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INVESTIGATION INTO NON-VISUAL SURVEILLANCE DEVICES

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Abstract

The ability of a soldier to detect and identify the enemy is vitally important to the outcome of any mission. This report examines various non-visual surveillance systems that may support dismounted infantry operations. The technologies investigated included acoustic, seismic, magnetic, electromagnetic, electro-optical and radar devices. The range of portability and size options for these systems were also assessed. The review included man-portable, remotely controlled (i.e., unmanned aerial vehicles), and unattended sensor systems with various sensor nodes and multiple sensor types that can be deployed to the area of concern and monitored from a safe location. This technical memorandum summarizes the results of this investigation.

Résumé

La capacité des soldats à détecter la présence de l'ennemi et à identifier celui-ci s'avère cruciale à la réussite de n'importe quelle mission. Le présent rapport donne une analyse de divers systèmes de surveillance non visuels qui peuvent être utilisés à l'appui d'opérations d'infanterie débarquée. Des dispositifs de technologies diverses ont fait l'objet d'analyse, notamment des dispositifs acoustiques, sismiques, magnétiques, électromagnétiques et électro-optiques, ainsi que des radars. Les différents niveaux de portabilité et les options de taille de ces systèmes ont également été évalués. L'analyse a porté, entre autres, sur les systèmes de détecteurs portables, les systèmes télécommandés (c.-à-d. les véhicules aériens sans pilote) et les systèmes autonomes avec divers nœuds de détecteurs et de multiples types de détecteurs qui peuvent être déployés dans la zone critique et surveillés à partir d'un lieu sûr. Le présent rapport technique résume les résultats de l'analyse effectuée.

Executive Summary

The ability of a soldier to detect and identify the enemy is vitally important to the outcome of any mission. While the Canadian Forces have advanced surveillance sensors available on select vehicle platforms (e.g., the Coyote Light Armoured Vehicle) there are only limited options currently available for the dismounted soldier. Recently there have been advances in the technological capabilities of surveillance sensors and the capability to process vast amounts of information generated by these sensors. Sensors vary in the technology employed and include acoustic, seismic, magnetic, electromagnetic, electro-optical and radar devices. Each of these different types of sensors has several advantages and disadvantages for detecting and identifying the enemy. This paper investigated a range of possible candidate non-visual surveillance system options to support infantry surveillance tasks.

The Internet was used to search for various non-visual surveillance systems between September 2002 and January 2003. The focus of the search was on finding currently available non-visual systems as well as systems in development. Company websites, articles posted in the on-line press and other articles found on the Internet were examined.

The results of this search identified many different types of non-visual surveillance sensor systems. Each different sensor system type has a different application for the battlefield. Handheld systems exist to enhance a soldier's hearing and enable soldiers to detect enemy through walls. There are hundreds of remote and controllable sensor systems soldiers can use from a distance to monitor and detect the enemy. These remote systems include UAVs and UGVs that vary in size depending on the task they are to perform. Also, numerous unattended ground sensors exist that once in place allow remote monitoring of numerous locations with various types of sensors by a single soldier.

The objective of implementing these non-visual surveillance systems is to increase the situational awareness of soldiers and ultimately the survivability of infantrymen. In future research the performance and usability of these non-visual surveillance systems in the field will need to be furthered assessed.

Sommaire

La capacité des soldats à détecter la présence de l'ennemi et à identifier celui-ci s'avère cruciale à la réussite de n'importe quelle mission. Bien que les Forces canadiennes possèdent des détecteurs de surveillance évolués sur les plates-formes de certains véhicules particuliers (p. ex. le véhicule blindé léger Coyote), un nombre limité d'options existe actuellement pour les soldats débarqués. Récemment, les technologies utilisées dans les détecteurs de surveillance et la capacité de traitement d'importants volumes de données générées par ces détecteurs ont été améliorées. Les détecteurs n'utilisent pas tous les mêmes technologies. Parmi les dispositifs utilisés dans les détecteurs, on retrouve les dispositifs acoustiques, sismiques, magnétiques, électromagnétiques et électro-optiques, ainsi que les radars. Chaque type de détecteur comporte plusieurs avantages et inconvénients en ce qui concerne la détection et l'identification de l'ennemi. Le présent rapport donne une analyse de divers systèmes de surveillance non visuels qui peuvent être utilisés à l'appui des tâches de surveillance de l'infanterie.

De septembre 2002 à janvier 2003, des recherches ont été effectuées sur Internet pour trouver divers types de systèmes de surveillance non visuels. Les recherches portaient principalement sur les systèmes non visuels disponibles actuellement, ainsi que sur les systèmes en cours de développement. Des sites Web d'entreprises, des articles affichés sur les sites de journaux en ligne, ainsi que d'autres articles trouvés sur Internet ont été examinés.

Les recherches ont permis d'identifier de nombreux types différents de systèmes de détecteurs de surveillance non visuels. Chaque type de système de détecteur est utile pour une application différente sur le champ de bataille. Il existe des systèmes portatifs qui permettent d'augmenter l'acuité auditive des soldats et d'autres systèmes qui permettent aux soldats de détecter l'ennemi à travers les murs. Il existe en fait des centaines de systèmes de détecteurs télécommandables que les soldats peuvent utiliser à distance pour détecter la présence de l'ennemi et surveiller celui-ci. Parmi ces systèmes, on retrouve les véhicules aériens et terrestres sans pilote, dont la taille varie en fonction de la tâche qu'ils sont censés effectuer. Il existe également de nombreux détecteurs autonomes au sol qui permettent, une fois qu'ils sont installés, la surveillance à distance de plusieurs endroits par un seul soldat à l'aide de différents types de détecteurs.

L'objectif derrière la mise en œuvre de ces systèmes de surveillance non visuels est d'améliorer la vue d'ensemble de la situation perçue par les soldats d'infanterie et, en fin de compte, d'augmenter leurs chances de survie. Dans les recherches futures, le rendement et l'utilisabilité sur le terrain de ces systèmes de surveillance non visuels devront être évalués plus en profondeur.

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1 Background

The ability of a soldier to detect and identify the enemy is vitally important to the outcome of any mission. While the Canadian Forces have advanced surveillance sensors available on select vehicle platforms (e.g., the Coyote Light Armoured Vehicle) there are only limited options currently available for the dismounted soldier.

