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Landmines Detection Using Autonomous Robots: A Survey

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Abstract

There are many countries affected by landmines which present a major threat to lives and cause economic problems. Landmines are harmful because of their unknown positions and often difficult to detect. The development of new demining technologies is difficult because of the tremendous diversity of terrains and environmental conditions in which mines are laid and also because of the wide variety of landmines. Currently, detecting and clearing mines demand specific expertise with special equipment. This paper presents different techniques used for landmines detection. It discusses the strategies that can enable the robot to detect mines by means of sensors. This paper deals also with the processing of the fused information from different sensors to guide soldiers when passing landmines. The purpose is to give an overview of the landmines detection techniques by using the autonomous robots which are capable of exploring and detecting buried landmines and marking their locations.

Keywords: Landmine detection, Autonomous robot, Explosive vapor detection, Multi-sensor devices, Sensor fusion.

1. Introduction

There are two major types of landmines: Anti-Personnel (AP) mines and Anti-Tank (AT) mines. AP mines usually placed under the earth and close to the surface, while AT mines are usually placed on the surface of the earth.Landmines are designed as area-denial weapons. They are used to create tactical barriers in order to prevent direct attack or to deny access by military and civilians to a defined area. Therefore, landmines can be consideredas perfect soldiers that never eat, sleep, miss, fall ill or disobey. Moreover, the landmine perfectly completes its job for much less one U.S. dollar than the human soldier does. In addition, landmines are long-term killersand they are active long after a war has ended. Currently, there are more than 100 millions of unrecovered anti-personnel and anti-tank mines can be found in more than 50 countries [3]. It is estimated that mines hill or mutilate tens of people every day. In countries where the presence of landmines became a part of the everyday life, the consequences of landmines problem on humanitarian and environmental levels are very high [25]. On the other hand, recent advances in the development of accurate and reliable sensors for mine detection are so promising. The researchers have become interested in the development of unmanned ground vehicles and robotic systems that can carry the sensors with the minimum interaction of human operators [6]. This is accomplished by broken down the overall system into two subsystems: sensor technologies and robotic device. Sensors devices include metal detector, ultrasonic range finder, and gas sensor. While the structure of the robot in our case consists mainly of a commercial off-the-shelf parts, which are available at low costs. The rest of the paper is organized as follows. Section 2 describes some technologies used for mines detection. In Section 3, the importance of using autonomous robot in mines detection is discussed. Section 4 represents the strategies or steps that researcher follow to detect mines. In section 5, some of the current related work in this field is presented. Finally, the conclusion and future work are discussed in section 6.

2. Mine Detection Technologies

The effectiveness of any technology is often evaluated by minimizing accidents to the operators specifically to those landmines that for any reason were moved away from their original position. To solve this concern, some countries nowadays performed the detection of buried landmines using several other methods, such as using dogs that sniff the explosive contents of the mines [24]. Various techniques used for the detection of landmines. Minesweeping and removing landmines carry certain risks and can be slow and costly. Employing an autonomous robot in the process of detecting mines will ensure the safety of local residents and those who are engaged in the minesweeping work and the demining process. A landmine-detecting robot sweeps the ground to detect the existence of a mine. The robot can use multiple sensors to search for mines. The current technologies fall under five main areas [14]: metal detector technologies, electromagnetic methods, acoustic/seismic methods, biological methods, and mechanical methods. These technologies will be discuss in the following subsections.

2.1 Metal Detector Methods

For mine detection, the metal detector is used to measure the disturbance of an emitted electromagnetic field caused by the presence of metallic objects in the soil. The popular, basic metal detector is easy and cheap to use and has an average success rate. However, when using more sensitive detectors for plastic mines, all metallic objects are identified while the problem is heightened [14]. Approximately 80% of all clearance accidents occur during the investigation of metal signatures. Landmines that for any reason were moved away from their original horizontal position mainly cause accidents [4].

