Bio-Inspiration and Mine Detection

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Abstract- There are many methods to detect explosives and landmines. However, most of them are limited by sensitivity and/or operational complexities due to type of terrain and soil composition, climatic variables, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels. Other methods are focusing on the detection of explosives itself since small amount of explosives routinely leak over time from landmines and can be found on surrounding ground and plant life. Hence, the robust primary indicator of a landmine is the explosive itself since the vapor of explosives signature such as TNT, DNT and RDX, as well as vapor from their casing materials of various types of plastics, metal, wood, or paint, can be checked in the air above or near buried mines or UXOs. Typically, humidity and temperature are key factors affecting vapor availability. The increase of temperature significantly increases the vapor availability above a given substance. In addition, signature scent above the soil is complex and can vary according to the amount of buried time. New approaches to landmine detection are being studied to improve the detection rates and to reduce the false alarm rate of the existing detection techniques. Developing efficient techniques and tools to identify explosives residue in mined areas represents an attractive approach. This paper aims to present, discuss and evaluate the potential and the of research development in the area of bio-inspiration and landmine detection from the prospect of humanitarian demining.

Keywords:
Mine detection, Humanitarian demining, Biomimetic, Biosensors, Landmines, Genetically Engineered bio-systems.

I. Introduction

Mine detection represents the most important step of the demining process, and the quality of mine detector affects the efficiency and safety of this process. The main objective of mine detection is to achieve a high probability of detection rate while maintaining low probability of false alarm. The probability of false alarm rate is directly proportional to the time and cost of demining by a large factor. Hence, it is important to develop effective detection technology that speed up the detection process, maximize detection reliability and accuracy, reduce false alarm rate, improve the ability to positively discriminate landmines from other buried dummy objects and metallic debris, and enhance safety and protection for deminers. In addition, there is a need to have simple, flexible and friendly user interaction that allows safe operation without the need for extensive training. Such approach needs to incorporate the strength of sensing technologies with efficient mathematical, theoretic approaches and techniques for analyzing complex incoming signals from mine detectors to improve mine detectability. This leads to maximize the performance of the equipment through the optimization of signal processing and operational procedures. Furthermore, careful study of the limitations of any detection device and technology with regard to the location, climate, and soil composition is critically important besides preparing the required operational and maintenance skills. It is important to keep in mind that not all high-tech solutions may be workable in different soil and environmental conditions. The detection technologies are presently in varying stages of development. Each has its own strength and weaknesses. The development phase of new technologies requires a well-established set of testing facilities at the laboratory level that carried out in conditions closely follow those of the mine affected area. In addition, the verification test should be carried out at the real minefield site. This should be followed by extensive field trails in real scenarios to validate the new technologies under actual field conditions for the purpose to specify benefits and limitations of different methods while fulfilling certain benchmark requirements. The work must be performed in close cooperation with end-users of the equipment while real deminers should carry out the test at a real site, in order to ensure that the developments are consistent with the practical operational procedures in the context of humanitarian demining, and that it is fulfilling user requirements. In addition, there is a need to have reliable process of global standard for assessing the availability, suitability, and affordability of technology with enabling technology represented by common information tools that enable these assessments and evaluations. The benchmarking is going to enhance the performance levels that enable the development of reliable and accurate equipment, systems and algorithms [2, 9, 10].

. The current mine detection process represents the slowest and the most dangerous step within the demining process. The quality of mine detection affects the efficiency and safety of this process. Many methods and techniques have been developed to detect explosives and landmines [2, 9, 10]. However, the performance of the available mine detection technologies are limited by sensitivity and/or operational complexities due to type of terrain and soil composition, vegetation, mine size and composition, climatic variables, burial depth, grazing angle, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels [1-3, 9-11]. New approaches to landmine detection are being studied to improve the detection rates and reducing false alarm rates of existing detection techniques. In addition, it is important and would be efficient to have sensing technology that can facilitate fast mined-area reduction. The robust primary indicator of a landmine is the explosive itself since the vapor of explosives signature such as TNT, DNT and RDX, as well as vapor from their casing materials of various types of plastics, metal, wood, or paint, can be checked in the air above or near buried mines or UXOs.

