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A Review of the Remote Sensing Laboratory's Techniques for Humanitarian Demining

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Abstract

Widely spread local war conflicts all over the world often involving non-regular (partisan) military units have resulted in intensive use of various types mines. Mines are installed both in the soil and on its surface and represent a material threat to the peaceful population for a long period after the conflict has been terminated. New technologies and devices are needed to resolve tasks in humanitarian demining operations. This paper represents a review of the humanitarian demining techniques, which were investigated and designed in the Remote Sensing Laboratory.

1 Introduction

Local war conflicts, which continually appear in the world, differing in nature and scale, are characterized, as a rule, by a wide use of both antipersonnel and antitank mines by conflicting parties. It should be noted that a significant part of installed mines are plastic-body mines, which are most difficult to detect. Considering that surface mines are relatively cheap, they are getting more widely used. The efficiency of mines affecting combatants is rather low. The military are trained accordingly and have some devices for detection and demolition of mines. Civil population, mostly women and children, are the main victims of mine weapons. The civil population suffers from mines both in the course of military actions and during a long period after they have been terminated. For example, in Europe there are unexploded ordnances (UXO) still undetected and dated as far back as to World War II.

According to the UN statistics, currently there are about 110 million mines installed within the territory of 65 countries (this number includes approximately one third of member countries of the UN), and 100 million more mines are available in the arsenals of various armies of the world. The numbers of land mines installed in different countries are available in Table 1 [10]. In 1994 a UN resolution prohibiting production, use and export of antipersonnel mines with unlimited field life was adopted. However, despite the extensive propaganda campaign and concluded international agreements on the ban of antipersonnel mines, a tendency for their using becomes more and more pronounced. As mentioned in Red Cross reports, up to 25 thousand people are perished on the abandoned minefields annually, and twice as much people are badly injured. A significant material damage is incurred as vast plots of land are removed from agricultural use until they are completely demined. Due to this reason the rural population in some places in the south of Africa is saved from starvation only through the food aid of international organizations.

Table 1
QUANTITY OF MINES Installed IN VARIOUS COUNTRIES

Country	Total quantity of mines, millions
Angola	10-15
Afghanistan	9-10
Egypt	22
Cambodia	8-10
Kuwait	5-10
Latin America	0.3-1
Mozambique	2
Somalia	1
Republics of former Yugoslavia	4.6*

* - without Kosovo.

Active use of mines in the course of military conflicts is explained by a number of reasons. They are: simplicity of design, which allows to install mines by low skilled personnel; low cost of manufacture allowing purchase of large lots at a price which even terrorist organizations can afford. Currently, some samples of antipersonnel mines cost $3, and the cost of antitank mines is around $75. However, it needs over $300 to clear one mine. According to the UN data, costs of mine clearance total on average $0.6 per 1 sq. m, and efficiency is within the range of 10 to 20 sq. m per sapper a day [6]. Overall casualties in third world environments are 1-2 sapper per

1,000 removed mines.

A number of problems arising during humanitarian demining operations are linked with shortcomings of the applied up-to-date technologies. For many years a set of means used by sappers have been rather limited. These are first of all: metal detectors, sapper handspikes and specially trained dogs for searching of explosives. In many cases, metal detectors turn out to be useless because of low content of metal in plastic mines and high degree of contamination of the ground with metallic impurities, such as bullets and fragments of shells left as a result of military action, and usual everyday household rubbish containing metal, as a considerable part of minefields is installed in urbanized localities, i.e. in the suburbs of population centres. Demining with the use of sapper handspikes is a very slow process and, besides, is not quite safe for the sapper as it can cause functioning of antipersonnel mines and booby traps.

There are limitations associated with use of canines. For instance, they are easily distracted, and are also affected by other creatures (and by other dogs). In the wild they can be sensitive to heat exposure. In some parts of the world their work periods can be as short as 30 min. Also, it has often been shown that experienced dog handlers are not able to tell when a temporary medical condition has degraded an animal's olfactory capacity.

These factors account for low rate of demining operations in the world. As a result, the number of installed mines exceeds that of destroyed. According to various estimates, 2 to 5 millions of ammunitions are installed annually, and only 100 thousand are extracted. As was mentioned earlier, total number of non-removed mines has currently increased to 110 million. Such amount requires for there destruction about $33 billion.

