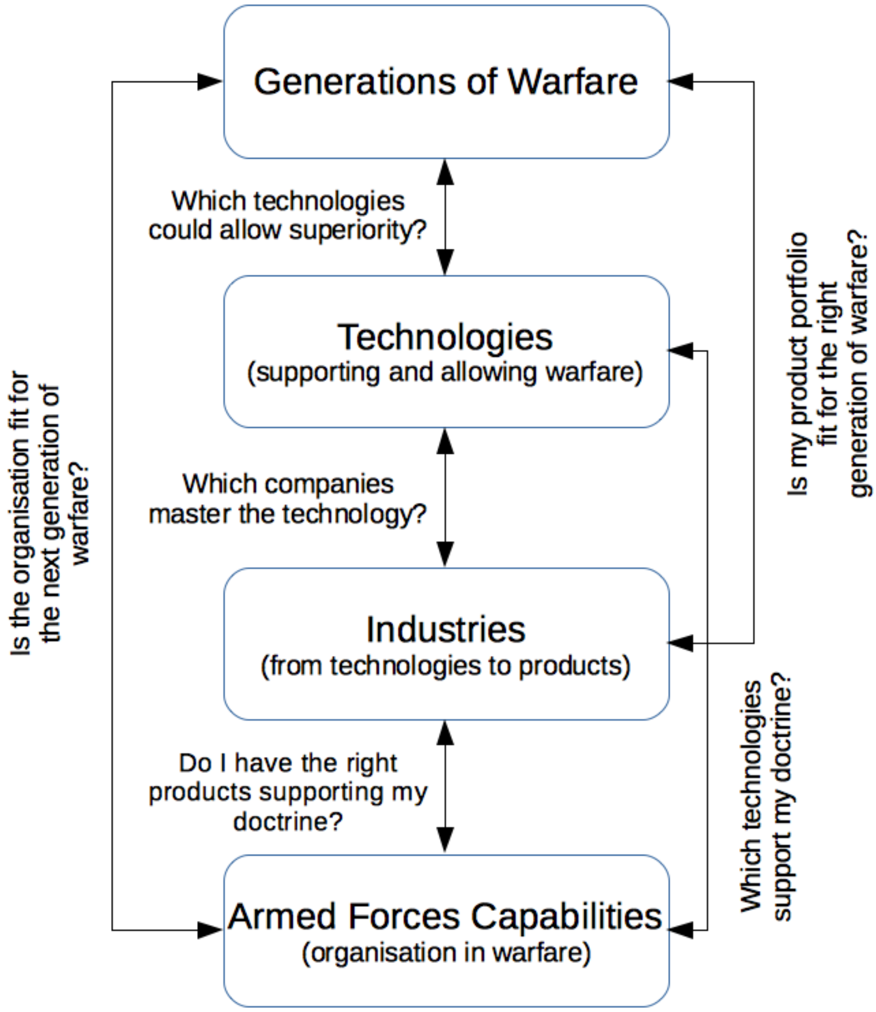


Figure 5.4: Thanks to a common taxonomy, it is possible to build the relationship between the technologies, the industry and the (Swiss) armed forces capabilities.

role.

- **Revolutionary** Technology is a technology that dramatically improves a given role in a component, a sub-system or a system. It increases the technology development cycle rapidly compared to related technologies and/or fills a role in a new market.
- **Disruptive** Technology represents a technological development which has the realistic potential for a qualitative or a very significant quantitative change in non-technical capabilities and thus can cause a qualitative or a very significant quantitative change in the relationships between states, people or persons and markets. It has its disruptive effect on the society within one or two generations and thus has the potential to overstrain the adaptability of human beings and the social system. A technological development which changes the conduct of conflict or the rules of engagement significantly within one or two generations and forces the planning process to adapt and to change the long- term goals, strategies, concepts and plans.

However, rather to decide if one technology belongs to one class or the other without explanation, we believe that a technology profile describes much better its potential as well as the risks it might face. This new methodology for profiling technologies is called **Readiness** and is being developed and validated together with Envisioning Ltd [Za].

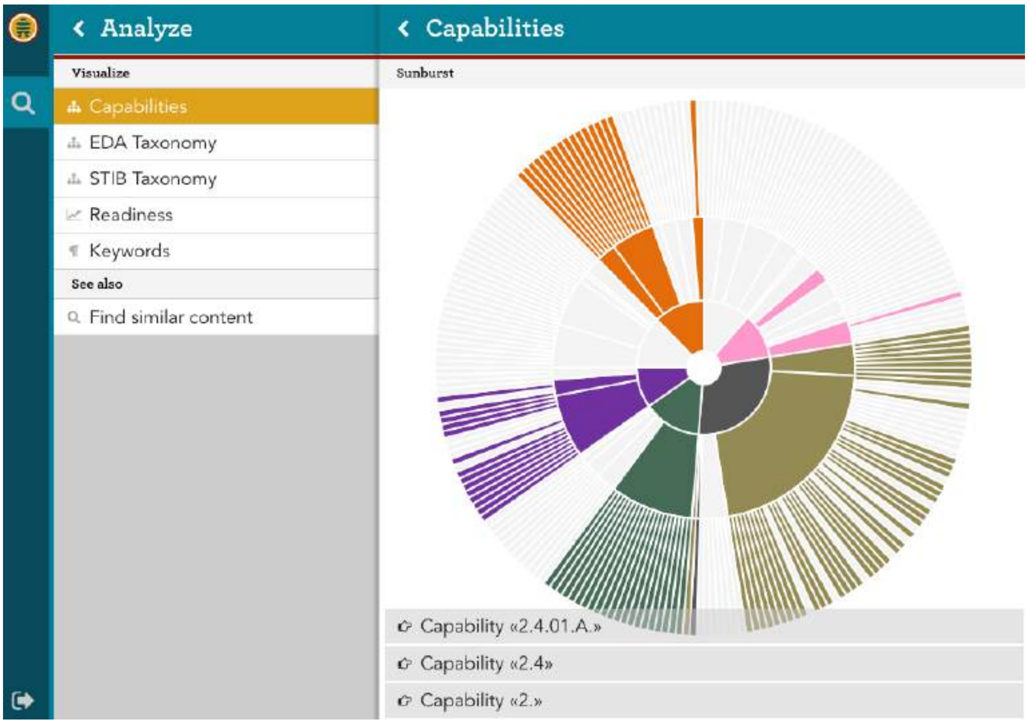


Figure 5.5: Concept of representation of the impact of a technology on the different Swiss armed forces capabilities.

Readiness is a mathematical model which aims to assess the readiness of emerging technologies and measure how close an idea is to reality. By determining common vectors of evolution, technologies can be compared. Readiness models an imaginary line between science fiction and science fact. It believes that technologies readiness can be assessed following the two main lines: *Can it be done?* and *Is it important?*

Each technology is assessed by answering the following 10 questions, to which a point score from 1 to 5 is given. The final score is calculated as the harmonic mean of the individual point scores. The final score indicates the overall readiness divided into the thresholds: *concept*, *prototype* and *product*.

Can it be done?

- Feasibility
  Is the technology scientifically viable?
- Demonstrability
  Has it been demonstrated to work?
- Breakthrough
  Measurably better than preceding technologies?
- Investment
  How far along the investment cycle is it?
- Cost
  How are development costs behaving?

Is it important?

- Explainability
  Do people understand it?
- Usefulness
  Do people use it?
- Necessity
  Do people need it?
- Competition
  Do people compete to develop it?
- Challenge
  Has it proven to address humanity's grand challenges?

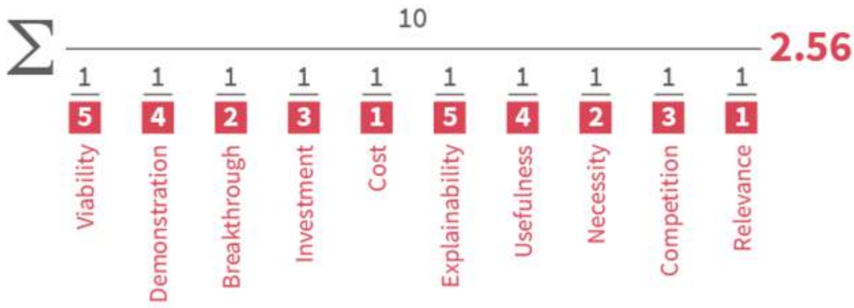


Figure 5.6: Computation of the harmonic mean as Readiness indicator. The computation is done as example for the delivery drone.

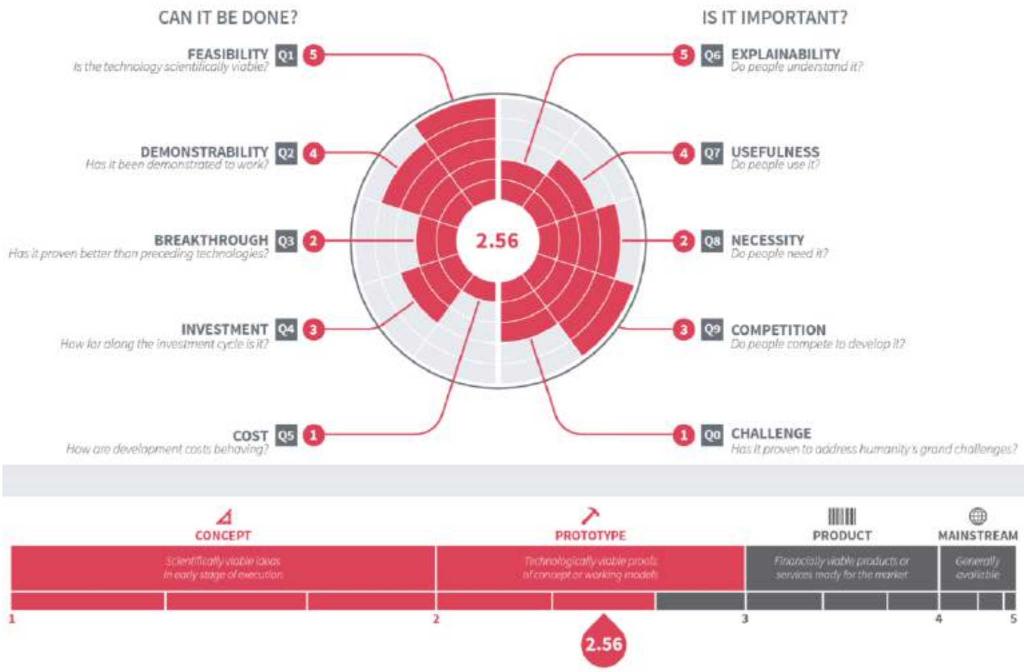


Figure 5.7: Representation of the readiness indicator both as radar profile and numeric value for the delivery drone.

5.5 Dissemination of the Information

An important step of the work is of course the dissemination of the information. This could be done by simply providing an access to the platform and letting the interested users draw their own conclusions. This approach appears a little bit too passive, and we decided to engage in more *push* activities.

1. DEFTECH **Workshops**:
   Serie of 1 day workshops during the year on specific technological topics presenting a future potential relevance for the Swiss armed forces.

2. Technology **Overview**:
   Structured information available for each technology and standardised on two A4 layout.

3. DEFTECH **Meetings**:
   Discovery and brainstorming activities on different topics with technology cards and imagination!

5.6 DEFTECH Platform

The visualization tool, as presented in Figure 5.8, and the DEFTECH technology platform are both accessible on the Internet at the following addresses.

- `http://visualization.deftech.ch`
- `http://platform.deftech.ch`
- `http://vision2015.deftech.ch/`
  A0 format printable poster; also available here in the correct resolution.

Please contact the author to get the necessary credentials.

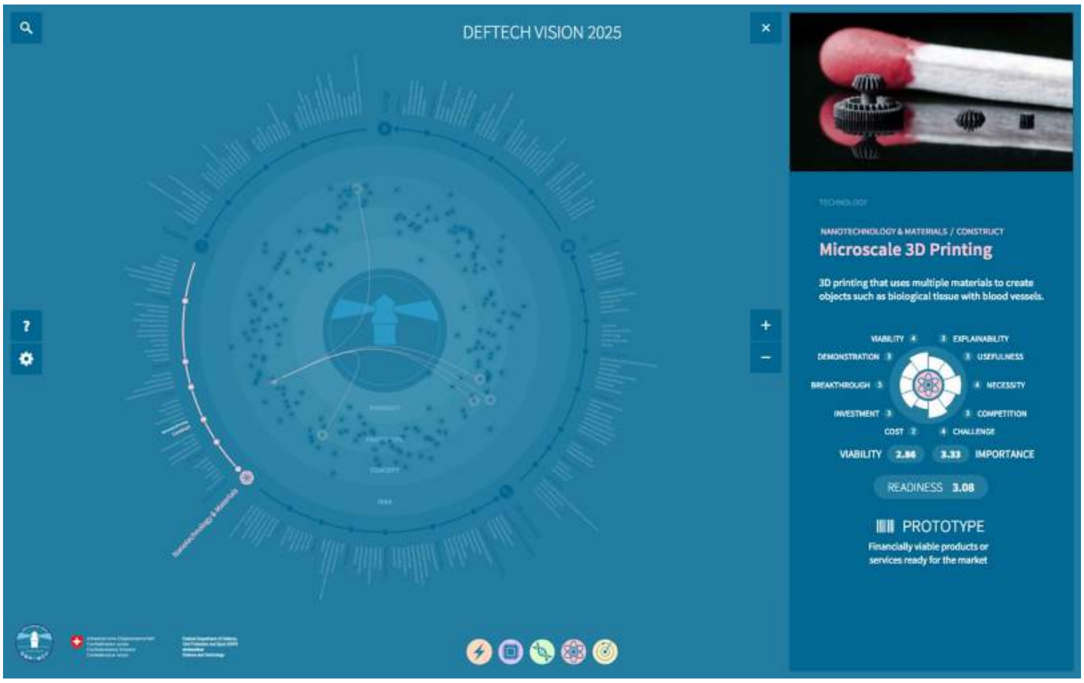


Figure 5.8: Printscreen of the DEFTECH visualization application which shows for each technology its readiness indicator, and materializes, among other parameters, the relationships between the different technologies.

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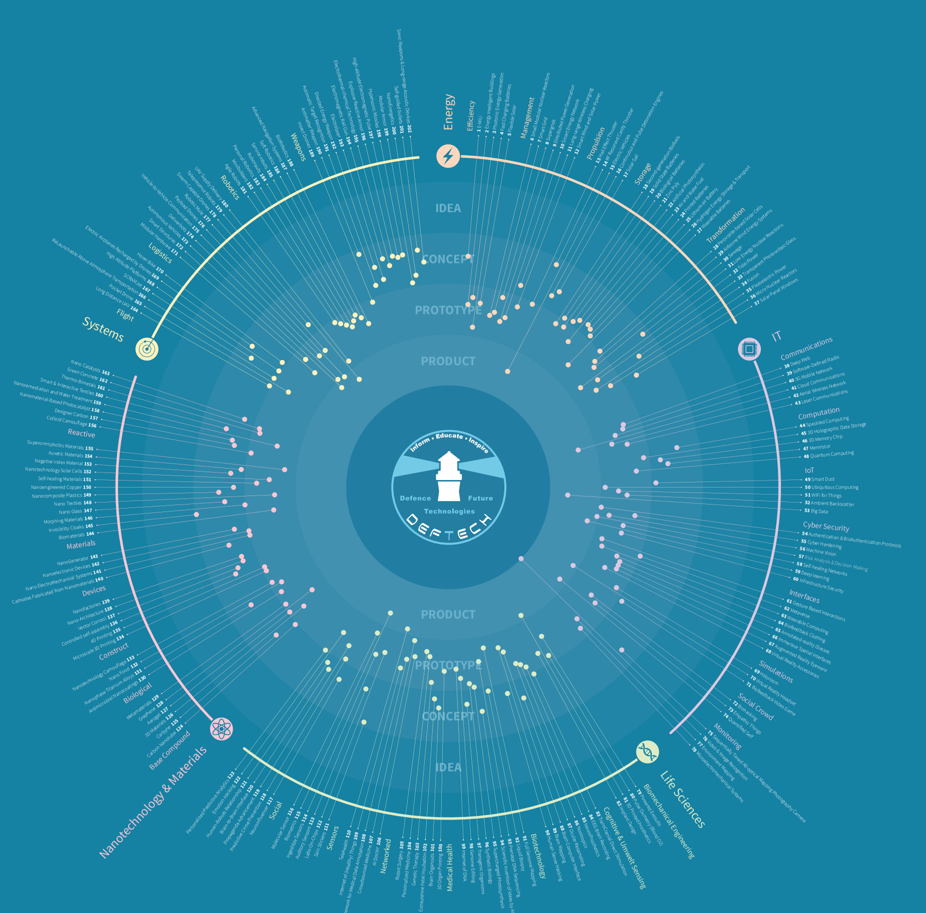
Science and Technology

DEFTECH VISION 2015

The Defence Future Technologies Foresight program deals with all observable technological trends that might have an impact on the defence landscape. Rather than picking the winners, the program is more about identifying the relevant races that defence and security organisations must address. As civilian investments and developments in technologies have overcome military resources in many research fields, dual-use technologies are become more and more present and important on the battlefield. We offer here a non-exhaustive 360° horizon of these different categories, clusters and technologies.



TECHNOLOGICAL EVOLUTION

IDEA	CONCEPT	PROTOTYPE	PRODUCT
Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system.	Representative model or prototype system is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this level represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.

Energy

Efficiency

Management

Propulsion

Storage

Transformation

IT

Communications

Computation

IoT

Cyber Security

Interfaces

Simulations

Social Crowd

Monitoring

Life Sciences

Biomechanical Engineering

Cognitive & Umwelt Sensing

Biotechnology

Medical Health

Networked

Sensors

Social

Nanotechnology & Materials

Base Compound

Biological

Construct

Devices

Materials

Reactive

Systems

Flight

Logistics

Robotics

Weapons

DEFTECH Technology Foresight is a research program from armasuisse Science and Technology which goal is to anticipate and get the necessary understanding of the emerging technologies which might have their implications for the military in general and the Swiss armed forces in particular.

↘ deftech.ch

ENVISIONING

Envisioning is a virtual research institute. We provide technological foresight to policy and decision makers worldwide. Our global team of academics, hackers and designers study technology to understand accelerating change. We share our work with our own tools, methodology and design.

METHODOLOGY
The relative level of technological evolution has been estimated using Envisioning's open-source Readiness methodology.
Find out more:

↘ envisioning.io

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Switzerland

6. Technologies

The profiles of the technologies composing this chapter are exported automatically from the DEFTECH platform. The layout and the structured information must allow a global understanding of the theme as well as a vision of its use in civilian and military contexts.
When new information becomes available, the profiles are completed such that the information is kept up to date and available on demand.
As the number of technologies can grow significantly, we conduct research in generating content automatically starting from the name of the technology only. Considering various sources of information, structured and not, this Big Data and Artificial Intelligence challenges offer practice in areas that will for sure become disruptive at some point in time.

	3D memory chips	Augmented Reality	Bio authentification	Biologically extended senses	Bionic Implants	Brain-to-brain interfaces	Comp Vision	Context-aware computing	Emotion tracking	Holographic technologies	Hypersonic technology	Immersive multi-user VR	Intelligent autonomous swarms	Internet of things	Labs on chips	Lase comms	Machine learning	Medical nanobots	MEMS	Nanobiotechnology	Nanoelectronics	Nanomaterials	Photovoltaic transparent glass	Portable Power	Predictive crime prevention	Quantum computing	Self-healing materials	Smart dust sensors	Smart materials	Stealth/camouflage	Telepresence	Wearable computing	Total connections
3D memory chips	o	x					x					x		x	x						x											x	7
Augmented Reality	x	o								x		x		x							x			x							x	x	8
Bio authentification			o		x				x						x			x		x													5
Biologically extended senses				o					x											x													2
Bionic Implants			x		o	x								x				x	x					x					x			x	8
Brain-to-brain interfaces					x	o						x				x				x	x	x										x	7
Computer vision (analyzing / understanding images)	x						o	x	x								x								x	x							6
Context-aware computing							x	o	x			x	x	x			x								x	x							8
Emotion tracking			x	x			x	x	o								x			x					x	x						x	9
Holographic technologies / holodeck type of experience		x								o		x		x							x	x				x					x	x	8
Hypersonic technology											o								x		x	x							x	x			5
Immersive multi-user VR	x	x				x		x		x		o							x		x										x	x	9
Intelligent autonomous swarms								x					o			x		x	x		x			x				x		x			8
Internet of things	x	x			x			x		x				o		x		x	x		x	x	x	x	x			x	x	x			16
Labs on chips	x		x												o				x		x	x		x				x					7
Laser communication / free space opticals						x							x	x		o					x			x									5
Machine learning							x	x	x								o								x	x							5
Medical nanobots			x		x								x	x				o		x	x							x					7
MEMS					x	x					x	x	x	x	x				o			x		x								x	10
Nanobiotechnology			x	x		x			x									x		o				x					x				7
Nanoelectronics	x	x				x				x	x	x	x	x	x	x		x			o		x	x				x		x			15
Nanomaterials										x	x			x	x				x			o	x				x	x	x				9
Photovoltaic transparent glass														x							x	x	o										3
Portable Power		x			x								x	x	x	x			x	x	x			o			x	x	x			x	13
Predictive crime prevention							x	x	x					x			x								o								5
Quantum computing							x	x	x	x							x									o							5
Self-healing materials																						x		x			o		x				3
Smart dust sensors		x											x	x	x			x			x	x		x				o					8
Smart materials					x						x			x						x		x		x			x		o	x			8
Stealth technologies & Dynamic camouflage											x		x	x							x								x	o		x	6
Telepresence		x								x		x																			o	x	4
Wearable computing	x	x			x	x			x	x		x		x					x					x						x	x	o	12

Figure 6.1: Example of the analysis that can be performed by cross referencing the difference technologies. This will help distinguishing which technologies can be combined the most and therefore could provide some indication about potential for disruption.

Illustration: Detail of the 1000-piece CMYK Color Gamut Jigsaw Puzzle by Clemens Habicht

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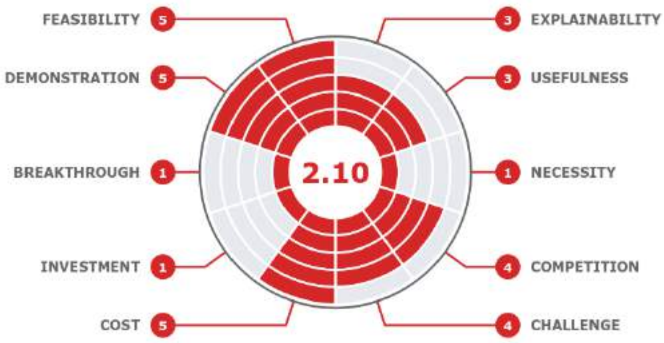
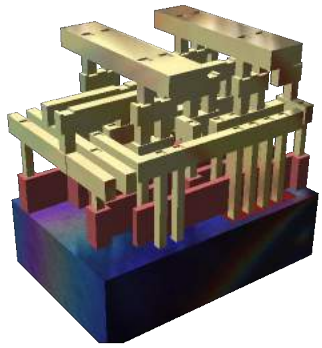
3D Memory Chips





Summary

Semiconductor
Fabrication
Memory
Silicon

Until recently, computer chips were largely 2D structures, created by a sequence of 2D patterns applied on top of each other through lithography. To keep up with consumer demand for faster, smaller, more power efficient chips, the semiconductor industry has been defined by a race to develop chips with smaller feature sizes. As feature sizes in memory rapidly shrink, quantum effects become more pronounced. Users demand increased memory storage in smaller sizes, but as shrinking the size of components becomes less viable, memory manufacturers developed a new approach: stacking NAND memory cells vertically, rather than horizontally, to effectively fit more cells within a given two dimensional area. AMD's flagship Fiji line of graphical processors uses a technology they call high bandwidth memory that stacks entire memory dies (pieces of silicon) on top of each other, rather than fabricating a new memory layer on the same die. Intel has also adopted some 3D space saving measures for its microprocessors for some time now by effectively twisting transistors on their side in what it calls “Tri-gate transistors”. In all these cases, moving from 2D to 3D structures improves performance, power consumption, and capacity.

