Preface

Overview of the world-wide landmine problem

On the first of September 1999, the 'Ottawa Convention' on the prohibition of the use, stockpiling, production and transfer of Anti Personnel Landmines, and on their destruction, has been signed by 135 and ratified by 84 states world-wide. Thereof, 14 EU Members States have signed and 13 ratified. Meanwhile the awful consequences of the Anti Personnel mines contamination must still be overcome. Today, about 60 million of uncleared anti personnel mines (AP mines) and anti tank mines (AT mines) can be found in more than 60 countries. It was previously estimated that as many as 110 million landmines were scattered in 64 countries. Those numbers were based on the limited information available in national archives and military records. In 1998, a growing consensus in the international community was formed that the number may be lower. New calculations, based on a more rigorous counting of the number of landmines in 12 severely effected countries, has led to a new estimation of the number of landmines in the region of 60-70 million. A good overview of the world-wide landmine problem and the Ottawa Convention can be found in [1] and [2]. Table 1 contains an overview of the best estimation of the numbers of landmines in the 10 countries with the highest number of casualties (source: [1]).

Country	Number of mines	
	Low estimation	**High estimation**
Bosnia-Herzegovina	600 000	1 000 000
Croatia	400 000	400 000
Afghanistan	5 000 000	7 000 000
Iraq	10 000 000	10 000 000
Cambodia	4 000 000	6 000 000
Somalia	1 000 000	1 000 000
Mozambique	1 000 000	1 000 000
Angola	6 000 000	15 000 000
Eritrea	500 000	1 000 000
Sudan	1 000 000	1 000 000
TOTAL	**29 635 000**	**43 535 000**

Table 1: Best estimation of the numbers of landmines in the 10 countries with the highest number of casualties

The map in Fig.1 shows the world distribution of the problem. This map also represents countries suffering from an UneXploded Ordnance (UXO) problem, which explains the presence of for instance Belgium and Germany. Attention must be drawn on the fact that most of the polluted developing countries are not landmine producers. The opposite is also true, most of the producing countries are not suffering from a landmine problem themselves.

More important than the actual numbers, however, is the far-reaching impact of the landmines on the people living in those affected countries. It has been estimated, that every year more than 26.000 persons are killed (about one person every 20 minutes). In Cambodia, for example, the estimated number of amputee's is 36.000, which is, in other words, 1 amputee for every 236 citizens.

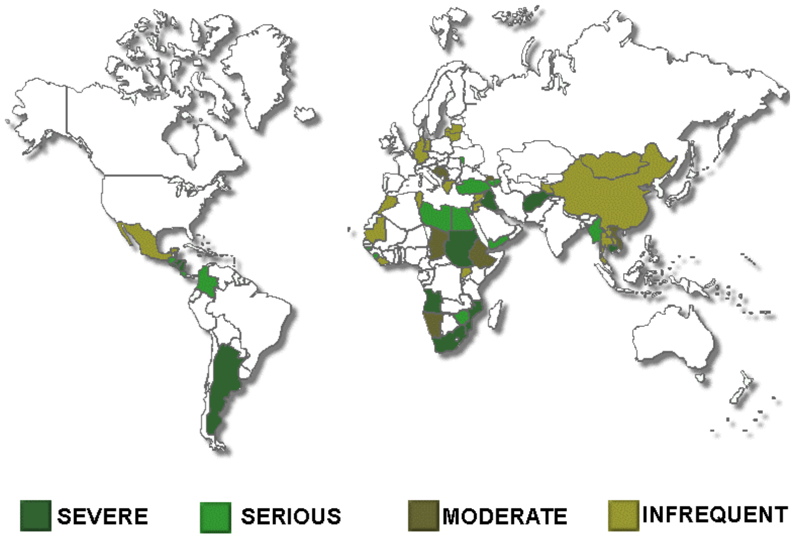

Fig.1: World-wide distribution of the landmines and UXO problem

The presence of landmines not only directly affects people's health, but has also a negative influence on the economic life of the country, by preventing access to precious rural land and other resources. Without mines, agriculture production could increase by 88-200% in Afghanistan, 11% in Bosnia and 135% in Cambodia (source: [1]).

So it is clear that, even if the 'Ottawa Convention' can prevent new mines to be laid, there is a real and even more challenging problem to be solved: the reduction of landmine contaminated areas and the assistance to mine victims. One aspect in this challenge is the detection, identification and clearance of landmines, called humanitarian demining.

Humanitarian demining differs from military mine clearance operations in many aspects. The military mine clearance as applied in conflict situations accepts low rates of clearance efficiency and a higher rate of casualties. For these purposes it is often sufficient to punch a path through a minefield. The costs of these kinds of operations is usually not an issue, time is. For the humanitarian demining purposes, on the contrary, a high clearance efficiency is required (99.6% is required by UN). This can until now only be achieved using the hand clearing method. Also the cost of the clearance operation and the safety of the deminers becomes important. In this work, only humanitarian demining will be considered.

