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The Potential of Technology for the Control of Small Weapons: Applications in Developing Countries

Juergen Altmann

Physicist, Doctor of Sciences
Scientific Staff Member, Physics Department,
Universitaet Dortmund, Dortmund, Germany

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*Scientific Staff Member, Physics Department,
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For specific information on this report contact:
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The Potential of Technology for the Control of Small Weapons: Applications in Developing Countries

Abstract

For improving the control of small arms, technology provides many possibilities. Present and future technical means are described in several areas.

With the help of sensors deployed on the ground or on board aircraft, larger areas can be monitored. Using tags, seals, and locks, important objects and installations can be safeguarded better. With modern data processing and communication systems, more information can be available, and it can be more speedily processed. Together with navigation and transport equipment, action can be taken faster and at greater range. Particular considerations are presented for cargo control at roads, seaports, and airports, for monitoring designated lines, and for the control of legal arms. By starting at a modest level, costs can be kept low, which would aid developing countries.

From the menu of technologies available, systems need to be designed for the intended application and with an understanding of the local conditions. It is recommended that states start with short-term steps, such as acquiring more and better radio transceivers, vehicles, small aircraft, and personal computers. For the medium term, states should begin with experiments and field testing of technologies such as tags, sensors, and digital communication equipment.

Acronyms

CCD	charge-coupled device
CFE	Conventional Armed Forces in Europe
CMC	Cooperative Monitoring Center
GPS	Global Positioning System
IAEA	International Atomic Energy Agency
INF	Intermediate-range Nuclear Forces
NATO	North Atlantic Treaty Organization
START I	Strategic Arms Reduction Treaty
UN	United Nations
WTO	Warsaw Treaty Organization

Contents

1. INTRODUCTION – GOALS, PROBLEMS, POTENTIAL.....	9
2. OBSERVATION, SENSING	12
2.1 SENSOR TYPES	13
2.2 GROUND SENSOR SYSTEMS.....	13
2.3 PORTABLE SENSORS.....	15
2.4 AERIAL OBSERVATION.....	15
3. TAGS, SEALS, AND LOCKS	17
4. INFORMATION PROCESSING	18
5. AUXILIARY SYSTEMS OR COMPONENTS	19
5.1 COMMUNICATION.....	19
5.2 NAVIGATION	20
5.3 TRANSPORT.....	20
6. APPLICATION AREAS.....	21
6.1 CARGO CONTROL.....	21
6.2 LINE CONTROL.....	22
6.3 CONTROL OF LEGAL ARMS	22
7. COSTS, PERSONNEL, TIME TO DEPLOYMENT.....	23
8. CONCLUSIONS AND RECOMMENDATIONS.....	23
APPENDIX: DESCRIPTION OF SENSOR TYPES AND THEIR PROPERTIES	27
ABOUT THE AUTHOR	37

Table

TABLE 1. Sensor types that could be applied in the control of small weapons.....	14
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The Potential of Technology for the Control of Small Weapons: Applications in Developing Countries¹

1. Introduction – Goals, Problems, Potential

West Africa is a region of bloody conflicts but also provides an example of successful peace-building.² Regional insecurity is in no small part the consequence of a proliferation of small arms. Whereas small arms do not cause war, they aggravate armed conflicts, make them last longer, and make peace more difficult to achieve and maintain. Recommendations to improve the proliferation of small arms in West Africa—ranging from general political, economic, and cultural issues to specific security forces ideas—have been made by United Nations (UN) advisory missions to several West African states as well as by the states themselves.³

In addition to developing economic opportunities and strengthening civil society and democracy, creating a secure civilian environment, including the control of small arms, is a key element of maintaining peace. Small arms control includes collecting illicit weapons, detecting and preventing the transportation of illegal arms, and closely guarding legal arms of security forces. The UN advisory missions have recommended, and states of the region have declared as their goals, that borders and air- and seaports be better controlled; that security forces exchange information, coordinate activities, and cooperate; and that a regional register of arms and arms transfers be set up.⁴ To realize these goals, political decisions have to be taken and organizational and administrative initiatives have to be implemented.

Technology can play an important role in this process. This is obvious with respect to transport and communication means where West African states perceive deficiencies. Technology can also contribute in other respects. Rather than considering well-known cross-country vehicles and radio systems, this report focuses on those technologies not often connected to small arms control.

¹ This report is based on a talk at the UNIDIR/UNDP Conference on Disarmament, Development and Conflict Prevention in West Africa Bamako, Mali, November 25–29, 1996. For this conference and its context, see S. Lodgaard, C. F. Ronnfeldt (eds.), *A Moratorium on Light Weapons in Africa*, Oslo, Norwegian Institute of International Affairs, 1998; J. Seck, *West Africa Small Arms Moratorium: High-Level Consultations on the Modalities for the Implementation of PCASED: A Report of the Experts' Meeting and the Civil Society Meeting, March 23–24, 1999*, UNIDIR 2000/2, Bamako, Mali, Geneva: United Nations Institute for Disarmament Research/Lomé: United Nations Regional Centre for Peace and Disarmament in Africa.

² R. E. Poulton, I. ag Youssouf, *A Peace of Timbuktu: Democratic Governance, Development and African Peacemaking*, UNIDIR, Geneva/New York: United Nations, 1998.

³ Lodgaard/Ronnfeldt (footnote 1).

⁴ See the Final Communiqué of the 1996 UNIDIR/UNDP Conference, in Lodgaard/Ronnfeldt (footnote 1).

Trying to improve the control of small weapons in developing countries involves a number of political and cultural problems, as follows:

- As long as there are armed conflicts or rebellions, banditry, and self-defense groups, motives will exist for acquiring and transporting illegal weapons.
- When the same ethnic population lives on both sides of a border, there will be frequent border crossings.
- The potential for smuggling increases when countries neglect economic development of border regions.
- The dangers and negative consequences of small-arms proliferation are not understood throughout the population.
- In some countries or regions, males traditionally carry weapons.

Though these problems have a clear impact on attempts to strengthen the control of small weapons, they will have to be addressed through political solutions and education. On a more practical level, there are other issues, as follows:

- Some countries are very large, with extensive desert areas and borders that are many thousands of kilometers in length.
- Borders are often porous.
- Security personnel are few (compared with developed countries) and lack equipment.
- Governments often lack the resources necessary to maintain control of small arms.

Technology can be important in alleviating such problems. In some cases, technology is cheap and, in others, aid from donor countries will be required. Technology can augment the effectiveness of individuals in traditional tasks or make new tasks possible by

- enlarging the area under observation,
- increasing the speed and range of action,
- increasing the amount of information available and processed, and
- strengthening the guarding of arms and sites.

To place the role of technology in context, it is important to present some peacekeeping and disarmament precedents that show how technology has already been used in monitoring international treaties and agreements. The first is the *sensor monitoring in the Sinai* after the

1973 Egypt-Israel war.⁵ Along two mountain passes, the U.S. in 1976 cooperatively deployed fields of sensors (ground pressure, seismic, acoustic, infrared, and video cameras) that relayed their data up to 20 km to a permanently staffed monitoring center. The goal was to detect the potential entry of illegal military vehicles or personnel intrusion of either side. The system was improved from time to time and worked reliably for over six years.

During the late 1980s, the then-Soviet Union demonstrated a change of attitude toward transparency, and consequently, *cooperative verification of disarmament* has grown immensely, mostly carried out by on-site inspections, but with significant support by technical means. Under the 1990 Treaty on Conventional Armed Forces in Europe (CFE), inspection teams may use tape measures, cameras, binoculars, and compasses. However, the bilateral 1987 Intermediate-range Nuclear Forces (INF) and 1990 Strategic Arms Reduction (START I) Treaties go much further: U.S. and Russian teams are permanently deployed at the other's ballistic-missile production facilities to count every outgoing missile and ensure that treaty obligations are upheld. At the portals and the perimeter, the parties employ weigh-bridges, arrays of light-beam interruption devices, nuclear-radiation sensors, and pressure-sensing cable. The U.S. has even installed a linear accelerator that is capable of X-raying whole trucks and railcars in Russia.