Weaknesses

3D memory chips do not have any substantial downsides, however they require semiconductor fabs to retool, and in some cases (such as for High Bandwidth Memory), the processes and complexity result in slightly lower yields (more chips rejected).

Related fields

Wearable Computing, Nanoelectronics, Internet of Things, Augmented Reality, MEMS, Computer Vision, Virtual reality, Semiconductors, Labs on a Chip.

Civil Uses

Civil computing systems for business and domestic applications. Essentially, any platform that requires data storage, especially systems that already use flash memory, will benefit.

Trends & Challenges

Yield
Power consumption

Like every other development in the semiconductor industry, the primary focus of 3D memory is to further reduce the size, power consumption, and cost of the components while simultaneously improving performance. Manufacturers are no doubt focusing on stacking more memory modules and fabricating the modules smaller than currently possible at reasonable yield rates. Principal challenges lie in the development of nanoscale fabrication techniques and in dissipating the large volumes of heat that will be generated in such systems.

General

The technology, although relatively new, is already in use in many commercially

valuation

Commercial

available products today. 3D memory technology will likely continue to see use until manufacturers reach the material limits of silicon substrates, and begin to explore more exotic materials and novel systems. Depending on the new material used, 3D memory techniques may be applied even after the switch from silicon to save space and improve performance. There are currently no near-commercialization technologies competing against 3D memory, however there are different techniques, depending on type of memory and structure, to manufacturing 3D memory. Like other semiconductor processes, 3D memory chip production is controlled by a few major fabricators, and has a huge cost barrier to entry. As such, it is extremely difficult for any start-up to enter the market.

Defence valuation

Forensic

In virtually every case, 3D memory appears exactly the same as conventional 2D memory, thanks to the "black box" method of computer design and manufacture. However, to an incredibly sophisticated computer forensic team using methods currently unknown in the private sector and bordering on the edge of theoretical plausibility, 3D memory, especially stacked NAND may prove more difficult to decipher than conventional 2D NAND.

Main actors

Micron, Sandisk, Intel, Toshiba, SK Hynix, Samsung, AMD.

Recommendation

Adopt
Try

For players with expertise in advanced digital forensics, including reading data from damaged SSD drives, then 3D memory may prove a useful technology to adopt (or at least try), so they may learn to read data from stacked memory cells as well. If not, 3D memory will have a relatively low impact on the operations of most companies and is not worth close observation.

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Augmented Reality

Summary

Information
HUD
Internet
Displays

Augmented Reality (AR) is a concept where a real world visual space is augmented by the addition of visual, audio or any other sensory information. AR is most commonly associated with visual augmentation and most mature applications have used Head-up Displays (HUDs) to provide basic pictorial and textual information to the user. AR differs from Virtual Reality (VR) in that VR entirely replaces the user's visual field with a virtual one, but the distinction between AR and VR is constantly evolving and being challenged.

Historically, military applications have provided the greatest technical developments with HUDs for pilots and, more recently, dismounted soldiers. However, in recent years the development of smart phones and tablets has put the potential for augmented reality into the hands of people that would never previously have been able to afford the bespoke, high cost technology used in military applications. An ethical and social acceptance issue of Google glass has temporarily held back the technical development of augmented reality due to its association with the camera system used within Google glass/

Weaknesses

Weaknesses include display resolution (unable to convey complex information), transparency (difficulties in projecting dark areas on to head mounted displays), unit size (for head mounted systems) and social/ethical acceptance issues.

Related fields

Portable power, Wearable Computing, Nanoelectronics, Internet of Things, Holodeck, Consumer electronics, 3D Memory Chips, Telepresence, Virtual reality, Voice Recognition.

Civil Uses

Manufacturing and maintenance/repair, video games, navigation.

Trends & Challenges

The main challenge facing AR technology is making the technology acceptable to use in mainstream social situations. While this is not a concern for many viable applications this issue will reduce the funding going into wearable AR technology and therefore AR technology as a whole. Developments in contact lens based AR may be a big step in the acceptance of mainstream AR.

General valuation

Ealys adopter
Fast moving
Privacy

For civil applications, AR is still relatively immature and is being held back mostly by ethical and social concerns over privacy due to the association of permanent camera surveillance with AR. This is despite AR not requiring camera information for many applications. Despite this association, limited adoption of civil AR headsets is expected within the next 5 years with the most likely applications being as additions to existing head mounted items, such as safety helmets, and in situations where visibility is poor or the hands are already involved in tasks. A civil example could be for cyclists.

Some commercial offerings have been available (notably Google glass) but these have been mostly intended to 'test the water' rather than as a full product. In January 2015 Google withdrew Google glass from sale but claims that it is continuing to develop the concept.

AR technologies are in huge competition with Virtual Reality (VR) technologies and other wearables such as smart watches.

Defence valuation

Basic systems
Navigation
Pilots

AR is already in mainstream use in military applications including for pliots and dismounted soldiers. However, these are largely high cost, bespoke devices built into safety helmets. Current devices used in the air domain provide basic pictorial and textual information, often monochrome vector graphics displaying information such as altitude or threat location. This information is also commonly a replication of data available to the user through other means. In the medium term (10-20 years) we may see greater display fidelity and therefore AR devices being used to replace information currently provided through other means within the cockpit.

Main actors

Google, Oculus, Lockheed Martin, Microsoft, Samsung, BAE Systems.

Recommendation

Adopt
Try

Military applications of augmented reality are already mature and have been in use for some time, notably for aircraft pilots. The adoption of AR is also quickly moving into other military applications including dismounted operations. Defense stakeholders should be trying and testing these opportunities immediately as the military domain is the most mature for applications.

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05.10.2015

Bio-Authentication

Summary Bio-authentication—or biometric authentication—is the application of characteristics of an individual's physiology or behavior in verifying that individual's identity. Importantly, these characteristics must be measurable and unique to the individual. Biometric solutions for security applications have been in use for decades and have experienced substantial improvements during that time. Their use has generated interest in recent years because of the increasing pervasiveness of the internet, the necessity to be a part of it, and the risk of security breaches. The most well-known form of bio-authentication is the fingerprint, which has found use in crime-scene analysis since the early 20th century. Fingerprint bio-authentication technology is simple enough today that it has been present in some high-end smartphones and tablets since 2011. Other physiological traits that have found use in bio-authentication include iris, retinal, vein-pattern, and facial recognition. Voice recognition is an example of a behavioral characteristic that is occasionally employed in the verification of identity. Walking gait and the way in which an individual interacts with a computer have also shown promise in bio-authentication techniques. Away from crime-scene analysis, DNA bio-authentication is not commonly in use for human security purposes, but has been placed on products to combat counterfeiting.

Weaknesses Natural changes in the biometric data of individuals have been a hurdle. Security of biometric data is key to the success of bio-authentication technologies. Biometric "passwords" cannot simply be changed.

Related fields Medical Nanobots, Bionic Implants, Nanobiotechnology, Retail, Consumer electronics, Software, Insurance, Sensors, Emotion Tracking.

Civil Uses Security, consumer technology, border control, office and home entrance systems, ticketing systems, crowd control, targeted marketing, banking, shopping/retail.

Trends & Challenges The use of biometrics in security verification is fairly simple and, as technology costs decrease, bio-authentication techniques such as iris recognition are becoming more common. The main challenge for this type of bio-authentication is security of the biometric data. Typically, bio-authentication is used for verifying a person's identity, but research is trying to improve methods of identifying unknown individuals. The challenge for this sort of identification is overcoming ethical, legal, and technical hurdles to build a secure database of biometrics that can be searched quickly. Other research trends are looking at alternative biometrics, including heart rhythm, brain activity, and microbiomes.

General valuation Bio-authentication is in many ways mature. Advances in, and decreasing costs of, sensor technologies have brought biometric verification—such as fingerprint and facial recognition—to high-end consumer electronics. Other bio-authentication techniques are in use by governments in border control, identity cards, and insurance verification. For example, the Social Security Institution of Turkey uses a biometric scanner from Hitachi and MIG that identifies patients on the basis of the vein patterns on a finger to ensure the country's Universal Health Insurance scheme is not misused. One of the major concerns over the use of bio-authentication is whether the public feel the storing of biometric data is an invasion of privacy. Warnings exist concerning the security of these data too. Criminals could steal biometric data not only through hacking but also through physical methods. For example, iris-pattern data could be stolen from a photo of an individual. Furthermore, unlike alphanumeric-based passwords, an individual cannot easily change their biometric "password" if it is stolen. For this reason, traditional passwords, personal identification numbers, and wireless RFID verification represent competing technologies. Multimodal bio-authentication and adaptive biometric systems are avenues of research that may give biometric verification the leading edge and overcome natural biometric changes.

Defence valuation Some militaries are already employing bio-authentication systems for access to secure areas. Such bio-authentication could also find use in weapons and vehicles in the field, preventing enemy forces from using captured equipment. Enemy biometric data may also prove useful. The US Defense Forensics and Biometrics Agency (DFBA) collects biometric data from non-US persons of interest to aid in identifying suspected or known adversaries. The next development for this sort of data would be to collect it covertly. For example, highly sensitive cameras that not only could capture multiple biometrics very quickly but also identify individuals would prove useful for surveillance. This sort of system could also help to quickly identify friendly individuals in the field. The threat from biometric systems comes from how enemy forces are gaining and using biometric data for themselves. Furthermore, the use of bio-authentication security systems may put individuals and their bodies at heightened risk.

Main actors Unisys, Go Vivace, Zwipe, Oxford BioChronometrics, Cognitec, MIG, Fujitsu, Nymi, ievo, Intel, Nuance, 3M, Descarted Biometrics, Hitachi.

Recommendation Bio-authentication offers significant opportunities for diversifying security systems. Defense organizations ought to try bio-authentication, not least because many other defense organizations are doing so. However, the security of the biometric data is paramount to the success of bio-authentication systems. Therefore, it is important to develop secure systems to protect these data. Bio-authentication of weapons and vehicles could be very useful in the field. However, the reality of how useful and how practical bio-authentication of equipment could be needs to be established. The use of biometric data in surveillance throws up a host of ethical and legal difficulties depending on the context of its use. It is recommended, therefore, that players observe the development of bio-authentication technology for use in surveillance until a time when the technology is proven to be beneficial enough to be worth adopting.

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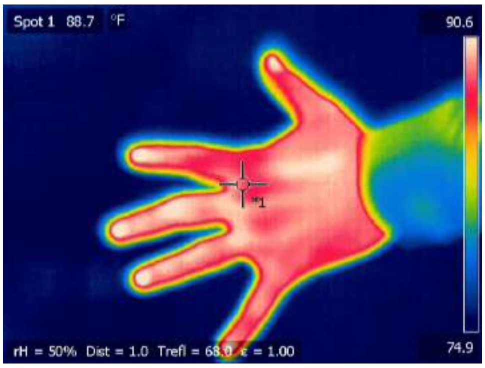
22.09.2015

Biologically Extended Senses



Summary

Olfactory
Night vision
Infrared

Correcting defective senses—particularly vision and hearing—has long been a staple of human technological development. As these technologies have advanced, focus has shifted from merely correcting defects to enhancing the human senses. Basic examples include night-vision goggles and infrared cameras. But the possibilities for extended senses have expanded through advances in various technological fields. The area of biologically extended senses is not a coordinated and fully formed field of research; rather it is a broad application of many different technologies. The main principle behind the application is the use of technologies and techniques to enhance the senses beyond that of typical human capabilities. Naturally, this definition includes the extension of hearing, sight, taste, smell, and touch separately but also includes the enhancing of all or most of the senses in order to remain alert. Many of the possible methods for extending the senses are initially developed for other purposes. For example, transcranial direct current stimulation (tDCS) was originally developed as a treatment for brain injuries but has shown promise as a method for enhancing the abilities of soldiers.

Weaknesses

Lack of collaboration and coordination between disparate fields to work toward enhancing the senses is a current weakness. Additionally, ethical questions could arise from some methods, in particular drugs.

Related fields

Nanobiotechnology, Construction, Neuroscience, Neurology, Industrial, Emotion Tracking.

Civil Uses

Consumer use for alertness, research tools, health and safety, education, sports and leisure.

Trends & Challenges

Disparate
Research focus
Consolidation

Technologies and techniques for extending senses are developing from very disparate areas, ranging from meditation methods to electronic devices to drugs. Meditation for focusing the mind and senses has a very long history, but new techniques are embracing technology. For example, the EU-funded INTERSTRESS project attempted to teach the process of lowering stress levels through biometric sensors and virtual-reality environments. The progression of neuroscience will play a significant role in the development of biologically extended senses. The field is increasingly garnering attention and funding. However, the main challenge for extended-senses techniques is consolidating and focusing research.

General

As a whole, the extension of the senses is a fairly immature field. However, narrower clusters of technologies and techniques are more advanced and

valuation

Disparate

Ethics

Emerging

progressing quickly. For example, tDCS and other neurostimulation methods are being developed specifically for enhancing the nervous system. Some neurostimulation devices—such as cochlear implants—are already available for people with certain disabilities. US company foc.us sells transcranial-stimulating devices commercially to the computer gaming community. Sleep science is a developing area of research that could have implications for methods of extending the senses. Research at Washington University demonstrated the use of a hormone to control the body clocks of mice. Some practices—including meditation, training techniques, and diets—claim to help enhance the senses. However, high-integrity studies of these practices are uncommon. Sports psychology is a popular method for improving performance in intense situations.

Some methods for extending the senses raise questions about health and safety. For example, some research has suggested that tDCS can cause side effects, including burning sensation, temporary blindness, and loss of consciousness. Ethical questions exist surrounding the need for such enhancement of the senses, particularly as automation via machines, sensors, and artificial intelligence are improving significantly.

Defence valuation

Covert

Darkness

In theory, extended senses could be very useful in defense. Indeed, modafinil—a drug for treating wakefulness disorders such as narcolepsy—has found use in operations by some armed forces, such as that of the United States and France. However, the necessity of biologically extended senses is questionable when much of the defense sector is moving toward remotely controlled—or even autonomous—machines. Although the alertness of those people operating the machines is important, replacing them with a fresh operator may be simpler than using sense-enhancing techniques at their current level of development. Nevertheless, extended senses could be very useful in intense, covert operations. The ability to enhance sensory perception on demand gives significant advantages—for example, the capability to perform the operation at any time of day—in these situations. However, the long-term side effects of using methods to enhance the senses needs to be considered.

Main actors

Brown University, foc.us, DARPA, University of Washington, Neuroscience Center Zurich, UCL Neuroscience.

Recommendation

Observe

Much of the research surrounding biologically extended senses is nascent and warrants monitoring. Observing developments arising from the field of neurological research is highly recommended because this area currently has a significant amount of momentum behind it and could produce discoveries of great importance to the extension of the senses. Other areas are worth trying. tDCS is of particular interest to many defense organizations, but it requires more research to help develop it into a useful and safe tool. Some approved medical drugs may be worth investigating for use in enhancing alertness if proved to be safe. While the usefulness of meditation and similar practices to enhance the senses is difficult to gauge, some psychological training techniques may be beneficial. Sports psychology is common in professional sports and is worth trying to see if it can be tailored to the defense sector.

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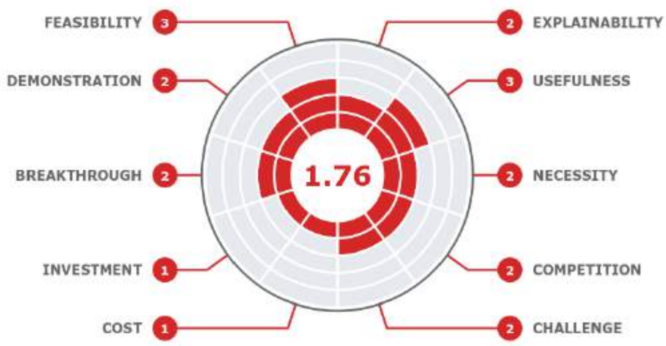
Bionic Implants



Summary

Prosthetics
Sensory
Stimulators
Enhancement
Augmentation

Bionic implants enhance or correct the function of organs or other body parts; these systems often mimic the functions and appearances of natural equivalents. These implants sense and react to the body's natural signals. Bionic implants covers a wide range of products and applications, from the commercially mature, to the conceptual. Pacemakers (not strictly speaking bionic devices, but nonetheless closely related) and cochlear implants are well-established devices, and artificial hearts are now available, albeit for temporary application. Retinal implants are in the early stages of commercialization, with some success treating specific blindness conditions. Advanced prosthetics are starting to become more bionic in their responses. Neural stimulators to treat epilepsy and Parkinson's disease are under development, as are implants to treat sleep apnea.

Neuron-connected prosthetics—that users can move with thought power—have long been the goal for limb replacements. In addition, researchers hope to develop prosthetic implants with sensory feedback. Further into the future, developments in nanotechnology could enable tiny bionic devices, such as *respirocytes*—artificial, mechnical blood cells that can replicate and surpass the human respiratory system; each artificial cell could transport 200 times more oxygen than a natural red blood cell.

Weaknesses

Bionic implants are nascent and expensive: Current devices stimulate muscle/neural tissue in a basic way. Understanding of physiological processes needs to improve before effective systems emerge.

Related fields

Medical Nanobots, Nanobiotechnology, Portable Power, Wearable Computing, Internet of Things, Smart Materials, Human Augmentation, MEMS, Brain-to-Brain Interfaces, Flexible Electronics, Bio Authentification.

Civil Uses

Technologies such as artificial sight and hearing devices; neutrally-connected prosthetics; artificial or enhanced organs. All could see use to correct debilitating conditions, or enhance human capabilities.

Trends & Challenges

Nanotechnology
Neuroscience
Cost reduction

Advances in technology—particularly nanotechnology—are paving the way for neuron-connected devices that integrate better with the body. Medical research is well versed in the workings of the eye and the optic nerve; as a result, many of the advances in neuron-connected devices are occurring in implants that connect to the optic nerve and aid with vision. For other applications, scientists need to understand much more about how the neural system functions. For example, the US National Institutes of Health (NIH) is proposing to fund research that focuses

Safety

on the mechanisms that underlie the electrical control of the body's organs.

General valuation

Trials

Emerging

Bionic-implant technology is growing steadily, with the capability of these devices depend upon scientists' understanding of body functions. Cochlear and, to a lesser extent, retinal implants are now available, but other devices that require connection to the body's neural system are still in a highly developmental phase.

In February 2013, Second Sight gained US Food and Drug Administration approval for its Argus II device. The prosthetic device restores some sight to people visually impaired by retinitis pigmentosa. The purpose of the Argus II is to restore mobility to the retinitis pigmentosa sufferers by allowing them to distinguish some objects. However, the device has the potential for restoring vision to other forms of blindness in which parts of the retina and the optic nerve are still functional. Future availability will depend on devices' costs. Currently, the Argos II costs $100,000. In the next ten years, the adoption of nanotechnology will reduce the limitations that prosthetics currently have. Consequently, the high price of the devices will likely fall, although for prosthetics like the Argus II the price will likely remain high because the Argus II is for a niche market. However, should prosthetics find wider use for augmenting healthy people—for example, a visual implant that enables the user to see infrared light—then the cost of such devices could fall further.

Defence valuation

Technology Transfer

In terms of threats, bionic implants could be used to improve the performance of military personnel. For example, a visual implant that enables users to see infrared light could enable soldiers to see in the dark. These devices are becoming more cost effective. However, ethical issues would surround the use of implants that are invasive.

In addition, bionic implants could restore many aspects of the lives of military personnel who are injured during active service. For example, implants could restore sight, hearing and perhaps some physical functions.

In all likelihood, it is more likely that lessons learned, and technologies developed from, bionic implants, are likely to spin off into defense applications. In particular, bionic-implant technologies could result in technologies that enable better wearable devices—for improving motion, vision, other senses, and so on.

Main actors

GlaxoSmithKline, KAIST, Retina Implant, EPFL, Second Sight, Touch Bionics, Chicago Center for Bionic Medicine.

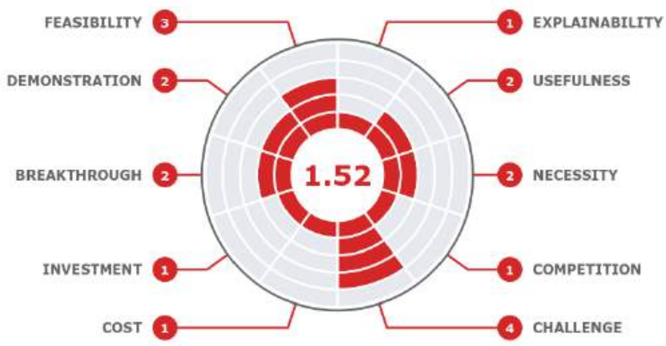
Recommendation

Observe

Try

This technology area falls somewhere between the observe and try categories. It is worth monitoring the numerous bionic-implant technologies and approaches, and assessing their potential to transfer into applications that are more directly related to defense and military applications (as discussed in Defense & Security Valuation, above).

Brain to Brain Interface



Summary

Remote control
Neurons
EEG

Brain-brain interface (BBIs)—sometimes referred as synthetic telepathy or silent communication—technologies enable thought communication. BBIs use neuroscientific principles: The nervous system—brain and spinal cord—comprises neurons, connected by neural synapses, which communicate using electrical signals. Neurons send messages to neurons, or networks of neurons. Neurons' complex firing patterns underpin multiple phenomena, including memory, consciousness, and motor functions.

While understanding of these complex neural mechanisms is incomplete, by using electroencephalography (EEG)—and magnetic resonance imaging (MRI) and positron emission tomography (PET)—researchers have developed brain-computer interface (BCI) systems that can interpret brain activity. Researchers have also developed computer-brain interfaces (CBIs)—in particular anscranial magnetic stimulation (TMS) systems—that transmit information to a brain; in some cases precipitating physical reactions. BBI is an extension of BCI and CBI.

BBI implementation will in part come through developments in these enabling technologies: DARPA has funded the development of neural implants for 'remote control' of animals. A 2003 Duke University BCI enabled a monkey to control a robot arm. In 2014, a University of Washington noninvasive BBI system captured brain signals from one researcher using an EEG, sent signals via the internet to a TMS attached to a second researcher, in an attempt to initiate finger movement.

Weaknesses

Only two BBI systems have been demonstrated; their efficacy is controversial. Neuroscientists do not fully understand the brain. BBIs only convey simple "on-off" messages. Equipment is currently slow and complex.

Related fields

Nanobiotechnology, Virtual Reality, Wearable Computing, Nanoelectronics, wireless/internet communications, healthcare, BCIs/BMIs, intefaces, microelectronics, Biotechnology, data security, Bionic Implants, organic computing, neuroscience.

Civil Uses

Healthcare and medicine, in particular, rehabilitation; training, instruction, and machine operation. Long-term, BBIs could enable wholly new, disruptive, communication concepts.

Trends & Challenges

Replication

Research trends are broad and aspirational. A major research area is the replication As highlighted above, BBI research programs involve combinations of BCIs/CBIs. Researchers have developed BBI systems that can transmit simple—almost binary in nature—pieces of information. For example, researchers at

Record, Store Brain Activity

Starlab Barcelona claimed to send a message between Kerala and Strasbourg; the binary message used a TMS to cause the receiver to see light pulses. Understanding brain function is a huge task, and a key challenge for future BBIs. Nevertheless, incredible progress has occurred in the past 20 years; progress that will continue. European and US researchers plan to create technology that can record, store, and play back, brain activity.

