A survey on instrumented prodding techniques for landmine recognition

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Abstract -. Manual prodders are still widely adopted among deminers to recognize unknown buried objects. Several technological improvements are possible to improve their perception capabilities and to reduce the risk of using more force than is required to activate a mine. The paper presents a brief survey on tools that use "contact" with the mine for detection: several categorizations of the tools are based on the sensors adopted, on features analyzed and on processing techniques to classify the extracted features.

I. INTRODUCTION

Prodding is one of the most adopted techniques used by deminers to identify the cause of a signal detected via a metal detector or other systems [1].

Our group is developing an intelligent prodder within the EC project TIRAMISU. Our first activity was to investigate on the state of the art of previous research activities on this topic.

Prodders are used mainly to detect the presence of a buried object that could be a mine; further efforts are needed to confirm the nature of the finding. The basic idea behind smart or instrument prodders consist in providing the tool with suitable sensing capabilities to enhance its skill in the identification of the nature of the material that is touched. A richer set of information is therefore available for the deminers to allow distinguishing between harmless buried objects, as pieces of wood or stones, and potentially dangerous objects that therefore need much more attentions and effort for the uncovering procedure.

The purpose of this paper is then to present an overview of the different methods adopted worldwide to improve a classical prodder into an automatic system capable to recognize the material in contact.

The methodologies can be classified with respect to the sensing principle adopted as ultrasonic, acoustic, piezoelectric, and piezoelectric with accelerometer. Some devices include actuators for exciting vibration on the material, while other approaches just process the vibration caused by the contact. Some approaches include a force feedback to measure or limit the contact force.

Another classification can be done on the basis of the different features extracted from the signal and the clustering strategies. Time domain or frequency domain features are usually extracted while Bayesian classifier, neural networks, fuzzy logic or K-means clustering have been proposed.

The developed prototypes have been validated using different kind of soils to simulate minefield conditions. Moreover mechanical systems have been usually adopted to guarantee the repeatability of the measurements. The classification is performed between mines, rock, wood pieces and other typical materials that can be found underground.

II. SENSING TECHNIQUES

The working methods of the devices that use contact with the material to be detected are based on prodder. A classical prodder generally is composed by a non magnetic needle (for situations where a magnetic device could activate mines) that should contact the buried material to be investigated and an ergonomic and comfortable handle, however comparative studies consider this kind of detecting instruments very unsafe for human operators, put at unnecessary risk [2]. This is why an improvement in manual mine detectors is today required and encouraged [3], [4], [5], for example including more complex sensors within the prodder. A classification of these innovative methods can be made with respect to the sensors, to the features analyzed or to the processing techniques.

ULTRASONIC

A first recognition strategy is based on the use of an ultrasonic sensor incorporated into the prodder. The tip of the prodder acts both as waveguide for transmitting the ultrasonic pulse and receiving reflected energy from the contact

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point with the buried material. The experimental tests were carried out with different materials (stone, plastic, steel) and acquired data were divided into “training set” and “testing set” in order to train and validate the classifier [6], [7].

Acoustic

Another sensing approach is based on the use of an acoustic microphone. In this case is not needed to transmit any excitation pulse, but the microphone is employed only as sensor for registering vibrations coming from contact between the tip and the material. When the prodder tip touches the object, the vibrations generated are acquired by the microphone, and registered using a PC sound card. The acoustic microphone has been integrated in a simple prodder as sensor so that a waveguide for transmitting the pulse is unnecessary. The experiments were performed evaluating four different materials: wood, plastic, iron, and stone [8], [9]. Another example using this principle is the first version of SmartProbe™. However the first version of this system did not function as expected [10]. Different improved versions including force sensors as feedback elements have been developed as the Instrumented Prodder by HF Research Inc. , that provided good results [11] , However extensive tests conducted by TNO-FEL have shown that the identification is not reliable when test conditions change [12], [13].

In the patents [14] and [15] the acoustic prodder is instrumented with a force feedback mechanism.

Other researches involved the development of rotary prodders to improve penetration into the soil, or prodder equipped via a microphone to give feedback of the contact sound to the operator [16], [17], or prodder that give a sound to the operator when the force is exceeding a given threshold [18] .