With the Canadian Forces participating in more peacekeeping duties and operations other than war, it is increasingly important to be able to maintain security zones between combatants by providing a degree of early warning for forward troops. In the past, anti-personnel mines have been used to provide early warning; however, recently they have become politically unpopular. The move away from anti-personnel mines is an important issue for North Atlantic Treaty Organization countries because of recent international accords to ban the use of these weapons. Effective alternative methods for detecting and denying opposing forces access to areas must be available to soldiers to allow operational flexibility. Surveillance systems with various types of sensors may provide an effective solution. The current challenge is to identify which of the many and varied non-visual surveillance devices offer the most potential for dismounted infantry operations.

The SIREQ cognitive task analyses (Reference A) identified a need for improved technology for surveillance tasks performed by infantrymen. While several surveillance studies have been conducted for the SIREQ programme, these have focussed mainly on systems that rely on the visual modality, including day vision systems, image intensification, thermal, and fused devices (Reference B, C & D), and not other non-visual systems.

Recently there have been advances in the technological capabilities of surveillance sensors and the capability to process vast amounts of information generated by these sensors. Many different types of sensors have been developed to detect intruders and deny opposing forces. Sensors vary in the technology employed and include acoustic, seismic, magnetic, electromagnetic, electro-optical and radar devices. Each of these different types of sensors has several advantages and disadvantages for detecting and identifying the enemy. The size and the level of sophistication of non-visual surveillance systems also vary. Some systems are man-portable, others are remotely controlled (i.e., unmanned vehicles), and still others are unattended sensor systems with various sensor nodes and multiple sensor types that can be deployed to an area of concern and monitored from a safe location.

This paper investigates a range of possible candidate non-visual surveillance system options to support infantry surveillance tasks.

2 Aims

The primary aim of this technical memorandum is to explore the different types of surveillance sensor systems available and their capabilities. The secondary aims include:

- Investigate the various technologies used in surveillance sensor systems (i.e., acoustic, seismic, etc.);
- Investigate surveillance sensor systems that can be mounted on the individual soldier (i.e., man-portable systems);
- Investigate surveillance sensor systems that are remote and controllable (i.e., unmanned aerial vehicles and unmanned ground vehicles); and
- Investigate unattended surveillance sensor systems (i.e., unattended ground sensors).

3 Methodology

The Internet was used to search for various non-visual surveillance systems between September 2002 and January 2003. The focus of the search was on finding currently available non-visual systems as well as systems in development. Company websites, articles posted in the on-line press and other articles found on the Internet were examined. Only websites containing information on non-visual surveillance systems thought suitable for an infantry soldier are discussed in the following sections.

The next section in the report describes the various technologies used in surveillance systems. The following three sections describe man-portable surveillance systems, remote and controllable systems surveillance, and unattended surveillance sensor systems, respectively.

4 Sensor Technology

Non-visual systems use various sensor technologies including: acoustic, seismic, magnetic, electromagnetic, electro-optical, and radar. Below is a brief description of each of these sensor technologies.

4.1 Acoustic Sensors

Acoustic sensors sense the acoustic energy (sound waves) emitted by a potential target. They allow observers to calculate the target's position by measuring the time of arrival of sound waves at several known sensor locations. They can also be used to identify or classify targets based on the emitted acoustic energy, or to monitor sounds and/or conversations.

4.2 Seismic Sensors

Seismic sensors detect or measure seismic disturbances generated by moving vehicles or personnel. They can be used to cue other higher resolution sensors (for example, acoustic or electro-optical sensors) and identify or classify targets.

4.3 Magnetic Sensors

Magnetic sensors detect changes in the ambient magnetic field caused by the movement or presence of metallic objects. Their range is extremely short, but they can be used to cue other higher resolution sensors and to identify or classify targets.

4.4 Electromagnetic Sensors

Electromagnetic sensors detect target-emitted electromagnetic radiation. Such sensors depend on target emission, target motion, or conversion of mechanical disturbance into electromagnetic radiation.

4.5 Electro-optical Sensors

Electro-optical (EO) sensor systems image potential targets to detect, locate, and identify. The most common are unattended infrared (IR) ground sensors, although sensors detecting in the visible end of the light spectrum do exist.

4.6 Radar

Radar can detect the presence of a stationary object as well as the speed of a moving target.

4.7 Piezoelectric Sensors

Piezoelectric materials convert mechanical energy into electrical energy and vice versa. Piezoelectric cable can be buried underground and will respond to vibrations when walking on or near it.

5 Sensor Systems on the Soldier

This section describes sensor systems that can be carried and used by an individual soldier. This section is split into three parts. The first part describes acoustic sensors that can be worn or hand held. The second part describes radar sensors that are hand held and have the ability to detect humans through a wall. The third describes man-portable surveillance radars.

5.1 Acoustic Sensors

Acoustics sensors can provide full 360-degree coverage, day/night operation, and non-line-of-sight capability in almost all weather conditions. Described below are various acoustic sensors that could be worn or held by an individual soldier.

5.1.1 Parabolic Microphones

Parabolic microphones are a hand held acoustic sensor. They increase the distance at which sounds can be heard. They enable individuals to hear conversations and other sounds at various distances. Because of the parabolic shape of the reflector, all the sounds along a very narrow angle of acceptance are directed into the microphone, enabling the user to pin point the direction of the sound.

An example is the Telinga parabolic microphone. It has a 22" clear polycarbonate foldable dish with a "Twin Science" microphone mounted at the focus (Reference E). See Figure 1.

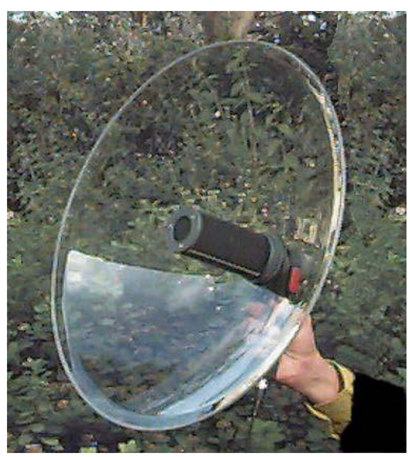

Figure 1: Telinga Parabolic Microphone

5.1.2 Four Microphone Headset

The Walker's Power Muffs **QUAD** is an acoustic sensor that can be worn (Figure 2). It is designed with four individual high frequency response microphones that amplify ambient sound. Each ear cup has a front and rear mounted microphone, covered with a high-density foam windscreen. The placement of these microphones creates stereo or surround sound. It has 50 dB of gain, with a maximum output of 110 dB. Each ear has adjustable volume control wheels that allow the user to control the loudness for different applications or environments. It also has an adjustable frequency tuning (AFT) circuit, giving the user the ability to adjust frequencies to their individual hearing needs or the frequency of the target vehicle or soldier sounds being sought. It uses a sound activated compression circuit that compresses loud sounds instantaneously to a safe level. The muffs provide a noise reduction rating of 24 dB. (Reference F).

