EMERGING TECHNOLOGIES WITH THE POTENTIAL TO IMPACT SAFETY IN DEFENCE

P. R. Caseley, G. T. Strong, D. J. Holland Smith, K. J. Bown, B. K. Madahar

Defence Science and Technology Laboratory, Salisbury, SP4 0JQ UK

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Abstract

This paper provides a summary of the findings of a short investigation conducted by Dstl horizon scanning science and technology specialists on new technologies with the potential to impact safety in Defence – weapons technology excluded. The investigation was carried out to inform MOD regulators and safety specialists on areas that may require new thinking, and perhaps regulation, in terms of safety and risk. The perspective of the analysis is military and not civil but in most cases the discussion also applies to the civil safety domain.

1 Introduction

Dstl's horizon scanning function routinely collects information on emerging S&T which may have relevance within defence and security. At the time of writing the overall collection contained information on around 2,000 of the most significant, openly-reported developments in science and technology in recent years [1]. This paper presents a short analysis of this collection with a view to gaining insight into which areas of new and emerging technology might provide opportunities for enhancing human safety in the future. The investigation was carried out to inform MOD regulators and safety specialists on areas that may require new thinking, and perhaps regulation, in terms of safety and risk.

The basic concept of this analysis was to interrogate the MOD/Dstl horizon scanning collection and to form a subset of those developments which were judged to offer some potential for enhancing human safety – weapons technologies were excluded from this analysis. Specifically, the selection of candidate technologies was based on analyst-perceived relevance, followed by agglomerative clustering [2] in order to identify technology groupings.

The 'safety subset', derived as above, contained 327 developments. This provided the foundation for all subsequent analysis, including the production of a technology taxonomy (shown in Figure 1) which represents the underlying technological areas that might contribute to safe operations.

The breadth of technologies covered in Dstl's horizon scanning collection reflects the remarkably broad technological interests of defence and security. As a consequence, coverage of technological domains is relatively complete, and it is reasonable to assume that the collection is unbiased in this respect. Based on this assumption, the pie chart (Figure 2) provides an initial indication of the technological domains most likely to contribute safety-relevant advances. This shows that the majority of opportunities for enhancing human safety by technological means are likely to arise from the technological areas of medical, materials and sensing. This finding, for example, might provide an input to portfolio planning.

