Electromagnetic Imaging System for Weapon Detection and Classification

Abdalrahman Al-Qubaa, Gui Yan Tian, John Wilson
School of Electrical, Electronic and Computer Engineering
Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
Abd.qubaa@ncl.ac.uk, g.y.tian@ncl.ac.uk, john.wilson2@ncl.ac.uk

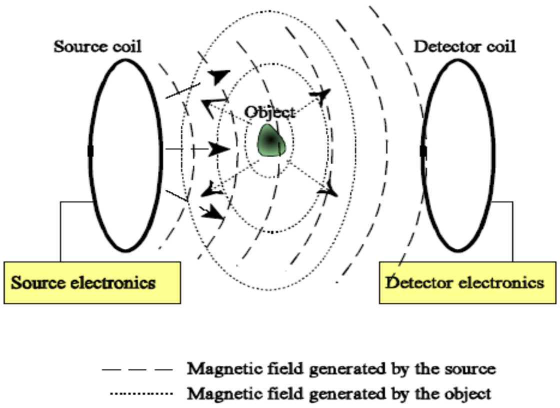
***Abstract*- The detection of concealed weapons is one of the biggest challenges facing the security community. It has been shown that each weapon can have a unique fingerprint, which is an electromagnetic signal determined by its size, shape, and physical composition. Extracting the signature of each weapon is one of the major tasks of any detection system. This paper addresses the issue of identifying conductive objects based on their response to electromagnetic fields. A system developed at Newcastle University using a walk-through metal detector with a giant magneto-resistive sensor array to measure the spatial magnetic field is used in the study. Threat and non-threat objects have been tested. Image visualization and feature extraction of the electromagnetic field were carried out. Classification was performed using cross correlation. Promising results indicating the feasibility of using electromagnetic imaging to identify objects have been found.**

Keywords- sensor array; electromagnetic imaging; weapon detection; object recognition; metal detection and classification.

I. INTRODUCTION

There is a growing need for effective, quick and reliable security methods and techniques to identify weapon threats using new screening devices [1]. Electromagnetic (EM) weapon detection has been used for many years, but object identification and discrimination capabilities are limited. Many approaches and systems/devices have been proposed and realised for security in airports, railway stations, courts, etc. The fact that most weapons are made of metallic materials makes EM detection methods the most prominent and systems/devices built on the principle of EM induction have been prevalent for many years for the detection of suspicious metallic items carried covertly [2]. Walk-through metal detector (WTMD) and Hand-held metal detector (HHMD) are commonly used devices for detecting metallic weapons and contraband items using the EM field. Most of the WTMD and HHMD units use active EM techniques to detect a metal objects [1, 3, 4] see Fig. 1. Active EM means that the detector sets up a field by a source coil and this field is used to probe the environment. The applied/primary field induces eddy currents in the metal under inspection which then generate a secondary magnetic field that can be sensed by a detector coil. The rate of decay and the spatial behaviour of the secondary field are determined by the conductivity, magnetic permeability, shape, and size of the target. Sets of measurements can be then taken and used to recover the position, the size and the shape of the objects.

a)



b)

Fig.1: a) PMD2 WTMD metal detector[3]. b) Diagram of a metal detector with an object inside the detection space[4].

Many other EM techniques have been also used in WTMD, such as Microwave imagers based on the EM Reflectometer principal [5], a wide bandwidth, time-domain EM sensor system to measure the eddy current time-decay response of a wide variety of metal targets [6], other advanced EM technique such as a magnetic real-time tracking vector gradiometer RTG using high-resolution fluxgate magnetometers used for incorporation into an unmanned underwater vessel to improve mine detection which comprises three primary three axis sensors and one three-axis reference sensor [7].