Considerable numbers of minefields are concentrated mainly on the territories of the third world countries, which are not capable to resolve the demining problem with their own resources as it involves heavy expenses. The UN undertakes main efforts on organization and material supply of appropriate demining operations within the framework of rendering humanitarian assistance to underdeveloped countries.

Mines are characterized by high damaging capability resulting in lethal or severe wounds requiring lengthy treatment and, as a rule, amputation of extremities. According to the International Red Cross data, the course of treatment of a person who was blown up by a mine, requires on average hospitalization for 22 days, whereas a person who has a firearm wound or has been wounded with a fragment needs treatment up to 11 days.

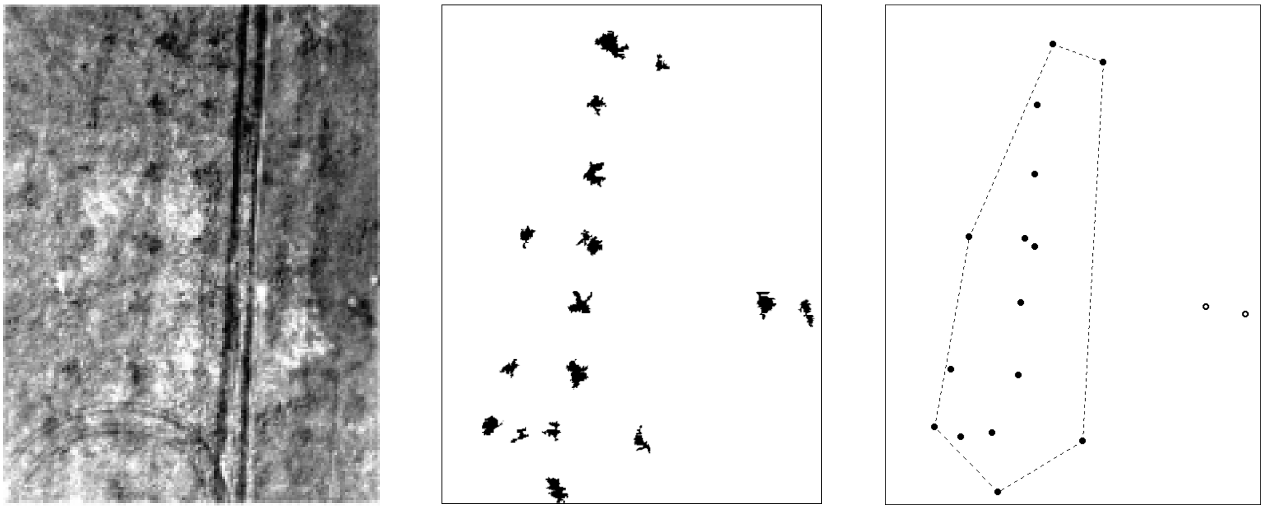
Option of a wide choice of mine types on the international arms market representing over 700 samples developed by 100 firms in 55 countries of the world. Requirement to reduce cost and increase rate of mine clearance can be met by developing new technical devices and wide use of computer equipment. Special attention must be paid to the necessity of reducing a number of losses among sappers. This will allow to use less qualified personnel during mine clearing and also more widely to recruit a local population after required training for works in demining operations. Reduction of losses among personnel engaged in demining can be achieved through the use of remote control devices. Further on we shall discuss some potential ways, how to resolve the problems of efficiency of humanitarian demining operations.

2 Airborne Reconnaissance of Minefields

The main advantage of airborne reconnaissance of minefields is its high efficiency and relatively low cost. When resolving problems of detecting minefields using data obtained from airborne vehicles: aircraft [3], helicopters, dirigible [7] and unmanned aerial vehicles (UAV), data processing can be split into a number of stages [4]. The image of a terrain section under investigation obtained by a sensor is transformed into a digital form and is stored in the computer memory, Fig. 1a. Then preliminary processing takes place to identify small-size objects (mines) and form binary images, Fig. 1b. At the final stage, the task of identification and decision-making about the existence of minefields on the terrain segment has to be resolved. Mutual position of marks of supposed location of mines is analyzed and the decision is taken to attribute a minefield to this or that type. The specific features of topology of minefields installed by various ways (using air dispenser, salvo missile systems or ground minelayer) should also be taken into account. To determine the position of minefield on the map, its boundary should be outlined and exact geographic coordinates are specified, Fig. 1c.