The 1992 Open-Skies Treaty allows *cooperative observation overflights* of 27 North Atlantic Treaty Organization (NATO) and former Warsaw Treaty Organization (WTO) states, including the full territories of the U.S., Canada, and Russia.⁶ The sensor types and their ground resolution are regulated in some detail. Lower limits are: video and photo cameras, 0.3 m; thermal-infrared scanners, 0.5 m; synthetic aperture radar, 3 m.⁷ Though the treaty is not yet in force, test flights have already been undertaken. In order to begin overflights more quickly, Hungary and Romania concluded a separate agreement in 1991 which is in force; each nation can conduct four overflights per year over the other nation. In light of the technological and financial limits of the two countries, only optical and video cameras are allowed currently.⁸

For many years, the International Atomic Energy Agency (IAEA) in Vienna has used *containment and surveillance systems* to verify that nuclear material in nuclear power installations is not removed and diverted for weapon-making purposes. For example, the IAEA uses seals to ensure that containers remain closed. Breaking the seals would produce scratches or disturb a unique signature that was produced when the seal was applied. Assessment by sealed video cameras can also be used to detect whether a fuel element has been moved in a storage site. Rather than recording images on a videocassette that must be checked and exchanged during inspector visits, stored images are increasingly requested and transmitted electronically by telephone lines.

⁵ M. G. Vannoni, *Sensors in the Sinai – A Precedent for Regional Cooperative Monitoring*, Albuquerque, NM: Cooperative Monitoring Center, Sandia National Laboratories, April 1996.

⁶ M. Krepon, A. E. Smithson (eds.), *Open Skies, Arms Control, and Cooperative Security*, New York/Washington: St. Martin's/Stimson Center, 1992.

⁷ The actual ground resolution depends mainly on the sensor system and the flight altitude and, to some extent, also on visibility. Thermal-infrared and radar may be used in future applications.

⁸ M. Krasznai, "Cooperative Bilateral Aerial Inspections: The Hungarian-Romanian Experience," in Krepon/Smithson (footnote 6).

This report describes the potential of several technologies to contribute to the control of small weapons.⁹ It offers options that differ in size, cost, and time for installation that can be used as building blocks in designing systems for controlling small arms. Concrete solutions will have to be developed among users who know the local environment and scientists or engineers who know the potential and the limits of the technologies. Economic capabilities must also be considered as well as knowledge from experience and adaptation over time.

The document is structured as follows: Section 2 discusses observation and sensing (specific sensor technologies are described in the appendix); Section 3 addresses tags and seals; Section 4 considers technologies for information processing; Section 5 examines auxiliary systems for communication, navigation, and transport; Section 6 presents examples for three application areas (cargo control, line control, and control of legal arms); Section 7 considers general aspects of costs and time to deployment; and Section 8 presents conclusions and recommendations for future steps.

Before the technical discussion, one general remark is in order: when thinking about technological options, one has to keep in mind that they are used by humans in a particular context (social, political, etc.). Technologies may have negative consequences that need to be prevented or contained. First, technological means of control must not endanger human rights or democracy, or unduly hamper the flow of goods. Second, humans will probably remain superior to even the most sophisticated computer systems with respect to intelligent reaction, flexibility, reasoning, etc. Thus, the human element should be systematically built into the design of control systems and procedures. Finally, more efficient controls require systems and persons for improved information intake and processing, as well as trained personnel with appropriate equipment to react should illegal or suspicious objects or actions be detected.

2. Observation, Sensing

The primary goal of observation is to detect illegal objects or actions related to light weapons, such as large or small vehicles on or off roads, pack animals such as camels or horses, or even individual people (e.g., in mountainous terrain, in border areas, or around arms stores). In principle, aircraft can also be used to transport small arms. In coastal states, transport by ships can occur that might evade harbor controls by off-loading to boats or even pirogues off the coast.

⁹ The author's applied physics research has focused on the detection of land and air vehicles by acoustic, seismic, and magnetic signals. He has studied other sensor types and applications through participation in verification conferences and projects on conversion agreements and UN peace operations. Since 1988, a group of physicists at the Bochum Verification Project (Ruhr University, Bochum, Germany) has done experiments with military vehicles measuring these signals; evaluation is ongoing. For a short overview, see J. Altmann, "Intermediate-range Sensors for Verification and UN Peace-keeping," in J. Altmann, T. Stock, J.-P. Stroot, *Verification After the Cold War – Broadening the Process*, Amsterdam, Free University Press, 1994. Specific results are published in the Verification – Research Report series (Bochum: Brockmeyer); J. Altmann, *Verification of Conversion Agreements Using On-Site Sensors – Installations for Land and Air Vehicles, Shooting Grounds, Low-Level-Flight and Test Areas* (in German), INEF Report no. 7, Duisburg, Institute for Development and Peace, 1994; J. Altmann, H. Fischer, H. van der Graaf (eds.), *Sensors for Peace – Applications, Systems and Legal Requirements for Monitoring in Peace Operations*, UN Institute for Disarmament Research, Geneva/New York, United Nations, 1998.

These various types of carriers are potential objects of detection. Whenever these carriers are numerous (e.g., trucks on a normal road), the problem is not detection of the carrier but detection of its illegal load, such as small arms or their ammunition.

2.1 Sensor Types¹⁰

Table 1 lists those sensor classes, and their most important properties that are potentially applicable to small arms control. The sensors are arranged according to their basic principles, beginning with mechanical-acoustical sensors, then electrical-magnetical-optical sensors and chemical sensors. In most cases, the sensor will require additional components (e.g., power supply, lens, and signal-forming electronics) to function in the field; these components are not treated separately but considered a part of the sensor itself. A more comprehensive description of each sensor appears in the appendix.

2.2 Ground Sensor Systems

A combination of several sensors and auxiliary components (for energy supply, data communication, processing, etc.) can form a permanently or temporarily deployable system.¹¹ By providing information from distant locations, such a system can extend the monitored length or area beyond visual range. Objects of detection can be vehicles, pack animals, persons and/or aircraft. Even though cost and complexity make comprehensive monitoring over hundreds of kilometers extremely difficult, in many cases limited deployment can be very useful. For example, when natural obstacles form a bottleneck less than a few kilometers wide or when circumvention of a road control point at a similar distance needs to be detected, passive sensors, such as geophones, microphones, infrared sensors and potentially low-light-level cameras, can be deployed every 100 m or more.¹²

Temporarily installed ground sensor systems are generally battery operated and transmit their signals by radio wave. A few national militaries already use such temporarily deployable systems for outside use (e.g., the U.S. (I)REMBASS or the United Kingdom CLASSIC¹³), which have advantages and disadvantages. Since they have been designed for combat use, they are rugged and weatherproof; they are also commercially available. Yet they include features superfluous to small arms control, such as time-compressed transmission, which make them more expensive.

¹⁰ For more information including references and producers, see Altmann (footnote 9); R. Blumrich, "Technical Potential, Status and Costs of Ground Sensors Systems," in Altmann et al. (footnote 9).

¹¹ Ground sensors can be buried, or installed on the surface or on poles, etc.

¹² "Passive" means that these sensors do not need "illumination" of a target to detect it.

¹³ For an overview of existing military ground sensor systems and recent development of new ones, see Blumrich (footnote 9).

TABLE 1. Sensor types that could be applied in the control of small weapons

For more detail, refer to the appendix.