Figure 2: Walker's Power Muffs **QUAD**

5.1.3 One or Two Microphone Hearing System

The Tactical Ear II is an acoustic sensor that can be worn (Figure 3). It amplifies sounds nearly nine times normal hearing. The device fits over the back of the ear and weights only 0.12 ounces. It allows for omni-directional (360 degree range) hearing with emphasis on high frequency sounds. It also has adjustable frequency tuning which focuses on specific sound frequencies for clearer reception in different situations (Reference G).

In addition, the Tactical EAR II provides hearing protection by providing a noise reduction rating of 29 dB A safety circuit shuts off the Tactical Ear II when a firearm is discharged, further protecting hearing. Also the Tactical Ear can be worn in one or both ears (one or two microphones) and no special fitting is required (Reference G).

Figure 3: Tactical Ear II

5.1.4 Guardian Acoustic Sniper Location Device

The Canadian military and a private defence company worked together to develop the Guardian Acoustic Sniper Location Device (Reference H). See Figure 4. This device can pinpoint the location of a sniper by analyzing the sound of a gunshot. It consists of a portable tripod with four microphones mounted in a directional array. The Guardian detects and recognizes a weapon's shock wave and muzzle blast. It screens out background noise, including other battlefield sounds, and compares the sound of the muzzle blast with a database of sounds stored on the system's computer. To assemble a comprehensive catalogue of the various noises rifles may make, the developers collected a 100 gigabyte computer database of nearly 3,000 different gunfire sounds using different weapons (Reference H).

The device weighs 20 kilograms and can be set up in 20 minutes. Attached to its tripod is a 50-metre cable connected to a computer. The operator can monitor the computer's analysis of the sniper's location from the safety of a wooded area, a vehicle, or other post. It has an operational radius of approximately half a kilometre but, under certain conditions, can detect sniper positions at distances of several kilometres (Reference H).

There is a plan to develop a smaller version of the Guardian that could fit on a soldier's helmet, as well as a system that can be added to military vehicles (Reference H).

Figure 4: Guardian Acoustic Sniper Location Device

5.2 Radar Sensors – Seeing Through the Wall

New radar technology has been developed that allows an individual to detect objects and personnel behind a wall. This device may help reduce battle casualties by acting as a soldier surveillance tool, providing early warning of enemy attack and an accurate picture of the enemy situation in complex and urban settings. Below is a description of four 'through-the-wall' radar systems that are currently being developed.

5.2.1 Radar Flashlight

A prototype RADAR flashlight (Figure 5) developed by Gene Greneker, a principal research scientist at the Georgia Tech Research Institute, can detect a human presence through walls and doors up to eight inches thick (Reference I). It uses radar and a specialized signal processor to detect movement. It is claimed that the RADAR flashlight is able to detect a stationary individual behind a solid wooden door, or standing three meters behind an eight-inch block wall, based on respiration signature alone. The flashlight uses a narrow beam of 16 degrees to detect body movement generated by breathing. The RADAR flashlight only requires a body movement of a few millimeters to detect a human presence. It can detect motion and/or respiration through brick, wood, plaster board, glass, and concrete. It will not work in water or on metal structures, such as mobile homes because these materials are electrical conductors. The RADAR flashlight is a self-contained seven pound unit (Reference J). The target sale price is $1,000 to $1,500 per unit (Reference I).

To operate the flashlight the user holds the device with a pistol-grip handle and pulls a trigger. Tthe device runs a 3-second self-test to verify that it is functioning properly (Reference J). The results will be displayed on a small LED display as a bar graph built into the device. Then the user presses the device against a wall, pulls the trigger and within 3 seconds the system automatically spaces itself from the wall at a distance designed for best performance. The RADAR Flashlight's narrow radar beam sends out a pulse of electromagnetic energy, and then detects the return signal, which is read by high-speed signal processing technology that quickly delivers bar-graph results to the user's display. As the person on the other side of the wall breathes, the graph display rises and falls with a rhythmic response.

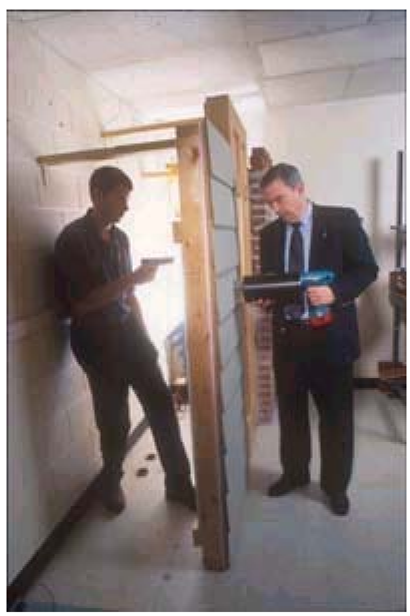

Figure 5: Radar Flashlight

5.2.2 Soldier Vision

The Soldier Vision device is the soldier's version of Time Domain's Radar Vision. Soldier Vision is a lightweight, low power radar with a signal that can penetrate walls. The U.S. Department of Defense Advanced Concept Technology Demonstrator Program awarded a $3 million contract to Time Domain Corporation to develop this device (Reference K).

Soldier Vision will use Time Domain's PulseON® wireless technology, which sends millions of pulses per second and is capable of penetrating multiple walls at a current maximum range of 30 feet (Reference K). Soldier Vision will be a small, hand-held device to be used by the U.S. military to detect movement through walls while determining the number and location of enemy or friendly forces on the other side of the wall. It is expected to have a detection range of 0 to 30 feet, be compatible with existing soldier equipment, and be ruggedized for harsh battle conditions (Reference K).

It is claimed that Time Domain's PulseON® wireless technology can carry orders of magnitude of more data than conventional communications systems, can support an unlimited number of users, and is virtually impossible to jam or detect (Reference K).