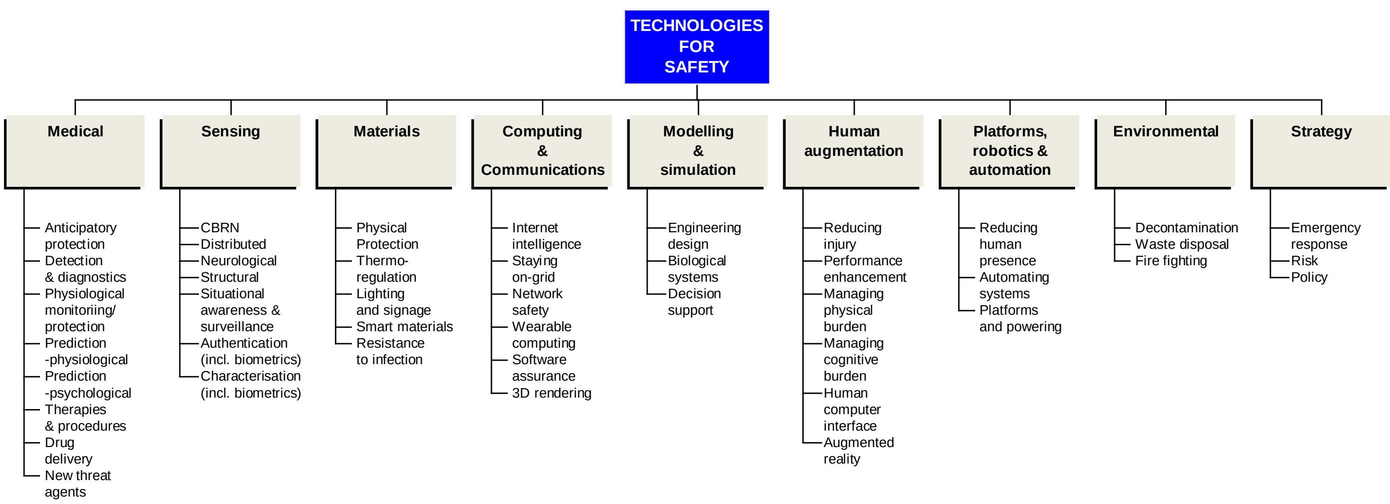

Figure 1: Technology taxonomy for enhanced safety

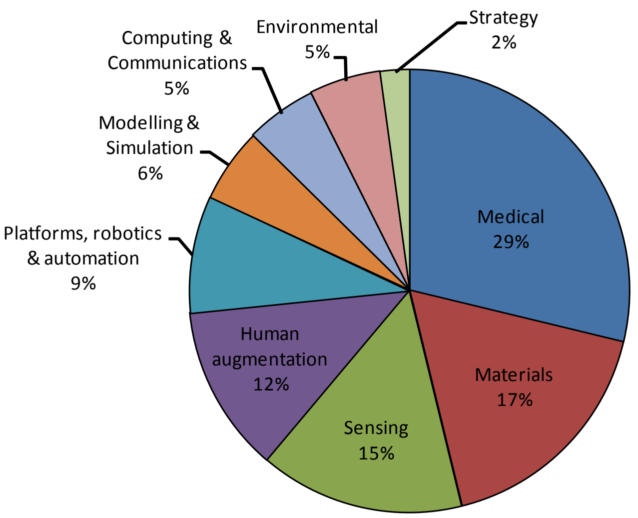

Figure 2: Indicative proportions of technologies affecting safety

Each of the following sub-sections visits a subject heading from the taxonomy at Figure 1, and provides a high level overview of the technology area, and its potential impact on safety, followed by one or more examples of new or emerging technologies from the horizon scanning collection.

2 Technologies for Safety

2.1 Medical technologies

Novel technologies are driving the improvement of prophylaxis both to disease-causing organisms and to adverse physical effects (e.g. radiation etc). Novel synthetic methods have led to the development of technologies with the potential to augment the body's own defence systems (e.g. antibodies). Emerging technologies such as carbon nanotubes are giving rise to exquisitely sensitive detection and diagnostic systems. Many such systems are highly suited to miniaturisation and implantation for persistent monitoring of physiological parameters and the presence of metabolic abnormalities. Allied to these systems, predictive markers have been identified for a wide range of physiological effects, some of which may be exacerbated by occupational factors and environments. Additionally, certain markers and neurological traits can be used to predict potential psychological vulnerabilities in personnel. The development of micro- and nano-based procedures and materials is leading to therapies and procedures previously unattainable. Such technologies may enable repair mechanisms within the body with minimal invasivity, as well as novel dressings and external applications.

'Plastic antibodies'. A range of technologies has been developed to produce 'designer antibodies' to augment the immune system in cases where the body's own response would be too slow, or where the threat presents little or no immune response. Approaches include molecularly imprinted polymers and cloning of human antibody-secreting cells. This technology has a clear health benefit, but may pose challenges in terms of assurance of the antibody design.

Example: Synthetic antibodies
Scientists have produced the first evidence that a simple, non-biological, synthetic material, with antibody-like affinity and selectivity, can function effectively in the bloodstream of living animals [3]. The plastic nanoparticles mimic natural antibodies and have been shown to be able to bind to melittin – the main toxin in bee venom. Mice given lethal injections of melittin, closely followed by a dose of the synthetic antibody, survived significantly longer than untreated mice. The antibodies are made by molecular imprinting. This process is outlined in Figure 3.

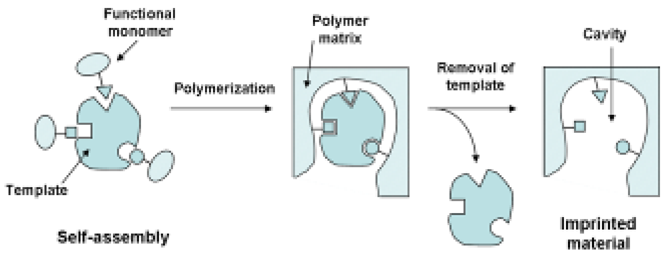

Figure 3: Molecular imprinting (Credit: Wikipedia, Satanata)

Ingestible sensors. As devices such as pH sensors, glucose monitors and cameras have become smaller, the practicability of incorporating them into an ingestible device for real-time monitoring has been realised. Allied to miniaturisation in transmitter and antenna technologies, this approach promises to allow a full-time capability of physiological monitoring for personnel. The technology could be applied to real-time health monitoring in hazardous environments.