Researchers are studying wide range of bio-systems and are trying to mimic (not necessary duplicating 100%) certain natural capabilities particularly where the performance of bio-systems exceeds the available artificial systems and technologies. However, many research questions remain to be answered and further research still needed.

II. BIOLOGICAL AND BIO-INSPIRED APPROACHES FOR LANDMINES DETECTION

Four categories of research directions can be recognized in relation to the biological and bio-inspired approaches for the detection of landmines, explosives and other chemical residues. The main research directions can be categorized as follow:

(a) Bio-hybrid systems. This category focuses on the possibility to integrate a suitable technology with a bio-system to boost its natural abilities.
This category focuses on studying and understanding the full range of species combined with creative thinking, design and innovative technology in association with possible and relevant applications. Bio-hybrid systems aim to boost the natural capabilities of selected biological systems to support certain applications and solutions that are more than just learning from nature.

(b) Bio-systems. The research within the category aims to understand and conclude how existing bio-systems can be trained and used efficiently as a stand detection tools.

(c) Genetically engineered bio-systems. This may include animals, insects, bacteria and plants.
This category focuses on the development of biotechnology and genetically modified microbial techniques to help in environmental cleaning, waste management, detection of (bio-agents, explosives and landmines), etc.

(d) Biomimetic systems. Exploring technologies that exploit natural abilities of bio-systems and biological organisms to get new understanding and inspiration that lead to build new systems and hardware.

This category is based on biological inspiration and attempts to produce engineered systems that possess characteristics, and resemble or function like living systems, i.e., new technologies can be developed from nature. Biomimetic systems can be designed by extraction of the biological principles that govern them, which is possible only by a synergy of the basic and applied sciences. Biomimetics has been utilized as a mechanism for technological advancement in an attempt to facilitate the realization of the novel features in nature. There is a growing awareness among scientists and engineers that biological systems can be a valuable source of inspiration for man-made materials and systems by mimicking novel aspects of biological systems. Scientists mimic everything from worm brains to fish jaws to create better technologies.

III. EXAMPLES ON BIO-SYSTEMS AND GENETICALLY ENGINEERED BIO-SYSTEMS FOR LANDMINES DETECTION

Animals and other species have senses more acute than those of humans. Biological systems offer excellent examples of highly sensitive, versatile, and robust sensors. Researchers are studying wide range of bio-systems while at the same time they are trying to mimic certain natural capabilities particularly where the performance of bio-systems exceeds the available artificial systems and technologies. Examples may include invertebrate-inspired sensory-motors systems, olfactory in dogs and insects where odors play a vital role in all aspects of life, locomotive skills of a cockroach to move easily over rough terrain, etc. In addition, there is no doubt that understanding animals' locomotive capabilities can help to apply such knowledge in developing new generation sensors and other intelligent mechanism.

Artificial vapor detection has the potential to compete with or be used in conjunction with animals. However, dogs, rats, bees and pigs are still far better vapor detectors than any currently available technology. Furthermore, animals are sensitive to many different scents concurrently, a property that has proven difficult to replicate artificially. Current examples of natural biosensors are dogs, honeybees, bacteria and microbes, plants, etc.

A. Dogs

The odor discrimination skills of dogs considerably exceed the abilities of laboratory equipment that are used to investigate those skills, and hence limiting the ability of researchers to study the capabilities of dogs for detection of mines. Dogs are considered so far the best detectors of explosives. Their sensitivity to the substances associated with landmines is estimated to be a factor of 10,000 higher than for a man made detector [4]. The availability of odor to dogs varies in complex ways with the environment in which the mine occurs. Influences include soil types, soil moisture, activity of micro-organisms, and climatic variables. Specially trained dogs are used to detect the characteristic smell of explosive residue emanating from mines regardless of their composition or how long they have been implanted.