Currently available weapons detection systems are primarily used to detect metal and have a high false alarm rate because the WTMD works on adjusting threshold to discriminate between threat items and personal items, depending on the mass of the objects which means increasing the false alarm level (Fig. 2) [8, 9], also a human body has affected the sensitivity of the detector so when dealing with low conductivity or small materials, the human body could give a stronger signal than the material. This would cause the material to pass undetected, giving poor reliability [10].

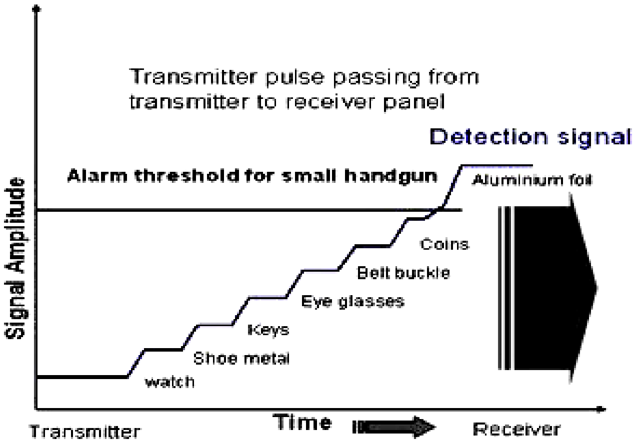


Fig. 2: Cumulative signal effects in active walkthrough weapon detector.

It can be concluded that the current EM imaging systems have several drawbacks such as: low-resolution images, the shape captured of EM signal not corresponding to the actual shape of objects, lack of detection with multiple objects, high cost for the 2-D array and the signal received correspond to the metal part only.

The aim of this study is to improve the characterisation capabilities of EM systems, especially in terms of object identification and classification, using visualization of an EM signal. A system developed at Newcastle University [11] and built in a lab using an ex-service CEIA WTMD, with the addition of a giant magneto-resistive (GMR) sensor array to capture the EM data, is used in this study. Features are extracted and integrated from the EM image to visualize, identify and classify metallic objects using cross correlation techniques.

This paper is organized as follows: Section II will describe the system design and set up. Section III will present the details of the classification approach and results and is followed by the conclusions and future work in Section IV.

II. TEST SYSTEM AND PRINCIPLES OF OPERATION

A. System design

The system used for the experimental tests is based around an array of NVE GMR sensors [12] used in conjunction with the excitation coil in an ex-service CEIA WTMD. Fig. 3 shows a block diagram of the system.

Fig. 4 illustrates the experimental system, converted from a typical walk through system. The signals from the sensor array are amplified using an array of signal amplifiers based on INA111 instrumentation amplifier. Data acquisition is performed using an 80 channel PXI based National instruments data acquisition system. The use of the PXI based system allows data to be acquired on 40 channels at a rate of 125kS/s or 80 channels at a rate of 62.5kS/s. The channel count is further increased to a maximum of 160 by the use of multiplexer circuits. A variable excitation waveform is provided by a function generator, the signal from which is also used for data acquisition synchronisation. The signal is amplified by a Kepco BOP 36-12ML bipolar power supply operating in constant current mode.

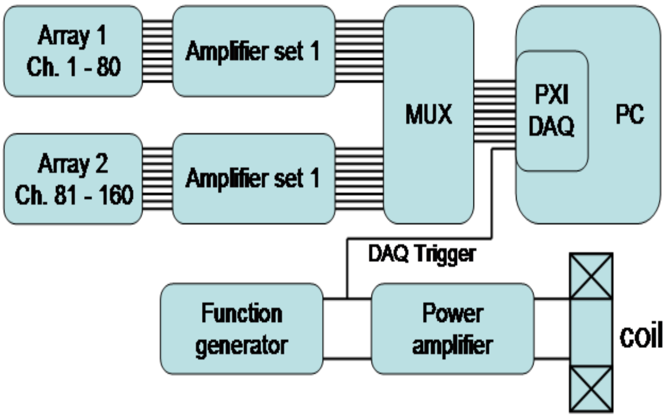


Fig. 3: System block diagram

Fig. 4: System set up in a lab at Newcastle Uneversity.