Example: Networked pill
A new system monitors which medication is being taken and its effects on the body. The pill contains an Ingestible Event Marker (IEM) comprising a microchip with a thin-film battery that is activated on ingestion. The IEM sends a high-frequency electrical current through the body's tissues which is picked up by a receiver on a skin patch that also monitors physiological responses such as heart rate and respiration. The data can be uploaded to a server via a cell phone [4].

2.2 Sensing technologies

Driven by developments in emerging technologies, sensing systems are becoming more pervasive; a trend that is likely to continue at an accelerating pace. The ubiquity of consumer devices such as mobile phones and tablet PCs enables increasingly distributed networks, nodes and detectors for sensing systems. In addition to sensor systems for 'external' threats (e.g. chemical, biological, radiological etc.), increasing numbers of technologies are reaching a maturity that may enable the determination of neurological 'intent' in humans, and 'structural health' in the built environment and vehicles. Many of the stand-off technologies developed are applicable to biometrics, both for authentication (e.g. for security purposes) and for characterisation (e.g. for counter-terror applications).

Structural Health: From a safety perspective, the integrity of buildings and vehicles has been experimentally monitored in a variety of ways including the use of self-reporting coatings.

Example: Permanent structural health monitoring
Networks of sensors that are mounted on aircraft to check continuously for the formation of structural defects, and the health of electronics, hydraulics and avionics, could reduce or possibly eliminate the need for aircraft inspections. One sensor being evaluated is the 'Comparative Vacuum Monitoring sensor' which is a thin, self-adhesive rubber patch which detects cracks in the underlying material. Any propagating crack under the sensor breaches internal air-filled, laser-etched galleries in the sensor, and the resulting pressure change is monitored [5].

Advances in nanotechnology and engineering have also enabled the development of highly sensitive nanosensors. Potentially, this will enable safety sensors to be more accurate and to be placed in previously inaccessible locations.

Example: Nanotube gas detector
Highly sensitive sensors have been developed using a method that enables the nanotubes to be precisely positioned. In one case, an ultra-thin perforated sheet of aluminium oxide was used as a mould. When the sheet was placed in a solution of tungsten ions, nanotubes were formed and effectively cast into place. Thin layers of gold were deposited on the top and bottom to act as electrical conduits. The new sensors were found to be more sensitive than current devices based on thin films, and could act as multiple sensors simultaneously [6].

2.3 Advanced materials

Advanced materials are being developed for a variety of functions that could contribute to future safety. Mouldable shear thickening foams can be used to provide 'instant' protection against blunt trauma. A range of flexible fabrics can now be treated to confer effective and long-lasting waterproofing, antibacterial, or self-cleaning properties. Fire-proof synthetic polymers could offer improved protection in aircraft and buildings, and some advanced coatings for turbine blades offer improved erosion resistance by incorporating erosive material into their structure [7]. Phase-change materials can be used to provide heat or cooling within protective clothing and a range of emerging smart materials offers the properties of self-healing, or can adapt to a range of physical and environmental conditions. Lighting for guidance and improved safety could be based on bioluminescent bacteria, light emitting diodes and advanced plasma devices.

Nano-engineered materials. The ability to create hierarchical structures at the molecular/nano-scale has enabled the development of stronger and more stable glass, and also allowed researchers to strengthen existing lightweight alloys, giving them the strength of steel whilst improving flexibility. The technique has already been used to improve the strength of aerospace-grade alloys, and future work is looking to strengthen magnesium with a view to using it in body armour [8]. Composite plastics, which exhibit the strength of steel but are lighter and transparent, have also been built at the nanoscale, and might be used in vehicle armour. Such developments have been enabled by advances in robotics and rapid manufacturing techniques, including 3D printing. Figure 4 shows a nanocrystalline form of vanadium dioxide that could find potential uses in extremely fast optical shutters, optical or infrared modulators, cameras, or data storage devices.

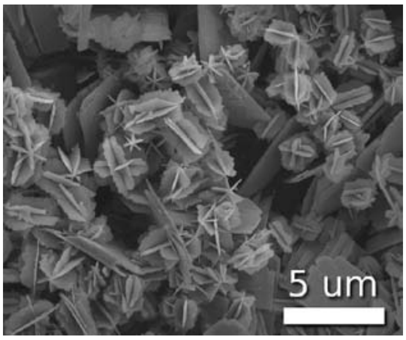

Figure 4: Nanostars of vanadium IV oxide (Credit: Wikipedia/Furmanj).