Sensor	Explanation	Objects Detected	Range/Span	Cost (in US \$)
Contact switch	Flexible tube on road	Axes, vehicles, speed	0	\$200 – \$500
Piezo-electric pressure sensor	Special plastics produce electrical charge when pressed	Axes, vehicles, speed, persons	0	\$300 – \$3000/sensor \$50,000 – \$100,000/km
Geophone	Ground vibration measurement	Vehicles, persons, animals, aircraft	10 m – 2 km	\$100 – \$7000/sensor \$30,000 – \$50,000/km
Microphone	Sound wave measurement	Vehicles, aircraft, ships	10 m – 5 km	\$100 – \$1,000 (for outside use)
Magnetic sensor	Disturbance of earth magnetic field	Vehicles, aircraft, ships	10 m – 40 m (future 200 m)	\$100 – \$3000
Induction loop (metal detector)	Alternating magnetic field induces current in conductor, interaction is measured	Metallic objects, vehicles	1 m	\$300 – \$600 (hand-held) \$3,000 – \$5000 (loop gate) \$10,000 – \$20,000 (traffic)
Infrared sensor	Longer wavelength light (thermal radiation)	Vehicles, aircraft, persons	5 m – 500 m	\$20 – \$3,000
Breakbeam device	Interruption of light beam	Any object; speed, vehicle dimensions (needs 2 or more); rough vehicle profile (needs array of many beams)	0 m – 100 m	\$50 – \$300/beam
Image intensifier/night viewing device	Amplifies faint light	Any scene (vehicles, aircraft, ships, persons)	5 m – 500 m	\$5,000 – \$20,000
Photo camera	Image on film	Any scene (vehicles, aircraft, ships, persons)	0 m – 50 km	\$200 – \$5,000 \$100,000 precision air cameras
Electronic still camera	Image on matrix of light-sensitive elements, digital storage	Any scene (vehicles, aircraft, ships, persons)	0 m – 50 km	\$300 – \$3,000
TV or video camera	Moving image on matrix of light-sensitive elements, analog or digital	Any scene (vehicles, aircraft, ships, persons)	0 m – 50 km	\$500 – \$30,000
Radar	Emission and reception of electromagnetic waves/pulses, localization of objects, range	Any scene (vehicles, aircraft, ships, persons)	100 m – 300 km	\$5,000 – \$5,000,000
X-ray device	Electromagnetic radiation of very small wavelength, penetrates through substances, images by differences in attenuation	Small weapons hidden in baggage, among load	0.1 m – 4 m	\$100,000 – \$20,000,000
Chemical sensors	Trace molecule detection	Explosives (from ammunition)	0 m – 50 m	(Still under development)

A permanently installed ground-sensor system would transmit its signal via a cable buried in the ground, with an energy supply provided, for example, by solar cells (with rechargeable batteries in reserve). A mobile or permanent radar system would require much more power; in remote locations, energy for such a system would have to be provided by a diesel generator or a comparable energy source.

The perimeter of a specific installation (e.g., a fence around an arms store or armory) is another candidate for control-line monitoring. In this case, the installation would normally be permanent, using cable and mains electric power as well as cameras equipped with searchlights.

2.3 Portable Sensors

Several of the sensor types mentioned in Table 1 are available as small, portable systems, such as the hand-held metal detector (induction loop) as well as all kinds of cameras. Other sensors are transportable by car and can be deployed quickly so that they can be used by patrols or at temporary road checkpoints.¹⁴

2.4 Aerial Observation

Overhead observation has two advantages if large areas are to be monitored: (1) the field of view is larger and (2) carrier vehicles can cover more ground in less time than ground-based systems. The disadvantages are that image details diminish as the vehicle's altitude increases and the amount of information that has to be transmitted and analyzed is substantial.

For these reasons, *satellite observation* is not a useful method of controlling small arms. Because even sophisticated military satellites (assuming they know where to look) cannot provide enough detail to be able to distinguish a small weapon from something similar in size, direct satellite detection of small arms is practically impossible.¹⁵ The most valuable application of satellite imagery would be in identifying suspicious vehicles, especially in vast desert areas. However, it is not likely that the two countries with satellites of this resolution (the U.S. and Russia) will focus their systems on developing countries specifically to identify vehicles active in small-arms transport. Additionally, low-flying satellites can only visit a certain area for a few minutes every few days or weeks. Photographs from civilian satellites with one to ten meters resolution are available, but vehicles are not easy to detect at this resolution. Satellite photos could identify temporary or permanent installations in regions that are largely inaccessible.¹⁶

Although satellites cannot play a significant role in small arms control, many observation tasks can be carried out using aircraft. In contrast to satellites, the flight path and altitude can be locally controlled so that systematic area surveillance can be integrated with immediate focus on a suspicious site or event. At aircraft altitudes, the photographic ground resolution can be centimeters rather than meters. Darkness and clouds reduce the effectiveness of aerial moni-

¹⁴ In this paper, a "portable system" can be carried by an individual. A "transportable system" can be moved by a vehicle or over a short distance by a group of people.

¹⁵ This is obvious for pistols and hand grenades. Theoretically, a single machine gun in the desert could be seen as a dark elongated spot, but it could not be differentiated from a piece of wood or a shadow.

¹⁶ For examples, see M. Krepon, P. D. Zimmerman, L. S. Spector, M. Umberger (eds.), *Commercial Observation Satellites and International Security*, Houndsdale/London, MacMillan, 1990.

toring but only temporarily. Since small weapons can be hidden easily, the objects of detection would be vehicles and/or animals transporting arms. Because these would mix indistinguishably into normal traffic, air control is sensible only for those roads where there is little traffic. Vehicles or caravans moving off roads can be detected in the desert and the savanna. However, aerial observation and photography has limited utility over dense forests, swamps, and mountains. In such difficult terrain, transport is likely only along certain routes where ground controls may be more effective.

Larger, faster airplanes are better suited for routine high-altitude (5-10 km) surveillance of larger areas (up to several thousand km per flight). In this case, aerial photography allows for detailed investigation but only after many hours of delay and only with a sophisticated organization of photo-interpreters.¹⁷ Thus, aerial photography monitoring would most likely focus initially on specific areas of interest. The most economical platform would be a twin turbo-prop aircraft with a range of approximately 1200 km.

Monitoring selected areas can also be achieved with smaller, slower propeller planes, which can cover many hundreds of kilometers in one flight. Visual observation, augmented by a hand-held photo and/or video camera for documentation of suspicious scenes, can be very useful. Helicopters travel at similar speed but are more maneuverable and allow for immediate intervention on the ground. Monitoring at slower speeds and lower altitudes can reveal not only vehicles or caravans but also individual people.

Large aircraft cost tens of millions of dollars and high-precision aerial photographic equipment adds approximately one million dollars to the cost. This is not prohibitive if states of the region share the cost. A single aircraft theoretically could monitor the land borders of a region the size of West Africa.¹⁸ once per week. In contrast, twin turbo-prop aircraft cost one to two million dollars, with camera equipment adding a few hundred thousand dollars. Helicopters cost from several hundred thousand dollars to several million dollars. The least expensive aerial platforms are small, two-to-four-seat propeller aircraft, which cost a few hundred thousand dollars each.

¹⁷ Photographing 1000 km (with non-overlapping images of approximately 6 km coverage) would produce 160 images. Depending on the amount of structure in an image, photo-interpreters may need from less than an hour to more than a day per image. For the different task of searching for military installations in a SPOT satellite photo (60 km², 10-m resolution), 1 to 2 days for a pair of experienced photo-interpreters has been mentioned, and one half-day for re-examining the same scene. See P. Zimmerman, quoted in H. Spitzer, "Technical Potential for Monitoring from Air and Space," in J. Altmann, H. van der Graaf, P. M. Lewis, P. Markl, *Verification at Vienna - Monitoring Reductions of Conventional Armed Forces*, Philadelphia: Gordon & Breach, 1992. To be useful for the control of potential illegal weapons transports, large-area surveillance needs to be repeated periodically. Since in the present context it would often suffice to find indications of transport through more or less empty landscape, significant success can already be expected with approximately 10 photo-interpreters.

¹⁸ The total length of the land borders of the 16 countries from Mauritania to Liberia in the west to Nigeria and Chad in the east is 25,000 to 27,000 km. Theoretically, flying this length with a speed of 500 km/h and 8 hours daily flight time would require 6 to 7 days to complete a cycle. This theoretical maximum path length would, in reality, be reduced, since air photos would neither be useful nor required in certain terrain or at some borders.