The AAL002-02 GMR sensors were chosen because of their sensitivity and noise suppression compared with other common sensors such as Hall Effect models [13]. The AAL002-02 has a linear range of 0.15mT–1.05mT and a sensitivity of 4.5µV/T. The L in the sensor model name indicates that low hysteresis (maximum 2%) GMR material has been used fabricate the sensor, this was chosen because it was initially intended to utilise an applied magnetic field varying from 0 to a maximum value and the lower hysteresis would minimise error at low fields. However, after initial tests, it was found that a more stable signal could be achieved by biasing

 ISBN: 978-1-61208-144-1

the sensor response into its linear region using a DC offset superimposed on the excitation signal.

B. Electromagnetic field imaging

Fig. 5 illustrates the different metallic objects and their EM field images. The samples represent common threat and personal objects carried by peoples. Five experiments have been carried out with each item and their capturing condition can be summarized below:

1. The object under inspection is moved through the detector with data acquired at a pulse repetition rate of 500Hz.
2. Sets of 10 pulses are averaged to produce a single pulse response to improve signal-to-noise ratio.
3. A single value is computed from each pulse response. In this case the maximum value of the difference signal (with object and without object) has been used.

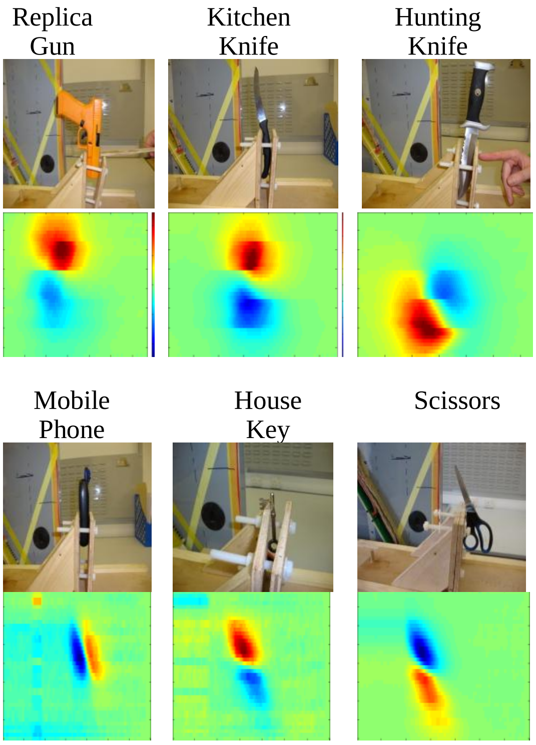


Fig. 5: Samples with the equivalent EMIs.

Thus the temporal EM field distribution as the object moves past the array can be determined. The sensors array is aligned with the coil to pick up any distortions in the applied field due to the presence of metallic materials, the interaction between the applied field and any sensor in the array will be capture and the pulse response from a group of sensors will be stored. If no object is present in the WTMD, the field measured by the sensor is unchanged; the presence of a metallic object causes a distortion of the field, which can then be measured by the sensor.

In the system, pulsed excitation is applied to the coil. Pulsed excitation provides the opportunity to apply an interrogating field with rich frequency components in a single waveform. In the tests detailed in this paper, a pulse repetition frequency of 500Hz is used with a pulse width of 1ms and an applied current of 0.5A – 1.5A.

C. Transient analysis

In order to extract more information about the objects in the WTMD from the test results, a form of transient analysis has been employed. In this transient EM signature imaging technique, the pulse response from each sensor is analysed and processed into sections, or time slots, as shown in Fig. 6a.

The values of the samples in each time slot are averaged, and using the data from all sensors for the whole test, an image is built up for each time slot. Fig. 6b shows a sequence of these transient images for the hunting knife.