General valuation

Immature
Controversial
Uncertain

BBI is an immature area and is available only in research laboratories. Nevertheless, related technologies such as BCIs are more mature. Some enabling components such as EEG, functional MRI, and TMS are already commercial. Progress in these enabling technologies will contribute to the success of BBI. Some simple BCI technology has crept toward the mainstream. In the mid-1980s, Atari experimented with an EMG headband to detect muscle movements. In the late 2000s, NeuroSky announced EEG/EMG interfaces for entertainment, automotive and health applications. The effectiveness of these systems is uncertain. As the technology progresses, becoming faster and more accurate, BBI is likely to become controversial—for numerous security and privacy reasons. Competing technologies include all existing communications approaches (voice, text, video), and also automation and robotics (effectively, machine-machine interfaces), because automation reduces the need for person-to-person communications.

Defence valuation

Communication
Privacy
DARPA

The prospect of seamless, wordless information transmission between people and personnel is highly significant—and already of interest to the global defense community. Indeed, a significant amount of BBI, BCI, and neuroscience research is funded by military organizations. For example, DARPA has funded research into BCIs and BBIs (including some work at Duke University). Opportunities exist for novel defense-related forms of communication—communication that could render spoken language obsolete in some applications. Training and tutoring is particularly important in defense settings; BBIs could revolutionize training, perhaps enabling instant training of military personnel. Beyond remote control and military-focused medical and rehabilitation applications, long-term opportunities also include connected living systems: Duke University researchers report to have connected the brains of rats, enabling a new form of swarm intelligence. Threats include surreptitious use of BBI, BCI, and CBI approaches. Currently, these technologies are either invasive or at least require wearable interfaces. As this technology becomes more compact, and perhaps more pervasive, new threats could emerge—in particular, hacking. Advanced interfaces could make privacy itself obsolete.

Main actors

Toyota (enabling technologies), Duke University, Brown University, Honda, State University of New York, DARPA, ATI, Shandong University, University of Washington, Starlab Barcelona (BBIs).

Recommendation

Disruptive
Observe & Try

Key recommendations include tracking and monitoring developments in this technology, and also in related fields (brain-machine interfaces, neuroscience). Although BBI technology is likely to see slow development and adoption, it could render a number of existing communications technologies obsolete. It could also compete with traditional rehabilitation and—importantly—training methods and procedures.

Computer Vision

Summary

Image recognition
Deep learning
Machine Understanding
Navigation

Image recognition is mature for certain domains, such as faces that look directly into cameras and quality control of manufactured goods. Machine learning—computers "figuring out for themselves" the mathematical features of images that humans have explicitly labeled as depicting, say, cats and dogs—helps machines spot those features in arbitrary unlabeled images. People use the term *deep learning* to describe architectures having many layers, typically of artificial models of biological neural networks. But alternative technical methods, especially probabilistic models, are also important to progress.

Some robots and autonomous vehicles implement computer vision for navigation and other purposes, often by comparing images to prepared maps and models. In some cases the robots and cars themselves explore an area to help prepare those maps and models.

Some research aims toward image understanding. Recognizing that an image contains a dog and also a dish of ice cream is distinct from recognizing that the dog is eating ice cream, and thereby deducing that in fact dogs sometimes do eat ice cream.

Weaknesses

Computers need many training examples to learn new objects, are prone to generating false-positive detections, and are poor at producing descriptions of what occurred when a photograph was captured.

Related fields

Connectomics, Photogrammetry, Machine Learning, Signal processing, Artificial intelligence, Sensors.

Civil Uses

Commercial technologies include radiological diagnosis, automated optical inspection in manufacturing, automated organization of photo collections, and searches for "similar" (often, labeled) images. Stakeholders expect to improve searching for unlabeled objects.

Trends & Challenges

Graphics processing
Benchmarking
Machine learning
Decision making

Large, brand-name companies, research institutes, and some startups are investing abundant resources in long-term efforts to achieve human-like visual intelligence. Researchers commonly participate in formal competitions that benchmark software performance—such as success in drawing a box around a dog and identifying its breed. Many, but not all, state-of-the-art computer-vision systems execute machine learning on graphics processor units—which can be, but are not necessarily, more economical and computationally efficient for the purpose than ordinary processors. People commonly inspect drawings to solve problems and make reasoned decisions, and some research aims to give computers similar abilities.

General valuation

Immature
Basic
Underused
High-cost

Basic forms of image recognition, especially the limited case of recognizing facial portraits, are somewhat mature. Some security technologies seem underused, such as systems that detect unattended baggage. The volume of advanced research activity is very high, fuelling recent steady improvements in computer-vision benchmarks, and justifying some expectation of further momentum.

But overall, computer vision technology is quite immature, with machines needing far more training images than their human counterparts, and poor recognition of faces captured by surveillance cameras. And deep learning's big-data approach, which has driven much of the recent progress, may not scale economically to machine-understanding tasks. Competing computer vision methods for navigation of vehicles, robots, and drones impose varying resource requirements, such as varying dependence on cloud services and prepared maps. As different sub-disciplines progress at different rates, requirements changes could disrupt long-range development projects.

A sufficiently dramatic improvement in face recognition could stimulate a public backlash against the loss of a customary sense of anonymity, say, in drugstores and bars.

Defence valuation

Automation
Friend-or-foe
Surveillance
Crime

Over a dozen companies sell solutions that detect specific events of interest to surveillance specialists, such as presence of unattended baggage and persons who fall, loiter, produce graffiti, shoplift, and prowl in the manner of a car thief.

Apparently, intelligence agencies aim to teach machines to perform key tasks such as friend-or-foe identification, but still have strong reliance on human image analysts. The analysis of aerial and satellite images is often a human-machine collaboration rather a fully automated process.

And notably, face recognition technology remains unreliable for images of people who are not looking directly at a camera, hampering efforts to, say, automatically identify that a person of interest has walked past a surveillance camera at an oblique angle, in situations where a human observer could have made the identification.

Main actors

Clarifai, Microsoft, Facebook, INRIA, NLPR, NUS, Baidu, University of Toronto, Vicarious, Google, Sentient, University of Oxford, ETH Zurich, EFPL, Amazon.com.

Recommendation

Observe
Try

Computer vision certainly merits observation by governments, military organizations, and their suppliers, who could benefit from likely improvements in automated surveillance and computer-assisted intelligence assessments. Observation and focused assessments can reveal the resource and performance requirements of systems that can attain varying (and evolving) tiers of computer-vision performance. Organizations with interest in the development of various autonomous vehicle, robot, and drone technologies also have reason to observe and try competing approaches to computer vision for self-navigation. With sufficient technological progress, machine understanding of dynamic environments might surpass navigation by matching images to prepared maps and models.

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04.10.2015

Context-Aware Computing

Summary

Autonomy
User experience
Intelligence

Context-aware computing (CAC) uses sensors, location, user preferences, activity logs, environmental information, and other data to proactively deliver information, execute commands, and adjust user interfaces in accord with changing conditions, with the aim of improving utility of software and quality of user experience, allowing users to focus on tasks and experiences rather than on the mechanisms of human-computer interaction.

Visions of pervasive computing and intelligent-agent software generally encompass the ideals of CAC, seeking to implement more or less autonomous software that identifies a user's needs and acts on user's behalf without explicit instructions, like a silent butler. CAC also aims to respond to fuzzy human needs, like the need not to be disturbed unless an incoming message is important, relative to perhaps innumerable explicit and implicit conditions.

Simple implementations include screen brightness controls that automatically adjust to ambient light; and PC software that presents menus appropriate to a current task. Applications that were considered advanced in past years are now routine, including video streams that automatically adapt to available screen sizes and data rates, and fitness apps that fuse sensor and location data to identify whether a user is walking or bicycling to automatically generate a calorie-burn estimate.

Weaknesses

CAC's many difficulties include poor indoor-location technology, ambiguities about which messages to prioritize, and challenges in detecting when to leave users undisturbed, say, during impromptu meetings and while driving.

Related fields

Virtual Reality, Internet of Things, Indoor location, Data compression, Sensor fusion, User interfaces, Predictive Crime Prevention, Adaptive systems, Behavior recognition, Quantum Computing, Situation awareness, Machine Learning, Computer Vision, Wearables, Artificial intelligence, Swarms, Sensors, Search engines, Emotion Tracking.

Civil Uses

Programmers will maintain and extend use of CAC for message delivery, search engines, augmented reality, smart buildings, driver safety, health and fitness applications.

Trends & Challenges

Automation

R&D efforts seek to detect and classify user activities; automatically detect presence and availability for messaging; improve indoor location systems; and use contextual information to interpret verbal commands that are otherwise ambiguous.

Contextual
Data fusion
Location

Significant challenges include improving safety by suppressing incoming messages to vehicle drivers but not to passengers; presenting a list of printers that are prioritized according to proximity; interpreting data from wearable devices to discriminate lifting hand weights from lifting eating utensils; and enabling follow-me services that automatically activate and deactivate lights, music, video, communications, and security systems as a user performs chores around and away from a house.

General valuation

Partially mature

In some senses the technology is quite mature, initially signalled by the ubiquity of office-productivity and graphic-design software that presents menus and tools that vary in accord with a task's context. Subsequently, smartphones began to contain suites of over a dozen sensors and multiple location technologies, enabling development of very many mobile apps that make use of such technologies.

At conferences on human-computer interfaces, location technologies, and pervasive computing, context awareness is merely one of many attributes of diverse applications that depend on sensor data, streams of social media messages, and other inputs. Significantly, the Interaction Design Foundation discontinued its Symposium on Location and Context Awareness (LoCA) conferences after 2009.

In another sense CAC is most immature because it has had very limited success satisfying its goal of determining user intentions without explicit input. Famously, people saw Microsoft's circa-2000 "Clippy" context-sensitive help assistant as intrusive and unhelpful. Users also shun the types of continuous surveillance and data aggregation that might improve automated context recognition. A related constraint arises when CAC would benefit from adding more sensors, but cost and ease of installation is unsatisfactory.

Defence valuation

Security
Automation
Pattern recognition
Prioritization
Threat detection

Some stakeholders see "context sensitive security" as important for cybersecurity, although the term may simply be a buzzword for wise practices such as policy-based security management and pattern recognition for anomaly detection. Decision support could benefit from systems that "do what I mean, not just what I say". Relevance rankings for a query like "where are the drones?" could depend on factors like whether a user is inventorying a warehouse or pinned down in a bivouac.

Situation awareness could benefit from context-sensitive prioritization of messages and intelligent fusion of sensors and other inputs. Otherwise, personnel risk information overload—especially as sources of digital information proliferate. That said, opposing forces might intercept and exploit sensors deployed for CAC purposes.

Main actors

Apple, Expect Labs, LG Electronics, Google, Motion Picture Experts Group, Microsoft, Samsung, FitBit, Interaction Design Foundation, MIT.

Recommendation

Observe
Try

Ideas about CAC serve to focus some stakeholders' minds on remedies for design shortcomings, especially for poor user interfaces that continue to plague users with demands. Such remedies may tend to make wise use of artificial intelligence and numerical methods to recognize and classify events that are relevant to a system's operation. Focused observation might uncover whether "context aware security" promises benefits that are distinct from those of best practices in security, such as policy-based management and pattern-recognition for anomaly detection.

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19.09.2015

Emotion Tracking

Summary

Algorithm
Entertainment
Sensing
Boredom
Interaction

Emotion tracking systems combine sensors and analytical tools to read and monitor subjects' emotional states or reactions. They may rely mainly on video, voice, or motion data, or a combination of data. Some systems look for specific changes in emotional states. For example, cameras on video poker and slot machines detect when a player begins to get bored, and reacts by offering side bets or some other novelty. Likewise, fatigue detection systems warn drivers to rest by analyzing tiny changes in eye movement that signal drowsiness. Other systems monitor a caller's overall emotional state: call centers sometimes have a "dashboard" that advises whether a caller is amused, aggrieved, or likely to agree to a purchase. A few systems, building on the work of MIT professor Sandy Pentland, use voice and motion data to measure group interactions, levels of engagement, and a workplace's emotional tone.

Emotion detection has improved greatly in recent years. Algorithms can train on large databases of recorded phone calls, photographs shared on social media, and motion data from fitness bands. Improvements in digital cameras, microphones, and accelerometers have virtually eliminated hardware barriers to emotion detection. Finally, demand for the technology in a range of industries has grown.

Weaknesses

The technology is prone to errors in bad conditions (low lighting, loud rooms), and, outside highly specific use contexts (like driving), can be a challenge to interpret and act on.

Related fields

Nanobiotechnology, Wearable Computing, Bio Authentification, Biologically Extended Senses, Predictive Crime Prevention, Consumer Electronics, Quantum Computing, Marketing, Context-Aware Computing, Machine Learning, Psychology, Computer Vision, Sensors.

Civil Uses

Emotion tracking has potential application in fields where emotional states affect performance, including but not restricted to law enforcement, finance, transportation, gaming, marketing, education, health and safety, occupational training.

Trends & Challenges

Responsiveness
Misuse issues

Emotion tracking has improved dramatically in recent years. As we move into a future of pervasive computing, always-on personal devices, and ever-richer sensors, potential application areas will expand.

Key drivers include: Proliferation of increasingly sensitive cameras, microphones, and motion sensors; Vast quantities of data for training algorithms; Efforts to make

Cameras
Integration

automated systems (from video gambling to online learning) more responsive to users.

Key barriers include: Integration of emotion tracking technology into products; High potential for misuse or poor deployment; Potential legal/privacy challenges in civilian use.

General valuation

Diverse
Emerging

Emotion tracking technologies have improved significantly in recent years, and will continue to improve as enabling technologies become cheaper, more sensitive, and more widespread. In the near future, the biggest adoptions will be in professions where performance is affected by emotional states in measurable ways. Examples include: Fatigue detection for drivers, doctors and nurses; Student engagement with / comprehension of material; Fatigue and emotions of soldier and law enforcement; Emotional states of bankers and stock traders.

In some areas, technologies will compete against each other. In fatigue detection, for example, different systems detect drowsiness using video, eye tracking, motion sensors, or respiratory activity. In others, systems using dedicated hardware will compete with smartphone- or laptop-based apps. Workplace emotion detectors, for example, mainly use "smart badges" today, but more modern systems will be able to use smartphone sensors.

The technology will be challenged by privacy advocates on the grounds that such monitoring is intrusive. Further, stories of false reports or misuse could hinder adoption of the technology.

Defence valuation

Training
Fatigue detection
Interrogation

In defence and security, the major uses of emotion detection will be: Fatigue detection. Recent research has revealed how strongly fatigue can affect judgment, reflexes and decision-making. In circumstances demanding rapid decisions and life-and-death choices, fatigue can lead to fatal errors. Having the means to detect and objectively measure fatigue will help reduce such errors, and contribute to destigmatizing fatigue. Training: The ability to accurately measure emotional reactions during simulations and training will be valuable in selecting candidates for stressful jobs, training people to improve their emotional control, and learn to make positive use of heightened emotional states. Interrogation: Emotion detection could be helpful for detecting potential threats, assessing the emotional states of suspects or prisoners, or even measuring the mood of prison populations.

Main actors

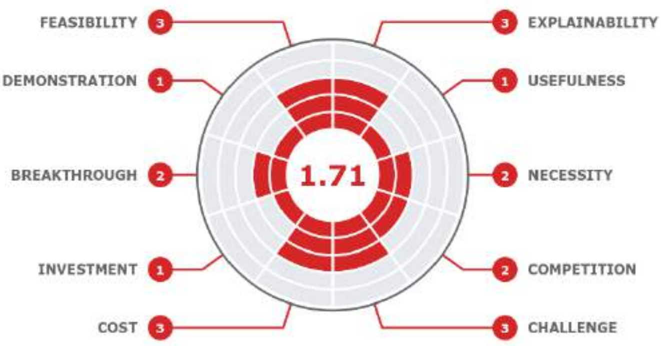
Sociometric, Fatigue Science, Affectiva, Emospeech, EmoVu, Optalert, MIT, Bally.

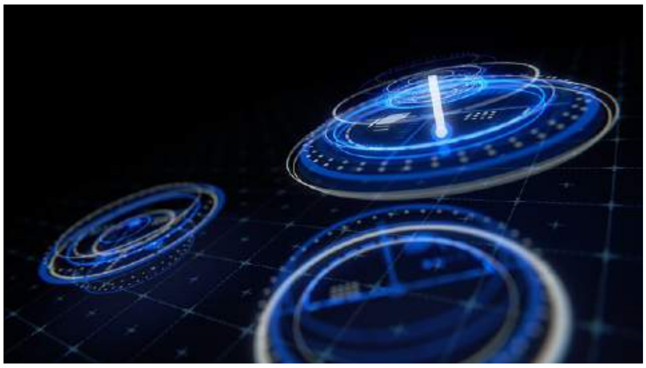
Recommendation

Observe
Try

As emotion detection technology advances, it will be integrated into a variety of products and workplaces, but it is important to note several caveats. **First**, emotion detection is a highly specialized field that draws on a variety of engineering specialties, psychology, and other disciplines. Adopting new technologies requires gigantic quantities of training data, complex algorithms, and machine learning systems. Like many high tech products, emotion detection tools will be at once easy to integrate into new products, but difficult to make. To draw a comparison: search is easy to add to Web sites through the Google API, but search engines are exceptionally hard to develop. **Finally**, outside highly specific applications their use becomes complicated, problematic, and sometimes even legally suspect.

Holographic Technologies





Summary

Hologram
Stereoscopic
Laser
Volumetric

Holodeck type experiences can be broadly divided into: Holograms, volumetric displays, stereoscopic 3D displays and virtual reality.

Holograms are a way of recreating the light from a physical scene using the diffraction pattern of the light involved. At present holograms can only be created on holographic plates, forming a still image. This gives the appearance of observing an object through the holographic plate as if it were a window.

Volumetric displays are currently extremely limited. Researchers using high-powered lasers have created rudimentary volumetric images by ionizing air particles.

Stereoscopic 3D displays are used to present movies in 3D both in cinemas and, increasingly, in the home. Most stereoscopic systems rely on users wearing special glasses that control the light reaching each eye. Manufacturers have also developed several auto-stereoscopic systems that create the same illusion without requiring special glasses, but with other limitations such as viewing angles.

Virtual reality frequently incorporates the use of special head mounted displays that provide different images to a user's right and left eyes and track head movements, creating the appearance of a 3D scene. (For a more detailed look at virtual reality systems please see the profile on Immersive multi-user VR.)

Weaknesses

Holograms are restricted to single static images. Volumetric displays face huge issues with energy consumption, noise, resolution and safety. Stereoscopic 3D requires either glasses or carefully controlled viewing conditions.

Related fields

Augmented reality, Wearable Computing, Nanoelectronics, Internet of Things, Telepresence, Virtual reality, Photography, Nanomaterials, Optical computing, Quantum Computing, Computer modeling, 3D printing, 3D scanning.

Civil Uses

Remote conferencing, videoconferencing, advertizing, virtual reality, gaming, cinema, optical computing/data storage, Computer Aided Design (CAD).

Trends & Challenges

Investment
Resolution
Increasing size

Static holograms and volumetric displays are not being widely pursued and offer only niche interest at present. Research in stereoscopic 3D is mostly focused on the home entertainment market. There is an ongoing push for larger screens and higher resolutions in the television sector and considerable effort has gone into developing ways of watching media in 3D. There is also interest in immersive 3D gaming experiences.

General

True holodeck experiences remain some way off. However, 3D displays is a

valuation

Incremental
Cost

relatively well understood technology that is slowly gaining acceptance due to consumer demand. However, any further developments in this field are likely to be refinements and improvements in industrial processes, reducing costs and increasing availability of stereoscopic, autostereoscopic and VR systems; the limiting factor is likely to be overall demand rather than direct competition from alternative technologies.

Whilst full holograms and volumetric displays do have significant potential, the gulf between the current state of the technology and the realistic is large, making any major short to medium term developments unlikely.

Defence valuation

Vehicle control
Training
Data interpretation
Reconnaissance
Data visualization

3D displays offer a way of presenting complex data in a convenient format allowing swifter interpretation than 2D displays. Potential applications include 3D maps and radar displays. It also has potential for combination with synergistic technologies, for example presenting 3D images captured by reconnaissance aircraft or remote unmanned vehicles. 3D displays could be used either as part of augmented reality displays or on their own to assist in vehicle maneuvers such as landing helicopters, guiding remote-controlled missiles, or piloting unmanned aerial vehicles. The potential for 3D imaging via virtual reality for training purposes is considerable.

Main actors

Sony, Samsung, Sharp, Philips, Sanyo, NTT Data Corporation, Panasonic, Itochu Corporation.

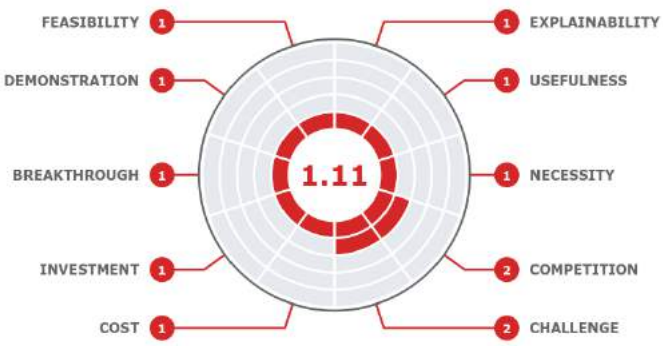
Recommendation

Observe
Try

Holograms, 3D displays and virtual reality are all relatively mature technology fields; their principles and potential are well understood. Whilst time and resources will lead to developments, there are major technological hurdles to further progress and it would seem unlikely that there will be any major leaps forward in the near future.

Players across a wide range of industries, including the defense sector, should consider trying the technology at its present state of development—in particular the use of 3D displays for conveying complex information e.g. for three-dimensional radar displays. Interested parties should also observe synergistic technologies, particularly 3D scanning techniques such as LIDAR that have the potential to allow rapid three-dimensional mapping of areas.

Hypersonic Technology



Summary

Friction
Mach 5
Missiles

Hypersonic speed is generally defined as being above Mach 5. However, there is no fixed speed definition because of physical changes in the airflow at the transition from supersonic to hypersonic. The ability to be able to accelerate objects to hypersonic speed, in air, has been available for some time and is used in many military missile systems. In theory, hypersonic speed can be achieved by any propulsion device that can overcome the frictional forces to continue to accelerate an object to hypersonic speed. However, at hypersonic speeds the friction of the object travelling through the air generates temperatures high enough to melt many traditional construction metals. This effect restricts the survivability of objects travelling at hypersonic speed.

Acceleration is also a big issue with achieving hypersonic flight, especially for the potential of human inhabited hypersonic flight. Humans cannot sustain g-forces greater than 4-6G and will feel discomfort at much lower G.

Most conceptual and experimental development of hypersonic technology has been for quick response delivery of tactical military operations including potential nuclear devices. While there has been a lot of development of commercial space projects, hypersonic flight is not required to achieve space flight.

Weaknesses

Survivability of objects at hypersonic speeds, including human survival (due to the friction-generated temperatures and the acceleration forces required to reach hypersonic speeds) pose significant problems.

Related fields

Materials Science, Nanoelectronics, Commercial Space, Smart Materials, MEMS, Propultion, Scramjets, Nanomaterials, Stealth & Camouflage.

Civil Uses

Physical limitations of human bodies, massive energy inefficiencies, and no matching problem space for the solution, limit civil applications. Logistics applications remain possible, but would struggle to achieve economic viability.

Trends & Challenges

Costs
Materials
Guidance
Survivability

The main challenge is the survivability of the object travelling at hypersonic speed. However, high cost solutions that can protect from extreme temperatures do already exist. Materials science advances, including atomic scale carbon, ceramics and composite materials may reduce costs.