3. Tags, Seals, and Locks

A tag marks an object uniquely. A seal or a lock links two objects. Both indicate whether an object has been tampered with.¹⁹ There are many different forms of tags, seals, and locks.²⁰

Tags must be permanently affixed. They can be applied externally (e.g., an adhesive label or a stamped mark) or contain an intrinsic feature (e.g., the microstructure of a metallic surface) that designates a particular object. In order to preclude falsification, tags must incorporate unique patterns that are very difficult or nearly impossible to reproduce. Attempts to remove a tag from its object must leave clear traces (e.g., an adhesive foil being so weak that it ruptures when pulled). The integrity of the tags must be identifiable to inspectors.

The general concept of tagging is not new; license plates and insurance stickers on cars are common examples. New possibilities arise if tags can be read automatically and their information can be processed by computer systems, especially if the objects in question number in the thousands (e.g., automatic optical scanners that can read bar codes). Tags also can be embedded with an electronic chip, which can be interrogated. This interrogation can be done by contact or, more practically and more safely, over some distance by inductive loops or radio antennas.

Simple, mass-produced external tags can cost as little as a few dollars. Even electronic, remotely readable tags can cost less than a hundred dollars. Hand-held optical or electronic reading equipment costs at least one hundred dollars.

For controlling small arms, tags would be used mainly to mark the *legal* arms (principally those belonging to government security forces). While tags would allow confirmation that individual weapons were still located in their proper places, the main purpose of tags would be to trace the source of confiscated illegal weapons. In this manner, tagging would discourage illegal traffickers from raiding legal armories and weapons caches.

The simplest tagging method is to stamp the barrels or bodies of guns, rifles, or pistols. Existing factory-stamped numbers may not suffice for identification. Additional stamps could contain country information together with other codes. If the arms are stolen, illegal holders may try to remove the stamp (e.g., by filing). Since stamping changes the material to some depth, however, it is virtually impossible to remove completely all identity marks.

More sophisticated tags could be used in conjunction with weapon lockers. Optical or electronic readers could register the tag each time the weapon is removed and replaced. Automatic registration, linked to a computer database, would be possible even at large arms depots.

¹⁹ For overviews see A. DeVolpi, "Tags and Seals for Arms Control Verification," A. Knoth, "System Aspects of Tag Technology," both in Altmann/v. der Graaf/Lewis/Markl (footnote 17).

²⁰ See, for example, *Verification Technologies*, Washington DC: U.S. Department of Energy, Office of Arms Control and Nonproliferation, Third Quarter 1992.

Seals and locks (a lock is the equivalent of a reusable seal) come in many different forms.²¹ The lead seal has often been used to ensure that containers remain closed. More sophisticated systems, such as an optical-fiber seal in which an irregular pattern of fibers forms on closure, are much harder to falsify than lead seals. Another type of lock uses one optical fiber to check whether a loop remains closed. A built-in microprocessor can register and record all openings and closures together with their time, and can utilize all kinds of number coding for opening. New sealing methods can be simple as well. A shrink-wrap seal (a heat-shrinking transparent foil with printed patterns on it) can be wrapped several times around the object(s) to be secured or connected. When hot air is applied, the foil shrinks to tightly enclose the object and the print patterns on the different layers become smaller as well as irregularly distorted. The resulting "fingerprint" is unique; it can be photographed and is virtually impossible to reproduce.²²

For the control of small arms, seals and locks could be applied to arms and munitions depots as well as to closed transport compartments for arms and munitions. Seals and locks could also be applied to confiscated weapons for short-term purposes. Seals and locks are not only simple and efficient but also inexpensive; one item often costs less than one dollar. Sophisticated electronic locks can cost a few thousand dollars and would only be appropriate when high-value objects need to be secured.

4. Information Processing

With the increasing proliferation of personal computers, coupled with their decreasing costs and increasing networking capabilities, qualitatively new levels of data storage and processing are available, even for developing countries. Information concerning small weapons (e.g., on legal imports and exports, seizures, or observations of transports) can be stored and made available on a regional, national, or international scale. Of course, different levels of access can be built into such a system, which would contain one or several databases.²³

Technological capabilities exist that would allow the movement of every legal weapon to be tracked. This is only practical, however, if automated modes of data entry are used. For example, a hand-held device could read the tag on a weapon when the weapon is issued from the weapon store to the individual member of a military force, as well as when the weapon is returned. Moreover, automated readers could register the tags whenever arms are moved in or out of their lockers.

Hand-held computers could be used to read tags on weapons and transport containers during spot checks. Data could be stored in the computers and consulted at the end of a mission or inspection tour. With radio capability, the data could be transmitted to a central monitoring

²¹ See footnote 20.

²² *Tamper-Evident Shrink-Wrap Seal*, SANDOC99-2455, The Cooperative Monitoring Center, Sandia National Laboratories, Albuquerque, NM, USA; S. Fraley, "Shrink-Wrap Seals," in *Verification Technologies* (footnote 20).

²³ See also I. Tiihonen, P. Gasparini Alves, "A Database on Conflict Prevention Issues in West Africa," *UNIDIR Newsletter*, no. 32, November 1996.

location in real time. Monitoring software could evolve over time, beginning with simple inventory databases and eventually including programs that could, for instance, detect irregular patterns of weapons handling and storage.

Personal computers cost a few thousand dollars while hand-held terminals only a few hundred dollars. Communication costs range from one hundred to several millions of dollars depending (1) on whether existing communication lines can be used or a new country- or region-wide system has to be established, and (2) on the intended speed of data transmission. Similarly, software costs can vary widely. Commercial database programs begin at a few hundred dollars, whereas new program development (in accordance with user specifications) could cost millions of dollars. For reasons of cost, and in order to gain experience, states could start with rudimentary systems with a few computers, non-specific software, and existing communication lines; the monitoring could focus on only large stores of weapons. These systems could expand and become more economically feasible over time.

In the present era, starting a new information storage and exchange system on small weapons without using computers (e.g., by writing on record cards, communicating by telex, fax, or phone) would result in markedly reduced efficiency and probably not much cost savings. Thus, computerization should be pursued consciously and resolutely from the beginning.

5. Auxiliary Systems or Components

Improved ways of acquiring, distributing, processing, and acting upon information on small weapons require the strengthening of several supporting technologies. This is especially true for means of communication, navigation, and transport. In the first two cases, new technological possibilities exist.

5.1 Communication

To improve the control of small weapons, traditional communication between security units, administrative levels, and states needs to be strengthened. Available communication technologies include telephone, telex, and fax, and radio for short, medium, and long distances. Since these are generally known, I will not discuss technical properties or costs. Improvement will mainly consist of buying more commercial equipment. These analog links can transmit digital information through modems. In the medium and long term, digitization will take place, allowing for direct, faster transmission of digital data.

Direct satellite communication offers a new technical alternative that is attractive for large regions, but may be cost prohibitive (a suitcase satellite phone costs about \$20,000). If only data (including fax or telex) need to be transmitted, the terminal could be less expensive than one required for voice transmission. For data-only transmission, the INMARSAT-C service is

appropriate; it stores digital messages and forwards them to ground stations by satellite with only a few minutes delay. The transmission costs are about \$0.20 for 256 bits (about 30 characters).²⁴

Wireless phone communication, which has become fashionable in densely inhabited centers of developing countries, will not be applicable soon in vast rural and desert areas.

Increased use of technology for monitoring, marking, and registering will require better and more extended communication lines than currently exist in areas such as West Africa. States in the region should take an incremental approach, introducing new communication systems together with new modes of control such as permanently staffed control posts, additional regions for patrols, or the temporary or permanent deployment of ground sensor systems.

5.2 Navigation

In contrast to inhabited areas or structured terrain, where navigation and determination of position is not difficult, a reliable method of navigation in the savanna and desert did not exist for a long time (except for the compass, which only determines direction). This has changed with the deployment of the Global Positioning System (GPS) by the U.S. Department of Defense, which consists of 24 satellites that continuously transmit the exact time, orbit data, etc. A receiver on the ground or in the air normally has three to five satellites within view and can compute its position in three dimensions at a precision of 150 m or better.

