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Sensing Technologies for Tripwire Detection

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Abstract

Tripwire-operated landmines form a major hazard to deminers, especially where the wire is concealed in vegetation which the deminer has to clear. It may be possible to detect the landmine by sensing the tripwire. Several sensing technologies such as acoustic, thermal imaging, and electromagnetic sensors, are considered as possible candidates for tripwire detection. Strengths and weaknesses of the various sensing technologies are identified in order to provide options for developing a reliable, small, inexpensive and long range detector which can find tripwires completely concealed in vegetation. Two possible tripwire detection methods have been identified for further investigation.

Keywords: bounding fragmentation mine, tripwire detection, electromagnetic induction, radar, acoustic

1 Introduction

Landmines are concealed explosive devices which remain dangerous even after fighting has ended. They cause injuries to civilians, and economic hardship to affected communities by denying access to land. More than 70 countries have a landmine problem, and perhaps more than 70 million mines remain in the ground. More than 15,000 casualties are reported each year [1]. Minefields are gradually being cleared by teams of deminers. A major hazard to such teams is the *bounding fragmentation mine*, which is normally tripwire-operated and typically explodes at waist height, sending out metal fragments at ballistic speeds. A typical device will have a killing radius of more than 20 metres. The deminer is most at risk when clearing vegetation, within which a tripwire may be concealed. A portable tripwire-sensing device would be an invaluable tool for the deminer. This paper considers some sensing technologies as possible candidates for such a device, and identifies two which appear to be worthy of further investigation

2 Possible Detection Methods

A method used for tripwire detection is a tripwire feeler, which is a thin stick that is held lightly at the fingers to sense the bouncing caused by the tripwire. However this method is often found to be impractical when tripwires are concealed in vegetation, and the deminer may be reduced to visual inspection. This section discusses and evaluates some possible alternative sensing technologies for tripwire detection, including radar, thermal imaging, electromagnetic induction, and acoustic and vibration sensors.

2.1 Radar

Potentially, radar can detect tripwires by sensing echo returns from a tripwire target. By analysing the reflected signal, the position of the tripwire can be determined. The different types of radar include continuous wave radar (CW), pulse radar, frequency - modulated continuous wave radar (FMCW), ultra wideband radar (UWB) and millimetre wave radar (MMW).

2.1.1 FMCW Radar

This is an extension of continuous wave radar, which transmits a continuous wave at fixed frequency. FMCW radar broadens the transmitted spectrum for better resolution by frequency-modulating the carrier [2]. A continuous signal is transmitted, and this varies with frequency over time. This allows the system to sweep a particular range of frequency, which may be an advantage over the single frequency operation in continuous wave radar. By measuring the difference of frequency between the instantaneous transmitted signal and the received signal from the target, a beat frequency is obtained which gives an indication of the range of the target. Li (1999) has evaluated FMCW radar for landmine detection [3]. In general the bandwidth and hence resolution are limited by the antenna [6].

2.1.2 UWB Radar

UWB radar systems have also been evaluated for landmine detection [4]. Typically a very short pulse is used, which occupies a wide bandwidth. This can combine good ground-penetrating ability with good target resolution. However, UWB radar facilities typically use large, wideband antennas and do not currently lend themselves easily to tripwire detection in minefields.

2.1.3 Millimeter Wave Radar

Millimetre wave radar has been evaluated for detection of stationary foliage-obscured targets [5]. If a target is stationary with respect to its surroundings, small movements of its surroundings (such as leaves and grass) can be detected. If a tripwire is considered stationary with respect to its surrounding foliage, millimetre wave radar could in principle be employed to locate it. However, there has to be some doubt about whether the tripwire could reliably be considered stationary under all conditions.

2.1.4 Evaluation of Radar Systems

Radar systems normally operate in the frequency range 1 GHz to 40 GHz [6], and at these frequencies the additional attenuation through vegetation can be significant. Clutter caused by unwanted reflections from vegetation may also inhibit detection. Phoon and Pang (2001) were unable to detect vegetation-obscured tripwires using a FMCW radar at X-band (8.2 GHz to 12.4 GHz) [6].

The millimetre wave radar experiments reported above were conducted with a stationary car target behind pine trees [5]. This is a rather different scenario to one in which a tripwire can be completely obscured by vegetation: the car is a large target, is stationary, and is also partially visible. It is not yet clear that this technology could be applied successfully to the much more difficult tripwire problem.

2.2 Electromagnetic Induction

There are several different types of electromagnetic induction technique, with each type having its advantages and disadvantages. Generally *metal detectors* can be divided into two main types: continuous-wave and pulse-induction [7].

2.2.1 Continuous Wave Method

A continuous wave detector operates by generating a transmitter coil current, which alternates at a fixed frequency and amplitude. Small changes in the phase and amplitude of the receiver voltage indicate the presence of metal targets. The very low frequency method also known as induction balance is an example of the continuous wave method. The very low frequency method utilises the properties of different phase shift of different metallic objects to discriminate between the target object and other objects, to reduce the false alarm rate. This is achieved since objects with high inductance will have a larger phase shift, whereas objects with high resistance will have smaller phase shifts [7]. Liao and Huang (2004) evaluated the continuous wave method for tripwire detection and noted high false alarm rates. [8]

2.2.2 Pulse Induction Method

The principle of operation of a pulse-induction detector is that a pulse generator supplies a pulse, which is turned on for a period of time, and suddenly turned off. The collapsing field generates a pulsed eddy current in the (metal) target, which is then detected by analysing the decay of the pulse induced in the receiver coil [7]. The pulse induction method has the potential to detect tripwires concealed in vegetation, as a suitable pulse signal may be able to penetrate vegetation well.