Research will continue to focus on defense applications for long range, short duration, one-shot tactical strikes which may only act as deterrents and may never be deployed in conflict.

Future research trends will focus on control, guidance and propulsion. Guidance is a particular issue as traditional control surfaces either do not work or will not survive extreme temperature conditions.

General valuation

Reduced Funding
Long-Term
Conceptual

The maturity of hypersonic flight technology for application outside of military operations is very, very, low and is unlikely to see anything more than experimental demonstration within 50 years.

The key reason for this is the lack of problem space that hypersonic technology can provide the best solution to. The sole reason for hypersonic technology is to reduce the time between the initiation of an action and its physical execution. There are many technologies experiencing huge current growth, which provide a cheaper, more reliable or socially acceptable method of reducing this time. In the military context, cyber warfare and stealth technology are both examples that would be preferable to hypersonic technology. The notable exception to the above rule is human transportation, but limitations on what acceleration a human will tolerate, hold back implementation.

Hypersonic technology has seen reduced funding and interest in recent years and some high profile projects have lost focus or been shelved.

Defence valuation

High Cost
Restricted

Defense will be the big driver of hypersonic technology and the first implementation will likely be within defense. However, the technology is likely to be restricted to nations with massive defence budgets and may well be used as a deterrent rather than being implemented. The threat of nuclear attack via a hypersonic missile or aircraft is possible but if nuclear war becomes a reality, the deployment method is largely irrelevant.

Due to the high cost of hypersonic technology, its deployment as a threat is extremely unlikely within the next 20 years.

Main actors

Chinese military, DARPA, NASA.

Recommendation

Observe

Defense stakeholders should not focus efforts on hypersonic technology. Observing developments within a small number of big players (DARPA, Chinese Military) would be an interesting exercise but the low likelihood of realizable applications means that this should not become a priority or occupy too much time. Defense players should use these observation exercises to keep an eye out for potential game changers within the technology, but it is unlikely that any significant changes to capability will occur within the next 20 years.

Immersive Multi-User Virtual Reality

Summary

Software
Virtual reality
Displays

Immersive multi-user virtual reality (VR) creates the illusion that users are inside shared three-dimensional digital environments. Users can typically interact with these environments using natural or physical actions such as turning their head to change their viewing position. VR differs from augmented reality because VR isolates users from the real world rather than integrating real and virtual content.

Many VR approaches use stereoscopic near-eye displays, head-tracking position detectors, and (sometimes) handheld controllers, sensor gloves or other input technologies. These VR headsets have existed since the 1980s but costs are falling and performance is improving due to efforts to commercialize VR headsets for consumer entertainment applications.

An alternative to virtual-reality headsets are CAVEs (cave automatic virtual environments)—rooms equipped with multiple projectors that present images over entire walls and sometimes floors and ceilings. EON Reality's Icube is one existing commercial example of this approach.

As well as the virtual-reality user interface, immersive multi-user VR requires software to create 3D environments and to co-ordinate between multiple users.

Weaknesses

Many users experience motion sickness when using VR headsets. VR content is limited and expensive to develop. Display resolution is poor relative to conventional displays. Consumer adoption is still uncertain.

Related fields

Augmented reality, Portable power, Brain-controlled devices, Smartphones, Wearable Computing, Nanoelectronics, Context-Aware Computing, MEMS, 3D scanning, Brain-to-Brain Interfaces, Telepresence, Simulations.

Civil Uses

Gaming is the key application of new VR headsets. Other, largely experimental, applications include immersive cinema, education and training, rehabilitation, phobia-treatment, architecture, and financial-trading support.

Trends & Challenges

Consumer demand
Refresh rates
Gaming

Reducing motion sickness is a key issue for VR headset manufacturers. Faster screen-refresh rates appear to reduce (but as yet not eliminate) motion sickness.

Uptake of consumer VR headsets is still uncertain, and without mass-market adoption the cost-reduction and technology-improvement of VR will progress only slowly (as with CAVE systems that remain niche). To create success for consumer VR headsets, providers need to create games and applications that are compelling enough to drive headset sales beyond those consumers that are interested in VR for its novelty value.

General valuation

Consumer electronics
Falling costs

Consumer-oriented VR headsets offer the best prospects for progress in virtual-reality. Mass-market consumer adoption, driven by gaming, will be the key breakthrough and Oculus VR, Sony, HTC, and Samsung all plan to release consumer products by the end of 2016 (developer editions of some headsets are already available).

Augmented-reality headsets such as Microsoft Hololens or Magic Leap may compete with immersive VR—particularly if these devices offer compelling gaming experiences. Conventional gaming devices also provide key competition.

For defense and security organizations (and for businesses), immersive VR needs to develop “must have” rather than “nice to have” applications. For example, although immersive VR may improve training outcomes, similar outcomes can perhaps also be achieved with game-based learning on conventional computers.

Although developments in consumer electronics are driving down the cost of virtual reality headsets, developing VR content remains fairly expensive. Improvements in 3D scanning technologies could help reduce development costs for creating simulated environments. VR development costs are also likely to fall somewhat if VR gaming becomes popular because supporting authoring tools and techniques are likely to progress.

Defence valuation

UAVs
Training opportunities
Planning
Rehabilitation

Defense organizations have experimented with VR-based training since the early days of the technology and training remains the most common defense application of VR. Such environments allow users to experience realistic situational training (for example, battlefields, submarines, aircraft) in a safe environment. VR creates highly engaging learning though its impact on training outcomes over other forms of training is uncertain.

Beyond training, VR offers potential applications in operations planning, drone piloting, rehabilitation, vehicle operation, and remote the monitoring and control of facilities and equipment (that could be replicated in virtual reality). For example, the Norwegian army has prototyped an Oculus Rift controller for tank driving.

Mass-market acceptance (or rejection) of consumer will impact VR costs.

Main actors

Intelligent Decisions, Sony, Facebook (Oculus VR), EON Reality, Microsoft, Samsung, Magic Leap, HTC, Virtalis, Valve.

Recommendation

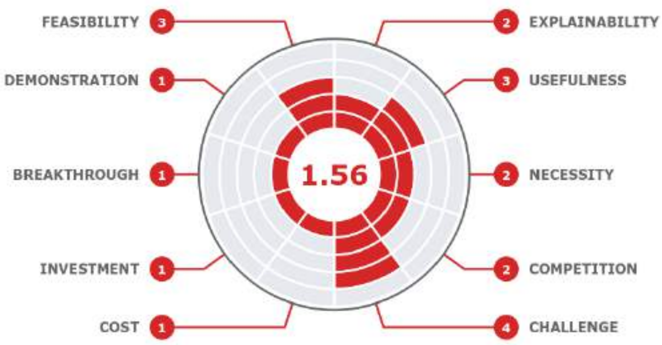
Observe
Try

Immersive VR is an important technology to observe, though its overall impact on the defense and security sector is likely to be one of incremental improvements within certain applications than of transformation.

Although some military training has used immersive VR technologies for many years, developments in consumer electronics are creating a new generation of high-performance, low-cost VR devices that can be repurposed for a variety of defense and security application uses. Although training is an established and likely worthwhile application to adopt, defense and security organizations should also evaluate and try other potential applications of immersive VR.

Consumer acceptance of VR is important to “observe,” as it will determine the future path of this technology area.

Intelligent Autonomous Swarms



Summary

Robotics
IAS

An Intelligence Autonomous Swarm (IAS) is a number of entities communicating and coordinating among themselves, autonomously, to achieve an objective. The objects in the swarm could be identical or different to each other, perform the same tasks or different tasks and could operate with a 'mother ship', which coordinates the swarm, or independently.

IASs exist in nature (ants or bees for example) and in recent years progress has been made to develop artificial swarms that function in a similar way. Investigations have been made into swarms on land, sea and in the air and in entities from large to small but the technology is still immature for most applications due to limits in power supply, communication technology and true autonomy. Most demonstration examples of artificial swarms have used semi-autonomous or human directed systems whereas fully IASs have only been conceptually demonstrated.

The military domain has seen examples of full-scale prototypes in recent years and is the most likely sector to see first implementation of semi-autonomous IAS. Other industries that will see their usage are likely to be agriculture, medicine and entertainment.

Weaknesses

Weaknesses include: A lack of true autonomy (systems are reliant on pre-programming); Energy storage/endurance; Miniaturization. Many limitations are also present in other autonomous systems—including drones.

Related fields

Medical Nanobots, Artificial Intelligence, Portable Power, Deep Learning, Nanoelectronics, Context-Aware Computing, MEMS, Smart Dust Sensors, Laser communications, Autonomous Vehicles.

Civil Uses

Civil applications could include capturing information from difficult-to-access locations (volcanoes, deep sea trenches or disaster zones). Healthcare/agriculture will likely adopt the technology to fight infections/look after crops, respectively.

Trends & Challenges

Miniaturization
Rudimentary

Current research is being directed towards the intelligent interactions of entities within the swarm to achieve collective objectives. This is partly due to it being an interesting academic problem but it also has importance in general AI research. However, this focus may hold back the development of more rudimentary swarm applications for data gathering and collective action.

General

When IASs are achieved, the technology has huge potential to revolutionise our

valuation

Conceptual

Emerging

world. Swarms could be deployed to perform a huge number of activities that current technology cannot, most notably autonomous monitoring of conditions and automatic deployment of responses to changes in conditions. A good example is medical nanobots that live within the human body and react to infections as they occur and deploy immediate responses. Another shorter-term example is the use of an IAS to monitor crop production, over a huge area, and automatically deploy nutrients, water or pesticides to optimise crop production. However, true IASs are still very immature (Technology Readiness Level 2-3) with semi-autonomous systems being much further along in development (Technology Readiness Level 4-5)

Defence valuation

Connected

New battlefield

IAS could be critical in defence and security. The technology will allow for persistent wide area surveillance, targeted attack and area denial by using devices small and large. Critical difficulties to be overcome within surveillance are miniaturisation and power management of the devices used.

The existing battlefield is already controlled and directed by large networks of manned and unmanned assets and this will only grow as swarm artificial intelligence improves. However, it is unlikely that true IAS will be used in military operations in the next 10 years due to a continuing choice to place men in the loop for command and control purposes.

Main actors

University of Lincoln (UK), Harvard University, Carnegie Mellon University, Sheffield Centre for Robotics, DARPA, University of Bristol, Tsinghua University.

Recommendation

Observe

All stakeholders within the defense sector should observe developments in IAS. The current low level of maturity means that real applications within the defense environment are still some time off. However, this is not the same story for semi-autonomous intelligent swarms, which will be deployed for defense purposes much sooner. Prototype swarm devices for reconnaissance have already been developed and tested by the US Navy. As such, interested parties should try and adopt these technologies where appropriate.

Internet of Things

Summary

Optimization
Connecting objects
Manufacturing
Sensors
Networks

The Internet of Things (IoT) is a broad set of technologies and applications that involve connecting objects other than conventional computing devices to the Internet. Such connected objects may include wearable sensors, smart thermostats, cars, industrial machines, and environmental sensors. Many more examples of connected objects exist and connectivity is spreading quickly. McKinsey estimate that IoT connections are growing at 15-20% annually and will reach 26-30 billion objects in 2020 (from a base of 7 to 10 billion objects in 2013).

IoT technologies include hardware such as sensors, actuators and power sources, networking technologies, and a wide-range of software technologies and products (from sensor networking software to IoT application platforms). Applications are as broad as the objects that they connect, but many involve collecting data from IoT sensors, performing data analysis in the cloud, and providing feedback and recommendations for improvements. Advanced IoT applications may also take action (for example, automatically optimizing a machines operation).

Weaknesses

Weaknesses include security (including personal privacy), energy management, and device-level interoperability (for example, many IoT applications are vendor-specific). Some IoT applications are more novelties than useful products.

Related fields

Portable Power, Robotics, Industry 4.0, Pervasive Computing, Nanoelectronics, Holodeck, Photovoltaic Transparent Glass, Laser Communications, Augmented Reality, MEMS, 3D Memory Chips, Big Data, Predictive Crime Prevention, Nanomaterials, Stealth & Camouflage, Medical Nanobots, Artificial Intelligence, Bionic Implants, Smart Materials, Context-Aware Computing, Smart Dust Sensors, Sensors.

Civil Uses

Consumer uses include health and activity monitoring, home automation, and connected cars. Business uses include retail, warehousing and logistics, monitoring and predictive maintenance for industrial machines and infrastructure.

Trends & Challenges

Security
Standards
Big Data
Industrial

Standards to enable interoperability between IoT devices is a significant challenge and various standardization efforts are underway. Though the Institute of Electrical and Electronics Engineers Standards Association has issued a number of IoT-related standards, wider standards development has fragmented into industry groups. For example, Thread focuses on home automation and the Industrial Internet Consortium focuses on industrial applications. Efforts involve competition between different software ecoystems and outcomes are uncertain.

Other current IoT research includes energy management (for example, standby power), cybersecurity for devices and data, and big-data analytics. Efforts to build cloud-connected robots are also important in the longer-term.

General valuation

Rapid Growth
Commercializing

Many IoT applications are commercial or near-to commercial. Samsung already sells many connected consumer products and says that every product it sells will connect to the internet by 2020. General Electric (GE) has built monitoring and analyzing data from its sensor-equipped machinery and related processes into a billion-dollar business. Cisco estimates that over 100 new Internet connections (people, processes, data, and things) occur every second.

Rapid growth of IoT seems likely and is expected by most analysts and vendors. However, lack of standards, security issues, and applications that deliver limited value could all temper IoT growth. Current trends suggest that IoT developments will be application specific (for example, home automation, industrial monitoring, connected vehicles) and IoT-adoption speed is likely to vary between these various application areas.

Many IoT opportunities require manufacturers to create new software and service businesses—sometimes a challenge for companies used to manufacturing only physical products. Many manufacturers need to build or acquire software and service capability, and learn to navigate the pitfalls of the software business (security, privacy, support, upgrades and more).

Defence valuation

Monitoring
Cyberwarfare
Networked Systems

Although the term “Internet of Things” is relatively new to many defence and security organizations, these organizations have been using IoT-related technologies for many years. Networked planes, land vehicles, weapons, and equipment routinely collect and share data. Autonomous technologies and surveillance systems are often reliant on network connectivity. Advances in networking and sensor technologies create the potential of equipping every military asset (including soldiers) with connectivity. Further, sensor networks (including smart dust) create the potential of situational monitoring of environments. Many military IoT applications are likely to rely on private networks rather than the open Internet (though some less sensitive applications may utilize standard cloud systems).

IoT developments are likely to change the landscape for cyberwarfare. For example, military organizations may help defend connected infrastructure such as power grids, pipelines, and manufacturing plants, against cyberthreats. Similarly, security organizations may help defend connected transportation and healthcare systems against cyberterrorism threats.

Main actors

Apple, Boeing, IBM, Intel, GE, Raytheon, Google, Lockheed Martin, Samsung, BAE Systems, Cisco.

Recommendation

Adopt
Try

IoT is a current technology within the defense and security sector, with significant potential for expansion into new application areas. Developments in the industrial IoT and in consumer IoT applications are likely to drive down device costs and create new connectivity solutions that can be repurposed for military applications. In addition, IoT growth in civil applications is changing the landscape for cyberwarfare. For these reasons, IoT is a critical technology to try and, in some cases, adopt.

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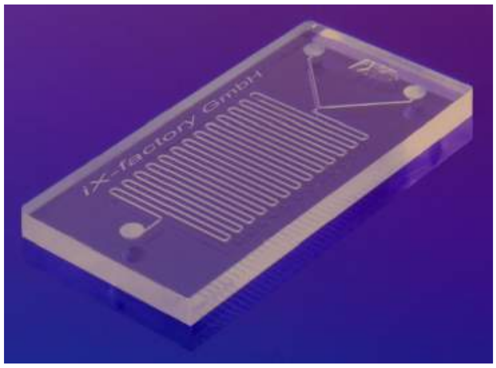
25.08.2015

Lab on a Chip



Summary

LoC
Microfluidics
MEMS
DNA

Systems vary greatly in what they integrate on the chip level and what they treat as a peripheral. Lab on a chip (LoC) systems feature micrometer-scale reaction chambers, channels, and sometimes pumps manufactured using techniques and substrates borrowed from MEMS and microfluidic research. Substrates include traditional semiconductors as well as glass, ceramics, metals, and PDMS. Because of their small size, LoC systems require lower fluid volumes to operate and offer faster analysis. For example, whereas DNA chips provide a large volume of data often with tens of thousands of DNA spots, many applications seek compact, rapid testing of only a dozen DNA markers. LoC systems downscale the sample preparation, DNA amplification, and DNA identification to a single chip to allow for compact and rapid testing.

Weaknesses

LoC devices tend to be single use, expensive, and often require large peripherals to operate. Designing LoC devices is difficult, as liquids behave differently on small scales.

Related fields

Portable Power, Nanoelectronics, DNA Analysis, Microfluidics, MEMS, Smart Dust Sensors, 3D Memory Chips, Bio Authentification, Chemical Analysis, Drug Delivery, Genetic Engineering, Nanomaterials.

Civil Uses

Civil uses for LoC technology are primarily portable rapid diagnosis of diseases and chemical concentrations. Similar technologies are used in drug discovery and manufacturing.

Trends & Challenges

Cost reduction
Improving Capabilities
Low-cost substrates

Because LoC devices are disposable, cost remains an issue for many potential applications. Many institutions are focusing research on inexpensive substrates as a method to combat costs, and paper microfluidics has seen substantial headway. Other research focuses on expanding the capabilities of LoC systems, especially improving the number of diseases they can detect.

General valuation

Testing
Mature

LoC systems are relatively mature and have seen substantial industry consolidation, although there is still substantial potential for improvement in the technology. LoC technologies may enable handheld rapid analysis of chemical and biological agents, or rapid blood tests capable of identifying a host of possible ailments in a single test. Plasmonics, a complementary rapid analysis technology, has seen some progress towards viability in the past few years, and could begin to reach its promised potential within the next few years. Because of the nature of the diagnostics market, it is difficult for new companies to enter and compete, unless they partner with an incumbent company.

Defence valuation

Rapid Diagnosis

Primary opportunities for the defence industry lie in the rapid diagnosis of diseases. This can be particularly important when testing troops, refugees, or others in military care to prevent outbreaks. Rapid diagnosis becomes especially important when troops venture into areas where dangerous diseases are rampant, the same areas where much of the world's conflict exists today. Theoretically, rapid tests may be completed as units are en-route to base from a mission. Rapid response and durability may be important to armed forces, and these organizations are less price sensitive than civil organizations.

Main actors

«empty»

Recommendation

Observe
Try

The LoC market is largely mature, but interested parties who are not directly involved with the technology may be able to engage with the market by partnering with a startup or existing diagnostic company to design and distribute, for example, rapid diagnostic tests. In the defense sector, the stakeholder's job would primarily be as a systems integrator, ensuring that the devices have military-grade readiness. Given the ease with which an incumbent diagnostic company may design its own military-grade versions of its LoC tests, it may be unwise for defense stakeholders to directly enter this market. Trials of "off the shelf" technology represents a viable route to adoption. However, the implications of this technology could be significant for the defense sector and defense players should definitely observe developments that could have a positive impact on the quick diagnosis of diseases in remote environments.

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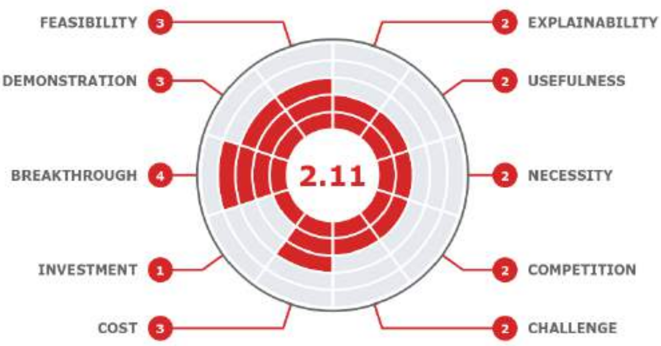
Laser Communication / Free Space Optics



Summary

Modulation
Optical wireless
Communications
Line-of-sight

Free space optical (FSO) communication (sometimes also referred to as optical wireless communication or OWC) is a method of data transmission between two locations that uses modulated visible (or near visible) light. Unlike radio communications, which can be transmitted through and around objects, FSO requires a direct line of sight between the transmitter and receiver; this also means that FSO systems are difficult to intercept as any eavesdropper would have to be positioned along the path of the laser beam.

FSO systems have been used to communicate between fixed locations, to communicate with moving vehicles and aircraft, and to communicate with orbital satellites. FSO systems typically use lasers as their light source, although some systems have been trialed using high-brightness LEDs.

Weaknesses

FSO systems are limited by atmospheric conditions and by requiring a direct line of sight. Communicating with moving vehicles or aircraft requires sophisticated tracking technology to maintain contact.

Related fields

Internet service provision, Optical computing, Portable Power, Communications, Nanoelectronics, Fiber optics, Internet of Things, Radio, Telecommunications, Mobile networks, Swarms.

Civil Uses

FSO can be used for satellite communication; urban telecommunications; rapid network deployment, for disaster recovery; and private networks, as it is often not regulated in the way radio frequencies are.

Trends & Challenges

Amospherics
Range
Algorithms
Error reduction

The key focus of research on FSO is increasing the effective range, which is predominantly limited by atmospheric conditions. One option is to combine FSO with a backup system such as a radio transmitter, for use in poor atmospheric conditions. Alternatively, researchers have looked at using error correction algorithms and adaptive optics to compensate for atmospheric disruption. Other approaches include using multiple beams or multiple communication paths to eliminate errors via redundancy or to use more powerful lasers when weather conditions are not conducive.

General valuation

Immature
Convenience

Unreliability is a key factor in the technology not achieving wider acceptance. At present optical fibre and radio communications offer more robust solutions for most purposes that require reliable year-round all-weather telecoms.

The future development of FSO is likely to hinge on niche applications. For example, initial tests using FSO for communicating with satellites has yielded

Secure

encouraging results. University researchers have investigated FSO as an alternative to WiFi, achieving data transfer rates of over 100Gbps in laboratory settings.

FSO is also relatively secure, unlike radio transmissions, which can be readily intercepted—line of sight requirements add an additional level of security. This also means that FSO could be employed without it being apparent to third party observers.

The transmission of data through free space also means that a network using FSO could be set up relatively quickly and cheaply, for example in densely built-up areas or as part of a response to natural disasters. FSO is one of several wireless transmission technologies being considered for both governmental and private large area networks such as Facebook's internet.org and Google's Project Loon that aim to provide internet access to remote areas via a network of high-altitude drones or low orbit satellites.

Defence valuation

Rapid deployment
Communications
Reliability
Secure

The difficulty in intercepting, or even detecting the presence of FSO communications makes it potentially very useful for military communications. In addition, the absence of any cabling requirements enables the rapid deployment of a telecoms network. The use of visible light frequencies also means that it is not prone to electromagnetic interference or radio jamming. Combining ground-based FSO transceivers with unmanned aerial vehicles as relay stations could dramatically increase the effective range of an FSO network.

As with civilian applications the unreliability of FSO due to poor weather conditions is a limiting factor. In addition, military use may include communicating with moving objects such as aircraft or ships; under which circumstances maintaining contact requires sophisticated tracking technology and the difficulty of maintaining contact grows exponentially with distance.

Main actors

Tesat (Airbus), IEEE, DARPA, LightPointe Communications, AOptix, Fog Optics.

Recommendation

Observe
Try

The current state of FSO technology faces substantial barriers to widespread adoption but is useful for niche applications.

Defense players should observe developments that can increase the range and reliability of FSO transmission such as adaptive optics. Attention should also be paid to advances in potentially synergistic technologies such as targeting/guidance systems and unmanned aerial vehicles (UAVs or drones).