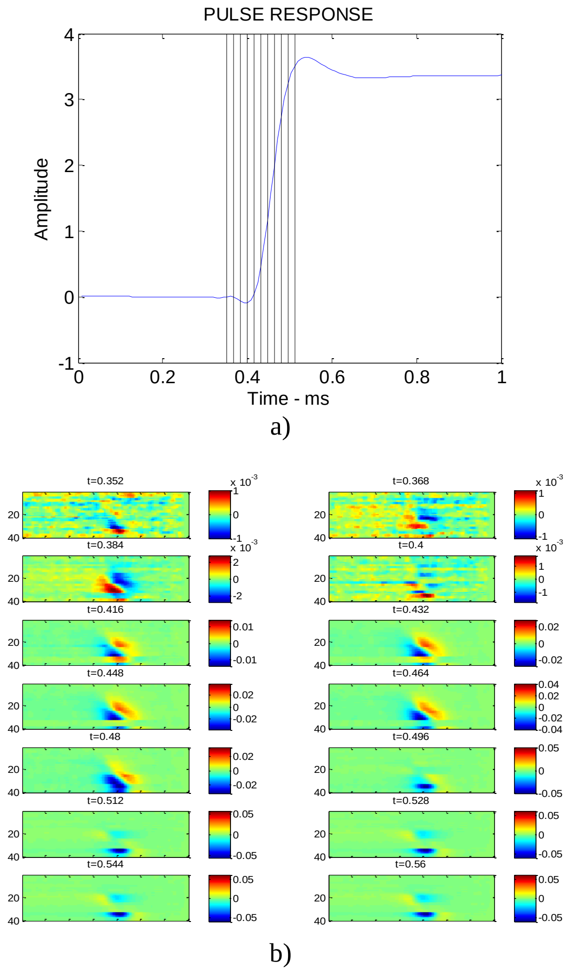
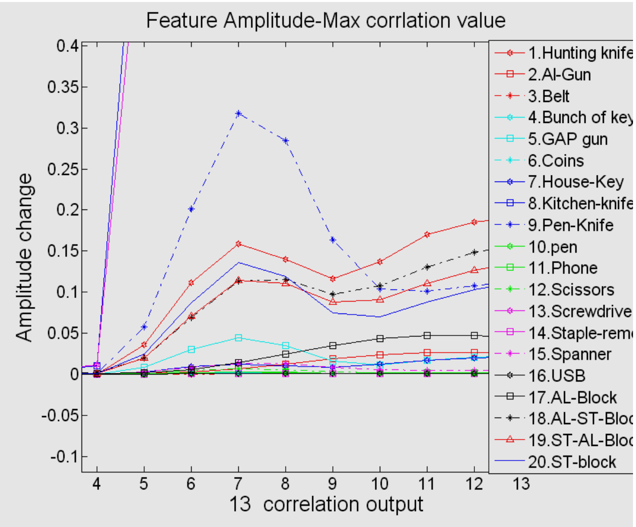


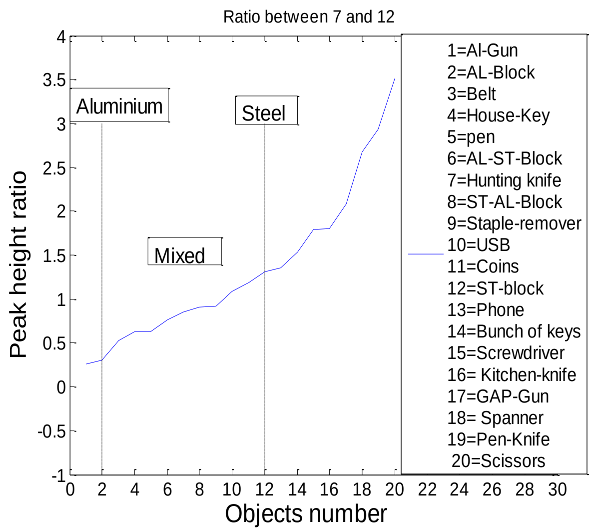
Fig. 6: a) Pulse response with time slots marked, b) Result of imaging the transient response from the hunting knife.