2.2.3 Electromagnetic Induction Spectroscopy

If a magnetic field is applied to a metallic object, the object generates its own magnetic field, which is called the secondary magnetic field. Since different metallic objects have different spectral responses, discrimination between the target objects and other undesired objects can be obtained by analysing the spectral response of the secondary magnetic field and comparing the received spectral response with the predetermined data of all the spectral responses for the possible metallic objects in the minefield [9]. In the tripwire detection case, different lengths of metallic tripwire have different resonant frequencies. Therefore by analysing its spectral response, the presence of a metallic tripwire may be able to be detected using additional information about the likely length of the tripwire. However, there are design complexities, such as the coil design and the algorithm for analysing and comparing different spectral responses.

2.2.4 Gradiometer

The gradiometer principle is based on the fact that two identical and perfectly aligned magneto-resistive sensors will give identical outputs in a uniform field. However, if there is a small magnetic field, such as the secondary magnetic field generated by a target object, the difference in magnitude of these two signals will not be zero, which indicates the presence of the object [10]. Calibration and positioning of the sensors are critical.

2.2.5 Evaluation of EMI Approaches

EMI approaches rely on the assumption that tripwires are metallic objects, which is not true for all cases. However, standard military tripwire does have a metal core, so EMI methods could be valid for this kind of wire. At certain frequencies, issues of vegetation attenuation arise, as for radar.

2.3 Acoustic or Seismic Detection

This approach to buried landmine detection uses a transducer to excite the ground with acoustic or seismic waves [11]. Since the landmine is a container, it can vibrate when excited to resonance by an acoustic or seismic signal. By sensing the vibrations on the surface of the ground, the presence of the landmine can be detected. Surface vibration sensors evaluated include geophones, and laser and radar doppler vibrometers [12]. We propose that the concept of the acoustic method might be applicable to tripwire detection. If the tripwire can be excited with an acoustic wave, it may resonate in a similar way to a piano string. The presence of the tripwire is detected by analysing returned acoustic signals. Issues for this method include the need for the wire to be taut, and for sufficient energy to be coupled to the wire. Metal content would not be a requirement.

2.4 Thermal Imaging

Thermal imaging can be carried out using an infrared camera to observe the potential tripwire scene. This method requires the temperature or emissivity of the tripwire to differ from its surroundings [6]. In practice this may be difficult to achieve. In addition, if the tripwire is fully concealed by vegetation, thermal images are unlikely to reveal it due to the thermostatic action of living plant material.

3. Tripwire Properties

Although standard military tripwire is often plastic-coated metal, tripwires are not always metallic, and can range from cotton thread to fishing lines [13]. Some tripwire properties have been identified that could be used to enhance detection.

3.1 Polarisation

In antenna polarisation theory, a vertical antenna receives vertically polarised signals best and a horizontal antenna receives horizontally polarised signals best. Since tripwires are normally horizontally placed above the ground, they are horizontally polarised if currents are induced in the tripwires electromagnetically. If an antenna system is set up for tripwire detection with one horizontal antenna and one vertical antenna, and the horizontal antenna receives more polarised signal than the vertical antenna, this gives an indication of the presence of a horizontally placed object, such as a tripwire.

3.2 Spectral Response

When an electromagnetic signal is transmitted to a metallic target, it induces a current in the metallic target, which generates its own magnetic field (the secondary magnetic field). By analysing the spectral response of the secondary magnetic field using the Fourier transform, a desired metallic object (such as a tripwire) can be identified from undesired metallic objects because of the different spectral responses. This is done by comparing the spectral response of the received signal to a library of data, which contains the spectral responses of all the possible targets in the minefield. It may be possible here to make use of tripwire resonant length.

3.3 Phase Shift

The continuous wave metal detector uses the phase shift property to discriminate between different types of metallic objects to decrease the false alarm rate. In theory, an object with high inductance is going to have a larger phase shift, because it takes longer to alter its magnetic field. An object with high resistance is going to have a smaller phase shift [8]. A phase demodulator can be used to monitor this phase shift to discriminate between the target and other objects. This can be applicable in tripwire detection as metallic tripwires generally have high resistance.

4. Methods for Investigation

There are two approaches that have been selected for further investigation. The first approach is an electromagnetic induction method which incorporates the polarisation and resonance properties of the tripwire to detect metallic tripwires. The second approach is an acoustic method that has the potential to detect any kind of wires provided that they are taut.

5. Conclusions

The aim of this paper has been to present options for developing a long range detector that can find tripwires concealed in vegetation. Possible sensing technologies include radar, electromagnetic induction, thermal imaging and acoustic methods. Some properties of tripwires, such as spectral response, phase shift and polarisation could be used to enhance detection. An electromagnetic induction method using polarisation, and an acoustic method have been selected for further investigation.

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