A minefield depicted on the photograph in Fig. 1a had been installed in the soil on depth of 10 cm several months before photographing, and it has resulted in change of vegetation over mines, which was clearly seen from the air. This aerial visible spectrum image was taken by helicopter flying at height of 70 m. The image resolution is equal to 3 cm. In general, images obtained in other parts of the spectrum, including infrared and microwave frequency range, could be processed also. Specific features of image filtration in this or that part of the spectrum would affect the choice of digital data of filter parameters, but methods of processing could remain similar to those, which are described in this section and in more detail in [4].

Air reconnaissance of minefields has considerable advantages, as it is absolutely safe for personnel engaged in the work. However, this method has also an essential disadvantage: it can be used, first of all, for detection of minefields installed on the ground surface. Its possibilities are limited for detection of mines installed in the soil as well as for surface minefields consisting of few mines (1-3 mines). It should be underlined that operation of air reconnaissance systems requires a highly qualified personnel involved in the maintenance and operation of aircraft and devices for processing and decoding results of aerophotography.



(a) (b) (c)

Fig. 1. Sequence of operations at the data processing of aerial photograph of a minefield:
(a) The image of a minefield
(b) Result of transformation of the initial image (Fig. 1a) into binary one
(c) Result of recognition and out-lining of the minefield.

3 Passive-Active Millimeter-Wave Radiometer for Detection of Mines Installed on the Ground Surface

It is well known that in the course of large-scale military operations anti-tank mines are usually laid on the ground surface that is related to high efficiency of this method. Besides that, the remote acting mine dispensers using aviation, artillery, salvo missile systems, etc. and having the highest capacity install mines only on the ground surface. The use of passive millimeter-wave radiometric sensor is one of the possible means for detection of scatterable mines with metallic cases installed by random throwing on the ground surface. In the passive mode of operation, a radiometer records the own and sky radiation reflected by mines [1, 8].

Initially in the experiments a passive millimeter-wave radiometer was used. However passive mode had low effectiveness of mine detection. On next stage we operated radiometer acting in passive-active mode, which used a noise illumination generator in the same frequency range [2]. Fig. 2 represents a view of set of the sensors and devices of experimental installation. It included 8-mm radiometer (a) with parabolic antenna (b), noise generator with horn antenna (c), TV camera (d). The devices were uniaxially anchored on the two-dimensional scanner (e) to ensure the survey of a terrain sector along azimuth and angle of elevation.

The testing ground is shown in Fig. 3. Nine Russian metallic anti-tank mines of TM-62M type were laid in three staggered rows on the ground surface in the foreground. The distances from the nearest and most distant mines to the radiometric installation were 10.0 and 22.0 m, respectively. The mines in the right row were installed on supports and inclined towards the radiometer antenna to enhance their contrast.

The radiation pattern of the main lobe of the noise generator antenna was wider than that of the radiometer's antenna. Such selection of the antennas parameters and positioning of the devices provided conditions of uniform illumination by the noise generator of a section on the ground surface observed by the radiometer's antenna. The stroboscopic mode of noise generator operation gives an opportunity for simultaneous recording of two images: the first image in passive mode when the noise generator is switched off (Fig. 4) and the second one in active mode when the illuminator is switched on (Fig. 5). When the noise generator is switched on, the image is changed qualitatively. The contrast of metal objects with respect to the background depends not only on the type of the surface but also from the shape of objects observed. Thus, flat metallic objects, which reflect the radiation with a high brightness temperature of the noise generator like a mirror, can be viewed in the image as objects having low brightness temperature. It can be explained by the fact, that they reflect only the sky radiation in the direction of the radiometer antenna. The metal roof of the building and the flat metal plates are such objects in the image. Mines and the tower having complex form change their contrast. We can see various reflections from local objects on the ground also.