Difficulties in establishing a reliable network mean that in many instances conventional telecoms technologies such as radio and fiber optics will offer advantages. It is unlikely that FSO will supplant these technologies and is more likely to progress in parallel in the short to medium term. Improvements in signaling distance may lead adoption in satellite communications and local area networking applications.

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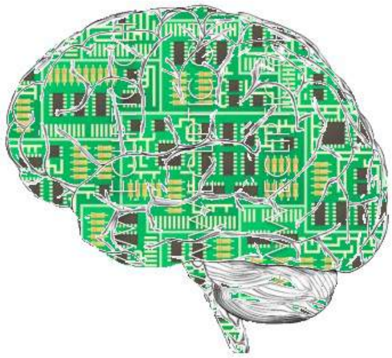
Machine Learning



Summary

Statistics
Software
Big Data
Algorithms
Neural networks

Machine learning is a class of software systems that generate behaviors by learning from examples, or by trial and error, rather than by rule-based programming. For example, a programmer creating rule-based translation software would need to define each explicit step in a translation process the software should perform (parse the sentence, examine dictionaries, and so forth) whereas a machine-learning translation system would build its own translation model by examining patterns in existing translations.

Examples of machine learning algorithms include neural networks, genetic algorithms, Hidden Markov Models, and statistical clustering. Some approaches require labeling of training data (e.g. “English text”, “German text”) and other approaches can learn from unlabeled data.

Most machine-learning approaches are not new but have benefitted from the rapid growth of data (big data) and from increasing processing power. In 2011, Google’s Chief Scientist said “We don’t have better algorithms than anyone else; we just have more data.” Machine learning is already somewhat common in civil and military software but its capabilities and application areas are growing as available data and computing power continue to accelerate.

Weaknesses

Vulnerability to errors and biases in input data (garbage in, garbage out), slow initial learning processes, and programmers are often unable to explain why specific inputs produce specific outputs.

Related fields

Artificial Intelligence, Quantum Computing, Analytics, Context-Aware Computing, Statistics, Computer Vision, Big Data, Predictive Crime Prevention, Emotion Tracking.

Civil Uses

Current applications include online advertising, fraud detection, spam detection, speech recognition, image recognition, predictive policing, automated financial trading, logistics optimization, and personal cloud assistants (for example, Siri).

Trends & Challenges

Deep Learning
Algorithms
Unsupervised Learning

Much current research interests focuses on “deep learning”. Deep learning is typically implemented as neural networks that learn from data in “layers”, identifying high-level features before narrowing down on detail.

Approaches to unsupervised learning are developing well (unsupervised learning avoids the overhead of people having to label training data). Developing machine-learning algorithms that can adapt and learn new tasks quickly is also under investigation.

No realistic solution to the "garbage in, garbage out" problem exists and this limitation requires programmers to implement machine learning carefully.

General valuation

Trust
Rapid development

Particularly in civil applications, machine learning has already proved itself superior to rule-based programming for applications requiring pattern recognition or judgment. As a result, machine learning has become the de-facto standard for building intelligent software (most recent innovations in artificial intelligence rely on machine learning).

Even greater progress is likely in the future. Global data is currently increasing by around 40 percent a year, and machine learning systems generally improve with more data. Researchers are making steady progress with new machine learning techniques, but most progress will come through the growing availability of large data sets and plentiful computing resources allowing programmers to get better results from existing machine learning algorithms.

How far machine learning will expand into new domains depends partly on technical progress (see Present Weaknesses, above) and partly on the attitudes of system designers. For example, whether designers are happy to entrust the outcomes of a system to probabilistic reasoning or whether they require explicit rules.

Defence valuation

Autonomous
Missile-tracking
Robotics
Image analysis
Drones
Satellite

Machine learning already has a wide-variety of important defense and security applications. For example, using missile-tracking data, machine-learning software can predict missiles' paths to guide intercept missiles. Many pattern recognition algorithms are useful for processing satellite, drone, and other imagery, and for identifying likely threats. Indeed, machine learning is the leading approach to automating image analysis. Machine learning can also guide military robots and other autonomous systems and can play a role in optimizing military logistics.

Much military research focuses on applying machine learning to robotics and other autonomous systems (for example, creating robots that can adapt to changing conditions and learn new ways of achieving their objectives), though in practice machine learning is a potential aid to any defense and security task that involves making a judgement based upon large amounts of data. Civilian organizations are starting to use machine-learning algorithms to aid recruitment processes.

Main actors

Digital Reasoning, IBM, Raytheon, Google, Lockheed Martin, Microsoft, Sentient Technologies, BAE Systems.

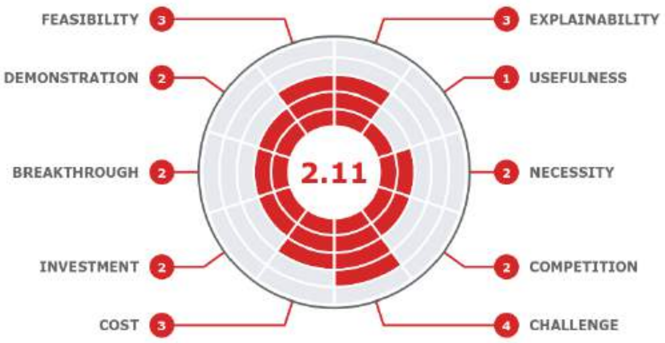
Recommendation

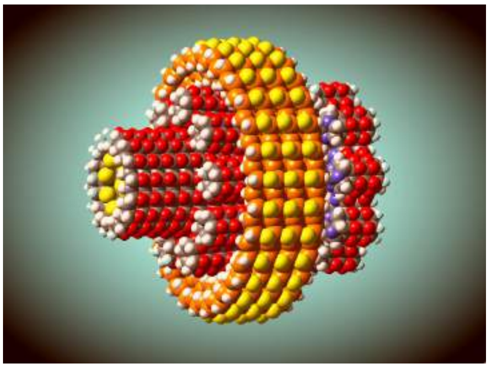
Adopt
Try

Machine learning is the leading approach to building software that makes judgments based on large amounts of data and is a proven technology, even as a component within safety-critical systems (for example, missile interception).

Because data is growing rapidly, and because machine learning generally improves with more data, rapid progress in machine learning is likely. Because of this growing capability, and because of the wide-variety of important applications, machine learning is a critical technology for across a wide range of industries, including the defense sector.

Medical Nanobots





Summary

Drug delivery
Microscopic devices
Microorganisms
Propulsion

Microscopic devices that can enter human bodies and autonomously perform therapeutic tasks, provide treatments, or gather data remain very immature. Generally, medical nanobots resemble true robots in name only—in practice, these microscopic devices need to be so small to travel through the human body that they cannot contain sophisticated control systems or even perform more than one or two actions. The simplest nanobots are little more than a microscopic structure that carries out some kind of physical task, such as opening to release a drug or attaching to tissues or pathogens. Simple artificial, as well as biologically based devices—such as modified proteins or microorganisms—can be useful in this kind of rudimentary role, although the term nanobot can be misleading label for devices that are little more than a complex particle. More sophisticated nanobots may be able perform a few functions, such as propelling themselves to a particular location and performing targeted action upon arrival. Researchers hope to eventually produce nanobots that more closely resemble their full-size artificial counterparts by employing actual electronics and logic systems to take intelligent autonomous action in the body, but such devices remain little more than a theoretical concept at this time.

Weaknesses

Weaknesses include controllability and survivability of nanobots in complex biological systems as well as general difficulties in manufacturing functional devices at such small scales.

Related fields

Bionic Implants, Nanotechnology, Medical devices, Pharmaceuticals, Chemical engineering, Robotics, Genetic engineering, MEMS, Synthetic biology, Micromachining, Nanofabrication.

Civil Uses

Medical treatments, health monitoring, biological research, veterinary medicine, therapy, environmental services.

Trends & Challenges

Regulations
Device design
Nanofabrication
Propulsion

Current research focuses both on creating nanobots to perform novel targeted action inside humans and developing propulsion methods for the microscopic devices. Examples of actions that nanobots can take inside bodies vary from semi-passive acts of delivering drugs by either implanting into tissues or opening to release treatments at specific locations to more active physical actions such as heating up to open a temporary hole in the blood-brain barrier. Research into propulsion methods includes work on swimming or crawling-like movement controlled by external electromagnetic fields or by inserting various chemicals into the body, as well as the development of self-propulsion methods—one recent project from the University of California tested a self-propelled nanobot that used a reaction between zinc and stomach acid to produce gas bubbles that successfully drove the device into the stomach linings of mice.

General valuation

Immature
Theoritical
Safety

Medical nanobot technology is at an early stage in development and will likely take many years before becoming available for human use. Furthermore, the prospects for advanced devices to actually operate semi-intelligently inside the human body remain purely theoretical—numerous improvements on micro- and nano-scale power systems, computational systems, and physical devices will be needed for any true internal robot to become practical.

Nevertheless, progress suggests that the fundamental concept of using nanobots in medicine is feasible. Constituent technologies like targeted drug delivery and propulsion using internal or external mechanisms have already worked in labs, and rudimentary nanobot technology could begin to see human tests in the next stages of research.

Other obstacles besides the feasibility of operation will affect the implementation of medical nanobots. Some otherwise functional nano-devices could prove to be unsafe in the human body, for example, and any signs of danger from one particular nanobot design could tarnish the reputation of all varieties in public opinion. Passing regulatory approval will likely be difficult as well since the technology has no precedent. Competition from traditional pharmaceuticals could also challenge nanobots, especially if traditional medicines remain either as effective or lower-cost.

Defence valuation

Health
Detection
Weapons

Although medical nanobot technology is not currently mature enough to provide significant new treatments in defense applications, at least in any capacity that exceeds its utility in treating civilian patients, as early adopters it could find use in defense markets earlier than civilian markets. Additionally, military research on micro-robotics and nanotechnology could prove to be synergistic to medical research on nanobots. More distant—but possibly more impactful—implications of medical-nanobot-technology development could be threats from hostile parties. Examples could include nanobot-deploying biological weapons or covert monitoring and surveillance of individuals using networked nanobots. Countering these threats might be incredibly difficult because of the detection challenges, as well as the potential lack of countermeasures or treatments for nanobot infections.

Main actors

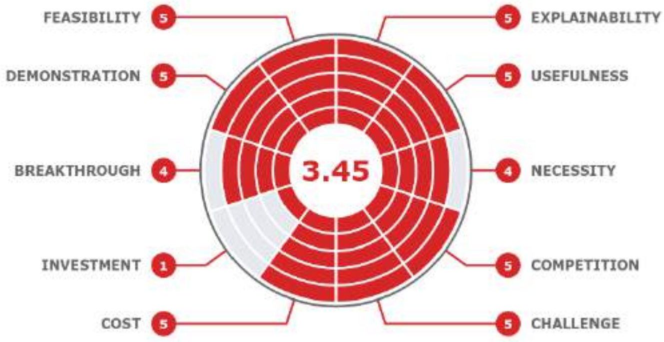
University of Montreal, Max Planck Institute for Intelligent Systems, University of California, ETH Zurich.

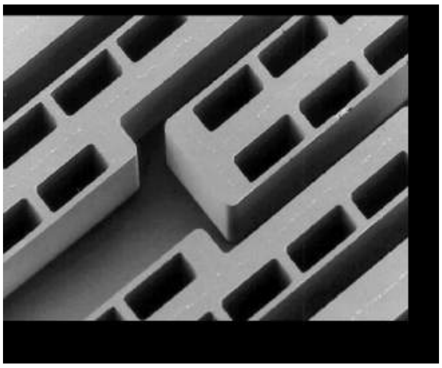
Recommendation

Observe

Adopting practical medical nanobot technologies would be extremely difficult at the current time considering that only a few successful devices have even been tested in research and development settings. However, monitoring nanobot technology will be essential for maintaining awareness of any new developments in the field and addressing emerging opportunities and threats. Additionally, initiating new research endeavors could be beneficial—and even critical—for any player hoping to have a stake in the development and use of medical nanobots. But because a limited number of researchers and institutions have working knowledge of nanobot development, partnering with existing developers will be essential.

MEMS





Summary

Consumer electronics
Sensing
Lithography

MEMS are micrometer-scale electro-mechanical machines, manufactured using lithographic processes adopted from the semiconductor industry. In fact, many MEMS foundries use equipment previously employed in semiconductor foundries. The biggest market for MEMS is sensing, including pressure sensors, accelerometers, and gyroscopes. In recent years, MEMS sensors have seen strong adoption rates in consumer electronics devices as enablers of new user interfaces. MEMS sensors are generally superior to macro-scale sensors because they are smaller, more durable, more accurate, consume less power, and are inexpensive to produce in bulk—usually sold for a few cents a piece. Non-sensor uses of MEMS include micromachined radio-frequency components (RF MEMS), switches, timing devices, optical image stabilizers, micro-pumps, and inkjet and 3D print heads.

Although some MEMS processes today employ nanoscale particles as sensing elements, nanoscale features in MEMS will become much more common over the coming decade, at which point MEMS may compete with devices manufactured using exotic technologies such as molecular manufacturing and self-assembly.

Weaknesses

MEMS manufacturing requires a very high initial investment, discouraging new startups, and uses some materials not shared with semiconductors. MEMS fabrication also has some limitations on manufacturing three-dimensional structures.

Related fields

Self-assembly, Solid-state microsensors, DNA sequencing, CMOS fabrication, DNA origami, Molecular machining, NEMS/nanomachines.

Civil Uses

MEMS already see use in vehicle safety systems, consumer electronics devices, computer components, displays, and genetic testing. Future applications include radiation-safe computation and micro-scale robotics.

Trends & Challenges

New devices
Sensor fusion
New markets

The largest current trend in MEMS is rapid expansion into new markets and devices, including watches, fitness trackers, headsets, remote controls, and virtually any device that adopts “smart” functions. Many MEMS manufacturers and device makers are trying to improve sensor fusion between discreet sensors. Sensor fusion combines information from multiple disparate sensors to generate a more complete understanding of a device’s surroundings. Sensor fusion is of particular interest to makers of virtual and augmented reality headsets, as well as researchers interested in indoor navigation and simultaneous location and mapping.

General valuation

Growing market

MEMS is a mature technology. MEMS sensors have not substantially changed in design for decades, and most innovation in the sensor area is in reducing costs and improving accuracy through software via sensor fusion. The market for MEMS sensors continues to grow through demand for smartphones, tablets, quantified self devices, and virtual and augmented reality headsets. Some optical technologies are competing against MEMS for generating position information, but more often than not, MEMS are paired with competing technologies through sensor fusion, simply because the cost of MEMS components is so low and the benefits of sensor fusion are great. Non-sensor MEMS applications have seen hit-and-miss success, largely dependent on yield rates, especially for displays. The MEMS market is likely to continue to grow in sensors (including microphones), but non-sensor MEMS applications will remain a small market for quite some time.

Defence valuation

Communication devices

Mature technology

Navigation

MEMS devices are important in the defense industry, but most of their uses have already been realized: through incorporation in navigation and safety systems in a wide variety of vehicles. However, MEMS may find use in non-traditional applications relevant to the defense industry. For example, RF MEMS may help miniaturize communication devices for espionage, or allow systems to change frequencies to avoid jamming. Primitive MEMS computers that are highly radiation resistant may be important for defense in controlling basic but essential functions such as altitude control in aircraft or reactor control in nuclear power plants, where radiation and electronic warfare risks may compromise traditional computers-and therefore human lives.

Main actors

Freescale, STMicroelectronics, InvenSense, Bosch, Analog Devices, Texas Instruments.

Recommendation

Observe

Adopt

Try

MEMS devices are already in use in a variety of defense assets, and sensor fusion software is often included at the package level by foundries. MEMS sensors may find useful implementation in distributed surveillance via mesh networks. However, the design of the sensors themselves, as well as their sensor fusion algorithms, is best left to incumbent manufacturers. Relatively novel use of MEMS technology, such as RF MEMS and MEMS computers, may be worth observing closely or trying, as the technologies are nearing commercialization and may provide substantial benefits to defense.

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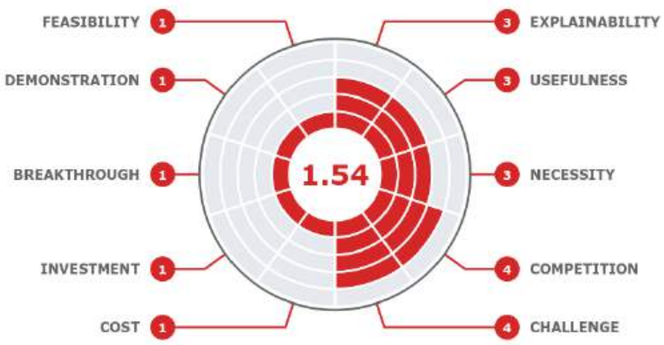
Nanobiotechnology



Summary

Nanotechnology
Biological systems
Pharmaceuticals
Nanomaterials

Nanobiotechnology is the convergence of nanotechnology and biology. Nanotechnology is an area encompassing research and technology developments involving structures typically 1 nanometer to 100 nanometers in length in at least one direction. Biology is a very broad and fundamental field, which means that the definition of nanobiotechnology encompasses a wide range of technologies. Generally, the fundamental principle behind nanobiotechnology is the interaction of nanotechnologies with biological systems. However, nanobiotechnology can also involve the combination of biological molecules with nanotechnology to create new systems and devices, or even the exploitation of nano-sized biological molecules to create new technologies. The use of microorganisms to create nanoparticles is also a part of the nanobiotechnology field.

Simple examples of the implementation of nanobiotechnologies include the use of titanium-dioxide and zinc-dioxide nanoparticles to improve the effectiveness of sunscreens. Although potential growth in cosmetics exists, the disruptive element of nanobiotechnology is arising in pharmaceuticals. The pharmaceutical industry provides nearer-term market opportunities through the development of developing more effective and targeted drug-delivery mechanisms, and introducing properties —such as controlled release—that enhance drugs' efficacy and safety. Other research—typically from universities and small companies—is seeking to exploit nanobiotechnologies for use in the materials and sensors industries.

Weaknesses

The main difficulty facing nanobiotechnology is the lack of knowledge about its possible harmful effects on health and the environment. The accuracy and ability of manufacturing techniques could limit nanobiotechnology.

Related fields

Medical Nanobots, Nanotechnology, Pharmaceuticals, Portable Power, Smart Materials, Environmental Management, Bio Authentification, Biologically Extended Senses, Home Care, Biotechnology.

Civil Uses

Advanced drug delivery, diagnostics, building materials, cosmetics, research tools, DNA sequencing, detergent, anti-microbial surfaces, biodegradable electronics, drug development, controlled-release systems, odor elimination.

Trends & Challenges

Testing
Understanding

Pharmaceuticals will be the first major industry on which nanobiotechnologies have a disruptive impact. Although achieving regulatory approval is difficult, the life-saving possibilities of the drugs will likely outweigh their potential toxic side effects. Pharmaceuticals will likely help to pave the way for the use of nanobiotechnologies in other industries by advancing the knowledge and understanding of

Regulations
Toxicity

nanobiotechnologies and developing regulatory frameworks. Currently, the lack of understanding of the potential threats from nanobiotechnologies is a major barrier to commercialization and has resulted in cautious regulations. However, signs suggest that regulatory authorities want to encourage the growth of the nanobiotechnology field.

General valuation

Standards
Breakthroughs
Consumer

The cosmetics and personal-care industry has long been a proponent and early adopter of nanotechnology to develop products—such as deodorants and toothpaste—with improved properties. After cosmetics, the most mature use of nanobiotechnology is found in the pharmaceutical industry. Some manufacturing processes and designs for, for example, drug-delivery systems have become standardized and dominant, which suggests a certain degree of maturity. However, since the first "nanodrug" achieved approval from the US Food and Drug Administration in 1995, few other similar drugs have become commercially available. Nanobiotechnology as a whole is fairly immature. Thus, the availability of nanobiotechnologies is low. Regulations surrounding nanotechnologies—particularly if they are likely to come into contact with humans—are often strict. Establishing safety standards will be key to the success of nanobiotechnologies. They offer the potential to vastly improve many common products, but are in competition with more typical technologies that offer incremental improvements at vastly lower costs.

Defence valuation

Heath
Biothreat
Structural materials
Sensors
Weapons

Nanobiotechnologies could find use as an important enabling component for other defense opportunities. For example, nanobiotechnologies could help facilitate the interaction between human-augmentation devices and the human body. These nanobiotechnologies could be hugely significant if they are the only means of making these defense opportunities viable. Some nanobiotechnologies in their own right could find use in the defense sector. For example, nanocellulose has a Young's modulus similar to Kevlar. The lightness of nanocellulose and its abundant source material (cellulose) may make it a desirable alternative to Kevlar. Nanocellulose has also been shown to encourage wound healing. Nanobiotechnologies also offer opportunities in biothreat detection and prevention. Nanobiotechnology sensors could find use in the early detection of biothreats and chemical weapons, with the possibility of relaying real-time data. However, nanobiotechnologies are a biothreat in themselves, offering up the possibility of biological weapons that persist in the body for longer periods of time.

Main actors

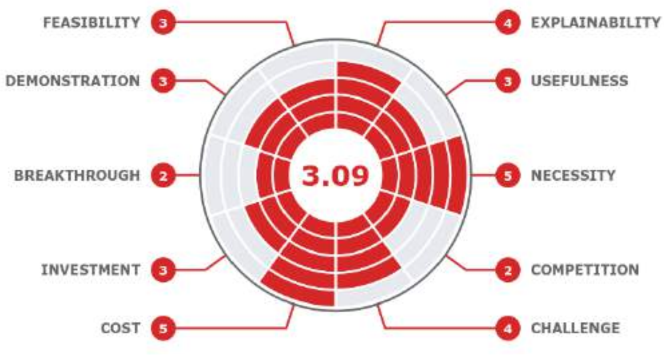
Johns Hopkins Institute for Nanobiotechnology, Nanoscience Diagnostics, CelluForce, Laboratory for Soft Bioelectronic Interfaces (EPFL), Innventia, Nucryst Pharmaceuticals, Oxford Nanopore Technologies.

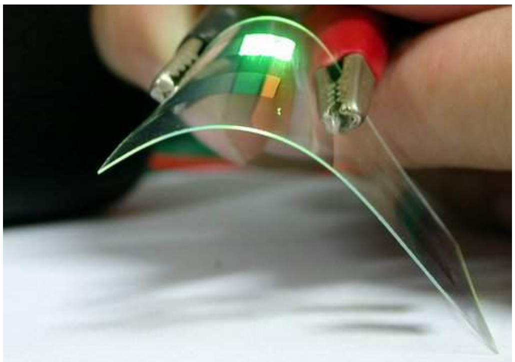
Recommendation

Observe
Try

Given the overall immaturity of the area, beware hype. Many small companies are involved in nanobiotechnology and will want to say their technology is game changing. Although their technology could be significant, it is worth bearing hype in mind while observing the progress of nanobiotechnology. Monitoring the regulations concerning nanotechnology is also important because they are likely to impact the rate of progress in nanobiotechnology and the applications in which it can find use.

Nanoelectronics





Summary

Materials
Nanotechnology
Manufacturing

The field of nanoelectronics can be defined as the use of materials and processes with features smaller than 100 nanometers to create structures with useful electronic properties. Decreasing dimensions in electronic devices has a long history of delivering cost and performance improvements. As the scale decreases to the nano level, new and enhanced material properties can arise because of quantum-size effects, interface phenomena, and very high surface-to-volume ratios. The standard top-down manufacturing processes that currently find use in the semiconductor industry represent only one option for fabricating nanoscale electronic components and devices. Indeed, such lithographic methods are too expensive for many applications. As such, solution-based nanoparticle growth methods, nanoimprint technology, and molecular self-assembly will become increasingly important for the future creation of novel nanoelectronic materials and structures.