2.2 Electromagnetic Methods

A number of innovative methods are being explored to search for buried mines based on changes in the electromagnetic properties of the surface soil and shallow subsurface. These methods include ground-penetrating radar (GPR) [29], electrical impedance tomography (EIT) [15], x-ray backscatter, and infrared/hyper spectral systems [14].For example,GPR detects buried objects by emitting radio waves into the ground and then analyzing the return signals generated by reflections of the waves at the boundaries of materials with different indexes of refraction caused by differences in electrical properties.

2.3 Acoustic/Seismic Methods

Acoustic/seismic methods look for mines by vibrating them with sound or seismic waves that introduced into the ground. Materials with different properties vibrate differently when exposed to sound waves. These methods are complementary to existing sensors with low false alarm rates and are unaffected by moisture and weather. Existing systems are slow and they do not detect mines at depth, because the resonant response attenuates significantly with depth. An additional limitation of existing systems is that moderate to heavy vegetation can interfere with the laser Doppler vibrometers [15] that commonly used to sense the vibrations at the ground surface.

2.4 Biological Methods

Biological detection methods involve the use of mammals, insects, or microorganisms to detect explosives. Like chemical sensors, these methods rely on detection of explosive compounds rather than on detection of metal or changes in the physical properties of the subsurface. Thus, they have the potential for reducing false alarm rates from metal clutter. Biological- sensing technology requires an understanding of how explosives migrate away from landmines as well as knowledge of the chemical and physical principles of the sensor [14].

2.5 Mechanical Methods

Clearing minefields by modified tanks or trucks is also a common method [12]. It does not 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. Another 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 [1].

3. Landmines Detector Robots

The option of detecting mines in a surface-laid minefield using autonomous robots is becoming more popular because it decreases the danger and the cost involved in manual detection [23]. Robots search mines with such a low pressure that mine explosions are not triggered. In order to cover efficiently all mined areas, robots should adapt to accelerated exploration in order to increase efficiency, especially if any surveillance team exists.Using robotsin landmines detectionprovides the ideal sensor for robots due to its low cost, wide availability, high data content and information rate. For highly dynamic adversarial tasks, being able to extract significant information about the world is crucial to operating effectively, making vision an appealing sensor. Additionally, the presence of adversaries mean that it is essential to process the sensory information in minimum time. An adequate mine-clearance rate can only be achieved by using new technologies such as improved sensors, efficient manipulators, and mobile robots [16]. Estimating the position of the buried landmines with the data of landmine detection sensors is important in election work. During demining operations, human operators would have to stay as far away as possible for safety. A reasonable intermediate solution might be found in teleportation and human-machine collaboration in the control loop, a scheme that is becoming known as collaborative control [16]. One of the problems with the current mine-detection robots is that they have quite a big structure and is very expensive. Because of that, they cannot be bought and used by local people. However, the locals mostly encounter the mines. Even though there have also been a number of inexpensive mine-detection robots being developed, most of them use simple algorithms such that they can only operate in simple environments with no obstacles [11]. There have been a number of robots developed by researchers all around the world. The development of lightweight, low-cost, semi-autonomous robots working together with a monitoring station (Personal Mine Explorers) is a well researched approached [32]. Robots search mines with such a low pressure that mine explosions are not triggered. In order to cover efficiently all mined areas, robots should adapt to accelerated exploration in order to increase efficiency, especially if any surveillance team exists. Multi-robot systems for area reduction form the next step in landmine searching. Some research has been carried out on a multi-agent-based architecture responsible for coordinating a progressive stochastic analysis of the terrain [33]. It includes a reactive obstacle avoidance method, and the development of mission control software to plan, configure, and supervise operations. The system uses legged, wheeled, and aerial robots. Finally, a sensorial payload system is described in this research with the use of Fourier analysis as the mechanism to effectively detect mines.