Humanitarian demining today

In present-day situations the classical humanitarian demining is done using metal detectors and prodding sticks, to manually detect and clear the mines. The demining procedure varies in function of the mine clearance scenario, depending on the climate, the type of vegetation, the variety of mines, etc. The procedure as applied in Cambodia by the bomb disposal unit (EOD) of the Belgian Army is as follows: The deminers work in groups of two and in corridors of 1m large. In a first stage deminer number 2 is on stand-by at a safety distance behind deminer 1. Deminer 1 starts with the execution of the tripwire drill, using a long stick. He will lift the stick up and look for wires. When there is no danger he cuts the vegetation. Deminer 1 will then step back and the demining process is proceeded by deminer 2. Deminer 2 manually scans with a metal detector an area of one meter large and 50 cm deep. When no signal is given, the zone is declared mine free and the procedure will start all over again. If there is a signal, deminer 2 will try to localise and mark the exact position of the signal. Deminer 2 will then step back and deminer 1 comes in again. He will probe the marked area, *i.e.* finding the object by sticking a dagger every 2 cm carefully in the ground and gently remove the topsoil from the suspicious object (Fig.2). This way the exclusion is made between a false target (false alarm) and a mine, and if it is a mine, its actual position and circumference is determined. The process is continued by excavating carefully the ground around the mine and by marking it with a red 'mine-danger' tetrahedron. The lane is now closed and the two deminers will continue on another lane. At the end of the day the explosion team will destroy all the detected mines *in situ*, to make sure the mines will not enter in circulation again.

A platoon of 30 well-trained deminers is able to demine approximately between 500 and 2500 m^2 a day. This method has not been changed since the Second World War.

Fig.2: Deminer prodding and gently removing the topsoil

The manual demining procedure is very time consuming and not without danger. Hence, manual demining is extremely costly. It has been estimated that an average of 1000 US $ is needed for a manual demining of the 10 US $ mine. The reason for it is the high false alarm rate of the metal detector. For each piece of metal detected by the metal detector, the procedure with the first deminer is initiated. Minefields are often situated in post conflict areas where the contamination with metal can be very high (grenade fragments, cartridges, etc.). Typical values are 100 false alarms for 1 real mine. There is an obvious need for a more efficient portable demining device in order to achieve a more cost-effective demining process.

Mine detector requirements

An ideal portable mine detector must meet severe user requirements. Some of these user requirements are listed below. The detector must:

1. Detect metal as well as plastic mines with very low metal content
2. Detect anti-tank and anti-personnel mines
3. Meet the UN-norm safety requirement of 99.6% clearance efficiency
4. Detect mines in all kinds of soils
5. Detect mines from 0 cm (surface laid) up to a of depth of 20 cm
6. Work on rough, vegetation overwhelmed terrain

7. Work in all seasons, in all climatic conditions
8. be able to operate 8 hours a day, 250 days a year
9. for safety reasons be held some cm above the ground
10. be light weighted
11. be reliable (mean time between failure of at least 1000 hours and a reliable self test)
12. not interfere with other sensors when used within 10 m from each other
13. easy to maintain
14. be simple to use (for local people, having a minimum of special training)
15. have a reasonable false alarm rate, in the order of 20 to 1.

The only technique that does meet almost all of these requirements (except requirement 15) is the combination of the metal detector and the prodding stick, but, as already mentioned, this method is to slow and not without risk.

The demining community is well aware of this problem and of the lack of good alternative mine detectors. Therefore, there is a call from the demining community towards the scientific world to contribute in solving this world-wide problem by looking to new and better demining techniques.

Table 2 lists some sensor types, together with their advantages and disadvantages, which are potential techniques for the demining application. At the moment, none-of these sensors meet all of the user requirements and probably never will, at least not without limiting the number of demining scenarios.