'Smart' clothing. Durable coatings can now be inexpensively applied to new or existing clothing to provide long-term protection against bacterial infection. Fabrics treated with nanoparticles can repel both bacteria and liquids (oil and water) allowing safer operation in hazardous environments.

Example: Permanent spray-on antibacterial coating
Permanent spray-on coatings of antimicrobial co-polymers can be applied to a variety of natural or synthetic materials in a simple, inexpensive and scalable process. Following a single application, treated textiles retained their antimicrobial properties after numerous hot washes. When exposed to a range of pathogens (such as *E. coli*, pseudomonas and acinetobacter), the coatings showed no contamination after 24 hours at 37°C. Such coatings could be used on medical equipment and dressings, on a variety of clothing, and in food packaging [9].

2.4 Computing and communications

The Internet provides an increasingly diverse range of services and resources that are of relevance to safety. At the most basic level, the Internet carries commands for and between control systems, but it also provides access to a vast array of literature and people-based resources that can inform and guide decision making. 'Cloud' computing represents a contemporary shift of paradigm in the provision of information services, and requires new thinking in terms of safety and risk. For hardware, with the trend towards the incorporation of computer processors into all kinds of items from the everyday prosaic through to specialist equipment, unreliable operation and network connectivity can be disruptive in ways that are difficult to predict. At a direct human level, where operatives are working in hazardous and stressful situations for example, enabling them to stay 'on grid' and in communication could be critical to a safe outcome. But along with these challenges comes great opportunity for enhanced safety, not least through advances in human-computer interfaces.

Wearable computing. This important trend which impacts on safety is underpinned by, e.g. flexible electronics, wearable sensors, and antennas integrated into clothing. At the extreme of this evolution are devices that are embedded in a user's body, potentially with displays and interfaces that are visible through the skin. It is interesting to note that early instances of this trend are tending to be demonstrated by private individuals. In a more formal setting, however, new safety regulation on the impact of these sensors on the human body will need to be in place.

Hardware and software assurance. Complex, reconfigurable and reprogrammable electronics are needed to meet the insatiable demand for computer performance. Additionally, software life-cycles are increasingly compressed, and the growth of the market for applications ('apps') introduces a wide range of potentially unknown suppliers. Our reliance on Electronic Control Units (ECU) seems set to increase—modern cars use as many as 70—whilst also increasing are instances of 'pre-installed' viruses distributed in new electronic products. Appropriate processes are needed to assure the safe and secure operation of software and functionality of devices. Of relevance to improving safety are developments in the automatic generation of software code (below), especially as programming complexity increases, and the use of advanced design methods such as *model based engineering*.

Example: Automatic verification of software code
A microkernel for low-level hardware control has been mathematically proven to behave correctly in all situations. This eliminates many common issues including memory leaks and buffer overflows as well as avoiding emergent behaviour, and can help mitigate any testing for higher level applications, although this does not obviate the need for some testing. This work is expected to be of most use in areas where security and reliability of software is of critical importance including the financial, medical, automotive, aero-space, and defence sectors [10].

Crowdsourcing. Developments which appear far apart on the surface such as *Wikipedia* and *Internet Eyes* [11] actually share a common reliance on engagement from a large number of people, including amateurs and even individuals without specific technical training. Both are examples of crowd sourcing, which now has a proven track record and currently is trending strongly upward. Use of this technique, and the wide discussion it typically engenders, has relevance for safety both in terms of promoting awareness in advance of an incident, and speed of response during an incident.

Internet Eyes exemplifies the potential for enhanced safety. This is an online community which shares surveillance imagery (stills and video footage) from CCTV cameras located in shops and shopping centres, to be analysed, interpreted and 'marked up' by a large pool of minimally trained analysts, taking time away from their usual work.

Rendering in three dimensions. One exciting prospect for safety arising from advanced communications devices is the rendering of true three-dimensional information. This includes both images and physical models that can now be produced to order by additive layered manufacturing techniques such as 3D printing. Figure 5 shows the 'RepRap' (replicating rapid prototyper) 'Mendel' 3D printer which can be assembled using off-the-shelf parts and those which the printer has produced itself. In principle, such a device could be used for the rapid prototyping of the ideal safety equipment for any situation that arises.