Nanoelectronics will have an impact on almost every industry because electronic devices and systems are becoming increasingly pervasive. Although information technology and consumer electronics industries have already felt the impact of nanoelectronics through applications such as enhanced memory storage, and will continue to do so through a “flexible electronics revolution”, new nanodevices are also set to heavily influence the future of a wide number of industries—including energy, lighting, and biomedicine.

Weaknesses

Further reductions in scale through the use of optical lithography is becoming prohibitively expensive. Many bottom-up alternatives (such as self-assembly techniques) are currently too immature to make a significant impact.

Related fields

Quantum computing, Biomedical, Integrated circuits, Organic electronics, Energy storage, Photovoltaics, Photonics, Lithography, Nanofabrication, Nanomaterials.

Civil Uses

Nanoelectronics are already widespread in civil applications. Examples include: memory technology, interconnects, energy storage, biomedical applications, displays, photovoltaics, sensors, lighting, transparent conductive applications (touchscreens), and flexible electronic applications.

Trends & Challenges

Materials

Improving top-down fabrication techniques to enable further reductions in the size of structures is becoming increasingly challenging, both technically and economically. Photonic computing, quantum computing, next-generation materials, and bottom-up techniques are under study but are relatively immature and will not

Fabrication

be in a position to challenge silicon-based technology in the near- to medium-future. However, graphene, and other atomically thin materials, are set to have a large impact on the electronics industry over the coming decade and will enable many flexible and rollable devices and applications. Product reliability is currently the key barrier to the commercialization of flexible electronics.

General valuation

Materials
Emerging

Nanoscale materials and structures give players within the integrated circuit industry access to electronic properties that would be otherwise unattainable. This sector of the industry is set to undergo a period of sustained growth as technologies gradually mature and begin to find use in commercial applications. Semiconducting nanoparticles—or “quantum dots”—represent the perfect example of nanomaterial research recently maturing to find use in the electronics industry. The materials were discovered in the 1980s but are only now beginning to find application in LCD televisions—improving the quality of the color palette to levels previously only achieved with OLED displays and without significantly increasing costs. Other materials find themselves at different levels of commercial maturity within the industry. In addition to quantum dots, other key materials include silver and copper nanoparticle inks for conductive applications, carbon nanotubes, metallic nanowires, conductive polymers, and graphene (alongside other two-dimensional materials such as molybdenum disulphide, silicene, tungsten diselenide, and boron nitride). Some health and environmental concerns surrounding the use of some nanomaterials (cadmium-containing quantum dots being a prime example) in the electronics industry do exist. However, any concerns are not as great as within the food or cosmetics industries.

Defence valuation

Electronics
Energy
Detection
Sensors

The ubiquity of nanomaterials and nanoscale structures within the integrated circuit industry makes the field of nanoelectronics of the utmost importance to the defense industry. All electronic devices currently in use in the military currently contain nanoscale structures of some description—meaning that this profile area already underpins huge swathes of defense technology. The importance of nanoelectronics is only set to increase as novel nanomaterials enable next-generation applications. For example, advanced communication systems, high performance sensors (chemical/infrared), energy-harvesting applications, and wearable devices/textile-integrated electronics will be of particular importance to the defense sector in the coming decades.

Main actors

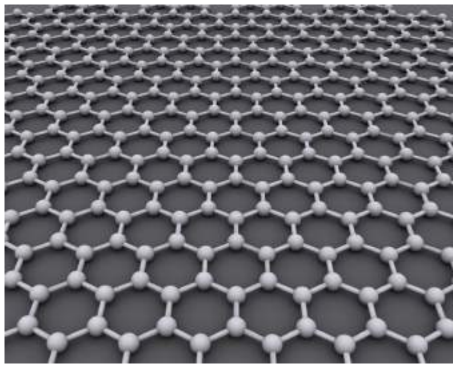
imec, Western Digital, Sandisk, IBM, GMZ Energy, Hewlett Packard, Seagate, BASF, QD Vision, Intel, Honeywell, Thinfilm, Samsung, Hitachi, Cambrios, OCSiAl, AMD.

Recommendation

Observe
Adopt
Try

Within the technology area as a whole, several materials and techniques are at different stages of development—meaning that stakeholders within the sector have the opportunity to simultaneously apply actions that come under the categories of Observe, Try, and Adopt. Nanoelectronics components for military-grade devices can often be sourced directly from commercial players because many products already perform to the standards required for defense applications. In other cases, more specialist, high-performance equipment can be developed in-house, in collaboration with academic/government research laboratories, or with industrial players with specific expertise.

Nanomaterials



Summary

Materials
Nanotechnology
Electronics
Energy
Consumer

Nanomaterials are materials that have dimensions or features between 1 and 100 nanometers and that possess unique properties as a result of these dimensions. At this scale, gravity no longer plays an appreciable role and other forces—such as electrostatic interactions—tend to dominate. Factors such as size, shape and even the nature of the surrounding material govern the properties of nanomaterials. Nanomaterials have the potential to outperform conventional materials in practically every sense. They exhibit enhanced mechanical and electrical characteristics as well as unique optical and thermal properties. These astonishing properties mean that nanomaterials have the potential to enable game-changing developments in almost all industrial sectors and address a variety of commercial needs. Indeed, nanomaterials already pervade our everyday lives to an extent that many people do not fully appreciate—finding widespread use in the electronics industry, the health sector, the production and storage of renewable energy, a wide variety of consumer goods, the construction industry, and the automotive sector. Research in this field is extremely fast moving but the "nanorevolution" is still in its infancy.

Weaknesses

Health fears, public perception (hype and concern), and increasingly strict regulations could limit commercial applications. High costs in developing materials and scaling up manufacture could also pose barriers to commercialization.

Related fields

Nanobiotechnology, Integrated circuits, Nanoelectronics, Photovoltaics, Internet of Things, Photovoltaic Transparent Glass, MEMS, Photonics, Nanofabrication, Organic electronics, Energy storage, Catalysis, Smart Materials, Smart Dust Sensors, Plasmonics, Self-Healing Materials, Lithography, Composites, Labs on Chips.

Civil Uses

Potential and actual applications are widespread: Cosmetics, touchscreen displays, drug delivery systems, components in photovoltaics systems, food additives, pigments, oil additives, high-strength polymer composites, polishing materials, functional coatings, next-generation electronics.

Trends & Challenges

Environmental
Commercialization

Market demand for materials with advanced properties will ensure that research into nanomaterials remains highly active. Key challenges currently involve transferring proven technologies from research labs to the marketplace and the development of cost-effective manufacturing processes for high volumes of material. In some cases lower cost alternatives are needed to ensure commercial viability. Health and environmental concerns are also of high importance.

Safety
Toxicity

Nanotoxicity research is still relatively immature. Research into the potential negative health effects of exposure to some nanomaterials is necessary in order to allay any safety concerns and improve the public perception of products that contain nanomaterials.

General valuation

Public perception
Cost
Mature

The real value proposition in the use of nanomaterials exists in the realization of superior material properties that could lead to novel applications. For example, nanomaterials lie at the heart of flexible applications that could revolutionize the consumer electronics industry. The market for nanomaterials is already relatively mature (worth several billion dollars per annum). However, each individual nanomaterial is at a different stage of development and should be considered to have a distinct commercial trajectory. For example, hundreds of thousands of tons of metal oxide particles are produced each year, while—although many are in development—very few commercial applications for graphene exist at present. Metal oxide nanoparticles and multiwall carbon nanotubes are approaching the peak of their commercial potential and sales will plateau. However, many other materials (such as graphene and other two dimensional materials, metallic nanoparticles, single-walled carbon nanotubes, and quantum dots) are likely to see sustained growth in the short- to medium-term future. An important risk to this growth is the potential for a major health scare involving a nanomaterial. This could have an adverse effect on the public perception of nanotechnology as a whole, "tainting" the technology area, and making further commercialization increasing difficult.

Defence valuation

Energy harvesting
Camouflage
Communications
High strength
Medical

High performance materials will always be of great interest within the defense sector and nanomaterials are likely to remain at the forefront of materials science for the foreseeable future. Unlike with commercial uses of nanomaterials, absolute material properties are of more of a concern than cost for defense and security applications. Despite cost not being a key concern, problems with large-scale processing technologies and health and safety issues could still hold up the development of military applications. Nanotechnology and nanomaterials are likely to find use in a host of future defense and security applications. Potential applications include optical metamaterials (see Stealth Technologies & Dynamic Camouflage), smart fabrics, textile-integrated electronics, wearable devices (see Wearable Computing), high strength and lightweight nanocomposites (armor-plating), next generation communication systems, energy-harvesting applications, sensors (chemical weapons/infrared), anti-counterfeit measures, and battlefield medical equipment (rapid healing of wounds).

Main actors

IBM, Solvay, BASF, QD Vision, DARPA, NASA, Bayer MaterialScience, BAE Systems, Evonik, Unidym, Dow Chemical, Samsung, DuPont.

Recommendation

Observe
Adopt
Try

The field is relatively fast-moving, with major breakthroughs occurring on a regular basis. All major research universities are engaging in nanomaterial-based research and some of the most impressive examples of research into advanced nanomaterials are emerging from academia. Similarly, the commercial sector is heavily involved in nanomaterials research and is leading the way in adapting novel materials and technologies for consumer applications. It is extremely important to keep abreast of major developments within this field.

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22.09.2015

Photovoltaic Transparent Glass

Summary

Perovskite solar cell
Dye-sensitized solar cell
Organic solar cell
Building-integrated photovoltaics

Photovoltaic (PV) transparent glass is an emerging segment of the solar industry that is advancing quickly and could enable more widespread use of PV-power generation. Leading PV materials that have the potential to be transparent include organic solar cells, dye-sensitized solar cells (DSSC), and perovskite-based systems. These solar cells achieve transparency by selectively harvesting non-visible portions of the solar spectrum, such as ultraviolet and near-infrared light, while letting a high percentage of visible-light wavelengths pass through (unlike conventional solar cells).

Several developers are working to commercialize thin, light PV transparent films that can generate power on any clear surface such as windows or cell phone and tablet displays. Examples include California-based Ubiquitous Energy, which is scaling up a fully transparent, small-molecule organic solar film that allows up to 90% of visible light to pass through.

The application of transparent solar films on glass is particularly promising because the glass industry has long been an integrator of solar-control window film and lamination processes are well established.

Weaknesses

Transparent solar cell efficiencies are low and difficult to improve because they collect light from only part of the spectrum. New perovskite cells have higher efficiencies but also stability challenges.

Related fields

Vacuum-deposition and film-coating techniques, Nanoelectronics, Organic electronics, Perovskite solar cells, Building-integrated photovoltaics, Glass manufacture, Nanomaterials.

Civil Uses

PV transparent glass can enable solar power generation on windows and other surfaces of buildings and automobiles, and power generation and battery life extension for portable and distributed electronic devices.

Trends & Challenges

Reliability
Efficiency

Research trends focus on improving transparent solar cell materials and components to achieve commercially-acceptable efficiency, longevity, and cost. Improving efficiency is critical to help lower costs, but transparent solar cells may never achieve the efficiencies of conventional solar cells that can capture more light energy. Perovskite solar cell materials are an active field of research to increase future power densities.

PV transparent film developers are establishing prototyping and pilot production capabilities in preparation for commercialization. Many technologies are only semi-transparent, which could limit their use, but tunable colors and variable transparency levels could also open up new PV design applications.

General valuation

Flexible applications
Building-integrated applications
New markets

Transparent PV products are still largely at the development and demonstration stage and are several years away from broad commercialization. Some underlying PV material technologies, such as third-generation DSSCs, are already available as opaque (non-transparent) solar cells. For example, G24 Power has commercialized printed, flexible DSSCs on a limited basis for indoor applications.

Small-molecule organic solar cells are generally in an earlier stage, although firms such as Heliatek are expanding demonstrations of semi-transparent organic PV films integrated with glass. High efficiency perovskite-based DSSCs might see commercialization within five years from companies such as Oxford Photovoltaics. Stability issues such as susceptibility to water damage could be a major barrier to perovskite commercialization.

Third-generation solar cells still represent only a minute share of the overall PV market in part because of strong competition from the dominant industry. Because of their combination of transparency and energy generation, PV transparent glass products may be able to access new markets in which conventional PV cannot compete. New organic solar materials also have potential to be less expensive to produce than conventional solar cells.

For all new PV transparent products, developers need to ensure their long-term performance and material integrity, especially in building applications.

Defence valuation

Distributed sensors
Communications

Many defense organizations are already adopting a range of conventional PV systems to generate clean, sustainable, and low cost power and to lessen dependence on traditional power generation and logistics.

PV transparent glass widens the range of possibilities to generate solar power for military bases, vehicles, and field equipment, although these potential applications still need development.

Transparent PV may be particularly useful to help power or charge proliferating distributed communications and electronic devices (medical and environmental monitoring equipment).

Main actors

CSIRO, Oxford Photovoltaics, Dyesol, Brown University, EPFL, Ubiquitous Energy, Michigan State University, University of Oxford, Heliatek, MIT.

Recommendation

Observe

Transparent photovoltaics represent an enormous business opportunity for startups developing technology in this sphere. For stakeholders in the defense sector, the area falls into an “Observe” category for the near term. The key recommendation is to monitor PV transparent glass technology development, reliability, and deployment in power-generation applications relevant to the defense industry. The establishment of clear signposts that judge and indicate at what point an interested party’s approach should shift from “Observe” to “Try” would also be a particularly useful exercise. An example of such a signpost could be the successful commercialization of products that can be tailored to specific systems and equipment.

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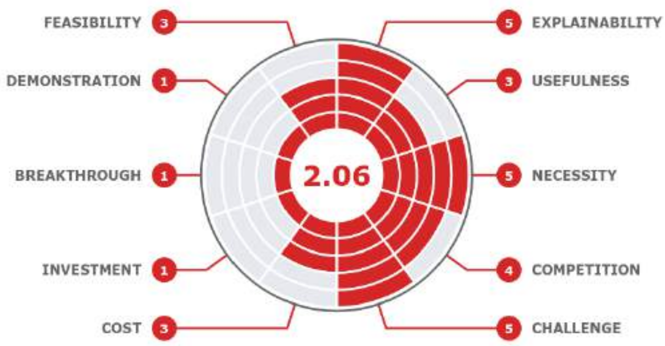
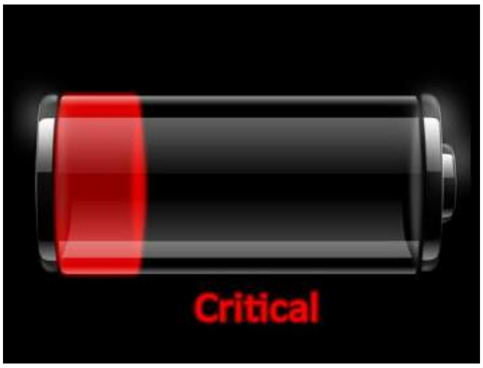
19.09.2015

Portable Power





Summary

Energy harvesting
Batteries
Solar
Electromagnetic industion

Batteries have been the predominant portable power source for several decades. Recently, Li-ion (lithium-ion) secondary (rechargeable) batteries have become virtually ubiquitous in higher-energy devices such as mobile phones, tablets, and notebooks. Li-ion batteries are also seeing increasing use in high-power portable applications like power tools and small-scale applications like wearable devices and wireless sensors. Older secondary battery technologies still find use for some applications, such as lead-acid cells for larger generator-replacement and NiMH (nickel-metal hydride) cells for high-power applications. Additionally, primary (disposable) cells are still a major power source for low-value devices and low-power equipment.

Non-battery technologies occupy niche spaces in this market but are maturing into more applications. For example, fuel cells, which use fuel to provide more energy in a smaller and lighter space than batteries can provide, have been used as a portable power source for some military and first-response groups for several years and are now commercially available. Energy harvesting also has potential for gathering low-level power from environmental sources like vibrations, heat gradients, and particularly solar energy. Recent research also focuses on standardizing short-range electromagnetic induction for wirelessly charging electronics, as well as improving the range and efficiency of radio-frequency wireless energy transfer.

Weaknesses

Energy densities and charge speeds continue to be the most pressing issues in portable applications—even Li-ion batteries take up too much space and do not recharge very quickly.

Related fields

Chemicals, Materials, Nanobiotechnology, Nanoelectronics, Energy storage, Photovoltaics, Smart Materials, Nanomaterials.

Civil Uses

Dramatic advancements in portable power technologies could open numerous new opportunities such as longer-operating implantable and wearable devices, longer-range and more powerful robotics, and overall smaller electronic devices.

Trends & Challenges

Charge time
Energy Density

Advances in Li-ion technologies continue as manufacturers reduce sizes, increase charge speeds, and address safety and durability concerns. Performance benchmarks for Li-ion cells, particularly energy density and price, continue to improve at a steady pace. Next-generation battery technologies—such as silicon-based anodes, solid-state electrolytes, and simplified manufacturing—should improve the capabilities of Li-ion and derivative battery cells. Still, physical

Safety
Manufacturing infrastructure
Durability

constraints on fundamental chemistries keep progress relatively slow compared to other portable electronics technologies. Durability and safety of high-energy materials remain major obstacles—battery researchers must balance energy densities with other parameters for their cells to have a chance at commercialization.

General valuation

Environmental
Investment
Improving
Mature

Li-ion battery storage has reached a point of relative maturity and widespread adoption, with major manufacturers producing large volumes to keep costs as low as possible. Increased demand could create battery or raw-materials scarcity as more electric vehicles and grid-storage systems absorb manufacturing capacity. However, growth in demand has been matched by increased supply and no constraints exist at present. Other risks include the rare but dangerous possibility of thermal runaway in large packs of battery cells, and environmental effects from resource extraction and limited cell recycling.

Competition for batteries in portable power applications remains limited, with technologies like fuel cells failing to become popular due to cost and convenience constraints. Energy harvesting and wireless power transfer can supplement the use of batteries in portable electronics, but low power levels and intermittent availability of power make them more synergistic than competitive.

Defence valuation

Robotics
Low weight
Communications
Reliability
Unmanned systems
Equipment

Portable power technologies are particularly important to defense and security groups, to minimize weight and size of the equipment. High energy-density power sources are also useful for security-related robots and unmanned aerial vehicles in which power capacities limit range and endurance. Although many military devices—particularly military analogs to civilian devices—use standard battery technologies, the requirement to reduce weight and increase endurance of various equipment have led to support for new alternative technologies, including portable fuel cells and energy harvesting devices. Defense groups have been some of the early adopters of fuel cells technologies, and for many military applications the benefits that portable fuel sources offer over batteries—including superior energy density, light weight, and instant refueling—far outweigh the higher costs of the technology.

Main actors

Sony, Energizer, PMA, Samsung SDI, SFC Energy, Intelligent Energy, WPC, BYD, Horizon Fuel Cell Technologies, Duracell, Panasonic, LG Chemical.

Recommendation

Observe
Adopt
Try

Portable power technologies are at a maturity level to merit some observation and some trials. Although radical technological leaps are unlikely to occur in this technology category, gradual changes mean that better and less-expensive portable power sources regularly emerge.

Observing progress in battery technology can reveal the most impactful developments in portable power. Lower-cost and higher-performance Li-ion cells in particular would make the largest impact because most portable electronics manufacturers already use Li-ion batteries.

Observing for major developments in alternative technologies such as fuel cells, ultracapacitors, wireless power transmission, and energy-harvesting devices also adds value because changes in these areas could potentially open new opportunities and applications that battery improvements alone would not offer.

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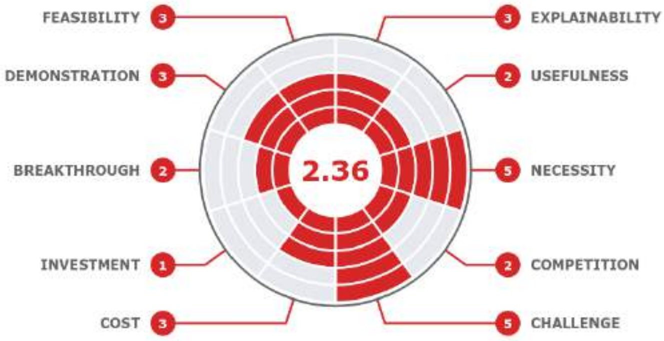
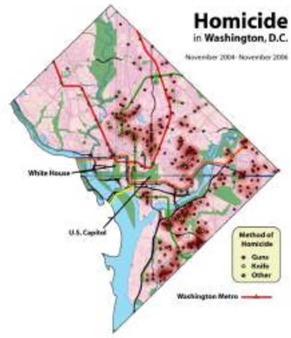
Predictive Crime Prevention





Summary

Big data
Artificial intelligence
Risk
Bayesian
Prediction

Predictive policing is among the first applications of AI in e-government. Neural-network security applications started to move into crime-prevention applications in the early 2000s. Currently, this area represents a prime example of an application for *big data* approaches. Typically, software that analyzes crime databases helps police agencies decide how to assign resources. The software uses statistics about the geography of crime to create *crime heat maps* and *risk terrains*; it does not predict specific crimes or identify criminals.

Numerous sources provide descriptions of the underlying technology: PredPol uses agent-based and Bayesian methods to create geographical profiles of criminal behavior for early versions of its software. An IBM white paper on the topic of predictive policing refers to machine learning. IBM is correlating past crime data with other data, including weather, paydays, and big local events. The company is also interested in integrating gunshot sensors and smart CCTV cameras that look for signs of suspicious behavior. And the US government's National Institute of Justice awarded a grant to the Chicago Police Department to evaluate an approach to predictive policing that makes use of algorithms that are similar to those in use for pattern matching in medical images.

Weaknesses

Accuracy: Existing systems pinpoint neither exact crimes nor criminals. Legality: In the future, people arrested as a result of predictive-policing software could challenge grounds for arrest.

Related fields

Internet of Things, Surveillance, Predictive analytics, Network analysis, Data modeling, Context-Aware Computing, Machine Learning, CCTV, Telecommunications, Computer Vision, Artificial Intelligence (AI), Sensors, Emotion Tracking, Neural networks.

Civil Uses

Police agencies are already adopting and testing software that helps assign patrol officers to high-crime areas.

Trends & Challenges

Accuracy
Algorithm
Big data
Legality

Current systems—as described above—clearly have limitations. Current R&D surrounds making use of new sources of data, to improve the accuracy of predictive systems. (For instance, integrating video analytics.) In addition some forces have been investigating advanced profiling of individuals: In 2007, Scotland Yard announced plans to develop a database of potential murderers and rapists before they even commit any crime. Challenges include causation; data could be able to predict where a crime will take place, but not why a crime will take place.

Causation
Sensor fusion

General valuation

Commercial
Legality
Trials
Evaluation

Remarkably, predictive crime prevention is already an active, in-use technology area—at least. However, one must remember that systems only create predictions; effective crime prediction relies on using these predictions to create useful actions. In combination with the use of intelligent policing, these seemingly small gains in predictive accuracy can result in significant crime reductions. US authorities in many US cities have begun using CompStat, a data system created by the NYPD that aids in the allocation of law-enforcement resources.

Competing technologies include human analysts, and some data has compared the two approaches' efficacy: In 2013, Kent Police in England reported 8.5% of street crime occurred within zones that PredPol's (Santa Cruz, California) software identified, whereas only 5% of street crime occurred within the crime-prone areas that human analysts identified. In Los Angeles, California, the corresponding figures were 6% and 3%.

A clear warning exists: Convictions result from evidence, not statistical models. Thus, predictive policing will likely join other AI-influenced practices in criminal justice—namely, use of surveillance cameras (use of face-recognition software occasionally contributes to solving crimes) and DNA identification (which relies on Bayesian analysis).