Piezoelectric

An alternative solution to the problem of material recognition is represented by piezoelectric transducers. In the approach developed by the University of Catania a tactile piezoelectric sensor touches the surface of a material so it can be observed a response signal related to the physical characteristics of the stimulated material. Two different experimental prototypes have been realized, and their performances evaluated for several materials like glass, stone, wood, iron and plastic [19], [20], [21], [22]. A different approach has been proposed in [23] and [24] where the piezoelectric transducer acts only as actuator to give the buried surface a vibrational solicitation through the stick of the prodder. An accelerometer is mounted on the prodder in order to measure the specific acceleration returning from the stick and depending on some characteristics of the material (e.g. its natural frequency or stiffness). A very original solution is reported in [25]. Survey operations can be performed by two controlled hands from a location at about 2 meters. This configuration provides some advantages; the main one is that the deminer can operate outside the blast zone, with a significant increase in safety. Experiments have shown it was possible to distinguish between soft and rigid materials.

Accelerometric

Other sensing techniques are based on acceleration measurements. In [26], is described a system with multiple probes where each one is equipped with a spring and an accelerometer to directly measure vibrations deriving from contact with objects. It’s possible to clear 1 m^2 in 2 min.

III. Extracted Signal Features

To obtain useful information, the signals detected from each sensor were analyzed to choose the features that better allows distinguishing between different materials.

For example in the case of ultrasonic sensor, the measured signal was analyzed in its time-domain representation and the selected features were the peaks of the time-domain signal and of its derivative [6]. A different approach was used for the features extraction of a signal detected by an acoustic sensor. First of all acquired signals were normalized by amplitude. Then, feature analysis was performed in frequency-domain representation, comparing average signal energy across different frequency windows [f_0, $f_0+\Delta f$], where f_0 takes values from interval [f_{min}, f_{max}-Δf] and Δf is the window width [8]. In the case of piezoelectric transducer used both as stimulating and sensing element, the signals (first acquired in time domain) were analyzed evaluating the energy rates in 4 frequency ranges in the interval [*100 Hz–3kHz*] (considering for every range the root mean square of the output as extracted feature) [21]. In the case of piezoelectric transducer with accelerometer a performance index was defined computing the square of the difference between the spectrum envelope from measured data and the reference spectrum envelope stored in advance, from a lower to an upper limit of frequency range [23], [24].

IV. Features Classification Methods

The next step is represented by feature processing. The features extracted are analyzed to eliminate the redundant or unnecessary ones. Subset of features can be classified with the fitness function based on the Euclidean distance, defined as a ratio between the average distance between instances from different classes and the average distance between instances belonging to the same class. At the end the features (belonging to training set) are statistically distributed into classes, so an unknown sample is assigned to the class whose probability density function (PDF) is largest, according to Bayes classification [6], [9], [27]. A back propagation neural network is capable to set up complex borders between classes and adjust them based on known samples. In the case of ultrasonic sensor results the neural network gives better results than the Bayes classifier.

In the case of acoustic sensor sequential search algorithms were used in feature selection [8], [9], [27]. The most common are the Forward Sequential Selection (FSS) and the Backward Sequential Selection (BSS).

FSS begins with zero features, evaluates all subsets with one feature and selects the one with the best performance. Then it evaluates every subset with previously selected features and adds the feature that yield the largest fitness function, until no improvement is obtained. Instead BSS begins with all features and repeatedly removes a feature whose removal causes the least decrease of performance. These algorithms allow reducing the size of feature vector, decreasing computational time but maintaining a good level of performance.

Piezoelectric signals were processed through a fuzzy logic algorithm, calculating the average energy in 4 frequency bands [21]. A clustering analysis was performed and a collection of rules (if-then) defined. The obtained fuzzy architecture was trained by a first set of 100 patterns and tested by a second set of 100 patterns, with good results in distinguishing among different materials.

In the case of piezoelectric transducer with accelerometer recognition process was performed with a statistical approach based on analysis of variance [23], [24]. A large number of tests were carried out and compared to some reference spectrum envelopes measured in advance at different conditions. A performance index was evaluated for every reference, and results were compared, choosing as best resembling reference, the one that minimizes the performance index.

V. Conclusion

In this paper a survey on instrumented prodding techniques for landmine recognition has been presented categorizing the methods with respect to the sensors adopted, with respect to the features analyzed and to the processing techniques to classify the extracted features. A detailed comparison between the different methods in similar conditions was never performed and most of the results were conducted in laboratory conditions. Most of the work reports succesfull result that however needs a careful and objective evaluation. As a consequence a detailed analysis of the different results is not reported.

From the state of the art and several discussions made with end-users, it results that an intelligent prodder is a useful device. However actual developed instrumented prodders are not well accepted by deminers. The reasons are because these are usually expensive with respect to the reliability level reached in the recognition process.

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