Figure 5: RepRap v.2 'Mendel' fused deposition modelling 3D printer (Credit: Wikipedia /Charles C)

Example: Hand-held 3D display
This device is a 10cm cube that allows a 3D still image to be presented from the palm of a user's hand without any special viewing glasses. The panels contain numerous tiny lenses on liquid crystal displays to provide different images from various angles. The developers plan to develop the cube so that it will be able to show images that move in real time, from all six sides. Vocal sounds may also be incorporated to give the impression that the image is speaking [12].

2.5 Modelling and simulation

Advanced engineering software and 3D models are being used to help understand how materials break, how non-rigid objects deform, and how stress is distributed through the skull in order to optimise the design of protective equipment such as helmets. Through ergonomic design, clothing can be optimised to suit a person's lifestyle, taking into account factors such as predominant posture, thermal regulation, moisture management and psychological wellbeing. Computer modelling is also being used to simulate the characteristics of training equipment with a view to designing for optimal safety and effectiveness. Within the medical domain, mathematical models are being used to determine how disease spreads so that the effectiveness of preventative measures can be determined. On a cellular scale, they are also being used to help determine how individuals will respond to infection by viruses. Improved algorithms can also aid decision support by providing a means of monitoring, managing and influencing complex systems, and 3D modelling can help to simplify data visualisation.

Design of protective equipment. Engineering design can be based on improved knowledge of the mechanics of biological structures such as the skull through techniques such as computer tomography. Alternatively, it can be based on a 'bio-inspired' approach of simulating the human anatomy.

Example: A bio-inspired helmet design
A new helmet provides improved protection by mimicking nature's design of placing skin over the skull. On impact, the outer membrane can stretch and slide over the main helmet shell to prevent the rotational force from being transmitted to the head and brain. The design consists of a strong synthetic material, able to stretch to eight times its length. This is located on top of a gel-like lubricant to form a protective layer across the surface. The developers claim that this new design reduces rotational impact by 50% and the possibility of brain damage by 67.5% [13].

Simplifying data visualisation. In the event of a disaster, a large amount of data is generated through social networks such as Twitter. This data can be managed and visualised, for the purposes of aiding emergency workers, by translating it into clusters on a smart phone map. Social networks can also be used to gather information on a variety of subjects that may affect safety, such as people's opinions on vaccination, which may have an impact on the spread of disease. Figure 6 shows an example of complex data visualisation – in this case a visualisation of Wikipedia as part of the World Wide Web [14].

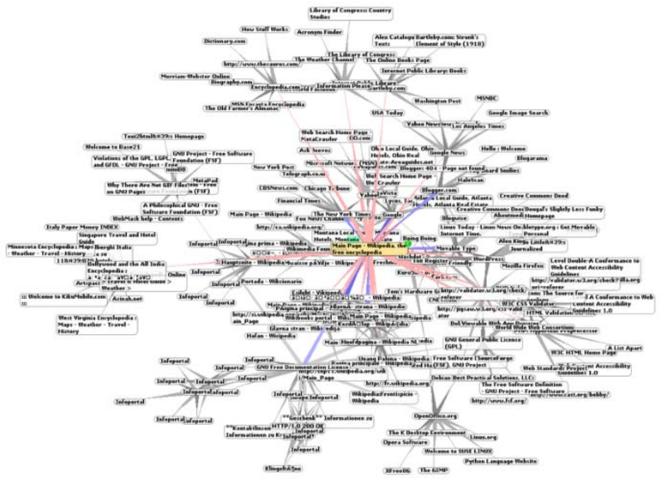

Figure 6: A data visualisation of Wikipedia as part of the World Wide Web (Credit: Wikipedia)

Domain convergence. As real and virtual worlds collide, the full immersion of humans within virtual worlds might be used for training and controlling real systems in hazardous environments. Also, this may provide the ability to emulate a range of scenarios and situations, including advance engagement of a general civilian populate where appropriate. In another area, the convergence of biology and electronics is leading to direct connectivity between 'neurons to electrons'; opening up a new dimension in human machine interfaces. This latter area may be a new challenge for regulation.

Data mining and discovery. Whilst the technique is largely not new, the availability of data does present new opportunities, some of which will be of value in identifying and speeding appropriate legislative and regulatory activity. The following development shows an early advance in the area of medical safety.