5.2.3 Motion and Ranging Sensor (MARS)

Raytheon (formerly Hughes Missile Systems) is developing a portable, briefcase-size device. This device, the Motion and Ranging Sensor (MARS), is a modification of a commercial motion detector sold by Hughes Missile Systems. It utilizes radar that can locate and track an individual through reinforced concrete or brick walls. (Reference L).

5.3 Attended Tactical Ground Sensor Systems (ATGSS)

Attended Tactical Ground Sensor Systems (ATGSS) tend to be small lightweight sensors that can normally be carried by military personnel during field operations for detecting intruders entering a secured area. Forces in the immediate vicinity monitor sensor alarms. Below is a brief description of an ATGSS.

5.3.1 Squire™ Man-Portable Surveillance Radar

Squire is a man-portable, battle surveillance system that is able to detect and classify moving ground targets at up to 48 km (Reference M). See Figure 6. Fixed-target cancellation is achieved by Doppler Fast Fourier Transform filtering. The system is a low-peak-power solid-state Frequency Modulated Continuous Wave (FMCW) radar that is virtually undetectable. It is effective at day or night and in nearly all weather conditions. Squire is portable in two backpacks each weighing 20 kg without the 24 VDC power supply (Reference M).

It features a user-friendly Windows interface and a colour liquid crystal display. Display colours are related to target speed, direction and classification to provide the user with a clear tactical picture for immediate interpretation.

Some of the Squire's features include (Reference M):

- Low power consumption, 10mW to 1W output
- Audio/visual detection alarm and detection/non-detection zones

- Automatic target tracking and classification
- Sector scan of a few degrees up to 360°
- Doppler signal for manual classification
- Spot window for detailed target observation
- PPI or B-scope presentations
- Background display of clutter map
- GPS input
- Mobile platform configurations available

It is claimed that Squire has the following range detection performance: pedestrian at 10km, helicopter at 15km, jeep-sized vehicle at 18km, and vehicle convoy at 40km (Reference M).

Figure 6: Squire Man-Portable Surveillance Radar

6 Remote and Controllable Sensor Systems

Remote and controllable sensor systems have been split into two parts: unmanned aerial vehicles (UAV) and unmanned ground vehicles (UGV). UAVs and UGVs can provide a battlefield commander with a direct sensing capability on the battlefield and even behind enemy lines, without endangering friendly personnel.

6.1 Unmanned Aerial Vehicles (UAV)

There are hundreds of various unmanned aerial vehicle (UAV) designs that exist today. UAVs can be categorized into the following seven classes (Reference N):

- Tactical – the catch-all for the ubiquitous 50 to 1000 lb deployable air vehicles;
- Endurance – capable of extended duration flight, typically 24 hrs or greater;
- Vertical Takeoff & Landing (VTOL) – self explanatory, typically rotary wing;
- Micro Air Vehicle (MAV) – defined as having no dimension larger than 15 cm;
- Man Portable – light enough to be back-packed by an individual, launched by hand-throwing or sling-shot mechanism, and larger than micro air vehicles. Also referred to as mini UAVs;
- Optionally Piloted Vehicle (OPV) – capable of manned or unmanned flight operations, typically an adaptation of a general aviation aircraft;
- Research – developed for specific investigation, typically with no production intent.

Brief descriptions of a few VTOLs, Man Portable UAVs and MAVs are described below. These categories of UAVs will be expanded upon since they are most likely to be used by infantrymen because of their size, weight and capabilities.

6.1.1 Vertical Takeoff & Landing (VTOL) UAV

VTOL UAVs are typically rotary wing vehicles. They are able to hover and thus may be more useful during urban operations than other UAVs. Below are brief descriptions of a few VTOL UAVs that exist today.

6.1.1.1 CL-327 Guardian

The Guardian is a VTOL surveillance system. See Figure 7. It offers 6.25 hours of endurance, a 105 kg payload capacity, and a 200 km range (Reference O). The land configuration stores two air vehicles per HMMWV and trailer, a downsized UAV control station, and enough fuel and payloads for a 72 hour operation (Reference O). Two personnel are required to operate the system. No pilot skills are required and the crew can be trained in four weeks. Sensors include combined EO/IR, communication relay, active ESM (Experiment Support Module) payload, and synthetic aperture radar. The guidance and navigation systems include Global Positioning System and inertial, automation flight patterns, autonomous flight, reversionary modes, waypoint navigation, and automatic target tracking.

Figure 7: CL-327 Guardian

6.1.1.2 Cypher

The Cypher UAV is 6.5 feet in diameter and is developed by the Sikorsky Aircraft Corporation (Figure 8). It combines the efficiency of a ducted airstream with a coaxial advancing blade concept rotor system. The rotors and the circular shroud surrounding them share in providing lift. Powered by a 50-horsepower engine, Cypher can cruise at 60 mph, for up to three hours, with a ceiling of 8,000 feet (Reference P).

As an autonomous air vehicle the Cypher holds position and navigates using a differential Global Positioning System. The Cypher is able to fly “hands-off” instead of being flown directly by a ground operator.

It is capable of landing remotely, camera-directed by its onboard television, on slopes as steep as 15 degrees. In confined area operations it can take off and land between obstructions about 12 feet apart. (Reference P).

Its maximum payload weight is 25 to 50 lb. The playload may include EO, forward looking infrared (FLIR), small radars, chemical detectors, magnetometers, radio relay, and non-lethal payloads. (Reference P).

Figure 8: Cypher

6.1.2 Man Portable UAVs

Man Portable UAVs are also referred to as mini UAVs or Hand Launched UAVs (HLUAVs). Listed below is a description of a few man portable UAVs that have been developed.

6.1.2.1 Dragon Eye

Sparta and AeroVironment have teamed together to produce the Dragon Eye Man Portable UAV (Figure 9). The twin propeller, 4.3 pound vehicle has a wingspan of 48 inches and breaks down into five pieces carried to the field in a backpack. Dragon Eye can be configured with various day and night vision camera payloads. A soldier using a monitor/ground control device containing a computer processor and a moving map display is able to obtain reconnaissance over a distant ridge or surveillance in an urban environment. (Reference Q).

