Emerging Technologies – Problems and Solutions

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Abstract:
Emerging technologies influence international security in two ways. On the one hand, they create new problems and dangers. Presently, the most urgent problems seem to lie in the areas of molecular biology – mainly by the potential for selective biological or chemical weapons – and micro/nano-technology; here, robot weapons of all sizes moving on land, in water, air and outer space as well as very small weapons would constitute new threats. Another aspect concerns non-medical manipulation of the human body. To contain such dangers, preventive arms control is needed. On the other hand, emerging technologies can provide new means that contribute to co-operative solutions for old and new security problems. This concerns detection and mitigation of threats (monitoring for dangerous substances, protection and decontamination) and verification of compliance with international commitments. Micro- and nanotechnology promise, e.g., miniaturised cheap sensor systems.

Keywords: research; development; military; arms control; disarmament; verification

1. Introduction

New technologies have in the past strongly influenced international security. One needs only to think of nuclear bombs, nuclear-propelled submarines and nuclear power stations, or of long-range ballistic missiles, space-launch rockets and satellites. New technologies have an ambivalent character. On the one hand, they can be used in the military field, for new weapons and other systems. The decades of the Cold War provide many examples where new military technologies have increased threats, reduced stability and intensified tensions.

On the other hand, new technologies have also contributed to better information about military capabilities of a potential opponent, reducing exaggerated fears. In particular imaging satellites, providing reliable verification of compliance, made conclusion of arms-control agreements possible. Since the late 1980s, these national technical means of verification have been supplemented by a widening array of technologies used co-operatively, with the International Monitoring System of the Comprehensive Test Ban Treaty a prominent example.

Even though the Cold War is over, the basic mechanisms of military threats and of the use of new technology to increase military effectiveness are still at work. In particular, despite massive reductions in the numbers of nuclear weapons, the risk of nuclear war is present all the time (Fig. 1).

This article will first cast a look on military technologies emerging today. Their dangers could be contained by preventive arms control that is described next. Finally, several new technologies useful for disarmament and verification are discussed.
Figure 1: Nuclear Stockpiles from 1945 to 2002. Present numbers: United Kingdom: 200, France: 350, China: 400; estimates for Israel: 200, India and Pakistan: together less than 100 warheads.¹

Figure 2: Military research and development (R&D) expenses of selected states since the final stage of the Cold War; China's expenses were estimated as $1 billion in 1994.²
2. Emerging Military Technology

If one wants to know what kinds of new military technology can be expected in the next decades, one can on the one hand analyse and extrapolate present scientific-technological progress. E.g., developments in molecular biology raise the fear of new agents that would make biological warfare calculable – by selective action using genetic traits, by timed self-destruction, by a binary principle or with the help of reliable inoculation of the own forces or population – and would thus undermine the Biological Weapons Convention.

On the other hand, it is instructive to look at the military research and development (R&D) of the USA which are by far the largest in width and depth (Fig. 2). The USA is also unprecedented in the level of transparency in military R&D – budget figures for individual programs are even available over the internet while similar data would not be available in public in countries such as Germany, the United Kingdom or France, not to speak of Russia or China. (However, details about military projects are not usually public in the USA, and secrecy prevails in many aspects of weapons of mass destruction.)

On a defence-wide level, the Defense Advanced Research Projects Agency (DARPA) is tasked with planning and administrating basic research, applied research and advanced technology development. Table 1 lists some of the DARPA projects. The services Army, Navy and Air Force carry out their own respective work in these three categories. Their major activities, however, lie in the development of concrete military systems, see Table 2. Overall defence research in Fiscal Year 2002 amounted to $9.2 billion (22% of R&D) whereas development was funded at $32.6 billion (78%).

One area of potentially problematic future technologies concerns robotic fighting systems. A first indication of what may come was provided by the destruction of a car, killing six putative Al-Qaida terrorists, in Yemen in November 2002. A Predator unmanned aerial vehicle – designed for surveillance purposes – had been retrofitted with a Hellfire missile that was launched under remote

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Table 1: The program elements of the US Defense Advanced Research Projects Agency with a few selected projects each. Total funds for these elements in Fiscal Year 2002: $2.07 billion, plus classified projects of $140 million and administrative costs of $36 million.³
control. However, envisaged are systems with autonomous action: unmanned helicopters, jet aircraft, tanks, surface ships and submarines. A particular category is formed by small robots (10 cm size, in the future potentially much below) enabled by micro- and nanotechnology. Transferring the decision to kill to an artificial system would represent a drastic change and would contradict the international law of warfare if the robot could not reliably detect when an enemy combatant is hors de combat or intends to surrender.