Defence valuation

Interaction analysis
Behavior analysis
Terrorism

A strong overlap exists between defense, security, and policing. Sophisticated data-analysis tools are seeing more use in studies of criminal behavior, creating many opportunities for systems providers and users. These systems are becoming important tools for security applications—and will likely enable many civil and military opportunities.

Similar tools are already in use in fighting organized criminal and militia activities. For example, Colombian prosecutors now use algorithms to create diagrams that show the interactions between authorities (government officials and law-enforcement agents) and drug-cartel members, identifying the people who connect the legal and illegal worlds; such approaches could also prove useful in identifying terrorists and terrorist cells, for example. Opportunities exist to use AI to help security agencies solve important problems—for example, using speech-to-speech translation and knowledge-discovery techniques (including semantic analysis) in databases.

Main actors

Carnegie Mellon University, IBM, PredPol, NYPD, LAPD, Scotland Yard.

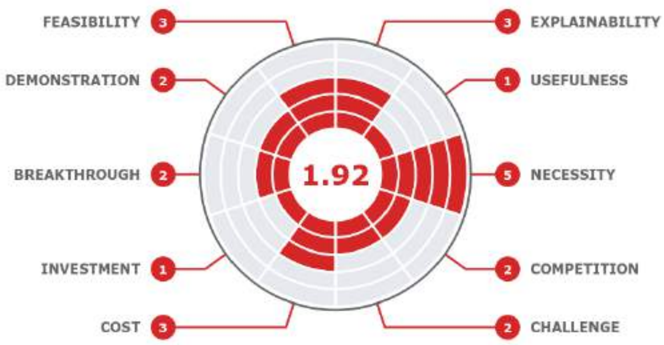
Recommendation

Try

Predictive policing approaches have clear overlaps with security applications, and in our opinion falls into the Try category.

At the very least, players in the defense sector should implement a project that covers this area – for example, they could collaborate with external partners to test a predictive system. However, use of any predictive system must go hand-in-hand with a framework for effective implementation that also includes robust human decision-making. Governments and individual police forces should try and, depending on the results of studies, adopt next-generation predictive policing methods as and when they reach maturity.

Quantum Computing



Summary

Accelerated computation
Entanglement
Qubit

Quantum computing (QC) refers to a set of proposed methods for achieving accelerated computation ("speedup") relative to the performance of conventional digital designs. Methods now in vogue exploit the properties of entanglement and superposition to yield small systems of qubits that can express a much larger number of possible states than a comparable number of bits can express, and that that rapidly evolve from an initial programmed state that represents a problem that someone wishes to solve to a final state that in some sense represents the answer to the problem. The programming, system evolution, and interpretation of the response proceed in accord with the mathematics of quantum mechanics. Some 100 years of experimentation have confirmed that with no exceptions, that mathematics corresponds to the probabilistic behavior of matter and energy at small scales. In a number of the systems under investigation, qubits consist of a collection of supercooled, superconducting Josephson junctions that interact with one another but only minimally with the external environment. The challenges of achieving such isolation are aggravated by need for human interfaces at input and output; errors are inevitable ("decoherence"), thus error-correction schemes are integrated into the algorithms that govern programming and interpretation of qubits.

Weaknesses

Prevailing implementations of QC embody specific algorithms, not general-purpose computers. Even for QC's natural problem targets like dynamic systems of particles, proof of speedup is weak and prospects are controversial.

Related fields

Artificial intelligence (AI), Superconductors, Meteorology, Biomedicine, Aerospace, Holodeck, Information technology (IT), Software development, Oceanography, Context-Aware Computing, Machine Learning, Computer Vision, Cryptography, High-performance computing, Emotion Tracking.

Civil Uses

Successful QC implementations would benefit diverse research efforts including design of aircraft, drugs, materials, and vehicles. Ideal implementation would benefit any data center or web service, including intelligent user interfaces.

Trends & Challenges

Temperature sensitivity
Performance improvement

Progress reports continue to focus on scaling up the number of qubits in quantum-annealing systems, improving the effectiveness and efficiency of error-correction algorithms, and proving systems, which has been a special challenge recently. Isolation of qubits from external influences such as temperature fluctuations and electromagnetic events during computation is difficult, and resulting needs for refrigeration imply the current roadmap is for data centers only. The process of correcting inevitable errors is more complex than in the corresponding case for

Stability
Efficiency
Error reduction

conventional computing, and resulting needs for redundancy increase the burden for researchers and developers of QC technologies.

General valuation

Immature
Uncertain
Disruptive

QC is an immature, high-risk, and potentially high-reward domain of research and development. One of its foremost advocates and experts, John Martinis remarked in 2014 that “It is still possible that nature just won’t allow it to work.” Replication experiments sometimes undermine claims that quantum computing is useful, or is even occurring, though it undoubtedly occurs sometimes. Alex Selby, who authored some of the software that ETH Zurich used to undermine some such claims, said during 2014 that even when developers succeed in isolating 2048 qubits, conventional computing “may still be competitive”.

Although current trends emphasize a particular approach to QC (quantum annealing), several alternative, competing QC implementations (such as quantum gate arrays) are also under investigation. Beyond QC, the general domain of next-generation high-performance computing has many competitors, the simplest being increased exploitation of parallelism, use of graphics processor nodes, and use of reconfigurable computers (FPGAs). Competitive domains of high-performance computing whose risk profiles are rough matches for that of QC include neuromorphic (`brainlike’) architectures and advanced analog computers (the two fields partly overlap). Competing domains that are somewhat promising but resource-starved include optical computing and spintronics. A wildcard among wildcards, “Super Turing” architectures, sees minimal research funding.

Defence valuation

Encryption
Vehicle design
Codebreaking
Stealth
Prediction

Both codebreaking and code construction are important potential applications for quantum computing; the technology would not necessarily confer asymmetrical advantages to codebreakers. In fact resource availability may tend to favor large organizations, much as today’s supercomputers are often government systems. And use of QC could strengthen cryptography, not just weaken it. Even so, adoption of QC could accelerate the eternal escalation of security measures and countermeasures experienced by the full range of stakeholders, from individual users to international organizations. For aircraft and spacecraft design and operation, any “more than Moore” technologies including QC could lead to dramatic improvements in stealth and agility both in the aerobatic sense and in the sense of mission versatility. Imaginably, intelligence communities could also exploit such technologies for information superiority, specifically efforts to “connect the dots”, collating public and secret information to automatically discover when adversarial entities have both intention and resources to cause harms.

Main actors

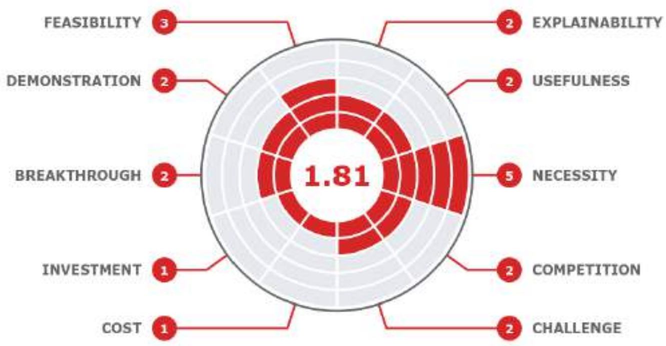
Planck Institute, IBM, D-Wave, UCSB, Microsoft, NASA, CQT, IQOQI, JQI, CQC2T, ICFO, RQC, Google, IQC, NSA, Lockheed-Martin, JFLI, ETH.

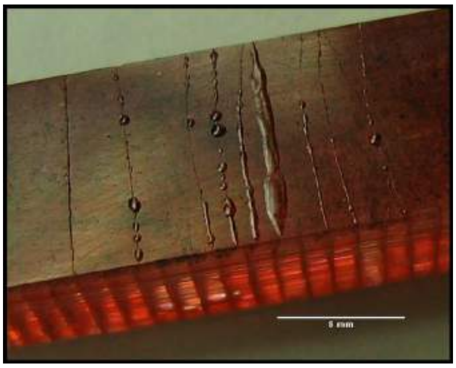
Recommendation

Observe

As part of a suite of technologies that aim to yield “more than Moore” rates of computational progress, QC is among high-priority items to observe that also includes neuromorphic and advanced analog computing. With regard to advancing the state of QC technology, stringent requirements for human and other resources are likely to pose obstacles for new entrants. Forming a consortium (or perhaps joining one such as JFLI or JQI) might also make advantageous use of research leverage.

Self-Healing Materials





Summary

Shape-memory
Smart materials
Composites
Chemical recovery

Imagine cracks in damaged structures that close up on their own and dents that spring back into their original shape, or systems that can eliminate defective parts on a production line and thus remove the need for inspection. An ideal self-repairing material has sense-and-act behavior similar to that of smart materials, in that it can sense damage and then act in such a way as to repair this damage, automatically. Several players have developed and commercialized simple elastomeric polymer coatings that use energy from sunlight to change shape and remove light scratches—in particular for consumer-electronics applications.

Perhaps surprisingly, a few solid materials already have intrinsic self-healing capabilities. Some concretes and rubbers can self-heal, thanks to the presence of residual raw materials. Researchers have also developed prototype composite materials—especially polymer composites—with self-repairing capabilities that require very little or no human intervention. A clear analogy is that of biological systems that automatically and autonomously initiate self-repair when they sustain damage. These prototype composites contain microspheres or microcapsules, fillers, and hollow fibers that contain chemical-recovery agents. Other researchers are developing self-healing systems that rely on shape-memory materials. In general, bulk materials have yet to see widespread commercial adoption.

Weaknesses

Lifetimes and cost-effectiveness are still uncertain. Materials must prove at least as reliable and strong in the first place as existing materials, otherwise substitution is unattractive.

Related fields

Portable Power, Advanced composites, Smart materials, Biomimetics, Shape-memory materials, Nanomaterials.

Civil Uses

Current: Coatings for consumer electronics devices. Emerging: Electronic components and circuits. Future: Large structures for transportation, aerospace and defense, energy.

Trends & Challenges

Scaleup
Cost

A great deal of recent R&D has focused on the creation of composite materials that can halt and repair small cracks that appear in a material under stress—especially composite materials. For self-healing technologies to see success, they must not only become cheap and easy to implement but also exceed the functionality of existing technologies by a margin.

General valuation

The commercial progress of self-healing materials is actually occurring fairly slowly and only in discrete applications—this serves as both a warning and an indication

Niche commercial applications
Emerging

of availability. Here is one example of 10 years' progress: In 2005, Nissan and Nippon Paint Company announced the development of a self-repairing coating for use on car bodies; in 2009, this technology was licensed by NTT DoCoMo for use in mobile-phone applications. In 2014, paint-manufacturer Natoco announced a self-healing, scratch-repairing coating for use in smartphone applications.

Beyond coatings, researchers and materials companies have some way to go before bulk self-healing materials become a commercial reality. Scientific interest and funding still focus on the development of self-repairing materials rather than their applications. However, numerous technical challenges still exist. Ideally, any self-repair mechanism would result in no degradation of the material's physical properties. Competing technologies include materials that are tough enough to withstand damage in the first place.

Although most research is at a very early stage, I expect to see researchers create materials that have useable self-healing functionality in the medium term. In particular, the area of self-healing materials for electronics applications is particularly promising, and a logical next-step forward from coatings.

Defence valuation

Mission-critical systems
Safety
Maintenance
Repair
Sensors
Durability

Self-healing materials could make life a lot easier for operators of systems that are traditionally on the end of rough treatment; the defense sector will undoubtedly be in a strong position to benefit from this. Ultimately, self-healing systems could lengthen product lifetimes, increase safety, and reduce maintenance requirements. If successful, they could negate the need for some repair operations—perhaps after sustaining attack. Portable equipment and vehicles (manned and unmanned) being perhaps the most obvious examples of systems that could benefit from self-healing functionalities. Mission-critical electronics, sensors, and batteries would be robust if they featured self-repairing components. It is worth emphasising caution with respect to defense applications; outside thin layers, structural self-healing materials remain some way from commercial availability.

Main actors

Nissan, University of Illinois at Urbana-Champaign, Arkema, Natoco, SupraPolix, Nippon Paint, University of Nevada, Reno, University of Bristol, Bayer MaterialScience.

Recommendation

Observe
Try

Coatings technology falls into the Try category, in particular technology that is applicable to important electronic equipment and batteries.

Bulk materials remain firmly in the Observe category. It is worth asking several questions before adopting any other self-healing technology, as it becomes more available: Will the mechanisms that the researchers propose work in any environment? Will these materials work at elevated temperatures and pressures? Are the materials harmful to humans or the environment? What safety testing will be necessary? Do any lifetime issues exist? These questions could be used to create signposts, upon which future actions could be instigated.

One potential action is involvement in fundamental or applications-specific R&D projects; instigating the development of self-healing materials for specific applications—for example, self-healing mechanisms for the protection of specific components or surfaces on electronic equipment, interfaces, or vehicles.

Smart Dust Sensors

Summary

MEMS
Sensing

The smart dust concept is one of millimeter-sized (dust sized) devices, which can perform a number of 'smart' activities including sensing vibration, temperature or chemicals. Theses devices can also communicate with each other or back to a central hub and possibly even perform activities.

Developments in microelectromechanical systems (MEMS) have supported smart dust progress but few devices are achieving the millimeter scales required. The miniaturization of the technology needed to achieve smart dust (power, sensing, communications) has not been in sync, with sensing capabilities generally being ahead. Some prototype devices have been made that are invisible to the naked eye but do not fully function as smart dust due to a lack of power or communications. While some devices have been demonstrated to be fully functioning smart devices in the sub-cm scale, the achievement of true 'smart' dust size devices still seems to be some way off.

However, longer term, the possibility of low cost smart dust devices that can be deployed in their thousands, or even millions, to achieve smart data gathering is entirely plausible. In the short-term devices that are slightly larger than 1 mm are already performing all of the actions required to be 'smart'.

Weaknesses

Energy supply and wireless communication methods are two key weaknesses. Despite sensing technology being available at the right scale, without energy supply and wireless communication, a complete system is unachievable.

Related fields

Portable Power, Nanoelectronics, Internet of Things, Mesh networks, Augmentetd Reality, MEMS, Integrated Vehicle Health Management, Nanomaterials, Medical Nanobots, Nanotechnology, Intelligent Autonomous Systems, Passive energy generation, Big data, Wearables, Swarms, Labs on Chips.

Civil Uses

Include: Invisible tagging, tracking of products, commercial data gathering; In vivo medical analysis; Hazardous environment/remote location data gathering. These are at varying levels of maturity (concept to demonstration).

Trends & Challenges

Internet of things
Miniaturization
Communication

Current trends focus on the miniaturization of devices to sub 1 mm scale and also methods to power such devices.

Commercial organizations wishing to use such technology to invisibly capture data about, and communicate with, its customers will drive development. Devices will be built into non-electrical products, such as clothes, and used to detect information such as location and temperature to inform marketing approaches.

Integration

Just as the Internet of Things has the potential challenge of competing standards among the big players (Apple, Google, Microsoft…), smart dust could be limited by competing data and communication standards.

General valuation

Rapidly maturing

Experimental applications

If the semantic of the 'dust' in smart dust is ignored then there is already a lot of maturity in the technology enabling smart dust. Devices, of the size of several millimetres, have already been made which provide computing ability, energy generation and wireless communication. Devices of this size should not be ignored despite not meeting the conceptual requirements for smart dust. For many applications these devices will provide all of the benefit of true smart dust devices.

Smart dust, under the above, wider categorisation, will undoubtedly have a big impact on the world within 10 years, largely due to the technology's ability to be a key enabler in data acquisition. However, due to the current low technology maturity level of sub-millimetre energy production and storage devices, true smart dust is unlikely to be in widespread usage before 2035. However, that isn't to say that true smart dust will not be deployed experimentally within the military or within meteorology within that timescale.

Defence valuation

Security Threat

Advanced sureveillance

Smart dust provides both a potential threat and opportunity to defence and security. Smart dust deployed to perform surveillance will, by definition, be hard to detect visually. Therefore, without advanced methods of detection in place, smart dust could provide a serious threat to the retention of sensitive information and opportunities for intelligence gathering. Smart dust could also be deployed actively to sabotage electronic networks or, for example, disrupt power supplies. The nature of smart dust will challenge the existing security measures put in place to protect secret information in military establishments that currently do not allow external electronic devices.

In new defence platforms, smart dust could be used for information gathering on the condition of the platform, for example, embedded into paint to monitor corrosion, temperature or humidity. Integrated Vehicle Health Management (IVHM) is a technology area that should benefit greatly from progress in smart dust.

Main actors

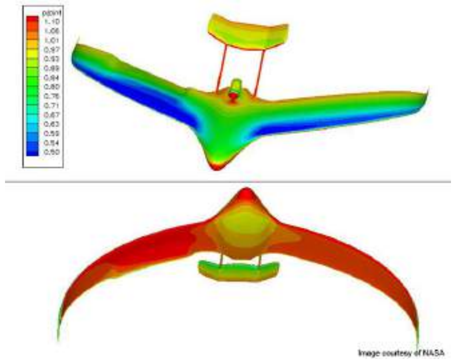
University of California, Berkeley, University of Michigan, DARPA.

Recommendation

Observe

Interested stakeholders, including those within the defense sector should put immediate observation activities in place to understand the potential threat from smart dust technology and, specifically, methods for detection and defeat of smart dust. While smart dust development will likely be pushed by commercial organizations, countermeasures are highly unlikely to be developed outside of the military domain so governments need to address this directly through investigating and trying emerging technologies that could neutralize the threats that arise from smart dust.

Smart Materials



Summary

Morphing structures
Smart fluids
Piezoelectric
Shape-memory
Electroactive
Thermochromic
Intrinsic responses
Thermoelectric
Magnetostrictive

Smart materials (SMs) is a catchall expression for a diverse set of materials technologies. In general, SMs produce direct, inherent responses to external stimuli; signals and responses include temperature, voltage, pressure, magnetic fields, light, and so on. These properties are often a result of a material's structure, and not device design. For example, piezoelectric materials have a noncentrosymmetric crystal structure. Applying a mechanical force to the structure disrupts its symmetry and generates a voltage across the material. Conversely, applying a voltage to a piezoelectric material causes the material to deform. Other important classes of SMs include thermoelectrics, shape-memory materials (alloys and polymers), electroactive polymers, electrochromics (including smart glasses), magnetrostrictives (including Terfenol-D), electrostrictives, thermochromics, and smart fluids (including magnetorheological fluids). Researchers are using these materials to enable shape-shifting materials, morphing structures, and even programmable matter.

Often, SMs are integrated into devices that use SM reponses to create useful devices such as sensors, motors, actuators, generators, or shape-shifting objects. Thus, designers can use SMs to simplify products, add features, improve performance, or increase reliability with relatively little added technical complexity.

Weaknesses

Weaknesses are often material-specific. However, common issues include poor level of response (time, magnitude, force), high cost, and a lack of familiarity on the user side.

Related fields

Self-healing materials, Smart packaging, Energy harvesting, Robotics, Advanced composites, Metamaterials, Biomimetics, Electronics, Programmable matter, Artificial muscles.

Civil Uses

Current and emerging: Piezoelectric components for electronics and automotive applications (sensors, speakers, injectors); Shape memory alloy medical stents; Thermoelectric coolers/generators; Smart windows; Energy harvesting. Future: Morphing structures; Programmable matter.

Trends & Challenges

Cost reduction
Efficiency
Improved responses

Key research centers on the development of SMs that are responsive—for example, creating materials that actuate with high force, with a demonstrable change in shape, color change, electrical output, or heating effect. Overcoming poor responsiveness is perhaps the main challenge for SM researchers. For example, current thermoelectric materials do not convert heat into electricity efficiently enough for widespread commercilization. To enable these improvements, researchers are investigating nanoscale technologies—for example, nanostructuring of SMs. In terms of more expansive concepts, researchers are also looking to create living materials (materials that incorporate organisms) and 4D printing systems (self-assembling components).

General valuation

Niche markets
Commercial

In many ways, SMs is already a highly successful technology area. Collectively, SMs are likely worth about $25 billion. Piezoelectric materials are the most commonly used SM, accounting for about one-third to one-half of all sales of SMs. Also commercial are a number of important niche applications, including shape-memory alloys (spectacle frames, medical stents), magnetostrictive materials (in particular, for defense/aerospace applications), thermoelectrics (in particular for small-scale heating and cooling applications, such as portable drinks coolers), smart glass (self-dimming automotive mirrors), and magnetorheological fluids (in particular for smart suspension systems, which are available on many high-end vehicles).

SMs are underpinning emerging energy-harvesting, energy-storage, and power-generation application; piezoelectric and thermoelectric energy harvesting systems are a prime example of SMs that are seeing use and investigation in this area.

Competing technologies include standard mechanical and electronic systems, such as sensors, actuators, and motors. At the moment, SMs struggle to compete with traditional approaches in many applications, mainly due to cost and performance issues. Nevertheless, the next few decades will see improvements in SMs that will make these materials become more attractive across numerous application areas.

Defence valuation

Monitoring
Strategic materials
Sensors
Stealth

SMs are extremely important across numerous defense and security applications. Several SMs have been developed as a direct result of defense-related R&D activities. The magnetostrictive material Terfenol-D was developed by US Navy researchers, with a focus on sonar applications. SMs already see use in vibration and noise control applications, advanced actuation applications, and structural monitoring applications, within the defense and aerospace arena.

SMs could also enable tactile sensors and actuators for robotic vehicles. The development of unmanned ground and aerial vehicles is accelerating, and smart actuators could enable accurate remote operation. Military players hope that SMs and adaptive structures will enable major advances in systems capabilities; for example, SMs could also enable armor that reacts or perhaps recovers after sensing an impact. Threats include limited or controlled access to some materials; useful SM formulations can be protected by IP.

Main actors

General Motors, Gentex, Georgia Tech, DARPA, Lord Corp., Murata, Gentherm, Marlow, HRL, Etrema, Fraunhofer Institutes, Bayer MateriaScience, 3M.

Recommendation

Observe
Try

The Smart Materials technology area is wide enough to split into a variety of material-dependent categories; many of these materials fall into the Try or Adopt categories—depending on application—because many commercial materials already exist (for example, piezoelectrics, thermoelectrics, shape-memory alloys, smart fluids, smart windows, and magnetostrictives.) Technologies that exist as prototypes—in particular smart fabrics—sit within the Try category.

Key recommendations also include tracking and monitoring developments in some advanced SMs, such as morphing structures—which nominally sit within the Observe category. One should establish clear signposts that initiate a shift in these technologies from the Observe to Try categories.

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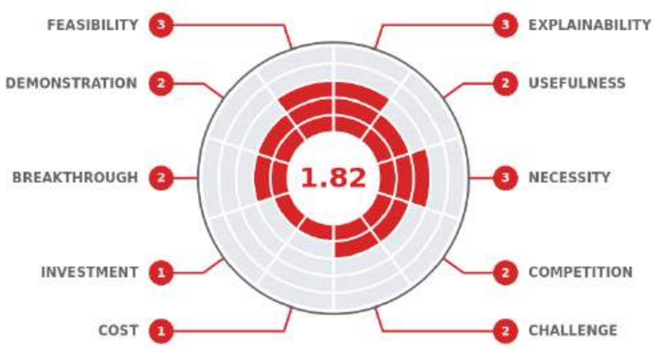
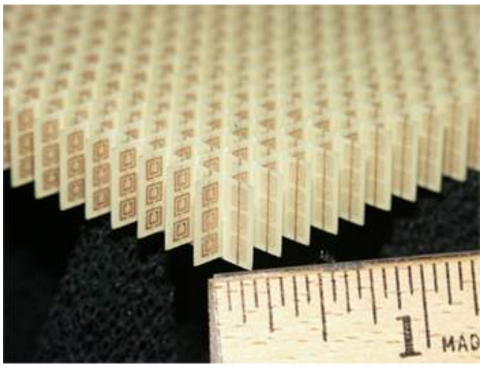
Stealth Technologies & Dynamic Camouflage





Summary

Metamaterials
Dynamic displays
Invisibility

Technologies designed to render objects hidden or invisible. Existing approaches enable shielding from radar or microwaves; or indeed hiding data. Future invisibility and chameleon-like camouflage could be illusions created either by manipulating light, or by actively projecting onto an object—either visually or thermally. An object is considered invisible if the human eye cannot see any absorption or scattering of light when it is illuminated, or if light appears to pass straight through the object and the object does not cast a shadow. Wrapping an object in a dynamic metamaterial—an engineered material with unique properties that derive from the material's ordered internal structure—could enable light hitting the object to refract around the surface of the object and emerge from the other side, thus appearing to pass through the object.