Dogs are normally used is in the search mode. Mine detection dogs can work in almost all types of terrain. Trained dogs work best in clear open country with vegetation no higher than calf to knee height. They are easy to transport, highly reliable and can clear screening land up to five times faster than manual deminers. Success has been reported from South Africa and Afghanistan, more in locating the edges of minefields than in finding individual mines. In spite of that, dogs can get tired and distracted, and can be effectively used as little as only few hours a day. The presence of explosive vapor within the soil and vegetation is essential element for the dog to perform its detection duty. Dogs can be overwhelmed in areas with dense landmine contamination. Like their human handlers, they don't do well under extreme weather conditions. Dogs can become confused if they can smell explosive coming from several sources at once. Dogs and other sniffers have high ongoing expenses, are subject to fatigue, and can be fooled by masked scents. The effectiveness of the dogs depends entirely on their level of training, the skill of their handlers, and on using them in the right place at the right time.

B. African Giant Pouch Rats

African giant pouch rats have very poor eyesight and hence they depend on their senses of smell and hearing. They have a better sense of smell, cheaper to keep and maintain, small in size, and they are suited to African climate with more resistant to tropical disease. African giant pouch rats have a relatively long life span, weight up to 4 kg, and they required shorter training time than dogs. In addition, once taught, the rats tend to perform repetitive tasks [5, 6]. A Belgian company (Apopo) has begun training these rats to locate buried bombs and mines due to their good sense of smell and tractable personality for mine detection. When an area has been thoroughly swept by the rats a team with metal detectors goes in to check and detonates all the marked mines in the area. In addition, large areas can be swept by multiple rats before a detonation team goes in to explode/remove the detected mine/UXO. In case of dogs, each landmine must be detonated or removed as it is detected, to avoid detonating the marked landmines.

C. Honeybees

Efforts were focusing to determine whether trained foraging bees can reliably and inexpensively search wide areas for the presence of landmine chemical signatures, such as TNT, at very low concentration, and possibly other explosive materials in bombs and landmines, as well as other chemicals of interest, including drugs and even decomposing bodies. Bees are free-flying organisms and have an acute sense of smell. When properly conditioned, it has been found through a series of repeated trials conducted in 2001 and 2002 bees behaved like a fine-tuned detector at vapor levels higher than 10 parts per trillion (pptr) from 2.4-dinitrotoulene (2.4-DNT) mixed in sand with low probability (less than 2%) of either a false positive or negative [12]. Bees are analogous to dogs for mine clearance, except that thousands of bees can be trained within very short time to fly over and search a field for explosives. Honeybees inhale large quantities of air and bring back water for evaporative cooling of the hive. As such, bees sample all media (air, soil, water and vegetation) and all chemical forms (gaseous, liquid and particulate). A honeybee's body has branched hairs that develop a static electricity charge, making it an extremely effective collector of chemical and biological particles, including pollutants, biological warfare agents and explosives [13].

D. Biotechnology and Microbial Techniques for Mine Detection

A microbe can often sense environmental dangers before a human can. During few decades of environmental engineering progress, biologists and engineers have used the fact that common, naturally occurring bacteria consume chemical compounds in soils to accomplish hazardous chemical cleanup objectives. The field of bioremediation evolved from this understanding. The microbiologists were trying to detect the presence of explosives and other chemicals. The Microbial Mine Detection System (MMDS) is an example of a living system that responds to explosives and provides the operator with an identifiable signal [7]. Attractive methods in this area include chemical and biological approaches that involve naturally occurring microbes or genetically engineered soil bacteria to cause the bacteria to fluoresce under laser light when in contact with TNT. However, these approaches are less developed but hold promise and need further development and evaluation.

In 1975 it was discovered that the chromosomes in bacteria could be modified to make the bacteria glow in the presence of certain chemicals. ORNL took the advantage of such microscopic creatures to genetically engineer it for the possibility to apply it in waste management technologies [7, 8]. They found that such bacteria, when applied to soil, will glow if the soil is contaminated with solvents like toluene or xylene. TNT is closely related to these solvents chemically, so it was fairly simple to modify these bacteria to fluoresce in its presence. The plan is to spray a solution of genetically engineered pseudomonas over a minefield. When the pseudomonas contacts the explosives and starts metabolizing it, they will scavenge the compound as a food source activating the genes that produce the proteins needed to digest the TNT, and this triggers emitting extremely bright fluorescence when exposed to ultraviolet light. The fluorescent signals are mapped, and the area is examined for the source. The method has been tested mainly in lab environment with test over a simulated minefield where in both cases mines were located successfully, but real-world conditions may not be similar. In the field, this method could allow for searching hundreds of acres in a few hours, which is much faster than other techniques, and could be used for area reduction and on a variety of terrain types. While it needs more time to adequately test the technique in real minefield.

