Detection Technologies for Anti-Personnel Mines

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Abstract

Sensitive, reliable and low cost sensors are the first and absolute requirement for the design of autonomous or semi-autonomous demining robots. Several technologies are available, but no single sensor will be reliable enough. The traditionally used metal detectors have to be completed, now most mines do not include metal any more, by odor sensors or impulse radar. An increase of applied research is urgent in order to remove the 100 million mines that plague so many countries in need of more agricultural land.

Introduction

Searching for mines and minelike targets is a quite difficult task. Recent anti-personnel mines do not include any metal, at best the needle of the fuse. The package is made of wood or plastic. The only sure thing is the presence of explosive components: TNT, RDX, PET, etc.

Hence great efforts are being done for several years to develop sensors to detect explosives [1]. The available airport detectors [10] indicate that it is possible to find drugs, explosives or weapons with a high level reliability in complex environments (e.g. luggage). However, these systems are very expensive, complex, large and therefore not suitable for clearing mine fields.

Short overview of mines

People creating mines are perversely imaginative. There exists about 2000 different types of mines for which catalogs exist [3]. Typical mines are shown on Figure 1. Generally mines are classified over 3 categories:

Tank-mines react on ground pressures of 150-300 kg or by induction. These types of mine do not concern humanitarian mine clearance, because they are normally not triggered by the weight of humans and are seldomly used in countries with civil war.

Anti-personnel mines with fragmentation are not or only partially digged inside the ground. In some cases, they bounce up before exploding or explode in a certain direction. Fragmentation mines are frequently triggered by wire and are lethal within a radius of about 30m.

Fig. 1: Assortment of the most common mines. On the background, two directional mines. Photo CICR

Blast antipersonnel mines include less than 100g. of explosive. These most common type of mine have a simple construction and a diameter of about 10 cm. When digged or surrounded by grass, they are difficult to see. Blast mines are triggered by a ground pressure of about 10kg/dm2, exceptionally by trip wire. These mines are not designed to kill, but to badly maim.

The later category represents the biggest problem. Antipersonnel mines are very cheap (down to one US dollar) and are very hard to locate. For these reasons they are extremely widespread.

Requirements

In order to protect demining specialists and to guarantee uniform search strategies, a robot should be used. A low cost demining robot cannot be large and heavy [4]. Ideally, mine sensors should have the following features:

- Compact and small size: <1dm3 and <5kg.
- Low power consumption (<2W) single supply.
- Simple interface and local pre-processing.
- Low cost (<$500).
- Reliability above 98%.
- False alarms below 20%.
- Response time 0.1 second (scanning speed above 1m/s when there is no mine).
- Mine detection/false alarm resolution < 5 s.
- Easy to maintain, MTBF > 1000 h (100 days).

If sensor lifetime is short, the sensor itself or a part of it should be easy to replace to allow one or several replacements per day.

It is important to mention that the overall reliability, defined as the number of mines found on the explored area, compared to the total number of mines still able to explode, must be far better that 99.9%, in order to guarantee a safe return of the population. This will only be reached by using several sensors and adequate sensor fusion. For instance, a metal detector will always be present, and be used to confirm the decision of the other sensors, according to the type of mine.

Demining technologies

Demining teams have a poor efficiency due to the inappropriate sensors they currently use. The cost for removing a mine is estimated at $800 by the specialized humanitarian organizations [5]. Some of the available, under research and conceivable methods are listed below [6].

Sight

Individual mines are usually difficult to detect by sight, even when they are surface laid. Mine fields with a high density of mines are more easy to recognize, mostly due to the effect of the already exploded mines.

Metal Detector

The metal detector is the most popular sensor to detect mines. It consists of a coil generating a magnetic field which may be disturbed by a metal object. The consequence is a higher power consumption or a change in the magnetic field induced into another coil. Unfortunately this method is often unreliable or time consuming, because some mines have minimum metal to detect and is not recognizable within all the kinds of metallic objects on a former battle field.

Hand clearance

Prodding the ground by hand is presently the only way that guarantees an exhaustive detection of any land mine. Well trained staff prod the ground with a thin steel spike every 2 cm at a shallow angle of about 30 degrees [6]. The resistance of the probe and the reaction of the surface define where to dig the ground around and carefully remove the mine. Of course, this is a dangerous and slow task. The mine may have turned on its side and the prodder hits the pressure plate rather than the side. Prodding is however the only way of locating each mine. One man can clear between 20-50 m2 per day.

