The development of an intelligent manual prodder for material recognition

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Abstract

The paper describes an active prodder for the recognition of touched materials. The proposed system has been developed with feedback from deminers expertise, keeping into consideration their remarks from past research activities for a better understanding of the reasons for failures in the adoption of the previously developed prodders.

It is important to underline that this intelligent prodder is not intended to be used directly for searching mines, but as a complementary tool to recognize the material of a suspected object once it has been detected by using other tools (metal detectors, GPR, etc.). According to the statistical data many accidents on deminers occurs during prodding and excavation; as a consequence the realization of an intelligent prodder could help deminers to recognize the material just when a small part of the suspected object is cleared.

The device conceived is based on piezoelectric actuating and sensing strategy and the elaboration of the obtained output signals was performed in frequency domain. Moreover, another advance was the integration of the prodder with other sensors such as a force sensor and an inclinometer.

The choice to integrate a potentiometer coupled with a calibrated spring as force sensor has the function to guarantee a constant application force since the operator's hand cannot assure it. This introduces the advantage to have a good repeatability of the piezoelectric response. The inclinometer gives useful information on the angle of attack to improve the reliability of the contact. A prototype was built and characterized in laboratory and outdoor in a simulated minefield. The activity had several phases: the study of state of art, the development of a recognition strategy and the design, fabrication and characterization of the instrumentation.

Introduction

One of the most important application fields for material recognition is humanitarian demining [1]. The prodder is mainly adopted as a complement to the metal detectors, so that once a possible target has been detected, the prodder is used to unearth an object from the terrain for the identification; nevertheless it still remains the major cause of accidents during demining operations [2]. This issue is primarily determined by two factors: when a classical prodder is used to recognize the object, the deminer often has not idea of the real force he is exerting on the unknown material surface and of the angle with which the object is approached.

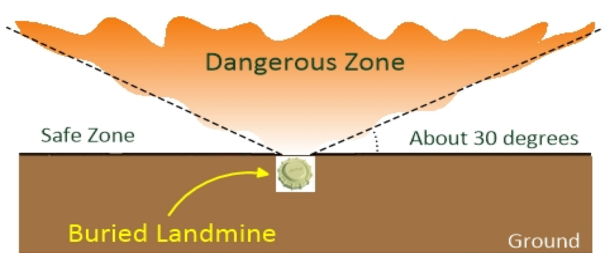

Fig. 1 Impact angle between prodder and terrain. It's possible to distinguish the dangerous zone from the safe one.

As it can be seen in Fig 1, the deminer should touch the object with an impact angle not greater than 30 degrees [3].

The intelligent prodder developed by this research team, within the EC project TIRAMISU [4], is equipped with two sensing units capable of giving continuous feedback information about the force applied to the unknown material and the contact angle between the ground surface and the direction of approach and to alert the operator when one of these parameter is out of safe range.

The recognition principle exploited is based on the analysis of the frequency response of a piezoelectric sensor. Any material in fact, when stimulated by a mechanical stress exhibits a particular deformation, due to the oscillatory motion of its external atoms [5]. This deformation depends on the intrinsic characteristics of the material and can be

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estimated using the direct piezoelectric effect. A piezoelectric sensor is in fact composed of a material that, when subjected to a deformation, produces an output voltage. Once the piezoelectric response is acquired, the recognition process ends with a second phase. The acquired signal is first analyzed in the frequency domain, by extracting the spectrum via a specific algorithm, then the spectrum is compared with other known spectra (as it can be seen in Fig. 2) of responses, relating to a set of materials previously processed and stored in a database.