E. Plant Indicators

It may be possible to genetically manipulate plants to have them change their behavior in presence of TNT or other explosive material, for example changing color, growing up fast and high or display any other detectable sign. These signs need be visible to human; other signs such as changes in UV reflection are also usable and measurable by simple tools. In this case, the plants would aid demining by indicating the presence of mines through color change, and could either be shown from aircraft or visually by minefield deminers. Aresa Biodetection Company has developed a genetically modified weed that could help detect landmines. The weed has been coded to change color when its roots come in contact with nitrogen dioxide evaporating from explosives buried in soil. Within three to six weeks from being sowed over landmine infested areas, a Thale Cress plant (Arabidopsis thaliana, it is a small flowering plant related to cabbage and mustard), will turn a warning red when close to a landmine. Aresa has succeeded at the laboratory level in growing the plant by using a combination of natural mutations and genetic manipulation.

However, because nitrous oxide can also be formed by denitrifying bacteria, there is some risk of generating false indicators through the use of this technique. In addition, no reported study has been conducted with actual landmines, though successful studies have been done in greenhouses [19]. Some scientists raised their concern that such bioengineered plants could escape into the wild and confer undesirable traits on wild plants. Genetically altered plants may be transplanted via planes, on roads or pathways, or by a number of other methods. Proper consideration should be given to water requirements and pollution issues.

IV. Artificial Protein and Synthetic Biology

Computational method has been developed to engineer proteins that can specifically detect a wide array of chemicals from TNT to brain chemicals involved in neurological disorders. This may constitutes an important step toward a new technology of synthetic biology, in which scientists will be in position to construct tailor-made organisms for a variety of tasks. Scientists at Duke University recognize the feasibility of this approach over the long term using computational design to create sensor proteins. Such sensor proteins can be re-incorporated into cells to activate cellular signaling and genetic pathways. The research team was able to establish control over molecular recognition of small molecules in biology. The researchers have demonstrated that it is not only possible to design highly specific receptors, but also to put them into biological systems and control them. It would be possible with this technique to develop TNT-sensing protein to provide free-roaming underwater and land robots with the capability of sniffing a plume of TNT emanating from unexploded ordnance, tracking it to its source, and help to clean up.

V. Conclusions

The presented techniques are promising approaches to help detect individual landmines and support area reduction, but some of the presented research are still years away to be effectively applicable in a real minefields. These techniques take advantage of the fact that all munitions will leak small amounts of their chemical constituents as vapors that can be found on the surrounding ground and plant life. Even very slow, low concentration, vapor emissions will be sufficient to allow interception and identification. Being conditioned on explosives, they will also pick up the scent from UXO. Landmines that might be manufactured to be completely sealed (which are not currently the case) cannot be detected by any of the methods listed in this paper. Important care should be applied in relation to safety, health and environmental concerns when developing genetically engineered bio-systems. It is a huge challenge to seek and optimize new technology and to make a meaningful difference in the elimination of landmines threat.

Although many studies have been conducted with promising results, and while there are additional studies are underway, there are still many more remain to be done in this area to,

(a) Have better understanding about the natural capabilities of bio-systems. This will lead, to enhance the development at the other three categories.
(b) Coordinate and develop efficient interdisciplinary research teams.
(c) Create new ideas and innovative technologies to boost the performance of already available techniques and new approaches as well.
(d) Fulfill the high level of interest in the detection of low-level concentrations of explosives such as TNT and RDX.
(e) Have better understanding the key features that identify the specificity of explosive and chemical signatures, and study the effect of humidity, temperature and other climatic parameters on them.
(f) Improving the sensitivity and fine resolution of sensors because it has a direct effect to determine what can be detected, at what location, and how quickly.

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