Fundamental barriers of a different kind are being put into question with respect to an electronics-brain interface and body manipulation. In animal experiments, rats could be directed along arbitrary paths by remote control with the help of three electrodes in their brains. Using multiple electrodes contacting the motor cortex of a monkey, the neuronal patterns causing arm movement were derived and successfully used to drive a robot arm. Whereas such experiments may lead to means of restoring motion in paralysed patients, the use of electrode and other implants in soldiers would raise strong ethical concerns. The DARPA “Brain Machine Interface” programme for deriving human-brain signals is for the time being – geared towards non-invasive sensing of brain excitation (e.g., for faster reaction times), but implants of computing and communication devices have already been discussed as visionary projects in a planning workshop.

Even though the USA are leading by far in military technology, some potential opponents will be able to follow and introduce similar new weapons and systems after several years of delay. Such systems may also proliferate to other countries and even to sub-national groups. The net result may well be an increased threat to all, including to the USA. Mutual preventive limitation would therefore in many cases improve national as well as international security.

3. Preventive Arms Control

In order to contain dangers from new military technologies, the concept of preventive arms control has been developed. Preventive arms control intends to stop or limit dangerous military developments before they become actual. A particular focus is on new weapons technologies.

Preventive arms control has been implemented already in the treaties concluded during the Cold War. Indirectly, the Partial Test Ban Treaty of 1963 limited experimentation under conditions of nuclear explosions. Had the Comprehensive Test Ban Treaty been concluded much earlier than 1996, it would...
have prevented many new types of nuclear weapons. The Nuclear Non-Proliferation Treaty of 1968 obliges the non-nuclear weapon states to remain in that status. The ABM Treaty of 1972 (abrogated 2002 by the USA) banned not only deployment, but also development and testing of certain kinds of anti-ballistic missile systems, namely those that are ship-, air- or space-based or mobile land-based. For the eventual case of systems based on new physical principles that could replace anti-ballistic-missile interceptor missiles, launchers or radars, an agreed statement to the Treaty stipulated that specific limitations would be subject to mutual discussions. (This was a point of contention in the discussions about laser weapons and satellite-based sensors in the U.S. Strategic Defense Initiative launched in 1983.) The Additional Protocol on Blinding Laser Weapons of 1995 to the UN Convention on Certain Conventional Weapons of 1980 prohibits only the use of such weapons, but has led to near-complete ending of research and development for them.

Preventive arms control consists of four steps: 1) scientific-technical analysis of the respective technology, 2) analysis of military and operational aspects, 3) assessment under preventive-arms-control criteria and 4) devising possible limits and verification methods that would not prevent positive uses and limit the costs. The criteria can be grouped in three categories:

- dangers to arms control agreements and the international law of warfare,
- dangers to stability (military situation, arms race, proliferation),
- dangers to humans, environment or society.

When applying the criteria of preventive arms control, one can find several areas of emerging technologies where dangers loom large with potential military applications. Among these are space weapons, autonomous fighting systems, more controllable chemical and biological weapons and body manipulation. Nanotechnology will provide qualitatively new military options in these fields, including the potential for very small systems. Closer to the area of nuclear non-proliferation is the problem of new nuclear weapons of relatively low yield (< 5 kilotons TNT equivalent) that are finding renewed interest in the USA under the illusory impression that they could destroy deep underground structures while avoiding radioactive contamination at the surface.

Containment of such dangers would be possible by adhering to the Comprehensive Test Ban Treaty and strengthening the Biological Weapons Convention by an effective Verification Protocol. New technologies should be covered by conclusion of additional agreements, such as:

- a general ban on space weapons (already proposed since decades),
- a ban on killing by autonomous systems,
- a moratorium on body implants that are not medically motivated.

4. New Technology for Disarmament and Verification

New technologies have also a potential to help in reducing military threats, mainly by providing technical means of verification of compliance with limiting agreements. The most prominent example – which in a sense made arms control first possible – is imaging satellites. They allowed independent assessment of the nuclear potential of the adversary in the 1960s and continue to be the main verification means of the bilateral nuclear limitation treaties. (However, one must not forget that most of the time they are being used for finding targets for nuclear weapons and make war-fighting more effective.) Progress in geophysical signal recording and evaluation was one precondition for the conclusion of the Comprehensive Test Ban Treaty.

R&D of new verification technologies remain crucial for further progress in arms control and disarmament. Promising developments can be seen in many fields. Some general areas will only be mentioned by name:

- electronics,
- computer technology,
- photonics/optronics,
- software,
- information processing technology,
- communication technology

– some of these are being discussed in other contributions to this workshop.
Sensor systems

Concerning remote sensing from satellites, commercial satellites are providing optical imagery in the visible spectrum at 1 m resolution and below. Infrared and hyperspectral capabilities are also increasing. As an active sensor, radar can penetrate through clouds and work independent of sun illumination.