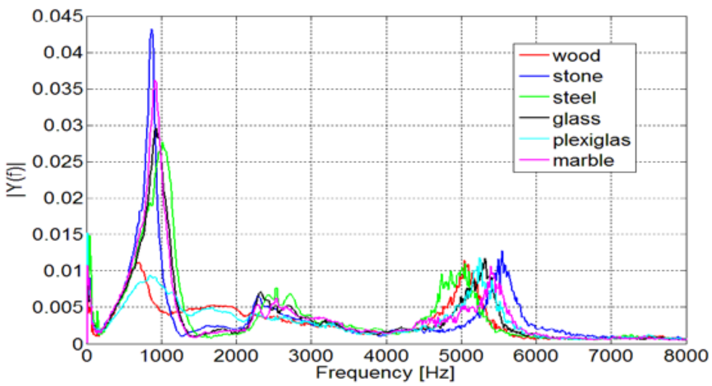

Fig. 2: Some characteristic frequency spectra for known materials. As it can be observed the hardest materials (e.g. steel, marble, stone) have a resonance peak at a higher frequency, differently from the softer materials (mine, wood).

Intelligent prodder

In this paragraph a detailed description of the developed instrumented prodder is given. The system can be used in many application fields where a material classification is required. It was decided to develop an active probe whose scheme is shown in Fig. 3

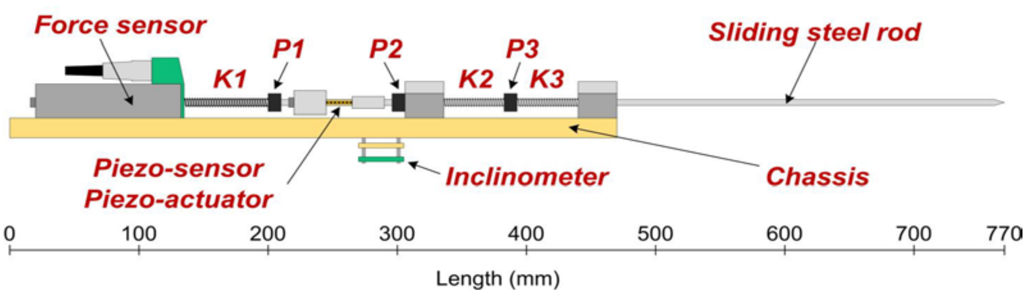

Fig. 3: Scheme of active probe.

This system is composed by four principal components:

- A pair of piezoelectric transducers, used as actuator and sensor.
- A force sensor used to know the force applied to solicit the materials.
- An accelerometer, which is used as inclinometer.
- A mechanical system composed of a chassis, a sliding steel rod, and other elements.

The main elements of the developed active probe are the two piezoelectric transducers. The first one is used as actuator to apply the mechanical solicitation to the material to be recognized through reverse piezoelectric effect, while the second one as sensor to transduce the response of the material.
The output voltage of the piezoelectric sensor is manipulated by a conditioning circuit, developed in order to allow the interfacing between the probe and the elaboration system. It includes an instrumentation amplifier to convert the differential signal of the piezoelectric sensor to a single ended signal, a low-pass filter to eliminate high frequency noise, a linear compression circuit, and a protection circuit.

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The force sensor has been implemented by using a position sensor and a system composed of some springs and pivots (K1, K2, K3, P1, P2 shown in Fig. 3), able to perform a linear position-force conversion. The choice of the spring constant values is related to the maximum applicable force to the material. This value must be lower than a safety threshold, but at the same time fixed and sufficiently high to give to the material surface a suitable solicitation. The force applied by the probe on material is equal to algebraic sum of three elastic forces:

$$\mathrm{R} = \mathrm{K1} + \mathrm{K2} + \mathrm{K3}$$

The pivots P1, P2 and P3 are fixed directly to the steel rod of the probe to define the working condition of the springs. When a force is applied, the springs K1 and K2 are compressed while K3 is expanded. Knowing the length and the spring constants of each springs, the conversion by displacement to force can be obtained. This element has a double role: to give force feedback information to the operator and to guarantee the repeatability of the solicitation to the surface material. As said before when material recognition is applied to humanitarian demining operations it's very important to know the impact angle with terrain surface, because for safety reasons the operator must stay out of the dangerous zone (as shown in Fig.1). For this reason a triaxial accelerometer has been mounted and calibrated to operate as inclinometer.