Researchers are developing prototype surfaces that can sense their surroundings and change color accordingly—in some instances to camouflage people or objects. Some prototypes work in a similar way to electronic paper (e-paper)—a low-power display technology. Other researchers are developing thermal stealth technologies to fool IR night-vision cameras; these match the temperature of a surface to that of its surroundings using, for example, thermoelectric panels.

Weaknesses

This is a formative technology area: Dynamic camouflage systems are largely conceptual. Invisibility approaches require significant technology advances; metamaterials are expensive and complex to produce.

Related fields

Wearable Computing, Nanoelectronics, Internet of Things, Smart Materials, Holodeck, Metamaterials, Autonomous Swarms, Thermoelectrics, Sensors, Displays.

Civil Uses

Technologies could enable advances in consumer electronics: For example, future televisions may display the image of the wall onto which they are attached, and thus blend in with surroundings.

Trends & Challenges

Theoretical

Challenges in invisibility systems include metamaterials design and production. Metamaterials capable of manipulating visible light will be more difficult to create than metamaterials suitable for making objects invisible to radar, because the wavelength of visible light is shorter than that of the radio waves that radar

Scale-up

detects. Making objects invisible to both humans and radar will be difficult because it requires two different metamaterials. In the visible region, new forms of invisibility and chameleonlike camouflage might also be possible through the confluence of displays and imaging technology—a key research trend across university and commercial research groups.

General valuation

Niche commercialization

High cost

Some stealth technologies are possible in the short term, following in the footsteps of anti-radar approaches. In particular, hiding data, with implications for data security and cyberwarfare, may be easier than hiding real-world objects; researchers at Cornell University use frequency modulation to disguise the addition, removal, or exchange of information.

Arguably, the concept of invisibility is no longer pure science fiction. Researchers demonstrated the first negative-refractive-index material (operating at microwave frequencies in 2000). Creating true invisibility will be very difficult (particularly at wavelengths that humans can see), and the technology will be expensive to manufacture. Metamaterials capable of manipulating visible light are difficult to create, because the wavelength of visible light is extremely short.

Other technologies that conceal objects from human vision, thermal vision, and radar are advancing. A surface that can sense its surroundings and change color accordingly—either to camouflage itself or to create an image—could become reality. Canadian player Hyperstealth reports that its Quantum Stealth material can bend light—rendering targets invisible. BAE Systems developed a technology called Adaptiv consisting of thermoelectric panels. Attached to a vehicle, panel temperature increases or decreases to match the temperature of the surroundings, rendering the vehicle invisible to night-vision systems.

Defence valuation

Cloaking

Game-changing

Many—if not most—of the applications for invisibility are related to defense and national security. Indeed, defense contractors are already heavily involved—as the examples of BAE Systems and Hyperstealth (above) highlight.

The implications of these technologies (including metamaterials) beyond military applications still require exploration before their long-term prospects can be evaluated accurately. One thing is certain: these technologies are potentially extremely disruptive. For example, in 2011, a Southeast University (China) research team announced the creation of a structure using metamaterials that can change the way radio waves interact with a copper cylinder so the structure appears to be a different material; ultimately suggesting use as a military cloaking device. An object that can masquerade as something else entirely is a highly promising—and potentially contentious—application.

Main actors

Duke University, Cornell University, Southeast University (China), Sandia National Laboratories, Lockheed Martin, BAE Systems, Hyperstealth.

Recommendation

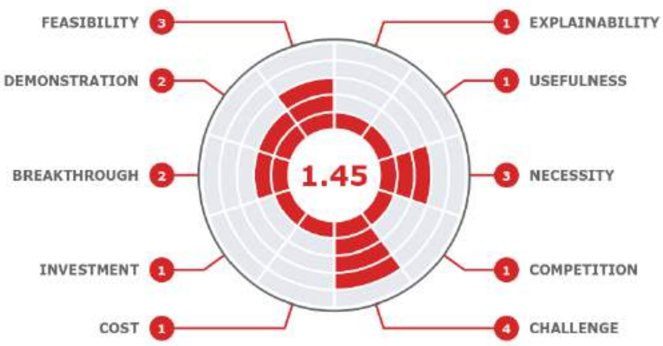
Observe

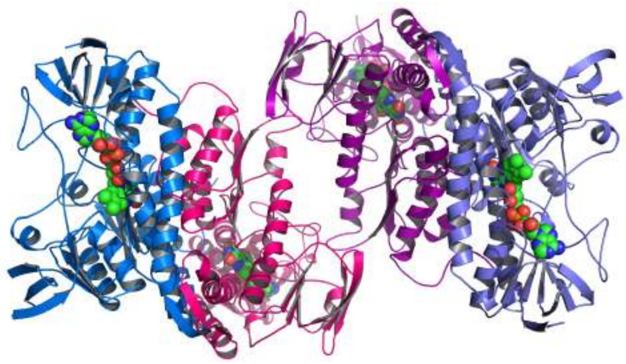
Try

Because of the direct relationship with defense and security, this technology area is worthy of observation, and in some cases further investigation. Likely, some hype surrounds the development of cloaking/active camouflage technologies, so any breakthrough technology should be assessed before deciding on any major future strategy. Metamaterials approaches fall into the Observe category, although instigation of a limited R&D project is a possibility.

Key recommendations also include tracking and monitoring developments in all the areas discussed above (many of which nominally sit within the Observe category). One should establish clear signposts that initiate a shift in these technologies from the Observe to Try categories.

Synthetic Biology





Summary

Food
Drug
DNA
Test

Synthetic biology has expanded dramatically in recent years. However, the field is still so nascent that scientists working in synthetic biology do not agree on a definition. Synthetic biology brings together aspects of other fields—such as biotechnology, genetic engineering, and DNA sequencing—to design and create new biological systems. The increase in activity in synthetic biology is linked to advances and falling costs in other areas; software tools and DNA-synthesis costs are decreasing, and their accuracy is increasingly facilitating previously unprecedented feats of synthetic biology.

Examples of developments in synthetic biology include the creation of the first synthetic enzymes, which scientists at the University of Cambridge engineered, raising the possibility of new methods for, for example, manufacturing pharmaceuticals and materials, remediating pollution, and the growing and processing of food.

Synthetic biology is also advancing DNA computing for applications such as data storage and reprogramming living cells. Although synthetic biology holds a lot of promise for a wide range of industries, this technology area is nascent, and real-world applications have yet to materialize. However, Jay Keasling (University of California, Berkeley) created a semisynthetic version of the antimalarial drug artemisinin, which Sanofi is now commercially producing more cheaply and reliably than from its original source plants.

Weaknesses

Synthetic biology is still an emerging technology; its very definition is disparate and somewhat controversial. At present, research efforts lack direction, and developers face myriad technical challenges.

Related fields

biomolecular computing, DNA sequencing, systems biology, biocatalysis, genetic engineering, biosensors, molecular biology, Biotechnology.

Civil Uses

Synthetic biology could find application in many areas, including pharmaceuticals, medicine, agriculture, biofuels, materials, cosmetics, and data storage.

Trends & Challenges

Fear from public
Destroy cancer
Side effects

Research trends are broad and aspirational. A major research area is the replication of life using synthetic DNA. Another research area focuses on using synthetic biology to create tools that help to solve problems, for example, creating a food crop that uses water more efficiently.

Experts propose genetic modifications to people, enabling resistance to flu, or radiation; programmed synthetic organisms to destroy cancers. Synthetic biology will face opposition from environmental groups and regulatory bodies will likely be very cautious because of unknown ecological side effects.

Synthetic biologists will have a difficult challenge in allaying these fears and proving the usefulness.

General valuation

Immature

Ecological effects

Warnings

Synthetic biology is an immature area and is available only in research laboratories. However, the scientific fields that constitute synthetic biology are more advanced, with some products based on genetic engineering already commercially available.

The progress of these other fields—both as enabling and competing technologies — will play significant roles in the success of synthetic biology.

The major concern for the future of synthetic biology is the possibility of its unintended ecological effects, but this uncertainty can only be estimated on a case-by-case basis after the vast majority of research into each synthetic-biology product has been completed. This cautiousness may result in the cost of developing some synthetic-biology products being on a similar scale to drug discovery and development.

Defence valuation

Materials

Biological weapons

Energy

Many capabilities and limitations of synthetic biology are yet to be established. As research and understanding into different genes progresses, more possibilities will arise.

The opportunity for some advanced materials, tailored to the particular applications and with specific traits, exists, as does the possibility of cleaner, cheaper energy.

Nevertheless, these potential applications are distant goals. Biological weapons and deterrents developed through synthetic biology represent both an opportunity and a threat.

The rise of biohacking—the practice of biological-technology development outside research institutions—increases the chances of bioterrorism.

Main actors

Synthetic Genomics, Medical Research Council Laboratory of Molecular Biology (University of Cambridge), SynbiCITE, J. Craig Venter Institute, Evolva.

Recommendation

Observe

Obsolescence of existing approaches

Track & Monitor

This technology area falls into an Observe category. Key recommendations follow:

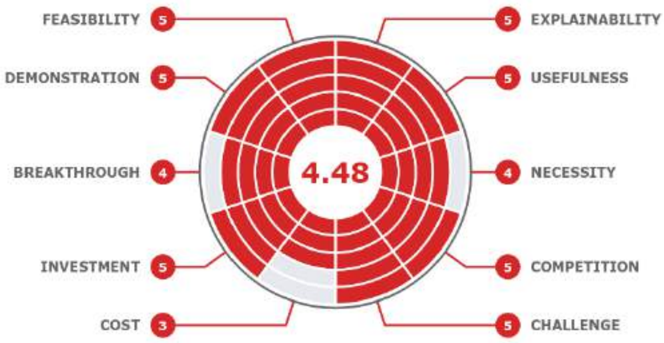
Create scenarios to help understand how the future could play out. Synthetic biology’s development could have profound, far-reaching consequences, but much is uncertain. Scenarios should be created with inputs from synthetic-biology technology experts, and defense/security experts.

Track and monitor developments in synthetic biology and related fields such as genetic engineering. Establish clear signposts that initiate a shift from Observe to Try. (For example: A fully synthetic version of a certain drug is developed.)

Synthetic-biology approaches could make existing approaches obsolete. For example, DNA computing could prove more effective than other novel computing approaches.

Others incumbents affected could include: 1st and 2nd generation biofuels; some pharmaceutical manufacturing methods; some irrigation, agriculture and food production practices; certain medical diagnostic procedures (e.g. colonoscopy); cancer treatments (e.g. radiotherapy, chemotherapy); some cosmetics; existing environmental remediation procedures.

Telepresence



Summary

Social presence
High-fidelity audio
High-definition video
Remote execution of tasks

Telepresence technologies allow users to observe, sense, and interact in remote environments. Manufacturers of high-end conferencing systems create presence by combining high-definition video, high-fidelity audio, and even matching furniture and wall colors to create a sense of seamless transition between connected locations. Other systems use video-mounted robots to allow workers to interact with colleagues in another location, and to move about just as they would in person.

More complex forms of telepresence give users the ability to perform skilled activities remotely. Unmanned aerial vehicles let pilots fly aircraft and conduct missions remotely. Ultimately telepresence researchers aim to eliminate functional and sensory boundaries between people and remote locations.

While it overlaps with remote control systems and robotics, telepresence aims to either create a sense of social presence for remote workers, or to give skilled workers the ability to execute complex, open-ended tasks remotely. Today, for example, telemedicine is a blend of video conferencing and data-sharing. In the future, researchers hope to outfit surgical teams with immersive displays, controls that function like traditional surgical tools, and a robotic field unit that they could use to operate on patients in battlefield hospitals or disaster areas.

Weaknesses

Outside UAVs, telepresence has struggled with poor interface and hardware design, high development and equipment costs. Adoption of office telepresence has been stymied by cheap, “good enough” alternatives like Skype.

Related fields

Robotics, Virtual Reality, Interface design, Holodeck, Augmented Reality, Audio and video, Sensors.

Civil Uses

Today: law enforcement, search and rescue, professional services, medicine, education, transportation, sports, video games.

Future applications: surgery, construction (esp. remote/dangerous locations), scientific exploration, space science.

Trends & Challenges

Operational presence
Social presence
Physical presence

Directions and obstacles for future research include: Social presence: Systems that “stand in” for operators need to seem natural and unobtrusive. This can be achieved through better design; but it will also require time and familiarity among users; Physical presence: Designing remote systems capable of acting with substantial freedom, and giving operators a sense of “being there,” requires advances in robotics, sensors, and interface design, particularly haptics and force feedback;Operational presence: A particularly difficult challenge as it requires creating near-seamless connections between users and remote vehicles/robots/etc., real-time feedback and operation, and interfaces that are familiar and easy to use.

General valuation

Robotics
Transport operation
Equipment operation

The concept of telepresence is one of the most enduring in computer science, but has proved one of the hardest to implement. Partly this is a problem of nomenclature: there is no industry standard definition of telepresence, and so the term has been appropriated by (and arguably dumbed-down by) the videoconferencing industry.

The recent proliferation of UAVs, and the development of other remotely-operated vehicles like mining equipment and earth movers, shows that in niche applications, telepresence can be useful and profitable today. These successes suggest that in the near future the creation of remotely-piloted systems like long-haul trucks, trains, and tanks will drive innovation in telepresence—but they'll face competition from autonomous navigation systems.

The grand dream of creating systems that provides users with a convincing, inviting (or in the battlespace, intimidating) physical presence in a remote location; that gather large quantities of real-time sensory information; presenting that data to users in ways that avoid information overload; and give users the ability to apply their knowledge and skill in that remote location, has proved extremely challenging, but recent advances in imaging and virtual reality suggest that these challenges could be overcome. Robotics will be both an enabling and competing technology.

Defence valuation

Reduced risk
Rapid "deployment"
Robotics
Unmanned vehicles

Telepresence offers the possibility of projecting the intelligence of soldiers into the battlespace, occupied areas, and other dangerous locations, without exposing them to bodily risk. Professional soldiers possess a level of tactical intelligence, flexibility, intuition, and assessment capabilities that no automated system can match. Further, telepresence could allow relatively small numbers of soldiers to be "present" in multiple areas, and "deployed" to new hotspots very quickly.

In the short term, the major opportunities are in unmanned vehicles, with ground-based and littoral vehicles.

Main actors

Fetch (robotics), Google (robotics), SAIC (underwater), DaVinci (telerobotics), Rethink (robotics).

Recommendation

Try

The recent pace of innovation in robotics, autonomous or remotely-piloted vehicles, and their underlying enabling technologies, has been remarkable. It's no longer a question of whether we will see delivery drones and robot assistants in the near future; it's merely a question of when.

While the level of trust in automated systems has risen, there is still plenty of opportunity for technologies that augment human capabilities, or project human skill into new areas. Innovations in telepresence are well worth observing. Exploring strategic alliances with robotics and telepresence companies, or trying an in-house telepresence pilot project, may also be worthwhile.

In a world of conflicts, violence, and resource competition, states and law enforcement need tools to extend their reach without expanding their numbers. The use of UAVs to monitor poachers in Africa is an early example of how even small, poorly-funded forces could multiply their power to do good.

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Wearable Computing

Summary

Smart Fabrics
Embedded
Displays

Wearable technology has seen a recent peak in interest focused around smart watches offering additional interfaces for portable electronics. Previous to this most commercially successful wearable technology has been in the healthcare and sports/fitness sectors. Wearable devices can incorporate sensors to record location, physical activity, pulse, blood pressure, blood glucose levels etc.

Beyond the current mass market, developers are looking at additional applications such as head-mounted displays, gesture recognition devices, wearable cameras, and exoskeletons.

Integrating electronics directly into textiles is perhaps the greatest innovation currently under study in the textile industry. Embedded devices could act as sensors—monitoring vital signs and athletic performance or measuring the concentration of airborne toxic chemicals. Textile-based electronics also have the potential for power generation and storage—enabling the realization of integrated communication devices.

Weaknesses

Wearable computing is currently restricted by several factors including limited functionality, cost and battery capacity. In addition, current use is limited to small discrete devices rather than being garment-integrated.

Related fields

Augmented reality, Portable Power, Virtual Reality, Internet of Things, Holodeck, MEMS, 3D Memory Chips, Telepresence, Social Networking, Bionic Implants, Stealth and Camouflage, Brain-to-Brain Interfaces, Emotion Tracking.

Civil Uses

Wearable computing can and is beginning to find use in several areas including healthcare, sports/fitness, social networking, navigation, remote working and policing.

Trends & Challenges

Applications
Usability

Future research will yield increased numbers of components specifically designed for wearables. Limited numbers of available devices are resulting in a strong emphasis on having a range of uses per device. Progress in terms of uses and software is likely to be incremental—with numerous uses being tried in an attempt to identify useful markets.

Research into other forms of wearable tech such as exoskeletons is at a less developed stage. These systems could be highly disruptive, but remain some way from implementation.

The development of lightweight, flexible batteries is a key barrier to the commercialization of textile-integrated electronics.

General valuation

Enabling
Uncertain
Consumer
Emerging

The full potential of wearable computing is not yet clear. Wearable computing is a technology largely built upon existing portable electronics and its success and development, will go hand in hand with other portable electronic devices. For example developments in flexible displays and improved battery capacities will benefit both smartphones and smart watches. The range of sensors currently being used is also a limiting factor and the incorporation of a wider variety of inputs measuring pressure, sound, electromagnetic fields etc. will open new avenues for wearable computing. CSIRO in Australia has developed energy-harvesting technology that can seamlessly incorporate into clothing and apparel that is already capable of delivering currents of several hundred milliwatts of power—large enough to run low-power electronics systems such as global positioning systems, mobile phones, heart-rate monitors, or radios in receiving mode.

Wearable tech that augments the wearer, such as exoskeletons, has the potential to be disruptive but are at a comparatively early stage in terms of maturity and availability.

Defence valuation

Monitoring
Safety
Information

Wearable computing has a wide range of potential military applications including the use of head-mounted displays, bio monitors and GPS. Head mounted displays could convey a wealth of relevant information. If combined with GPS systems these could enable navigation without the need to stop and consult maps. Bio monitors could enable effective monitoring of individuals for signs of fatigue, loss of concentration and enable rapid assessment of injuries. In addition to sensing applications (such as monitoring vital signs), integrating electronics directly into textiles also has the potential to reduce the mass of the loads that soldiers are required to carry.

More general wearable tech has similarly large potential. Exoskeletons could augment a person's strength or improve fine movement stability, for example in aiming a weapon or performing surgery. Smart fabrics may enable dynamic camouflage and garments that can adapt to changes in the weather.

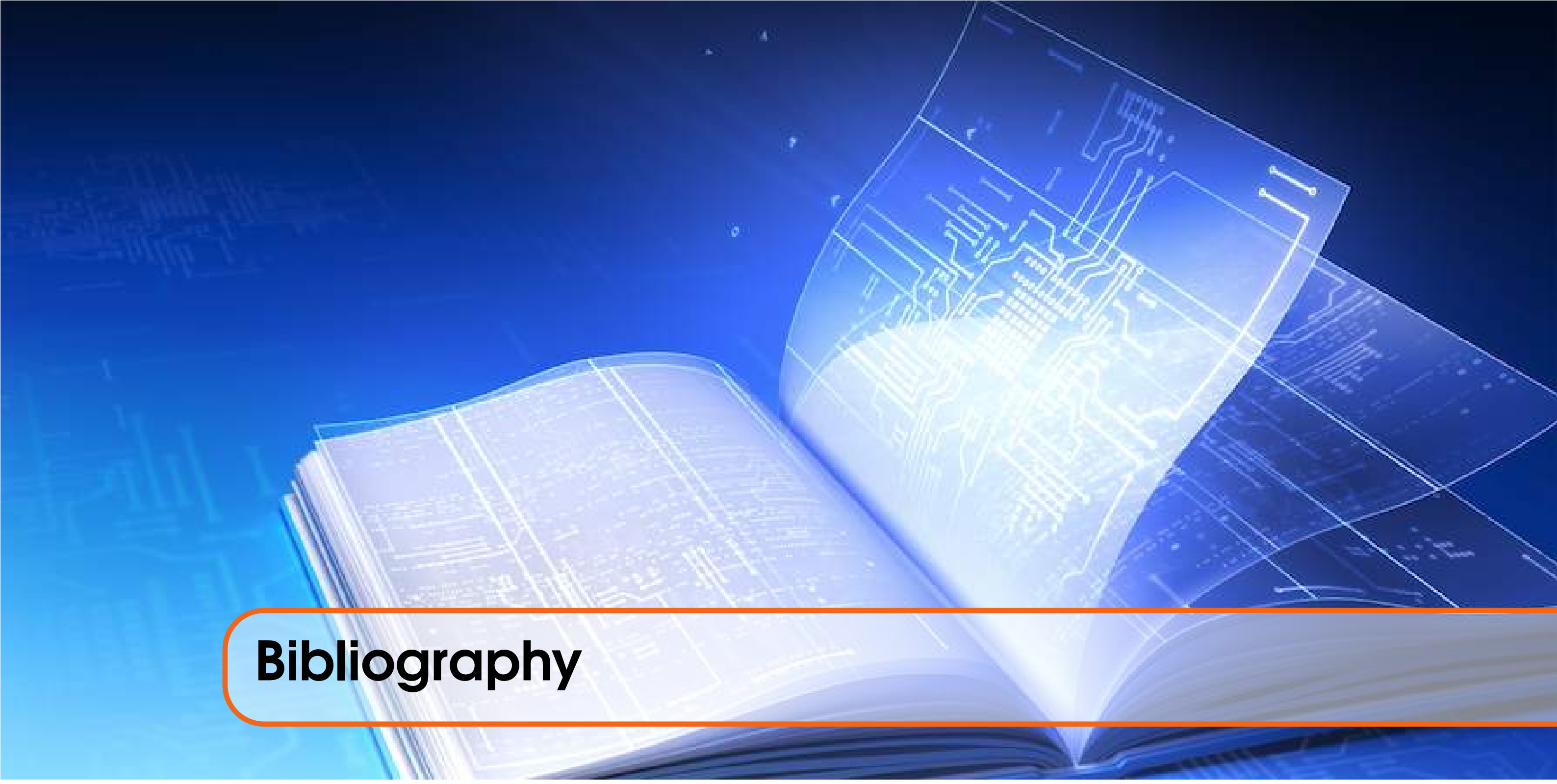
Main actors

Apple, CSIRO, United States' ARL, Google, Lumo BodyTech, Samsung, FitBit, Fujitsu.

Recommendation

Try

Wearable computing is an important emerging technology that is likely to prove highly disruptive—both in commercial applications and in the defense sector. Potential military applications make wearable technology of high interest to all major stakeholders within this sector who should closely observe this area for new and novel uses. Developments are likely to occur in an incremental fashion, gradually increasing the range of uses for wearable technology. It is also worth observing the development of new materials such as smart fabrics, which could open new avenues of research and development.



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Symbols

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Illustration: Greek alphabet in tonal strips as a rolling background fill pattern - www.spoonflower.com

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