Example: Mining for the unexpected
A data mining method has been developed to identify unanticipated adverse drug reactions which might occur as a result of taking a combination of different drugs. Conventional data mining techniques seek to identify frequently occurring patterns making identifying rare and unexpected drug reactions challenging. The new method incorporates rules and parameters to manage unexpectedness, and utilises event-oriented data preparation techniques to manage the infrequency. The technique was used to shortlist seven known reactions from a healthcare database [15].

2.6 Human augmentation

Some technologies offer the potential to augment or enhance a person's abilities or personal effectiveness beyond that which is considered 'normal'. Whilst, these abilities could enhance human safety in a range of situations, new regulation may be required to ensure that the techniques themselves are safe in use. Mechanical enhancements include artificial muscles and external weight-supporting skeletons, which could help to reduce the incidence of injury by managing the physical burden, whilst optionally generating electricity to provide additional power for hand-held devices. Medical enhancements include biochemical compounds which work to maintain or increase alertness, or decrease the incidence of fatigue. Cognitive stress or psychological overload can be mitigated through the use of technology which is designed to transfer the cognitive burden from the human to an external (optionally body-worn) device which emulates some of the functions of the human brain, e.g. the collection of visual and auditory data. Advanced human computer interfaces also enable the user to control a variety of external devices, such as robots or computers, with different parts of the body even including their mind, offering the advantages of removing physical burden and maintaining increased standoff.

Total recall. The social trend of personal data acquisition, together with the rapidly decreasing cost of computer memory, and the miniaturisation of sensor technology, is driving the commercial market to produce hand-held devices with the ability to record events visually and aurally. For the purposes of supplementing a range of human senses, devices that are being discussed in the literature [16] offer the potential to create a digital record of everything a user sees and hears. Body-worn IR sensors [17] alert the user to changes in the environment, such as the presence of another person, and associated software allows all data collected to be annotated and classified. For the purposes of enhanced situational awareness and safety, a person could be equipped with a similar system that collects data based on subconscious cues such as their physiological and neurological responses to events that they may not consciously recognise as important. Such a recording device would effectively perform the function of video analytics at the point of collection.

Example: Augmented reality glasses
By taking a two micro liquid crystal displays mounted in the arms of a pair of glasses, and projecting the image to a small part of the lenses, a pair of 0.52-inch displays can be generated on each side of the nose. Combined, they offer a 960×540 resolution display, controlled by head movements or voice control. With both a camera and global positioning system embedded into the glasses, the user's vision could be augmented with addition information such as points of interest or navigation data. The developers plan to augment the user's reality with head and voice-controlled images, GPS, and a 3G/4G connection [18].

2.7 Platforms, robotics and automation

In this paper, *robotics* is defined broadly to include both mechanical and virtual agents, and both those which are fully autonomous and those which operate by remote control. The safety benefits of using robots in place of humans for carrying out hazardous work are well established, although it is only recently that the true potential seems to be coming within reach.

Robotics for reducing human presence. As a recent illustration, a range of robotic devices were put to use following the tsunami which struck Japan and its Fukushima nuclear plant. Whilst underwater search robots worked to locate victims of the tsunami; sophisticated disaster relief robots entered areas too contaminated for human operators in order to set up monitoring equipment and to film the surroundings, and helicopter drones sampled radiation levels in the environment. A number of problems were encountered but, following the disaster, the Japanese Ministry of Agriculture is reported to be planning to create an experimental 'farm' in which robot operators will work on land swamped by the tsunami [19].

A potentially interesting observation in terms of the *perception* of safety comes from an 85-year old Japanese lady who, after the tsunami, was provided with a robotic 'pet' seal, "If I hold onto this, it doesn't matter if there's a typhoon outside, I still feel safe" [20].

Autonomy and intelligence. Fully autonomous robotic systems with increasing 'intelligence', including 'agents' within software networks, are set to become more prevalent. This is a very broad area with a range of potentially negative implications from safety (and legal) perspectives, including the assurance of single systems, use alongside humans and safety when interacting as part of a 'flock' or complex system. On the positive side, however, autonomous systems might themselves be used to provide monitoring and assurance for other entities within a wider systems context.

Anthropomimetics. This is a 'wild card' idea, but the trending suggests that non-autonomous 'humanoid' robotics is set to emerge, perhaps emphasising civil markets. Some devices, which have been developed only recently, go some way towards realising the eventual aim of full tele-presence. From a safety perspective, and in addition to separation by range, such devices have the potential advantage of being able to interface with equipment.