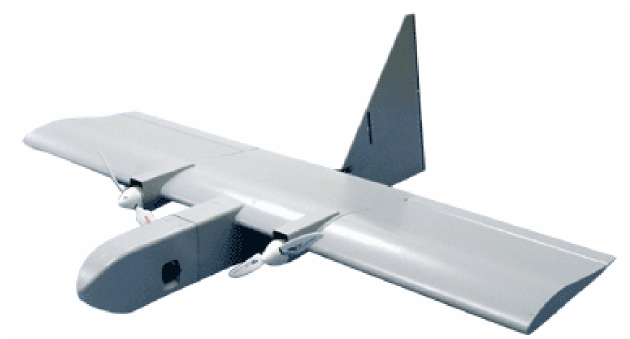

Figure 9 : Dragon Eye

6.1.2.2 Javelin – BAI Aerosystems

BAI Aerosystems' Javelin is a hand-launched UAV with the option of being either gas (aerosol can) or electric (battery) powered (Figure 10). It is portable, lightweight, easy to operate, low cost, and provides high quality video. It has a length of six feet and a wingspan of 8 feet. A pilot flies it from the ground station, where a camera operator directs the electronically stabilized colour TV camera to areas of interest. The 24:1 zoom ratio camera has a standard NTSC format, and is also available in PAL format. The Javelin system can be quickly assembled and can be easily operated with only minimal training. (Reference R).

Figure 10: Javelin

6.1.2.3 Pointer / Raven

The Pointer UAV is a low-cost electric UAV developed and produced by AeroVironment (Figure 11). It can be hand-launched and recovered in minutes without special equipment on unprepared terrain. The Pointer can carry an 8-12 micron long-wave infrared uncooled camera or a color vision camera, and fly for 90 minutes using high-performance lithium-sulfur dioxide primary batteries. The airframe with batteries weighs 8.3 lb., and the entire system fits in two rifle boxes, but is heavy enough that it is usually carried on a vehicle. The U.S. Army's Military Operations in Urban Terrain program tested the Pointer in 1999 for evaluation and reported favourable results, but found the ground station too large for dismounted operations. (Reference S).

Pointer systems have been deployed with U.S. military troops around the world, including operations Desert Shield and Desert Storm. (Reference T).

Figure 11: Pointer

AeroVironment shrank the ground station to less than half the size of the original Pointer, and also shrank the airframe to a 4.4-ft wingspan from 8.4 ft. The new version is called the Raven and has the same payload as Pointer, but now is man-portable. The aircraft fits in two packs that weigh a total of 8.5 lb. Endurance is about 80 minutes. Like Pointer, a joystick can mark many waypoints or directly control the aircraft. (Reference S).

6.1.3 Micro Air Vehicles (MAVs)

In 1997 Defense Advanced Research Projects Agency (DARPA) began a multi-year development program to develop "micro aerial vehicles" (MAVs). The target of the DARPA projects was a microdrone with no dimension greater than 15 cm, weight no more than 140 grams, fly up to 2 hours and have a range of 10 km, operate in winds of up to 48 kph, have autonomous navigation capabilities, carry a day-night camera relaying information back over a radio link, and be difficult to detect. Also, once in production, each unit should cost less than $1000 US. (Reference U).

Possible missions for MAVS are squad-level combat, battle damage assessment, air or artillery spotting, sensor dispersal, communications relay or detecting mines and hazardous substances.

Also, MAV's that are able to hover could be used to scout out buildings for urban combat and counter terrorist operations.

A MAV fulfilling all of these requirements has not yet been built. However, below is a brief description of the capabilities of some of the prototyped MAVs.

6.1.3.1 AeroVironment's MAVs

As part of the DARPA MAV effort, AeroVironment Inc. developed the "Black Widow" (Figure 12) and the "Wasp" (Figure 13).

The AeroVironment's Black Widow is powered by an electric motor driving a small propeller in the nose, with a lithium battery permitting about 20 minutes of flight. It carries an off-the-shelf camera chip giving it a color video resolution of 510 by 492 pixels. It does not have autonomous navigation capabilities, and is controlled essentially like a hobbyist's radio controlled airplane. AeroVironment went on to develop an improved follow-on to the Black Widow named the "Wasp" (Reference U).

Figure 12: AeroVironment's Black Widow

The Wasp is a flying wing aircraft, with the wing in the form of a rectangle with a slightly swept leading edge (Figure 13). The Wasp's main improvement over the Black Widow is that the lithium-ion battery and wing structures are one and the same, allowing maximum battery capacity relative to MAV size. The Wasp has a wingspan of 33 centimeters and a weight of 170 grams (Reference V).

The aircraft is stable and simple to fly using manually operated ground control of the aircraft's throttle, rudder, and elevator surfaces. It is able to fly for one hour and 47 minutes (Reference W). The next generation of WASP is expected to incorporate a simple autopilot and carry a colour video camera payload (Reference V).

Figure 13: AeroVironment's Wasp

6.2 Unmanned Ground Vehicles (UGV)

An Unmanned Ground Vehicle (UGV) is a powered, mobile, ground mover that does not have a human on board, can operate in one or more modes of control (autonomous, semi-autonomous, tele-operation or remote control), can be expendable or recoverable, and can have a lethal or non-lethal mission package.

UGVs are ideal for dangerous tasks such as tunnel and sewer reconnaissance and demining.

The United States Department of Defense Joint Robotic Program (JRP) classifies UGVs based on weight. These classifications are (Reference X):

- Micro - less than 8 pounds
- Miniature - 8 to 30 pounds
- Small (light) - 31 to 400 pounds
- Small (medium) - 401 to 2,500 pounds
- Small (heavy) - 2,501 to 20,000 pounds
- Medium - 20,001 to 30,000 pounds
- Large - over 30,000 pounds

Also, UGVs can be defined as man portable and man transportable. Man portable is a UGV or components of a disassembled UGV, capable of being carried by one person over long distances without serious degradation of performance of his/her normal duties. The upper weight limit is 31 pounds. Man transportable is a UGV that is usually transported in another vehicle, and has integral provisions for periodic handling by one or more individuals for limited distance (100-500 meters). The upper weight limit is 65 pounds per individual. (Reference X).

The United States Department of Defense JRP has funded a Man Portable Robotic System (MPRS) program. Its goal is to develop lightweight, man-portable mobile robots for operations in urban environments (indoor, outdoor, and underground) (Reference Y). Below is a description of a few UGVs currently being developed.