For the selection of complex-shaped objects like mines, an algorithm was proposed which operated in accordance with a scheme of coincidences and separated only those objects in the images, which changed sign of their contrast relative to the background at the moment when the noise generator was switched on. Fig. 6 demonstrates effectiveness of the proposed algorithm.

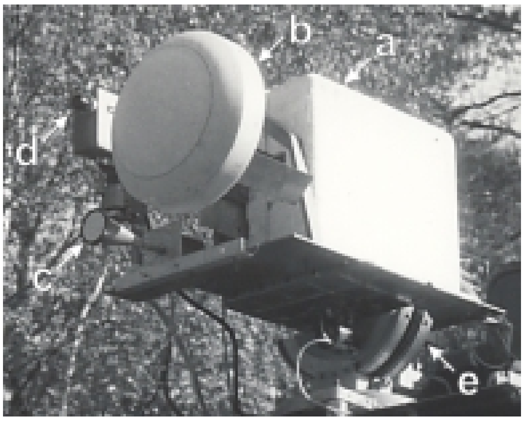


Fig. 2. Experimental installation includes radiometer (a), radiometer’s antenna (b), noise generator with horn antenna (c), TV camera (d) and two-dimensional scanning device (e)

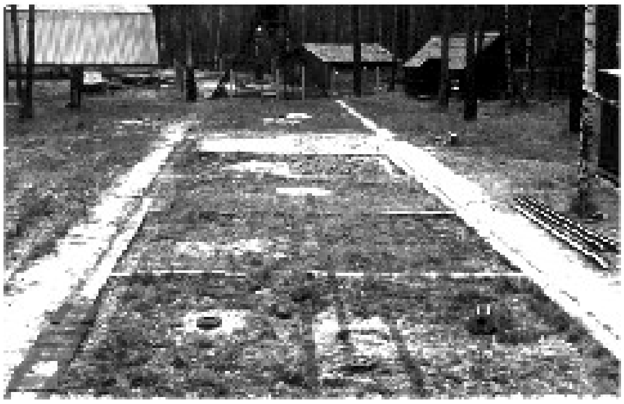


Fig. 3. A view of the testing ground with installed mines

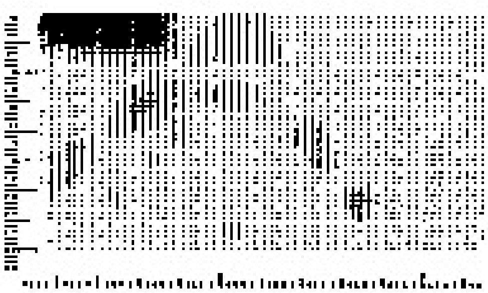


Fig. 4. Passive radiometric image of testing ground

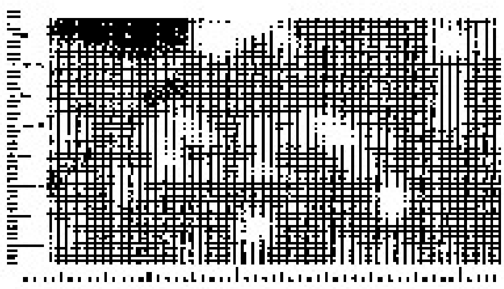


Fig. 5. Active radiometric image of testing ground when noise generator was switched on

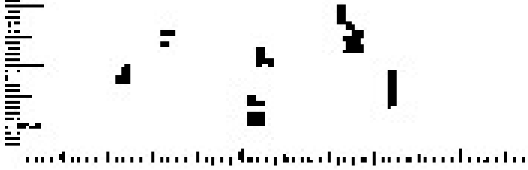


Fig. 6. Results of co-processing of the images in Figs. 4 and 5

4 Remote Control Mine Detection System with GPR and Metal Detector

A potential area of application for ground-penetrating radar (GPR) is humanitarian demining operations. Despite significant efforts and the expenditure of large sums of money, GPR's use in the course of practical works of mine clearance remains in question. First of all, it associates with the difficulties of identification of signals reflected from UXO and natural heterogeneities of the soil and also from different anthropogenic objects in the soil (bricks, cans, etc.), which are a lot in urbanized areas. To overcome these obstacle, it had been taken an initiative in the development of MiRascan ground-penetrating radar to enable the operator to detect and identify objects buried under the ground surface at shallow depth (up to 20 cm) based on analysis of object's shape [5].