2.8 Environmental

Developments in materials and nanotechnology have driven a variety of solutions for dealing with problems caused by land, air and water that has been contaminated with toxic industrial chemicals, heavy metals or radioactive substances. Toxic or carcinogenic persistent organic pollutants can be destroyed using ultrasound, or absorbed using variants of polyelectrolytic gels or nanoparticle composite gels, which swell to many times their original size. Solid radioactive compounds such as strontium-90 can be removed using synthetic sulphides. Small amounts of powdered nanomaterials are highly effective in removing radioactive particles from water (i.e. nuclear reactor leaks) and porous semi-conducting aerogels can be used to remove mercury from water with high efficiency. Fungi have the ability to colonise areas contaminated with depleted uranium and convert the metal into harmless minerals which they retain, thereby effectively preventing further contamination of plants, animals or the water supply. An interesting emerging area is the development of surfactants whose properties can be reversibly altered using a magnetic field [21].

Waste disposal. Potential technology solutions to the problem of waste disposal include approaches which aim to render commonly used items biodegradable (e.g. car components, and cutlery that dissolves in sea water for use on naval vessels). Another interesting and novel approach has been enabled through the improved understanding and practical application of plasma. Portable plasma torches, which can reach temperatures of 5000°C, can be used to completely destroy waste by gasifying organic matter and melting inorganic compounds into a recyclable inert vitrified product. They also offer the option of power generation as the gas can be used to drive a turbine with an end-to-end electrical efficiency of up to 40%. The plasma gasification of biomass may even allow the production of second generation biodiesel.

Fire-fighting. Novel approaches to dealing with fire could offer improved safety for emergency workers.

Example: Fire-fighting using electricity
Electricity is known to affect the shape of flames, causing them to flicker, bend, twist or be extinguished. This observation has been exploited to produce a demonstrator in

which a 600W amplifier was connected to a wand and used to project beams of electricity at a flame (0.3 m in height). The instant extinguishing of the flame has led to speculation that this technique could eventually be used to control the movement of (and extinguish) fire, especially in enclosed areas, or to develop electric ceiling sprinklers in buildings [22]. This method also allows fires to be controlled from a distance, without delivering material to the flame. Such a situation could involve fighting fires at aircraft facilities (see Figure 7).

Figure 7: Fire-fighters wearing personal protective equipment tackle an aircraft fire during a drill at Dyess Air Force Base in Abilene, Texas (Credit: Wikipedia/DVIDSHUB).

The discovery that fire can be 'controlled' using beams of electricity could underpin a new generation of fire-fighting devices that can suppress fire rapidly without damaging electrical equipment such as computers. The system shows particular promise for fighting fires in enclosed quarters, such as armoured trucks, planes, and submarines.

2.9 Strategy

This section considers some of the more strategic issues and the use of technology, and the insights it provides, to assist with planning and decision making.

Example: Policy for emergency response. A research team has determined that 'sheltering in place', as opposed to evacuation, can be a more efficient response to certain emergency situations such as dirty bombs and chemical spills, but also including more common emergencies such as electrical blackouts, snowstorms and hurricanes. Engaging a population is a key step, and a set of tools has now been created to help people to anticipate and address the problems they might face in an emergency [23].

More generally, technical approaches are now becoming available which seek to support strategy formulation for the governance of complex environments, and even the identification of specific interventions to maintain a chosen course. One such development based on co-evolutionary scenarios aims to provide a 'theory-informed' approach to take into account the complexities of technical innovations within (co-)evolving socio-technical environments [24]. Other researchers in complex adaptive systems are reporting early success in being able to intervene (successively) at the level of individual 'nodes' in order to promote benign outcomes across the whole system.

Risk management. Collaboration based around an agreed (technical) monitoring system appears to be a successful model for managing risk. One such intervention is underway to provide some governance for the rapidly developing field of nanotechnology. Nanotechnology is an area of S&T that is widely reported to be advancing and 'proliferating' at a rate faster than regulation. The development describes one response that might be a model for similar circumstances: the world's first certifiable risk management and monitoring system for nanomaterials. The global food supply chain is also being subjected to technical analysis to identify potentially weak or otherwise vulnerable points which might be exploited by terrorist groups. Suggested responses include increasing vigilance through to undertaking supply chain verification and validation.