6.2.1 Solem Robot

The base for the prototype for the MPRS is a modified Foster-Miller Lemming base. The Solem Robot developed by Foster-Miller Lemming is a 15 kg robot that is controlled through a two-way RF link from the operator control unit that provides video and data feedback for precise vehicle positioning at distances up to 1 mile (Figure 14). It is equipped with drive wheel encoders, a three-axis compass and an arm potentiometer so the operator knows the vehicle's distance, heading, and arm angle. The operator control unit features virtual reality goggles, a handheld control unit, and vest-mounted electronics. In the standard configuration, the color camera can be elevated to 15 inches above the vehicle to see above brush and obstacles. The camera has a resolution of 400 TV lines, 1.0-lux illumination, and auto shutter. Also, many different specialized attachments and payloads have been developed for the Solem Robot. Optional attachments include LUXOR (Light UneXploded Ordinance Reconnaissance head), gripper claw, zoom camera, laser pointer, night vision camera and thermal sight camera (Reference Z).

Figure 14: Solem Robot

6.2.2 PackBot

Defense Advanced Research Projects Agency (DARPA) has funded iRobot's PackBot project. The goal of the project is to develop a robust robot to aid reconnaissance operations in urban terrain. Currently the prototype robot is designed for durability and versatility, featuring robust systems and onboard data processing capabilities that will enable rapid response to a dynamic, urban environment. It is small enough to be portable. It's self-righting mobile platform is equipped with tracked "flippers" that allow the robot to climb hills and stairs, and assume an upright posture suitable for navigating narrow, twisting passages. The PackBot is durable enough to survive a 3-meter drop onto concrete. The PackBot is able to operate autonomously or under remote supervision. It sensors include cameras, microphones, sonar, infrared sensors, inclinometers, laser scanners, and micro-impulse radar. (Reference AA).

Figure 15: PackBot

7 Unattended Ground Sensor (UGS) Systems

Unattended ground sensor (UGS) systems are designed primarily to detect and classify troop movements, as well as wheeled and tracked vehicles. These systems can report alarms over great distances, use satellites, and do not usually have the human operator present.

UGS systems may consist of a battery-powered single or multiple co-located sensors, with signal processing capability to analyze target characteristics, and transmit target recognition information to a remote monitoring location.

Some of the advantages of using UGS systems include: great growth potential as intelligence sources; can detect movement and activity patterns not previously exploited by other sensors; can detect and relay actual sounds; have a nearly instantaneous intelligence capability; cue other sensors; and, a single operator can monitor a large number of remote surveillance sites simultaneously, for an efficient use of time and manpower.

Some of the limitations of UGS systems are: they must be placed by other systems, the environment affects the sensor; and expensive, sophisticated, and secure relay equipment is required.

Discussed below are the capabilities of some of the current UGS systems that exist today.

7.1 Remotely Monitored Battlefield Sensor System (REMBASS II)

L-3 Communication Systems developed the Remotely Monitored Battlefield Sensor System (REMBASS), which it subsequently upgraded to Improved REMBASS (IREMBASS). The company has supplied more than 6000 examples of the latter for use by the US Special Forces (in the air force and the army), light divisions and overseas customers (Reference BB). More recently, L-3 has developed REMBASS II (Figure 15). This uses a seismic/acoustic target-classifying sensor running the same algorithms as in IREMBASS, complemented by infrared and magnetic sensors to determine the target's direction of travel.

This UGS can detect, classify and determine the direction of movement of personnel, wheeled vehicles, and tracked vehicles. L-3 Communication Systems claims it can provide day/night, all-weather early warning surveillance and target classification (Reference CC). Units can operate up to 90 days or longer without maintenance. The system sensors are hand-emplaced along likely avenues of approach or intrusion and respond to seismic and acoustic disturbances, infrared energy, and magnetic field changes. The sensor information is incorporated into short digital messages and communicated by VHF radio burst transmission.

The passive infrared and magnetic sensors are implemented as plug-in modules that work in conjunction with the seismic/acoustic sensors. These modules determine and report the target's direction and can be used to count targets. All sensors feature false alarm rejection algorithms. The plug-in configuration for the passive infrared and magnetic sensors reduce the size and cost of the equipment. (Reference CC).

A remote monitor/programmer is used to receive the target detection and classification data, either directly or through repeaters. The monitoring unit can act as an automated sensor monitor by connecting to a computer running a custom graphical sensor mapping application. (Reference CC).

Figure 16: REMBRASS II

7.2 Active Laser Break Beam Sensor

Protech Armored Products, working with Applied Design Concepts, has developed its Skorpion active laser break beam sensor to interface with existing systems such as IREMBASS. Skorpion, which employs an eyesafe laser, has a range of 500m. It weighs 570g and can operate off 9V batteries for up to 60 days (Reference DD).

7.3 Covert Local Area Sensor System for Intruder Classification (CLASSIC)

Thales Defence Communications (formerly Racal Radio) has supplied its Covert Local Area Sensor System for Intruder Classification (CLASSIC) system to more than 35 countries worldwide, including 12 NATO members (Reference EE).

CLASSIC consists of the TA2781 Sensor Unit, which has a miniaturized radio transmitter with a range of up to 21km, and a battery life of 90 days. It is linked to the MA2743 seismic, MA2744 passive IR, MA2770 magnetic or MA2772 piezoelectric cable sensors. When the sensor detects movement the TA2781 transmits to the RA2786 monitor unit, which gives an audio or visual display. A ruggedized printer is available to give a record of movements. If the information is being displayed in a secure HQ, a MA2775 data interface can be shown on a computer-generated map (Reference FF).

The seismic system measures vibrations through the ground and has a range of 1 to 150 meters depending on ground conditions. It can identify personnel on foot, and tracked and wheeled vehicles (Reference FF).

The passive IR beam on the MA2744 has two direction paths, and can indicate the direction in which a man or vehicle is moving. It has a range of 60 meters, but will pick up vehicles from up to 300 meters (Reference FF).

The MA2770 magnetic unit will pick up the mass of a vehicle and, if two units are emplaced, can indicate direction. At 5 to 20 meters it will detect cars; at 10 to 40 meters tracked vehicles, and at 1 to 10 meters it can indicate whether a soldier is carrying a weapon such as a rifle (Reference FF).

The MA2772 piezoelectric cable is dug into the ground just below the surface and stretches for 750 meters. There are two types of cable: the high sensitivity cable will detect personnel, while the low sensitivity cable will indicate vehicle movement. Where two cables are used the system will indicate direction of movement (Reference FF).

The CLASSIC TA2781 can also be used with pressure pads, contact switches, trip wires, inertia switches and NBC sensors. With the RTA2785 Relay Unit the range of the TA2781 can be increased to 30 km (Reference FF).