Sensor type	Advantages	Disadvantages
metal detector	• has proven its usability in most conditions	• High false alarm rate • can not detect pure plastic mines • limited sensitivity in ferruginous soils.
conventional ground penetrating radar	• good for locating and depth estimation • can detect non-metallic objects	• limited depth resolution • poor object classification
ultra-wideband ground penetrating radar	• Good depth resolution and better object classification	• poor penetration in very wet conditions and in clayey soils.
microwave radiometer	• Good resolution and object classification	• poor penetration in very wet conditions and in clayey soils. • sensitive to external noise sources
IR 3-5 and 8-12 mm-band	• good object recognition	• need of thermal contrast • only for shallow buried and surface laid mines
Polarimetric IR	• discrimination between natural and man-made objects	• only surface laid mines
Multi-specral imager	• good object recognition	• only for surface laid mines
x-ray diffraction and neutron bombardment	• searches only for explosives • good explosive classification	• High power consumption • can be hazardous for the deminers health.
nuclear quadrupole resonance	• searches only for explosives • good explosive classification	• High power consumption • sensitive to external noise sources
biosensors (dogs, rats,..)	• can smell the presence of buried explosives at the surface	• long training • only operational for a limited period during the day
Mechanical deminer	• fast in clearing roads and flat areas	• heavy • too low clearance efficiency (<80%) • Can not reach all terrain

Table 2: Promising techniques for demining

A more schematic approach to the problem can be found by representing the Receiver Operating Characteristic (ROC) of the mine detector. For a given scenario, each mine detector is characterised by its ROC, representing the detection probability (p_d) of the detector as a function of the probability of false alarm (p_{fa}). A typical ROC of a metal detector is represented in fig. 3, curve A. The region in which the detector operates is close to p_d=1. What is needed for a more cost-effective mine clearance, is to obtain for a given probability of detection a lower probability of false alarm, such as represented by curve B. Such an improvement can be achieved in two ways: first it is always possible to enhance existing sensors or to investigate new sensor techniques. Secondly an improvement can be found in fusing the data of different sensors. It is commonly accepted by the research community that data fusion will be indispensable if all of the user requirements must be satisfied in all demining scenarios.

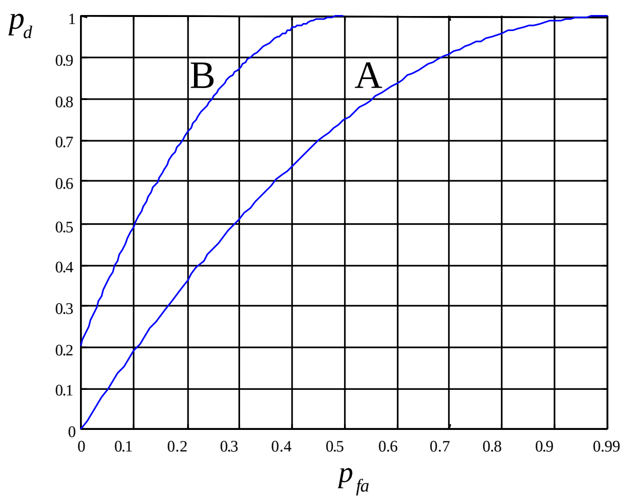

Fig. 3: Typical receiver operating characteristic of a detector

From the mid 90's, several research groups supported by national and international programs have concentrated their work on the humanitarian demining. In 1998, for example, the European Union has committed more than 16.7 M EURO to support research and development of enhanced mine detection systems [3]. The Belgian government has also taken its responsibility in this matter, resulting in a project called "HUDEM".

The HUDEM project

Late 1996, a Belgian project on humanitarian demining (HUDEM) has been initiated by the Belgian Ministry of Defence and is supported by the Belgian Ministry of Defence and the Belgian State Secretariat for Development Aid [4]. It is carried out in collaboration with laboratories of other Belgian universities, *i.e.* the 'Facultés universitaires Notre-Dame de la Paix' (FUNDP), the 'Katholieke Universiteit Leuven' (KUL), the 'Universiteit Gent' (RUG), the 'Université catholique de Louvain' (UCL), the 'Université de Liège' (ULg), the 'Université libre de Bruxelles' (ULB), the 'Universitaire Instelling Antwerpen' (UIA) and the 'Vrije Universiteit Brussel' (VUB), and it is co-ordinated by the Royal Military Academy (RMA). The research project aims at contributing in solving the anti personnel landmine problem by funding research grants devoted to basic research on mine detection. Research is focussed on increasing the knowledge on sensors and on sensor/ground characteristics, on designing new sensors or tuning old ones and on processing the data produced by sensors. Furthermore, it considers the detection as a global process wherein the outputs of the sensors, considered as skilled specialists, are integrated in a fusion operation. There is also a group working on a realistic design of a rough terrain robot for a platform mounted system.

From the list of promising sensors in table 2, only a limited number is addressed in the scope of the project. The work performed on the ultra-wideband (UWB) ground penetrating radar as a possible demining sensor is reported in this thesis. It has to be clear that, in accordance with the philosophy of the project, the intention of this work is not to produce a ready-to-use mine detector. The work consists in a contribution to one type of sensor, the UWB GPR. In some parts of the work a feasibility study will be done, in other parts the advantages and shortcomings of the sensor will be shown, as to help industrial designers in the development of this kind of sensor for the demining application.

REFERENCES

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