Example: Nanotechnology risk management
The first certifiable nano-specific risk management and monitoring system has been developed to meet the challenges presented by nanomaterials, specifically uncertainty regarding their mid and long term effects on human health and the environment and legal uncertainties as to the extent to which current regulations for traditional chemicals apply. The system ensures that health and safety risks are assessed according to state of the art standards and latest findings from science and technology are included in the process [25].

3 Illustrative rating for 'interest'

Previous work within Dstl concluded that a utilitarian measure for the 'interestingness' of a unit of information could be formed from the (weighted) product of its *timeliness*, *relevance*, *unfamiliarity*, and *exploitability* [1]. This short section undertakes a very cursory rating of the safety collection in order to draw to attention to those developments which might be of particular interest.

To simplify the exercise, a new variable termed *significance* is used for the combination of *timeliness*, *relevance* and *exploitability*, and mapped against an estimate of *unfamiliarity*. For each of these measures, a qualitative estimate was made based on a scale of one to five for each technology.

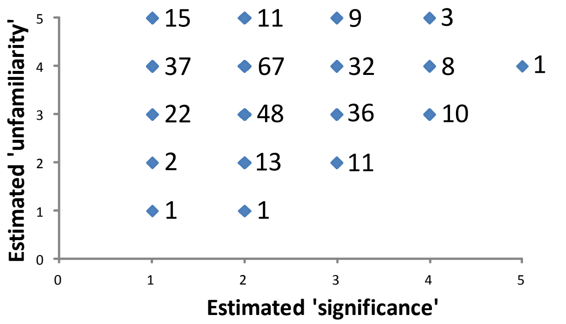

Figure 8: Spread of Technology – Significance/Unfamiliarity

Figure 8 shows the results for the whole set, with the number of developments at each point shown on the graph. The plot indicates the expected pattern that relatively few developments are both highly significant for enhancing human safety *and* unfamiliar. Taking only those developments whose ratings sum to 16 or greater produces the following list[1].

Bio-capsules for remote medical treatment. These implantable capsules may contain cells are engineered to detect and treat potentially threatening medical conditions.
Medical uses for non-thermal plasma. Non-thermal plasma has been shown to be capable of killing a range of bacteria, even on living tissue, within seconds without causing side effects
Injury code. This is a novel encoding scheme which works to provide rapid and reliable assessment of varied and complex injuries based on measured levels of biomarkers.
Miniature unmanned air vehicles. An ultra-portable, high-capability UAV that is capable of streaming video from remote and perhaps hazardous locations.
Body sensor. This capsule, which would be implanted under the skin, provides *in vivo*, 'automated' diagnosis and medical treatment for a range of illnesses.
Smart phone applications. An early example of a cost effective augmented reality system, based on a smart phone, and combining maps with a buddy list.
Bio-inspired helmet design. To counter the vulnerability of the head to impact injury, this innovation supplements a protective helmet with an outer membrane that can stretch and slide so as to absorb rotational force.
Fire-fighting using electricity. In this unanticipated development, beams of electrical energy are found to provide a potentially effective means for controlling fire.
Permanent spray-on antibacterial coating. Following a single application of this polymer coating, treated textiles are claimed to retain antimicrobial properties, including after numerous hot washes.
Modafinil for sleep deprivation[2] In this development, people deliberately deprived of sleep were able to maintain cognitive performance after taking a drug.
Simply effective data visualisation. In this innovative development, the efficiency of information visualisation is improved by carefully tailoring to the subject matter and, where possible, simplification.

If the ratings have been applied correctly, this list should give some insight into the ability of horizon scanning to expose technologies which are cross-cutting between domains.

4 Summary

This short informal review, based around the MOD/Dstl horizon scanning database, has identified in excess of three hundred new and emerging technologies that may serve to enhance human safety. From these, it has been possible to infer an underlying taxonomy that indicates the relevance of technical domains such as medical, sensing, materials, human augmentation and robotics. The 'profile' of each domain is described, based on the developments it contains, and specific examples are used to draw out some of the key points and insights that emerge. A simple rating process is used to reveal a shortlist of technological developments that are believed to have high significance for enhancing human safety but whose potential role in this context may not be widely understood.

[1] Two records on the medical uses of plasma appear in the original list, one of which has been omitted here for clarity.
[2] The efficacy of this claimed development should be reviewed in light of related experimental work within the UK MOD which is reported at: http://news.bbc.co.uk/1/hi/6083840.stm

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