Experimental validation and results

Fig. 4: Samples of materials used to test the experimental setup.

The frequency spectra for the six materials shown in Fig. 4 have been calculated by averaging 150 trials (training set). Then, 100 additional experimental tests for each material (test set) have been carried out to perform the material recognition and test the validity of the proposed approach. This preliminary test (both training and test set) have been performed in laboratory with an impact angle of zero degrees, as it can be seen in Fig. 5:

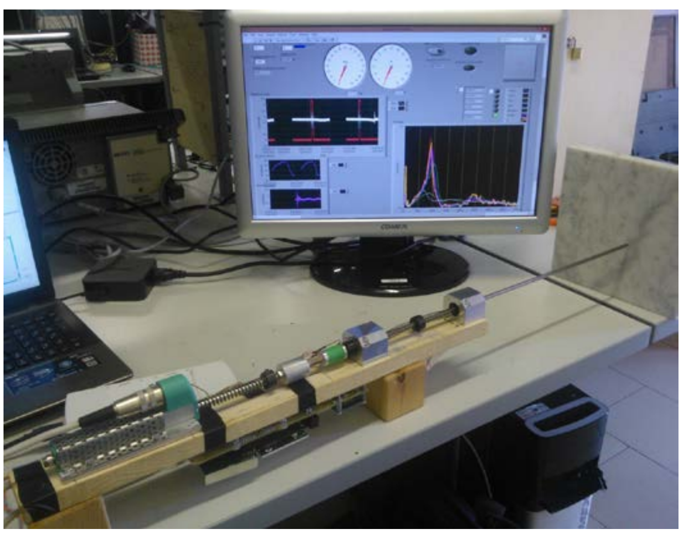

Fig. 5: The experimental setup: the instrumented prodder, a sample of marble and the monitor showing the graphic user interface of the material classification software.

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Results obtained during these preliminary evaluation tests are reported in Tab. 1:

Tab. 1: Experimental results obtained by carrying out 100 tests for each considered materials.

IN \ OUT	*Wood*	*Plexiglass*	*Steel*	*Glass*	*Marble*	*Stone*
Wood	83	17				
Plexiglass	3	97				
Steel			94	9		
Glass			4	96		
Marble					89	11
Stone					9	91

By reading the data obtained and presented in Table 1, it can be summarized that the failed tests have been 53 out of 600 performed, which corresponds to a rate of 8.83%. It should be observed however that these failed tests are among materials that are similar in term of their stiffness.

Conclusion and future trends

This paper describes the work carried out in order to develop an intelligent prodder able to perform a classification of different materials, exploiting the direct piezoelectric effect. An experimental prototype has been designed and fabricated to test the validity of the proposed working principle. The prodder is also equipped with a force sensor and an inclinometer in order to give a useful information feedback and to guarantee the repeatability of the applied mechanical stress. Laboratory experimental trials, with several materials, have been performed and the instrumented prodder has exhibited promising results.

Acknowledgments

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References

[1] S. Baglio, L. Cantelli, C. Costantino, F. Giusa e G. Muscato, «A survey on instrumented prodding techniques for landmine recognition,» in *10th International Symposium on Humanitarian Demining coupled with the 11th IARP WS HUDEM’2013*, Šibenik, Croatia, 2013.

[2] J. Trevelyan, «Statistical Analysis and Experiments with Manual Demining,» in *EUDEM2-SCOT conference on requirements and technologies for the detection, removal and neutralization of landmines and UXO*, Brussels, 2003.

[3] N. Furihata and S. Hirose, “Development of Mine Hand: an Extended Prodder for Protected Demining Operations,” *Journal of Mine Action (JMA),* vol. 18, no. 3, 2005.

[4] Tiramisu project web-site http://www.fp7-tiramisu.eu/.

[5] S. Kocis e Z. Figura, Ultrasonic measurements and technologies, London: Chaoman & Hall, 1996.

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