At the same time, aerial imagery in the visible spectrum is an established technique that can deliver much better ground resolution, however at lower speed and area coverage; in many cases, aircraft can fly below the clouds. Progress is being made in recording images digitally, with infrared sensors and with radar systems. Aircraft are much cheaper and much more flexible than satellites, however they need permission to enter the air space of a state. Aircraft can easily take air samples, to be analysed for certain chemicals, biological material or radionuclides. In Europe (plus Asian territory of Russia) and North America, the Open Skies Treaty provides for overflights of the member states’ territories taking images with ground resolution of 0.3 m in the visible region, 0.5 m in the infrared and 3 m by radar. The possibility of expanding the use for additional purposes, beyond monitoring military forces, is already foreseen in the Treaty – there is a great potential for applications in the context of nuclear safeguards and other treaties. Agreements for other regions could be based on the Open Skies Treaty.

Supplementing infrared sensors, passive microwave detection can provide information on the temperature of surfaces. High image resolution combined with depth information can be provided by laser radar. While this technology has been under R&D since decades, it seems that its potential has not been exhausted.

Fixed sensors can be used to gain local information, but also about remote sources if the mode of transport respectively propagation is known or can be derived. Trace analysis of radionuclides is an established technique. In the chemical and biological fields, the sensitivity is improving continuously. Acoustic and seismic sensors provide possibilities to detect movements of land and air vehicles.

Micro/Nanotechnology

Microsystems technology (dealing with structures of 0.1 to several 100 µm size) and nanotechnology (0.1 to 100 nm) are broad areas of present vigorous R&D. Singly or combined, they provide many new possibilities for sensing. In many cases, processing electronics can be integrated and series production allows very low cost. Etched membranes and movable sample masses allow to measure pressure, including fast variation (sound), and acceleration. In the electromagnetic area, magnetic field strength can be sensed; optical sensors and sensor arrays provide for spectroscopy or images in the visible or infrared range, the latter potentially without cryogenic cooling. Accessible chemical properties include pH, other ion concentrations or presence of specific molecules. Concerning biological substances, e.g., proteins, DNA with specific properties, or viruses and bacteria can be detected.

Various principles can be used. In microsystems technology, often scaled-down versions of traditional analysis systems are used, e.g., gas chromatographs. In the nanotechnology area, e.g., there is the technique of cantilevers (of sub-µm size) as in scanning-probe microscopes. If the end is coated with the appropriate antibody or DNA segment, specific molecules will bind there, increasing the mass of the lever which in turn can be sensed by a change in the mechanical resonance frequency. In another scheme, selective binding closes a pore in a membrane which reduces the ion current through the pore. If the selective coating is applied to magnetic nanoparticles, they can be used to remove the agent of interest from a solution.

Using microsystems technology and/or nanotechnology, a great variety of systems useful for verification purposes are becoming feasible that are only centimetres, in size in the future even below, and consume little power. One is a complete chemical-analysis system. Another example is a tag that senses quantities that are important for the transport history of an item (e.g., acceleration, temperature, humidity), records them in memory and can be interrogated with radio frequency. A third application is a network of small sensors that communicate with each other, characterising and locating sources that emit characteristic signals.
Mobile Robots

Mobile robots for entering dangerous areas have already been developed. Progress in hardware for motion and manipulation as well as computing and control software will make such systems more flexible and more autonomous. In a verification context, where main tasks would consist in taking of samples or sensing, full autonomy does not seem urgent – remotely controlled operation by an inspector will normally suffice. Similarly, small robots of centimetres size or much below, as they may become feasible by microsystems technology and nanotechnology, respectively, do not seem an urgent priority – on the contrary, their potential for covert intrusion would probably produce the more resistance, the smaller they would become.

Miscellaneous

Emerging science and technology provide many more principal possibilities for verification applications.

One is biometrics to identify persons, e.g., for access to restricted areas. Another idea is to take samples of body fluids to search – by biochemical or genetic methods – for effects of undeclared agents on facility personnel that may have accumulated effects over a longer period. As an alternative, biochips could be deployed on site that monitor the air or liquids in tubing. Because such technologies can be quite intrusive and have a significant potential for misuse, the possible disadvantages should be weighed against the positive uses in each case.

A relatively non-intrusive means of detecting the presence of high-density material is a gravity gradiometer. It has been discussed for verifying the number of warheads on top of ballistic missiles without lifting the shroud. Its utility for safeguards should be assessed.

5. Conclusion

Emerging technologies, if used militarily, can influence international security negatively. At present, the most urgent dangers seem to be connected with selective chemical/biological weapons, robot weapons in all environments, and body manipulation. Preventive arms control can contain such dangers; for this purpose, specific limits and verification methods need to be devised and agreed upon.

On the other hand, emerging technologies can also contribute to disarmament and co-operative solutions of security problems, e.g., by providing new possibilities for monitoring for dangerous substances, for protection and decontamination, and for verification of compliance with limitation agreements.

Furthering these purposes needs, first, an active research and development programme. Second, significant political efforts are required.

6. Notes and References


6 Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects


9 Networks of small sensors could also be used to monitor people and infringe on their privacy. Prevention of such misuse should be an element of the design process.