Recently, Thales Defence has developed a new system know as 'CLASSIC 2000' (Figure 16). It is half the size and weight of the CLASSIC and is easily deployed. It is a hand emplaced 'route' or 'critical point' UGS (Reference EE). The CLASSIC 2000 has the following applications: point surveillance; area surveillance; perimeter protection; and route monitoring. Thales Defence states the CLASSIC 2000 has the following features (Reference EE):

- Low cost
- Small, robust and lightweight
- Rapid deployment
- Alarm reporting over VHF radio
- Support system range extensions via Satellite or GSM cellular radio
- Ability to increase range via relay or by sensor enhancement
- Single and multi-function sensors including: seismic, piezo-electric cable, passive infra-red, contact closure, and magnetic
- Data fusion (comprehensive alarm data allows implementation of advanced data fusion techniques to further improve detection rates while minimizing the incidence of false alarms)
- Supports GIS-based alarm reporting
- Intrusion classification of tracked vehicle, wheeled vehicle, and personnel
  - Intrusion count and direction data
  - Time-tagged alarm data
  - Manprint – simple user interface with minimum controls
- FLASHTM technology (allows enhancements to be implemented as improvements are made in transducer signal processing)
- Monitor indicates each alarm event in real time
- Extended battery life allows short or long term deployment

Figure 17: CLASSIC 2000

7.4 Hornet – Arkonia System Limited

Arkonia System Limited, Borden, Hampshire, England developed a remote UGS for the British Army called the Hornet (Reference GG). It is a small self-containing device that is easy to move. It consists of a passive infrared (PIR) detector mounted on top of a microwave Doppler radar module. All of the major components are contained in the waterproof ruggedized body. The entire system, including the detector, tripod, bag, and ancillary equipment, weighs less than 5 kilograms and fits into a soldier's backpack. A soldier can assemble the system within 30 seconds (Reference GG).

The PIR has a range of 100 meters. Any heat source entering the detector arc causes it to activate the radar, which emits a 3-second burst of signals. Return data is then analyzed against the Hornet's built-in classification library, and the information is transmitted to a soldier equipped with a pager. The signal tells the soldier the target type and bearing. Arkonia officials claim the device is 90 percent accurate (Reference GG).

The Hornet's PIR is a digital device consisting of right and left detectors that create a data stream. Based on the time constants of the incoming information, the sensor can ignore phenomenon such as bright sunlight or rain. The detector covers a triangle 100 meters long by 70 meters wide. However, this front can be expanded up to 200 meters by simply turning the device on its side, which enlarges the beam's width (Reference GG).

The logic power for the Hornet comes from an Arkonia-designed real-time fast Fourier processor, which allows the system to accurately identify a soldier crawling on the ground at 100 meters. Mathematical models have been developed for human movement and for a variety of vehicles and helicopters. These models are stored in the Hornet's classification library. If something is detected that does not meet the device's criteria it will be identified as a target.

The Hornet system that became available mid-1999 is currently in use with the Macedonian army and is being assessed by the British Army and the U.S. Federal Bureau of Investigation. The British army is waiting for Arkonia's next generation of detectors that will feature quadrate radar (Reference GG). Also, future systems may contain 'sensor scouts'. 'Sensor scouts' would be placed 100 to 150 meters from the radar sensors. These devices would detect the magnetic field of any person or vehicle passing within 20 meters. A signal is sent back to the Hornet, which then switches on, classifies the target, and sends the information to a sentry or command center.

7.5 Hornet (WAM) – Textron Systems

Hornet is developed by Textron Systems and is an unmanned, rapid deployment, top-down firing defensive weapon (Figure 17). This is currently being used by the US Army and is known as the Hornet, Textron Systems' Wide Area Munition (WAM) (Reference HH). It is an autonomous munition for defence against tracked and wheeled threat vehicles. When the Hornet detects an aggressor, a sublet is launched to a point above the target. A built-in sensor then fires an Explosively Formed Penetrator (EFP) downward, which penetrates and stops heavy armor from moving. The Hornet can be hand emplaced or dropped from a vehicle in virtually any terrain. It will operate on flat or sloped surfaces (Reference HH).

Hornet can be safely activated manually using safe separation time settings to allow personnel to move clear of the area unharmed. It can also be left in pre-armed mode to be activated by remote control (M71 remote control unit) for up to 60 days, and can self-destruct upon command from the remote control unit. It can also be preset to self-destruct at a specific time. (Reference HH)

Upon activation, self righting legs erect the munition. Once in position, seismic and acoustic sensors monitor the ground and environmental conditions to detect and classify tracked and wheeled military vehicles. (Reference HH)

Upon detection of a target, Hornet tracks the vehicle and launches a sensor fused sublet over the target. An infrared sensor on the sublet detects the target and initiates the Explosively Formed Penetrator Warhead to defeat the vehicle's top armour. Hornet's sublet selectively engages and destroys enemy vehicles at distances up to 100 meters from the munition (Reference HH).

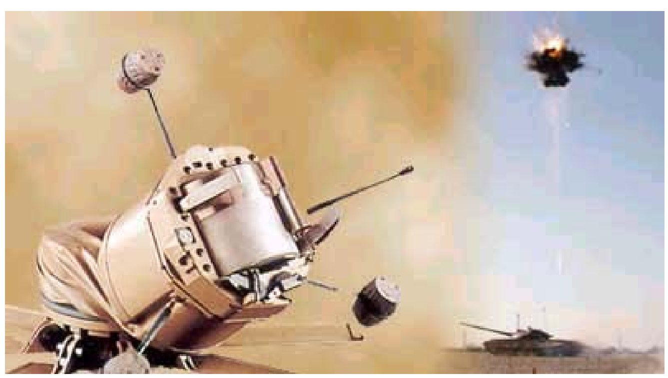

Figure 18: Hornet (WAM)

7.6 Terrain Commander

The Terrain Commander is also produced by Textron Systems. It is a surveillance system that enables large sensitive areas to be monitored from a distant central monitoring facility. It combines communications and mapping technologies with a supporting array of acoustic, seismic, magnetic, electro-optical, and passive infrared sensors. Textron claims that the system works effectively in daylight and darkness for remote surveillance around the clock (Reference II).