III. OBJECT CLASSIFICATION

Analysis of the transient image sequence can be used to extract more information about the object under examination especially for object classification. For example, it has been observed that aluminium objects exhibit a tendency for the EM signature to appear later in the image sequence and to increase in intensity over time. In contrast, the EM signatures corresponding predominantly to ferromagnetic objects, such as the hunting knife, have a tendency to appear earlier in the sequence, peak in amplitude at a particular point and to change in distribution over time. Consequently, through analysis of the image sequence generated by the transient analysis, any object detected by the system can be classified. An example of this is shown in Fig. 7, where a cross correlation technique has been applied to the transient image sequence [14] and processed to classify the objects into paramagnetic (aluminium=AL-block), ferromagnetic (steel=ST-block) and combinations of both. Fig. 7a represents a maximum cross correlation values between each two frames. Fig. 7b shows the result of computing the ratio between two peaks which are evident in the cross correlation plot shown in Fig. 7a, where different objects have unique transient features reflecting materials and geometrical characters. The results can be applied for object classification and are sorted by ascending amplitude. It can be seen from Fig. 7b and Table 1 that a clear distinction can be made between paramagnetic, ferromagnetic and mixed objects thus allowing very good discrimination.



a)



b)

Fig. 7: Material determination through transient analysis; a) Cross-correlation between images in transient sequence for 20 different objects, b) Peak height ratio for results shown in (a).

TABLE 1: CLASSIFICATION RESULTS

Class 1 Para-magnetic	Class 2 Mixed	Class 3 Ferro-magnetic
AL-Gun	ST-AL-Block	ST-Block
AL-Block	AL-ST-Block	Screwdriver
	Hunting-Knife	Kitchen Knife
	House-key	Pen-Knife
	Belt	Gap-gun
	Stapler-rem.	Scissors
	Coins	Spanner
	USB	Bunch of keys
	Pen	Phone

IV. CONCLUSION AND FUTURE WORK

This paper has demonstrated a new EM metal detector system and investigated the feasibility of visualizing the EM signal in a WTMD for object identification and classification purposes. A system to obtain the EM images has been built and features have been selected using the cross correlation between 14 EM frames to discriminate between the 20 different objects depending on the material properties. The system show promising results for the visualisation of EM signal especially in security applications.

In comparison with conventional induction based WTMDs, the GMR array based system has shown great potential in material discrimination as the samples are made from mixed material is clearly distinguished. Whereas the induction based WTMD can only discriminate between metal and non-metal, this system has taken it a step further. The proposed cross correlation technique is more advanced in object characterisation as it depends on the amplitude distribution of the EM field making training possible using a database of objects; unlike traditional thresholding adopted in the induction based system, which largely depends on material volume. On the whole the conventional WTMD based system had a limitation to present results in images, however, the proposed system has superior performance when using proposed sensor in terms of using imaging for localisation and material discrimination as buttressed by the results discussed in this paper.

The discrimination capabilities of the system could be developed to the point that individuals could pass through the system without removing metallic objects from their person. This would be realised through "training" the system to identify threat objects by presenting the system with a wide variety of threat and non-threat objects and programming the response accordingly.

Further study is necessary to extend these results to smaller metallic objects in not controlled environment to investigate concealed weapons. EM images from other objects will be investigated and compared with the results of this study. Other features such as: metallic density, total area of metallic density

 ISBN: 978-1-61208-144-1

and metal proprieties will be investigated. Features will be optimised and prepared to use as input data in a classification algorithms.

ACKNOWLEDGMENT

This project is funded under the Innovative Research Call in Explosives and Weapons Detection (2007), a cross-government programme sponsored by a number of government departments and agencies under the CONTEST strategy. The authors would like to thank cross-government departments for joint experimental tests.

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