The operating principle of the radar is based on the method of multi-frequency sounding of condensed mediums such as construction materials, soils, etc [9]. The radar has five operational frequencies in the range of 1.5 - 2.0 GHz and transmits unmodulated signals at each frequency. Signals reflected by object are received in two polarizations. Power emitted by the generator is consistently switched from one frequency to another. It amounts less than 10 mW that provides for the complete safety for operator. The induction loop of the metal detector is located on the butt end of the MiRascan antenna that ensures spatial coincidence of recording images from two channels of the mine detector. Operating frequency of the metal detector is 2 MHz, and the diameter of the induction loop is equal to 120 mm. The successive reception of signals from the metal detector and at each frequency and for both antenna polarizations of GPR is carried out in the process of scanning of the ground surface.

The MiRascan mine detector has remote control system. The operator via the remote control box, connected to the cart by the cable of 15 m length, exercises control over the movement of the device. The experimental results are displayed in the form of gray scale images on the monitor screen for both channels. A view of the MiRascan mine detector being used during experiments is presented in Fig. 7.

Experiments were conducted to record on two channels the images of antitank and antipersonnel mines of different types placed in the soil. The Russian-made TM-62M and PTM-3 type antitank mines presented metallic-body mines. The Italian-made TC-6.1 and TC-2.5 and Russian TM-62P3 type antitank mines were used to simulate plastic-body mines. As antipersonnel mines, Russian plastic-body mines of PMN-2 type were used. We also applied a MS-3 booby trap with plastic casing. The results of scanning a Russian TM-62M antitank mine are presented in Fig. 8. Microwave images are shown in two polarizations of GPR (the left image is for the cross polarization of received and transmitted signals and the center image is for the parallel polarization). The right image presents data of the metal detector. For this type of mine the round form is clearly seen in images depicted by the GPR and metal detector.

The main destination of MiRascan device is reconnaissance of all types of mines in the soil containing a considerable quantity of outside subjects, which hinder the use of traditional mine detectors. We hope the use of remote control along with increasing the productivity of works will allow reducing the losses of personnel involved in the mine clearance works directly in the field.

Fig. 7. Two-channel MiRascan mine detection system.

5 Conclusions

The paper summarizes experience of specialists of the Remote Sensing Laboratory in designing of technologies for humanitarian demining operations, which use airborne and surface robotic devices. The main aim of robotic and remotely controlled devices is to reduce losses among sappers and civilian population. It also reduces cost and increases efficiency of demining operations.

At the same time it is necessary to complement purely technological measures with political and legal ones within the framework of international organizations as well as using the potentialities of the UN. The international community should apply efforts to achieve reduction of intensity and duration of local conflicts if there is no chance to prevent them. It is necessary to achieve reduction in the production and accumulation of mine reserves in the world, and especially of the most dangerous of mines – antipersonnel ones. The problem of mined areas have global character and its solution is possible only on the international level.

Acknowledgements

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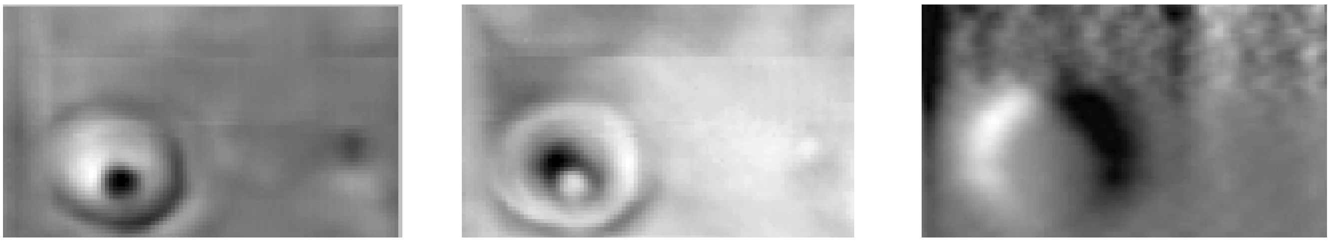

Fig. 8. The images of Russian antitank mine type TM-62M.

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