With miniaturization and mass production, GPS receivers have become relatively cheap. Hand-held receivers with rechargeable batteries cost several hundreds of dollars. More advanced receivers for vehicles or ships range from one thousand to several thousands of dollars. Thus, the cost is not prohibitive even for developing countries.

GPS receivers can be coupled with automatic radio transmitters to continuously report position to a monitoring center. This can be used to direct search-and-rescue operations in emergencies (on sea or land). The GPS can also be used to continuously track the path of a vehicle carrying highly important cargo. In the U.S., such a system has been developed for transports of proliferation-sensitive goods.²⁵ Because such a system costs tens of thousands of dollars, it would be used in small arms control only for the most threatened and most valuable transports.

5.3 Transport

New technologies for detecting objects or activities related to illicit small weapons need to be augmented by the corresponding capabilities of security forces. Wide-area/long-distance observation can be improved with either permanent personnel deployment at many intermediate sites or fast transport over long distances. The capabilities and prices of the different carriers are

²⁴ Slight variations arise with the country/global region of call origin and destination. The message header requires about three 256-bit segments.

²⁵ Besides the GPS position, shipment-related and environmental data are transmitted in encrypted form via INMARSAT to a monitoring center. See *Authenticated Tracking and Monitoring System (ATMS)*, SANDOC 99-2433, The Cooperative Monitoring Center, Sandia National Laboratories, Albuquerque, NM, USA.

generally known (camels, four-wheel-drive cars, helicopters, propeller and turbo-prop aircraft, and small boats and ships) and need not be repeated here.

6. Application Areas

The development of a specific technological system for monitoring small arms traffic depends on unique local conditions, such as available personnel and funds. This section suggests how technological and other components could be combined theoretically for three types of applications.

6.1 Cargo Control

Small weapons can be easily hidden under other cargo. The problem increases as more goods are transported. A common control point is where roads cross a border or at the limits of a designated control zone. Lorries or containers on trucks need to be inspected as well as vans, small cars, or pack animals. At seaports and airports, inspections focus on containers or bags. At seaports, loose mass goods that are transported from ships' holds into lorries or railcars are also important for control purposes.

For cost reasons, X-rays of complete lorries or large transport containers are not practical.²⁶ However, an X-ray system designed to inspect 1-meter objects (boxes, bags, etc.) could be used at road control points and at central air- and seaports. In addition, hand-held metal and explosive detectors could scan individual bags, boxes, camel loads, etc. A somewhat larger X-ray system, supplemented by gate-type metal and explosive detectors, would be applicable to air cargo containers and to small cars or vans, either systematically or selectively. Since the road network in West Africa and similar regions is narrow and there are a limited number of sea- and airports, the use of a few strategically placed systems could have a strong effect by forcing smugglers to use longer or more complicated modes of transport. Portable explosive detectors, known as chemical sniffers, will soon become available.

Systematic checks of large vehicles and containers for hidden small weapons or ammunition take a significant amount of time and require many people. Even if technology can accelerate the search process, the ability to conduct thorough inspections will remain limited. Consequently, additional information is necessary to focus the efforts as much as possible on suspicious transports.

For this purpose, an improved information-processing system would be helpful. Every cargo control post—permanent or temporary—could be equipped with terminals for access to the respective databases. Other equipment for real-time communication could also be available.

²⁶ At sea- or airports with very high turnover, the investment (about \$20 million, see appendix) may already at present be warranted by the ensuing reduction of false declarations and increases in duties.

6.2 Line Control

Lines of ground sensors (consisting mainly of microphones, geophones, and infrared sensors augmented by magnetic sensors or TV cameras) can detect the passage of vehicles and caravans through a specifically defined area, such as a strategic pass or terrain bottleneck. Such permanent lines would also sense low-flying aircraft. At costs of tens of thousands of dollars per kilometer of line, it is unrealistic to plan to cover extensive border regions.

Temporary ground sensor lines using the same sensor types but with radio communication and battery power supplies, similar to those used by some armed forces, can be set up in a relatively short period of time. These rugged systems are very expensive, costing up to \$100,000 per kilometer, yet their flexibility enables them to be used at sites that change frequently, or by patrols that must monitor large areas.

In order to control shores for secret landings of boats and vessels changing cargo with boats offshore, radar could be installed at intervals of between 20 and 50 kilometers (depending on height, power, and target size). The distance should be uniform, allowing for overlap. At a cost of approximately \$100,000 per station, complete coverage of a coastline is possible, especially if deployment of systems is distributed over several years. Of course, selective installation in high-priority areas is also feasible. Small boats (such as fishermen's pirogues) that depart and land frequently and in high numbers would complicate this type of monitoring, requiring the collection of additional information to help identify those carrying suspicious cargo.

6.3 Control of Legal Arms

As mentioned above, legal arms should be marked or tagged, beginning with the stamping of barrels. Eventually, more complex tags that alleviate automatic reading should be used, coupled with automated locks in the weapon storage areas. Imports, exports, and transports of legal arms and ammunition should be accompanied by computerized bookkeeping, which would allow for the tracking of individual arms and would facilitate the integration of automated reading and registering equipment. For transport enclosures, traditional seals or locks could be replaced by more sophisticated ones, which are difficult to open clandestinely or to falsify, for example, requiring codes and recording all openings/closings.

Weapons stores inside security forces' sites, as well as the sites themselves, could be secured along their perimeters and at their exit/entry points. Personnel can execute the main controlling functions, but their capability to check for illicit transport could be enhanced by metal-detector gates and barriers requiring identification cards. Along the perimeters, fence sensors, microphones, geophones, and TV cameras can be installed that could transmit alarms or signals to a watch center inside the site. Sophisticated sensor fences cost up to several hundred thousand dollars per kilometer, and thus would likely be deployed only at the sites of highest importance.

7. Costs, Personnel, Time to Deployment

Technology offers many different possibilities for improving the control of small weapons with costs varying widely. Some systems, such as those required to X-ray a large truck, are extremely expensive. However, there are less expensive alternatives, such as tagging weapons, that can have a positive effect. Thus, cost should not be a prohibitive argument.

Expense can be reduced by the random-sampling principle: to deter illegal behavior, it is usually not necessary to establish a comprehensive monitoring regime. Even a small chance of detection will eventually reduce the number of violators by discouraging them from attempting to conduct illegal activity in the first place. Thus, technology should be selected with an emphasis on flexible use and mobility.

One obvious truth needs nevertheless to be stated: costs of technology comprise not only an investment in initial implementation, but also in supply, maintenance, and repair. While a stamped barrel remains stamped for all its life, aircraft need fuel, portable sensor systems need batteries, electronics may have to be repaired or exchanged, etc. Sensible planning, such as using smaller aircraft, buying standardized items, paying attention to modular design, and choosing rechargeable batteries, can keep these costs low. One could argue that using technology may reduce personnel costs but, in this context, technology could more effectively enhance the work of existing human monitors. In fact, additional people may be required to service new systems, to build and populate databases, to make use of the increased amount of information and to intervene at suspicious events. Of course, if new technologies are introduced, training will be required for the new users at large. Normally, this can be done within a few weeks.

The majority of the applicable equipment can be bought from commercial vendors, such as transportation and communication and computer systems. Ground sensor systems and database software are available but would need to be modified for their particular monitoring use. Such systems development can take as long as a few years but this should not be considered an obstacle.

8. Conclusions and Recommendations

Technology can play an important role in achieving the goal of controlling small arms. Technical means can enhance the efficiency of personnel in several ways: (1) larger areas can be monitored; (2) action can be taken faster and at greater range; (3) more information can be available and it can be more efficiently processed; and (4) important objects and installations can be better safeguarded. Another advantage is that technical means work in a neutral and impartial way.