Depending upon the configuration of the system, it can detect activity, capture and process images of the activity, and transmit subject data and images to the central monitoring facility in near real time. It only transmits images and data upon detection and discrimination of an intruder to reduce the occurrence of false alarms (Reference II).

There are two major components to the system. The equipment deployed in the field, and the central monitoring facility. Two distinct options for field deployed equipment are currently available: OASIS (Optical Acoustic Satcom Integrated Sensor) and ADAS (Air Deliverable Acoustic Sensor). The type of field equipment used would be based on mission requirements.

The OASIS is the eyes and ears of the system (Figure 18). Its main unit is comprised of sophisticated, extended range acoustic sensors and signal processing, day/night electro-optics, and satellite-based global communication. It is man portable with all of its components fitting into an oversized backpack. It can be assembled by one person and be fully operational within minutes. (Reference II)

Figure 19: OASIS (Field Component of Terrain Commander)

The acoustic sensor of OASIS can detect and classify a variety of intruders including ground vehicles, watercraft, and rotary and fixed-wing aircraft (Reference II). The acoustic sensor, combined with digital signal processing capability, allow OASIS to identify acoustic signatures and differentiate between predetermined threats and unimportant activity at the surveillance site. Upon acoustic discrimination of a threat, the electro-optical system automatically pans to the targets' bearing. It then captures a series of images, which is then processed, compressed and transmitted to the central monitoring facility.

The OASIS unit also functions as the receiving and central processing unit for an integrated array of additional devices. Seismic, magnetic, piezoelectric, and passive infrared sensor can be customized to meet the needs of specific surveillance operations (Reference II). These supporting sensors also detect and classify intrusions, including personnel, in the surveillance area and transmit data to the OASIS for analysis.

Integrating a variety of special use sensors including meteorological, nuclear, chemical and biological detectors can further customize OASIS.

An alternative configuration of Terrain Commander field deployable equipment uses ADAS (Figure 19). ADAS features the same extended range acoustic sensor and signal processing as OASIS, without the electro-optic component.

Figure 20: ADAS (Field Component of Terrain Commander)

Used in clusters of three or four, ADAS units are typically networked (Reference II). They are designed for long range precision tracking of air and ground vehicles in remote or hostile territory. It can be used in conjunction with various lethal and non-lethal munitions for unmanned terrain domination missions.

Local area network capabilities enable ADAS nodes to talk to each other and share real-time information. Textron claims that networks have been particularly effective in tracking jets, UAVs, and helicopters at extended distances (Reference II). The network can also locate the source of acoustic impulses such as artillery firing.

The central monitoring facility includes a field-rugged laptop computer, printer, and long haul communication equipment designed to interface with OASIS or ADAS equipment deployed in the field. The software is capable of displaying maps of the local area based on any digitized terrain database or even satellite imagery. Sensor reports can be displayed for the operator to review the history of recent reports. The visual pictures from the OASIS can also be displayed. Imagery transmitted is displayed on the monitor as three consecutive still photographs of the area and a three-frame movie. This multi-frame motion detection feature enables the viewer to identify distant or obscure images that would be invisible in a static display. (Reference II)

7.7 Monitor of Enemy Movement (MEMO)

Developed in the Netherlands, the Monitor of Enemy Movement (MEMO) is a system designed for detection of personnel, in addition to ground vehicles (wheel or track). The MEMO is networked and uses communication links back to a monitoring station. (Reference JJ).

7.8 BSA

In Germany, the BSA system has been developed with the capability of detection, classification, and type identification of personnel and ground vehicles. Several sensors are combined to improve the probability of detection and classification, including acoustic, seismic, magnetic, and piezoelectric. (Reference JJ).

7.9 HALO

In the UK, HALO is used to monitor artillery fire. A few unattended acoustic and meteorological sensors are deployed for long-range detection of transient signals emanating from artillery fire. Bearing information is extracted from the various unattended ground sensors and transmitted to estimate source location. (Reference JJ).

8 Discussion

The SIREQ TD program has begun to investigate the usability and utility of some of these non-visual sensors. During the Fort Benning Experimental Series #5 (FBES #5) in March 2003 man-portable audio enhancement sensors, a hand held radar system, UAVs, and a UVG were investigated. The findings of these investigations are generalized below.

The ability to determine the direction of a sound was investigated during FBES #5 using the Telinga parabolic microphone, the Power Muffs, and the Tactical Ear II audio enhancement devices. The soldiers found the audio enhancement devices would provide a benefit in OP, LP and recce tasks; however, the filtering of background noise needs to be improved to increase the likelihood of hearing target sounds.

The Soldier's Vision hand held radar system was piloted during FBES #5. During the pilot soldiers' comments were observed. Soldiers found the capability to determine what is on the other side of a wall to be valuable. However, the current state of the technology needs to be improved in order for this radar system to be useful. The soldiers also recommended the system be made smaller and lighter.

During FBES #5 UAVs and a UVG were used in a mission planning exercise. The UAVs and UVG provided real time information on the general layout of the disposition of enemy forces, obstacles, and terrain features surrounding the objectives. The soldiers found this real time information invaluable, especially since they would be able to control where and what information UAVs and UVGs gathered. Therefore, early results support the use and continued investigation of the usability and utility of non-visual surveillance devices.

Many different non-visual surveillance sensor systems have been developed and are in use. Each different sensor system type has a different application for the battlefield. Handheld systems exist to enhance a soldier's hearing and enable soldiers to detect enemy through walls. There are hundreds of remote and controllable sensor systems soldiers can use from a distance to monitor and detect the enemy. These remote systems include UAVs and UGVs that vary in size depending on the task they are to perform. Also, numerous unattended ground sensors exist that once in place allow remote monitoring of numerous locations with various types of sensors by a single soldier.

The objective of implementing these non-visual surveillance systems is to increase the situational awareness of soldiers and ultimately the survivability of infantrymen. In future research the performance and usability of these non-visual surveillance systems in the field will need to be furthered assessed.

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(U) The ability of a soldier to detect and identify the enemy is vitally important to the outcome of any mission. This report examines various non−visual surveillance systems that may support dismounted infantry operations. The technologies investigated included acoustic, seismic, magnetic, electromagnetic, electro−optical and radar devices. The range of portability and size options for these systems were also assessed. The review included man−portable, remotely controlled (i.e., unmanned aerial vehicles), and unattended sensor systems with various sensor nodes and multiple sensor types that can be deployed to the area of concern and monitored from a safe location. This technical memorandum summarizes the results of this investigation.

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