4. Strategies of Landmines Detection Robotics

In order to clear up landmines, two major steps need to be done. The first step is to detect the location of the mines. The second step is to deactivate or destroy the mines. Searching for the location is the process that takes the most amount of time. This is because, every single inch of the land needs to be manually and carefully probed with a mine detector [11]. There are three kinds of minesweeping strategies ranging from a manual based minesweeping, a mechanical equipment based minesweeping, to an advanced robot based minesweeping [24]. The manual based technique relies on trained deminers sweeping the ground using metal detectors. Well-trained staff prod the ground with a thin steel spike every 2 cm at a shallow angle of about 30 degrees [1]. 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 based demining uses machinery to roll over the landmines and destroy them while they are still in the ground. This technique is known as the fastest demining technique. However, the machines employed in this approach are expensive to operate and can only be used when the terrain is suitable. Additionally, in most situations, this technique is not 100% reliable; thus, the need to employ another technique to check the minefield's clearance. Employing an independent robot in the process of detecting mines will ensure the safety of local residents and those who are engaged in the minesweeping work and the demining process. A landmine-detecting robot sweeps the ground to detect the existence of a mine. The robot, through computer vision, decides whether a mine exists or not [24]. When robot uses different sensors such as ultra sound sensor, vapor detector sensor [9], metal detector sensor, and wireless sensor;the advantage of decision-level fusion is that all knowledge about the sensors can be applied separately. Each sensor expert knows the most about the capabilities and limitations of their own sensor and they can use this information to optimize the detection performance. The availability of this expert knowledge was the reason for choosing decision-level fusion for these application [10].To compensate disadvantages of each sensor, a combination of several sensors should be used. Mines of both metal and plastic bodies can be detected by means of a combined sensor block that contains devices based on different principles. The proposed combined sensor block information provides high reliability of mine detection [17].

5. Current Mine Detection Systems

There are many researcher work in this fieldand evaluated the performance of mine detection technologies. Researchers in physical, chemical, and biological sciences are studying and developing methods that could reduce the false alarm rate and maintain or increase the probability of detection for mine clearance. New detection concepts involve searching for characteristics other than mine metal content. Varieties of techniques that exploit properties of the electromagnetic spectrum are being explored. For example, Plett et al. [3] proposed detection method, which use a separated aperture microwave sensor and an artificial neural-network pattern classifier to detect simulated land mines using data collected from a mine. This data consists of a set of measurements made with a separated aperture sensor operating in the wave guide near cutoff mode. Their work has shown that neural-network pattern classifiers can successfully detect antitank mines. This method has some drawbacks that the level of false alarms may be made arbitrarily lowand the system's complexity. Waymond et al. [4]proposed a hybrid technique that simultaneously uses both electromagnetic and acoustic waves in a synergistic manner to detect buried land mines. The acoustic source causes both the mine and the surface of the earth to be displaced. The electromagnetic radar is used to detect these displacements and, thus, the mine. The displacement of the mine is different from the earth, because the acoustic properties of the mine are quite different from those of the earth. Najjaran et al. [6] implemented a software of a terrain-scanning robot capable of autonomously manipulating typical handheld detector for remote sensing of buried landmines in a manner similar to a human operator. The software includes a twofold process of map building and path planning that is implemented into a real time software platform to take place in parallel to the other functions of the robot.The drawbacks that the high cost and Reliability of a metal detector, determined by signal to noise ratio, largely depends on the distance, orientation, size, and scanning speed of the sensor. Pedro [7]developed a low cost mine detection system useful for small nonmetallic mines by image processing. In addition, finding mine targets from a set of candidates is proposed. The intention of the solution is to analyze a set of infrared data sequences, which is called dynamic thermography. The necessary image processing methods are introduced as four topics, filtering, feature extraction, gray-scale morphology, and segmentation.The drawbacks of this method that the ambiguity of the target signal and the image processing level is limited unless the sensor provides good information about the target. Sathyanathet al. [8] proposed a system calledArtificial Immune System (AIS) which is an evolutionary paradigm inspired by the biological aspects of the immune system. The model is applied to a mine detection and diffusion problem.The results prove that AISIMAMhas solved the problem successfully. The mine detection can be performed efficiently by deploying mobile robots that have enough intelligence, communication, and coordination to detect and diffuse the mines. Albert et al. [9] developed instrument to detect low-level 2, 4-dinitrotoluene (DNT) vapors. The system is based on previously developed artificial nose technology and employs an array of sensory materials attached to the distal tips of an optical fiber bundle. Each sensor within the array responds differentially to vapor exposure so the array's fluorescence response patterns are unique for each analytic. This detection system has been applied to detect 2, 4-DNT, an analyte commonly detected on the soil surface above buried 2, 4, 6-trinitrotoluene (TNT) land mines, in spiked soil and aqueous and ground samples. The drawbacks of this method that this system Suitable only in soil condition Schavemaker et al. [10] proposed a system, which is a vehicle, mounted, multi-sensor, anti-personnel landmine detection system for humanitarian demining. The system has three sensor types: an infrared camera, a ground penetrating radar and a metal detector. The output of the sensors is processed to produce confidence values on a virtual grid covering the test bed. A confidence value expresses a confidence or belief in a mine detection on a certain position. The grid with confidence values is the input for the decision-level sensor fusion and provides a co-registration of the sensors. Anuar et al. [11] designed a small, low-cost autonomous mine detection robot for solving the navigation problems. The first step is to detect the location of the mines and the second step is to deactivate or destroy the mines. Use specially designed vehicles to detect and destroy land mines. While has an advantage of being able to destroy the mines on the spot due to the vehicle's mechanical structure that can withstand mine explosion. The drawbacks of this method, in certain environments the robot perform less effectively and performance of the object avoidance need modification to climb big obstacles Acar et al. [31] have investigated some methods in path planning techniques in robotics. The first is sensor-based coverage according to exact cellular decomposition in terms of critical points. The robot executing the coverage algorithm incrementally constructs this cellular decomposition while it is covering the space with back and forth motions. The second technique, the probabilistic method, is for where time is limited and there exists a priori information about the minefield. This method works by minefield parameter extraction. Once the parameters are determined, the minefield layout is fixed, allowing opportunistic robot guidance to decrease demining time.The drawbacks of this method, in few instances, the system was not able to identify correctly the landmine due to the segmentation process where the K-Means clustering algorithm failed to effectively extract the exact objects' platforms from the image, high cost,GPR is larger and heavier, and GPR is more power hungry Zhang et al. [31] proposed a probabilistic method for robot landmine search, focusing on optimization search strategy determining location of mines and/or unexploded ordnance. They first extract the characteristics of dispersion pattern of the minefield in order to construct a probability map and then design a path for the robot searching.