Technology offers a menu of options that address a variety of tasks in a wide range of costs. Many factors should be considered when designing a technical monitoring system, including the following:

- Requirements for more stringent controls (where to look, what to look for)

- Priorities of control
- Geographic factors such as terrain, transport routes, climate
- Capabilities of components and systems
- Simplicity of use
- Costs of installation and operation, including maintenance
- Required infrastructure, including communication and transport
- Required personnel
- Financial limits of states or of aid
- Growth paths concerning quantity and quality

Recommended first steps that only require inexpensive and currently available technology would include the following:

- Mark legal small arms
- Acquire more and better radio transceivers for short and medium distances
- Acquire more four-wheel-drive vehicles and/or camels for more patrols and/or faster reaction
- Acquire one or more propeller or turbo-prop aircraft and conduct observation flights in regions where off-road or sea-to-shore transport is suspected; small aircraft can be shared between countries and some may already be available in the region
- Acquire more patrol boats equipped with radar
- Acquire a few X-ray cargo-control systems for the most important roads, seaports, and/or airports
- Acquire computers with commercial database software and set up information systems on small weapons

To prepare for medium-term improvements, states of the region, in collaboration with sponsoring industrialized countries, should conduct collaborative experiments and limited field testing with the following new technologies:

- Automated tag readers, portable data entry terminals
- Electronic tags, seals, and locks

- Ground sensor systems for (limited) area or line controls
- Digital communication networks
- Perimeter monitoring technology
- Shore radar stations, if applicable

Firms offering technology will not hesitate to praise their products. A few groups and centers in academia and in government laboratories currently analyze monitoring technology and can provide advice and participate in experiments and tests.

Strengthening the controls on small arms will benefit from technology, yet controls will continue to depend on human implementation. Both the technological and the human aspects require a strong commitment if the control of small arms is to be improved.

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Appendix: Description of Sensor Types and Their Properties

1 Contact Switch

A flexible tube is installed on the surface of a road. When vehicles pass, the wheels compress the air inside, which closes a pressure contact beside the roadway. Thus, axles can be counted. By using two contact switches in a short distance, the speed can be measured and axle distances calculated, so that general classification of vehicles is possible.

The cost is relatively low (several hundred dollars). A problem is that the rubber tends to deteriorate because of the recurring deformation.

2 Piezo-Electric Pressure Sensor

A special plastic produces an electrical charge when compressed that is proportional to the mechanical pressure or force. It can be produced in tile or cable form (the latter is flat or round), and is usually sheathed by, for example, rubber. The charge can be determined quantitatively to measure the pressure or force, or, if compared with a threshold, it provides only the information that something is passing, similar to a contact switch.

On a hard road, flat cable can be glued to the surface, or installed in a groove with a metal frame. At a soft road or in terrain, round cable is buried at a depth of 10 cm. At a road, two piezo-electric pressure sensors can be used to count axles and measure speed and axle distances, as with contact switches. The additional pressure/force information can improve the classification. When buried, only rough pressure/force measurement is possible, but the sensitivity suffices in principle to detect persons walking.

Piezo-electric cables can also be tied into fences where they can measure vibration and thus detect climbing or cutting.

A road sensor cable with charge amplifier costs several hundred to several thousand dollars. For longer lines or fences, the cost can escalate to \$50,000 to \$100,000 per kilometer, making it practical only for important installations, not for complete coverage of a long border.

3 Geophone

A geophone measures the vibration of the ground, usually electro-dynamically (i.e., the electrical output is proportional to ground velocity). Vibration is produced directly when varying forces are applied to the ground, as by moving vehicles, persons, or animals. This vibration propagates as seismic waves. Additionally, ground vibration is excited if sound waves in the air impinge on or pass along the ground. Geophones are more than one thousand times more sensitive than humans are; thus, signals produced by heavy vehicles can be detected over several hundred meters if there is no unusual background noise. For small cars, the range is in the region of 100 meters; for persons, the range is several meters to several tens of meters. Aircraft can be sensed about as long as their sound is audible. On an airbase or airstrip the noise is very strong,

and the touch-down pulse or bumps in the runway produce additional seismic signals; thus, geophones are well suited for monitoring takeoffs or landings.

The vibration signal form is very complex and can be used for sophisticated evaluation and discrimination; however, this requires considerable signal processing. Geophones have dimensions of about 0.1 m. Usually geophones are buried for protection and better coupling to the ground.

A simple geophone costs about \$100. Processing electronics and cable or radio connection can increase the price to several thousand dollars. If vehicles crossing a designated line through terrain are to be detected, one geophone is required about every 100 meters, leading to costs of several tens of thousands of dollars per km. This allows wider use than with pressure-sensing cable, but complete control of long borders becomes prohibitively expensive.

4 Microphone

A microphone usually measures fast variations of air pressure that occur with propagating sound waves. Land vehicles, aircraft, and ships produce characteristic sounds from the engines, tires, auxiliary equipment, and the body/hull/fuselage. With low background noise, detection of large vehicles may already be possible at several kilometers distance. Persons walking silently are difficult to detect over more than a few meters. Similarly to geophones, microphones are capable of sensing aircraft movements on airbases or airstrips.

Microphones have to be exposed to free air; thus, they are usually mounted on a pole or mast. This requires measures for weather protection and makes microphones more vulnerable than geophones. The microphone signal carries complex information on the sound source comparable to the one of a geophone, but processing it to derive source properties is simpler because sound moves with only one constant speed (whereas seismic signals travel with many speeds, which leads to superposition of signal parts produced at different times). Using arrays of three or four microphones (typical distance 1 m), the direction towards a sound source can be determined. With two or more such arrays at some mutual distance (e.g., 100 m), the point where the direction vectors cross each other gives the source location (because of atmospheric effects, however, the elevation angle or height is reliable only over a few hundred meters).

A weather-protected microphone costs several hundred dollars. For processing and transmitting, about the same cost as with a geophone applies; however, this cost can be shared if both sensors are co-located.

5 Magnetic Sensor

Land vehicles, ships, and aircraft usually contain steel components that are either magnetic themselves or are magnetized in the magnetic field of the earth. Both effects modify the field in the vicinity. Thus magnetic sensors can detect vehicles. Since the magnetic field decreases strongly with distance (normally with the inverse third power), conventional highly sensitive sensors (e.g., of magneto-resistive or flux-gate types) have detection ranges for vehicles

and aircraft of 20 to 40 meters. A longer range (about 200 to 400 meters) is promised by a new technology (the so-called "SQUID" principle), which is under research and development.

Magnetic sensors cost from several hundred to several thousand dollars. The short range of present technology is an obstacle to the sensor's use in longer control lines. For the control of roads or airstrips, however, magnetic sensors are useful.

6 Induction Loop

An alternating current flowing in a loop produces an alternating magnetic field, which induces a voltage in a metallic object in the vicinity. This creates a current, which produces its own magnetic field and in turn influences the current in the primary coil. The frequency is in the kilohertz to tens of kilohertz range. This active sensing principle reacts to any conducting material, independent of its magnetic properties; thus, it is often called metal detection. It is used to detect small arms at airports and mines. In hand-held devices, the loops have about 0.1-m diameter; person gates are door-size. The detection distance for small arms is centimeters to decimeters. For vehicles, loops measure typically 2 by 3 m². The wire is installed in 2- to 3-cm-deep grooves that are then refilled with, for example, asphalt (the same would hold for air base runways). The induction signal of a passing vehicle is determined mainly by the bottom height and the axles. With two loops, speed, axle distances, and length can be determined so that a general classification is possible. Since the object has to be in the immediate vicinity of the loop, this sensor has its main use on roads or for person control. Since a vehicle contains much metal itself, the signal from hidden small arms inside or on top cannot be detected.

Two traffic induction loops with a control unit cost \$10,000 to \$20,000. A loop gate for persons is \$5,000 to \$7,000; a hand-held metal detector costs about \$300.