Mechanical

Clearing mine fields by modified tanks or trucks is also a common method [12]. It doesn't need sensors and is efficient on a suitable ground. Chains attached on a rotating roller are hitting the ground in order to explode or destroy mines. An other possibility is to mount ploughs in front of a tank which dig out the mines and moves them away, mostly without exploding. Mine ploughs are slow (6.5km/h), but used in conjunction with rollers, this system can provide a virtually 100 per cent mine clearance effectiveness.

Thermal Imaging

Advanced aerial photographic techniques can be used to identify temperature anomalies in the ground. Buried mines have a different density than the surrounding ground - thus retaining or dissipating heat at a different rate. These temperature differentials can be identified using thermal imaging, I-R and enhanced photography, particularly when photographed at certain times of the day such as just after dusk or shortly after sunrise. This technique works well only in ideal circumstances and can be used to locate danger areas [6] [7].

Plant indicators

A not yet explored idea to find buried mines is to imagine plants sensitive to presence of TNT in the soil. Hence it could be possible to genetically manipulate plants to have them changing their behavior in presence of TNT, for example changing color, growing up very high or any other detectable sign. These signs have not to be visible by men; other signs such as changes in UV reflection are also usable and measurable by simple tools.

Odor sensor

Dogs are used to find mines at close distance. Their nose is so sensitive that a trained dog can smell the presence of explosives encapsulated inside a metal mine. However dogs get tired and the reliability is low. Chemical reactions in the odor sensor of insects are particularly sensitive. Artificial odor sensors exist and are used in agroalimentary industry. However, in these cases concentrations are very high compared to the few TNT molecules to be detected. Many people are working on this topic, and the sensitivity is rapidly improving [7] [8].

Antibodies

Antibodies are very selective to other molecules and are therefore suitable for building sensors that react to specified molecules. There are several techniques to realize sensors using antibodies. In a very simplified way, one of these techniques could be split in tree steps: The first is to produce an antibody sensitive to TNT. This part seems realizable, because there is already a big market for antibodies and a very similar type (DNP = dinitrol phenol) is already available on stock.

The second step is to put this antibody on a surface to build a selective layer.

The last and most difficult step is to detect those antibodies that have already reacted with TNT molecules. This can be done for example by measuring the change in the angle of refraction. Unfortunately, already reacted antibodies are unavailable for further reactions. Of course this change the sensitivity of the sensor. It is very hard to refresh used antibodies, therefore this system seems not suitable for continuously scanning over a long time period [13].

Biosensor

Some particular molecule belonging to the trinitrotoluene (TNT) family relaxes a tense muscle (Fig. 2). The principle has been tested by the National Defense Research Establishment in Sweden and works down to 10-14 Mole TNT. However, lifetime is limited [7].

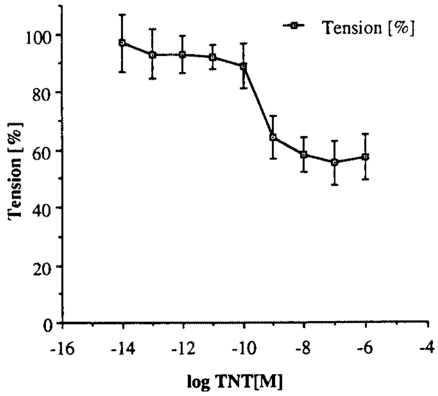

Fig. 2: Tense of a muscle

Forced reaction of TNT by Laser

Another possibility for an TNT sensor is to use light absorption. Light energy triggers the explosive reaction of the molecule; the heat increase can then by detected. The IBM research lab in Switzerland has found a new type of temperature sensor based on the deformation of nano-technology cantilever beams (Fig. 3) [8], which is sensitive to very small changes of temperature (some 10^{-5} degree, equivalent to a few pJ). So it should be possible to detect molecules of TNT by exploding them on the surface of the sensor by a laser. Currently the sensor is working, but there is no experience of its use with TNT.