6. Challenges

There are many challenges in landmines detection. The first is the changes in weather factors led to the disappearance of the mine underground spaces. The second is the ability to stop the effect of mines without a vision underground. The third is not only the presence of the mine is required to be discovered, it also needs the robot to mark the location of the mine with an accuracy of 5cm radius. There is great motivation to research new counter-mine systems. Current anti-personnel land mines cost between $3–$25 per mine and clearance methods cost between $300–$1000 per mine removed [3].There is work to be done in fusion of landmine detection technology in order to enhance its performance, since every approach has good results within limited conditions. Due to the aforementioned limitations, a multi-sensor system based on signal and algorithm fusion should be developed. Rather than focusing on individual technologies operating in isolation, mine detection research and development should emphasize the design from first principles and subsequent development of an integrated, multisensory system that would overcome the limitations of any single-sensor technology. Combining different kinds of sensors would certainly obtain better results in landmine detection.

7. Conclusion

This research aim is to provide a survey for developing a robot that can detect mine,as the robot may employ several sensors in order to help in mining. Incrementally improving existing technologies, increasing the probability of detection, reducing the false alarm rate, and planning useable deployment scenarios. There is no single method for efficient landmine detection. Several technologies can be found, but their direct results cannot be generalized. Rather than focusing on individual technologies operating in isolation, mine detection research and development should emphasize the design from first principles and subsequent development of an integrated, multisensor system that would overcome the limitations of any single-sensor technology. Combining different kinds of sensors would certainly obtain better results in landmine detection. Finally, some more attention should be given to sensor fusion and metal detectors. All of these issues should help to discriminate useful data, which is critical as large numbers of false alarms increase uncertainty and limit future research.

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