7 Infrared Sensor

Infrared light has longer wavelengths than visible light (0.8 to 20 μm versus 0.4 to 0.8 μm). Warm objects emit infrared light. Impinging infrared light from another source is reflected and scattered as well, so objects can be detected also by infrared light from the sun or from infrared searchlights. Infrared sensors come in many types. The most sensitive ones have to be cryogenically cooled and are not well suited for routine monitoring; however, even uncooled sensors deliver good performance. Simple ones consist of one piece of infrared-sensitive material with an aperture that limits the observed angle to typically 45 to 120 degrees in two dimensions. Thus, there is no spatial resolution. Since the background usually varies (clouds, day, night, etc.), in many cases the sensor or its electronics react only to fast changes such as when an object moves into or out of the observation cone. Small infrared sensors are used in security systems or to automatically switch on lights. For moving objects with weak infrared signals such as persons or vehicles, detection ranges are several meters. If the sensor is provided with a lens, the angle subtended can be markedly reduced, and the range increased to tens of meters or more for very hot objects.

A simple infrared sensor costs under \$30 while sophisticated ones (e.g., with some wavelength specificity or a lens) can cost up to several thousand dollars.

8 Breakbeam Device

An arrangement of light source and detector can determine whether the line between both is free or blocked by an object. The distance can be from millimeters to more than 100 meters, so that roads and even airport runways can be controlled. The two-way arrangement of source and detector at one side with a retroreflector at the other—which saves cable and installation—is not suited to a monitoring context since an additional reflector put in front of the source-receiver combination would simulate a free beam whereas behind it anything could pass unnoticed. In order to render the system independent of external light conditions, the beam is usually modulated, and only the modulated light is detected. Often, near-infrared light is used in addition. With two breakbeam devices, speed and vehicle dimensions can be determined, similar to contact switches or induction loops. With a vertical array of many beams, a rough vehicle profile can be measured. Such system is in use by the U.S. inspection team at the Russian Votkinsk missile production plant under the INF and START Treaties. This is an enclosed area with very few exits and little large-vehicle traffic so that slow passing does not introduce significant hindrance, and a nuclear strategic missile is so large that its transporter vehicle can be easily distinguished by its size. In the present context, breakbeam devices would not contribute much to control the flow of small weapons at portals. For normal roads, they would mean unacceptable restrictions for the traffic. The main possible use can be for no-entry areas near or between fences.

A one-way breakbeam device costs from \$50 to \$300.

9 Image Intensifier/Night-Viewing Device

Even at night, there are light sources, though faint ones. By using highly light-sensitive material and electronic amplification, images of terrain can be produced with the light of the moon or even of the stars. The quality increases with the illumination; whether an object can be detected against the fluctuating background and at what distance depends on the light level, the color, and the size of the object. Persons can be seen at tens of meters to a few hundred meters, vehicles at up to several kilometers. Usually night-viewing devices are hand-carried and equipped with magnifying optics, so that one uses them similarly to a telescope; heavier ones are mounted on a tripod. (For the use of this principle in video cameras, see below.)

Better images with less fluctuation result if one uses the infrared (thermal) radiation from the scene. Another advantage is that warm objects such as vehicles or persons can be seen through bushes or trees, if the foliage leaves gaps. Modern infrared-sensitive cameras (displaying the scene on a monitor) are electrically cooled, so cryogenic cooling is no longer necessary.

Hand-held, image-intensifier night-vision devices cost several thousands of dollars. More sophisticated ones cost \$15,000 or more. The cost of infrared observation systems starts at \$15,000.

10 Photo Camera

A conventional photo camera produces an image on light-sensitive film, which has to be developed after exposure. Films are available in black and white, in color, and for infrared light (with the latter, only the very near infrared up to 0.9 μm wavelength can be used). The three-dimensional scene is projected onto the two-dimensional image, which produces perspective distortion and masking. Depending on film size and focal length of the lens, angles from 10 to 120 degrees can be covered. A camera is a passive sensor; if there is insufficient illumination, an additional light source has to be used such as a flashlight or a searchlight. The resolution delivered by film is still unequalled by other sensors. Because film reacts nonlinearly to light, small intensity differences cannot be recorded in the presence of large contrasts. Special cameras with larger and longer film, stabilized mounting, etc., exist for aerial photography, but the more sophisticated ones are mainly needed for mapping purposes. For documenting evidence gained during routine air observation, simpler types suffice, maybe even down to the normal hand-held camera taking photos through the normal window.

A normal photo camera costs several hundred to several thousand dollars, depending on quality and equipment. Because of the need for developing, and since the images are not immediately suitable for electronic transmission, conventional cameras are not well adapted to automatic monitoring. For documentation by patrols, road control personnel, etc., they are a good choice.

Good hand-held aircraft cameras cost \$10,000 and above. The very specialized fixed ones cost \$100,000 or more and are required only for systematic precision evaluations.

11 Electronic Still Camera

This camera type has become available only in the last few years, after the maturation of video cameras and with the increasing miniaturization of digital memory chips. It corresponds to a conventional photo camera; the main difference is that instead of the film there is a light-sensitive sensor with many (hundreds of thousands up to millions) elements that are read out successively, usually by the charge-coupled device (CCD) technology. The charge from each cell is converted to a digital number that is stored in digital memory. It can then be reproduced on a display device, written to a permanent storage device (e.g., a CD-ROM), or transmitted via cable or radio. Usually, the semiconducting sensor elements are sensitive in the visible and near-infrared region, so that, with appropriate lenses, near-infrared images (up to about 1 μm wavelength) can also be recorded. Since the elements react linearly over several orders of magnitude,²⁷ small intensity differences are preserved even in the presence of large contrast, and later computer processing can be used to analyze the former. The image contains less detail than with film, but this disadvantage is more than compensated by the immediate availability in digital form. Thus, this camera type is well suited to automatic monitoring applications.

The price of electronic still cameras has decreased from well above \$10,000 to several hundred dollars. It is to be expected that they will become cheaper with the continuing progress

²⁷ An order of magnitude is a factor of 10.

in digital electronics and with mass production. In the present context, protection against weather and other disturbances as well as transmitting equipment will tend to keep costs in the range of \$1000 and more.

12 TV or Video Camera

In a TV or video camera, the lens projects the image on a matrix of light-sensitive elements (charge-coupled devices) as described with the electronic still camera, with the difference that the readout is done continuously and fast enough so that 50 (or 60) half images are registered per second. Up to the present, the electrical signal from the rows of sensor elements is mainly transmitted and recorded in analog form, usually on magnetic tape cassettes. As stated, video cameras preceded the still ones, and the change to digital storage is now just beginning. Usually video cameras are equipped with zoom lenses so that the observed region can be varied. The amount of detail resolved is inversely proportional to the viewing angle. Concerning small intensity differences, the same principle holds true for video cameras that was stated for still cameras. However, before signals can be computer-processed, values from analog videotape have to be digitized.

Equipped with suitable lenses, most video cameras can also be used to record near-infrared light. For mid-infrared applications, however, specialized, mostly cooled sensor arrays and special optics are required, which makes such a camera more complicated and costly. For use at night, a low-light-level camera is another choice. Here the output of an image intensifier is not presented to a human eye (see above), but transmitted electronically or recorded. Similar to night-viewing devices, they can work even with starlight.

For image processing, there are many techniques that work on a lower level (e.g., manipulate amplitude or color), and analyze neighbor relations or time variations. On a higher level, there are methods to find edges, detect motion, link related objects, remove perspective distortions, find similarities with known objects, etc. Programs for these tasks are very complex and often expensive (several thousands to hundreds of thousands of dollars), but they immensely alleviate the tasks of a human image interpreter. Nevertheless, image analysis is so complicated that it is usually not done completely automatically, but under human supervision.

Video cameras start at about \$500. Studio-quality ones or ones equipped with remote-control swivel and zoom for outside mounting may cost several thousand to tens of thousands of dollars. Cameras for the mid-infrared with special (cooled) sensors and optics start at \$15,000 and can go up to over \$100,000. Low-light-level cameras with image intensifiers start at \$10,000.

13 Radar

If electromagnetic radiation impinges upon an object, part of it is scattered (also refracted or reflected) in all directions. By emitting radiation, receiving the back-scattered portion, and measuring the time delay between both, the distance to the object can be determined using the speed of light. Usually this is done with pulsed emission, but also with continuous power the

round-trip time can be determined if the frequency is varied systematically. Typical wavelengths are in the meters to millimeters range (frequencies of megahertz to gigahertz). Shorter wavelengths and higher frequencies are used for shorter distances. If the radiation was focused into a narrow beam or fan, the direction to the object is known as well, so that its location can be determined in three or two dimensions. If the object moves with a velocity component to or from the radar, the frequency of the echo is shifted up or down by the Doppler effect. By measuring this shift, the radial speed component can be determined. The Doppler effect can also be utilized to discriminate small moving objects from a large, immobile background such as when looking from above onto the ground.