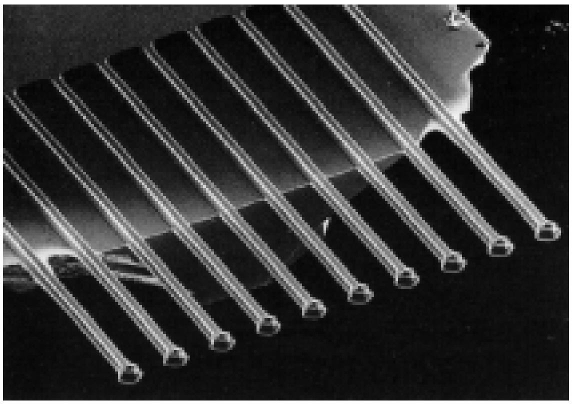

Fig. 3: IBM temperature sensor

Explosion of a TNT molecule transmits also light energy and should therefore be detectable by a very sensitive light sensor (photomultipliers can detect single quantum of light).

Ion Mobility Spectrometry (IMS)

IMS separates ionized molecular compounds on the basis of their transition times when subjected to an electric field in a tube (Fig. 4) [2] [11]. This time is then compared to stored transition times of known compounds. Therefore it is possible to distinguish TNT from other molecules. This technique is fast and makes a compact device possible. Unfortunately the sensitivity is not very high, in particular for compact designs.

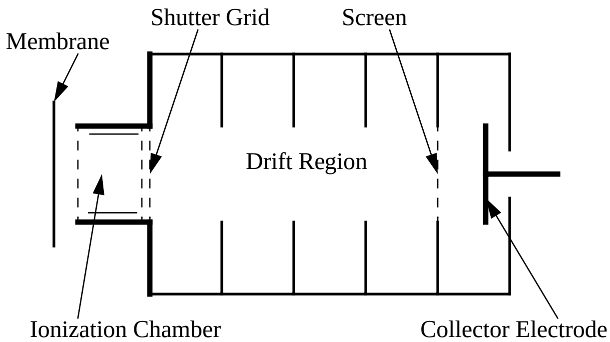

Fig. 4: Schematic of ion mobility spectrometer

Impulse radar or microwave

The measure of the resonance frequencies of the ground to a radar impulse depends on buried objects. At frequencies whose wavelengths are comparable to the overall size of the object, the smaller details of the structure are irrelevant, making it possible to describe the shape and the material properties of a body with only a limited number of parameters [14].

For example, the Joint Research Centre at Ispra in Italy developed microwave sensor, which detects and distinguishes miscellaneous mines [9]. This sensor is still under development.

X-ray tomography

In X-ray tomography, the emitted radiation, either in the form of neutrons or gamma rays, is designed to react with different elemental components of the object of interest to produce a reaction particular to the specific detector application. To detect plastic explosive, it is necessary to produce the particular energy that reacts with the subject chemical element in the explosive. In general, plastic explosives contain several elements, such as nitrogen, which has unique characteristics that lend itself to a host of nuclear detection method, such as thermal neutron analysis and others. A radiation of neutrons react with nitrogen nuclei to produce specific detectable gamma-rays.

Need for an association

Financing activities in the development of sensors and demining robots is difficult. Fundamental research money cannot be obtained when there is a clear application and pre-industrial development is required. On its side, industry will not take the risk for a not yet existing market. Finally, directly concerned countries are not rich enough for such developments, which are infeasible in their technical schools.

An association must hence be formed to support these activities with adequate funding. Several personalities should support with their name the fund raising. A scientific committee should define priorities, select the project and verify the advancements.

Conclusion

In the demining problem, the robot problem is only the tip of the iceberg. All the work to produce sensitive and reliable sensors has still to be done. Many technologies are promising, but none is in the sensitivity, size, weight, manufacturability and price range required for a demining robot. Hence a better exchange of research result is required; this seems to occur in 1995 thanks to several conferences:

SPIE, Session on Detection Technologies for Mines and Minelike Targets, Orlando, April 17-21; 1995

Transducers'95 - Eurosensors'95, Stockholm, June 25-29; 1995 Workshop on anti-personnel mine detection and removal, Lausanne, June 30-July 1; 1995

FEBS'95 Session 12 on Biosensors, Basel, August 13-18; 1995

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Philip Mächler got the diploma in Electrical Engineering at Swiss Federal Institute of Technology in Zurich in 1993. For his diploma, he designed and built a high speed SCSI-interface for real time vision computing on the MUSIC parallel computer (Prof. Gunzinger, ETHZ). Afterwards he designed a robot system for a CD-changer, which is now a commercial product. He joined LAMI in March 1994, where he is working towards a Ph.D. He is interested in robot control and in coordinated behaviour of multiple agents.