Radar systems exist in very many forms from a briefcase-sized speed control system to multi-story buildings to monitor space objects over thousands of kilometers. In the present context, air surveillance radar may play a role to control air traffic. Their large (200 to 400 km) range applies only to high-flying aircraft. In low-level flight, the curvature of the earth (and potentially hills or mountains) prevents detection except over much shorter distances. Thus, for the present application, smaller ground-based air radar, with a distance of tens of kilometers, set up on hills would be more suitable. Complete coverage of long borderlines would be justified only if illegal transport by aircraft to hidden places was a problem. To monitor only suspected routes, temporary deployment of truck-mounted mobile systems would suffice.

Radar on ships or deployed along the coast can monitor the ocean for vessels and boats, with ranges of 10 to more than 50 km, depending on target size, radar altitude, and power. There is also radar for ground observations, that, if used from high ground, provides vehicle detection over a range of many kilometers. Small radar (with a range of a few hundred meters to a few kilometers) can be used to detect aircraft that are rolling, taking off, and landing at airports. With a range of tens to hundreds of meters, radar can detect intruding persons. Its principal capability to measure and characterize vehicles on roads (e.g., from bridges or masts) over meters is not really useful in the present context.

Aircraft-mounted radar can be used to detect ships and boats on the sea. Here the reflection from the objects is stronger than, and can be easily distinguished from, the one from the sea surface. Air-based radar over land, on the other hand, would normally get a large signal deriving from everything hit by the beam at the same time, be it soil, trees, vehicles, etc., and since the beam in some distance is several hundred meters wide, everything would mix. This problem can be overcome by synthetic aperture radar, where the beam looks sideways, sweeping over the landscape with the aircraft motion. If the reflections are recorded continuously, an image showing the individual objects can be gained by very complicated computer processing. This technology delivers a similar amount of image data as aerial photography. Synthetic aperture radar has worse ground resolution than that of photography, and it is much more expensive than the latter. Therefore, it is not suited for the present application.

Because radar frequencies are shielded by metal, this technology cannot normally be used to detect hidden small arms.

Whereas small, series-produced radar can cost as little as a few thousand dollars, larger, more robust ones with a range of tens of kilometers will cost about \$100,000. A mobile air-surveillance radar can cost one or a few million dollars.

14 X-Ray Device

Electromagnetic radiation of billion-fold smaller wavelength ($10^{-10}..10^{-12}$ m)²⁸ is no longer shielded by metal, but penetrates any substance. The beam is attenuated according to the material; the losses increase with density and atomic number. Centimeters of human tissue and bones can be penetrated with photon energies of tens of kiloelectronvolts, whereas centimeters of steel and heavier metal require about 1 megaelectronvolt. In the traditional medical application, a film is exposed and developed. The image shows a two-dimensional projection of the three-dimensional reality. With arrays of photon detectors and computer processing, much more information can be gained. When the object is penetrated from many directions, a full reconstruction of the three-dimensional distribution of attenuating material inside is possible, which is known as tomography. But even without tomography, computer processing can focus on small attenuation differences to detect edges, to automatically search for certain shapes, etc.

For X-raying bags, trunks, or sacks, table-size devices with particle energy of 0.1 megaelectronvolts and electron-beam power of 10 watts suffice, as they are known from baggage control at airports. A larger system of approximately 0.3 megaelectronvolts is capable of registering the rough outline of the load on vans or penetrating air cargo containers. This method would be able to detect small weapons if they were not well shielded. A canvas or wooden hull poses no problem, but sacks of grain, sugar, etc., do. Steel boxes can be seen under the same conditions, but not their contents. Such a system, mounted in one or two containers, can be transported and deployed temporarily within a short time.

Investigating complete large vehicles (such as cargo containers) for hidden objects (e.g., in hidden compartments inside the load) requires particle energies of megaelectronvolts and beam powers around 1 kilowatt. This requirement necessitates special measures to protect persons, such as shielding walls, or having the driver leave the cabin. One building on each side of the control lane is needed. A system of this sort has been installed by the U.S. at the portal of the Russian Votkinsk missile production plant for X-raying outgoing ballistic missile containers on trucks or railcars. Routine use of such systems by customs is just beginning in a few of the largest seaports worldwide.

A system for X-raying 1-meter, nonmetal objects costs about \$100,000. A system for the load outline of cars or vans is five to ten times as expensive. Large systems capable of finding arms or their components through metal cost 10 to 20 million dollars; thus they will not play a

²⁸ The corresponding frequencies are $10^{19}..10^{21}$ Hz; since here the particle character of electromagnetic radiation is dominant, such radiation is usually characterized by the energy of a single photon, which is several tens of kiloelectronvolts to several megaelectronvolts. An electronvolt is the energy that one electron gains when it passes through a voltage difference of 1 volt, $1\text{ eV} = 1.6 \cdot 10^{-19}$ Joule, 1 Joule = 1 Newton-meter = 1 watt-second. An X-ray photon produced by impact of an electron on the anode gets maximally the electron energy.

role in the present context in the near future. Beginning with transportable, medium-size equipment is probably the best way to proceed.

15 Chemical Sensors for Explosives

Trained dogs can smell minute quantities of certain chemicals. Thus they are used to detect narcotic drugs or explosives in monitoring baggage at airports or when vehicles are being searched. Dogs can detect ammunition from its smell, even if packed in tight containers. This is, of course, not "technology," but needs to be mentioned here because of the utility for the present purpose.

Recently, technical chemical sensors are becoming available that provide similar sensitivity for the vapors emitted by explosives. One type, developed in the context of mine detection, uses high-speed chromatography with chemoluminescence.²⁹ Vapors and particles are collected on a filter and cryofocusing trap, then released into a chromatography capillary, separating the compounds. The output is pyrolyzed, converting the explosives to nitric oxide, which then reacts with ozone, producing light, which is detected. Such a system could detect picograms (10^{-12} g) of explosives within a minute and could be portable and battery-powered. Development is still under way, thus it cannot yet be bought, and practical experiences do not yet exist.

²⁹ P. Horowitz (ed.), *New Technological Approaches to Humanitarian Demining*, McLean, VA: JASON/MITRE, 1996; K. Tsipis, *Report on the Landmine Brainstorming Workshop of August 25-30, 1996*, Appendix D, Report no. 27, Program in Science and Technology for International Security, Cambridge, MA: Massachusetts Institute of Technology, November 1996.

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About the Author

Jürgen Altmann is a physicist specializing in problems of disarmament. He holds a physics diploma and doctor of sciences degree, both from the University of Hamburg, Germany. After research work in molecular physics, laser radar, and computer pattern recognition, in 1986 he started to work on the scientific and technical problems of disarmament. In this area, he studied space laser weapons and defense systems against short- and intermediate-range ballistic missiles. In 1988, he founded the Bochum Verification Project at Ruhr-Universität Bochum, Germany, which investigates the potential of acoustic, seismic, and magnetic sensors for cooperative verification of disarmament and peacekeeping agreements. Beside the experiments, evaluations, and application studies connected to that goal, he continued to work on prospective assessment and preventive limitation of new military technology, e.g., in the field of non-lethal weapons. Recently, he performed a detailed analysis of potential acoustic weapons. Altmann has published many scientific papers and reports; he has co-organized international workshops on verification and edited several books. He has worked as a consultant with the Office of Technology Assessment at the German Federal Parliament. From August to October 1997, he was a visiting scholar at the Cooperative Monitoring Center of Sandia National Laboratories, Albuquerque NM, USA. At present, he is a scientific staff member at the Department of Physics, Dortmund University, Germany, doing a project on preventive arms control for microsystem technologies.

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