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Design of an electromagnetic imaging system for weapon detection based on GMR sensor arrays

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ABSTRACT

Concealed weapon detection is one of the most challenging issues facing the security community. It has been shown that each weapon can have a unique fingerprint, which is a set of electromagnetic (EM) signals determined by its size, shape, and physical composition. Extracting the signature of each weapon is one of the major tasks in any detection system. This paper addresses the design of a detection system for the identification of conductive objects based on their response to EM fields. The system consists of commercial Walk-Through Metal Detector (WTMD) and a Giant Magneto-Resistive (GMR) sensor array has been designed and built. Also, this paper describes how to construct a two-dimensional image from the measured signals to be used for image processing purposes. The system validity is then checked based on two concepts: data validation and multiple object separation. Finally, initial experimental work on the automatic detection and classification of different metallic objects has been carried out. The promising results indicate the feasibility of using this EM imaging method to identify objects.

1. Introduction to imaging and weapon detection technologies

In light of the abuse of guns and knives, automatic detection and characterisation of weapons has attracted much attention in recent years. Many approaches and systems have been proposed and realised for security in airports, stations, law courts, etc. The fact that most weapons are made of metallic materials makes electromagnetic (EM) detection methods it the most prominent methodology and systems built on the principle of EM induction have been prevalent for many years for the detection of suspicious metallic items carried covertly.

The Walk-Through Metal Detector (WTMD) is a commonly used device for detecting metallic weapons and contraband items using EM fields. Most WTMD units use active EM techniques to detect and classify metal objects, see Fig. 1 [1–5]. An active EM field, in this instance, means that the detector sets up a field using a source coil, this field is then used to probe the environment. The applied, or primary, field induces eddy currents in the metal under inspection, which then generates 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 target's electrical conductivity, magnetic permeability, shape, and size. Sets of these measurements can be then taken and used to recover the material, position, size and shape of the objects.

EM imaging has potential applications in medicine [6] and industry [7] using the Magnetic Induction Tomography (MIT) technique. MIT is an imaging system based on the same principle as the WTMD. It is based on an image's spatial distribution of the electrical conductivity and magnetic permeability of objects [8]. MIT applies a magnetic field from an excitation coil to induce eddy currents in the material to be studied; the magnetic field from these is then detected by sensing coils. MIT is sensitive to all three passive EM properties: conductivity, permittivity and permeability.

Fig. 2 shows how a ferrite and copper bar can be distinguished using MIT [4]. The image is reconstructed using an inverse algorithm [9], however this solution is frequently poor because of the nonlinear relationship between scattered field and object. A poor solution means poor image quality and consequently reduced detectability [10].

This magnetic imaging technique has been used to detect and discriminate between objects using several receivers and a single transmitter as detailed in [11]. The spatial resolution of this prototype system is presently 5 cm. Consequently, the image of a handgun would not be precise but it would be discernible. The inverse problem in this system is solved by a complex mathematical process, which adds more complexity.

Microwave imagers have been developed based on the EM Reflectometer (EMR) principal, EMR measures the EM waves reflected from an item in the wave-illumination region. Images can be built up by scanning the device over the object under

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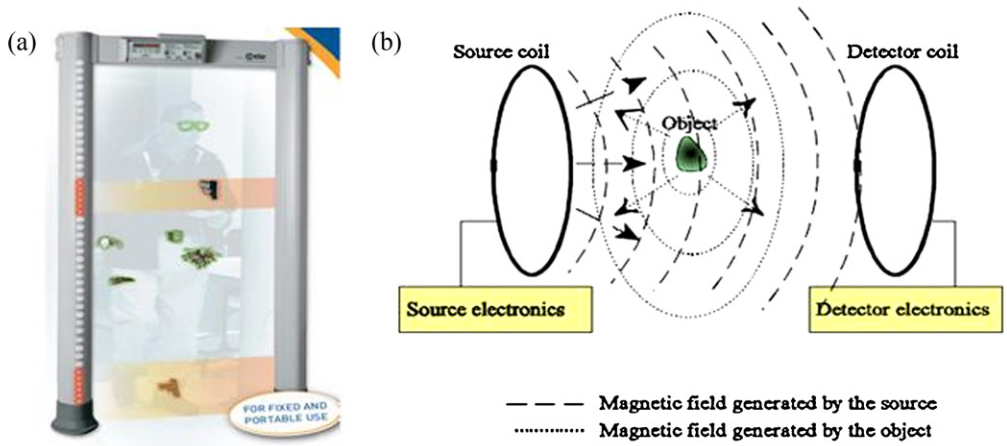

Fig. 1. (a) PMD2 WTMD metal detector [2]. (b) Diagram of a metal detector with an object inside the detection space [3].

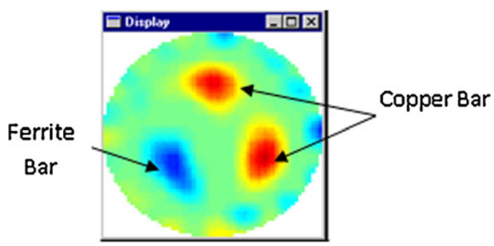

Fig. 2. Discrimination between a ferrite bar and two copper bars using the MIT system [4].

inspection, or using an array of antennae comprising of multiple pairs of transmitters and receivers [12], as shown in Fig. 3. An antenna array is moved around a person by a cylindrical shaped mechanical scanner. The scan takes 4–7 s before 3D cylindrical holographic images are produced. The holographic imager can detect threats such as weapons constructed of metal, plastic and ceramic as well as explosive solids and liquids. Although these systems can produce very impressive results, a constrained environment is required.

Currently available weapons detection systems primarily detect metal objects, they are either large in the case of WTMD, giving the possibility of circumvention, or for the hand-held metal detector require close proximity to the person being searched, putting the operator at risk [13]. Additionally, the WTMD works with an adjustable threshold to discriminate between threat items and personal items, depending on the mass of the object, which can increase the false alarm level, see Fig. 4 [14]. Furthermore the human body itself affects the sensitivity of the detector, so when dealing with a material with a low conductivity or small size, the human body may mask the signal of the object causing the material to pass undetected, resulting in a poor reliability of detection [15]. There are several other EM techniques used for gun detection such as: millimetre waves (MMW) [16], terahertz (THz) imaging [17] and infrared imaging [18]. Each of these techniques has advantages and disadvantages.

It can be concluded that the current EM imaging systems have several drawbacks; low image resolution, the shape of the EM signal may not correspond to the actual shape of objects, poor detection in a multiple object scenario, high cost, privacy invasion issue (when using MMW and THz), harmful (using X-ray) and the signal received only corresponds to the metallic part of the material which may hinder the detection and classification of concealed weapons. All these increase the false alarm rate of EM detection.

This paper details the design and operation of a new metallic object detection system utilising an array of Giant Magneto-Resistive (GMR) sensors in conjunction with pulsed excitation to develop a new WTMD for deployment in unconstrained environments, i.e. without users divesting themselves of metallic items. This paper also describes how to construct a two-dimensional image from the measured signals to be used for image processing purposes. The system validity is then checked based on two concepts: data validation and multiple object separation. Finally, initial experimental work on the automatic detection and classification of different metallic objects has been carried out.

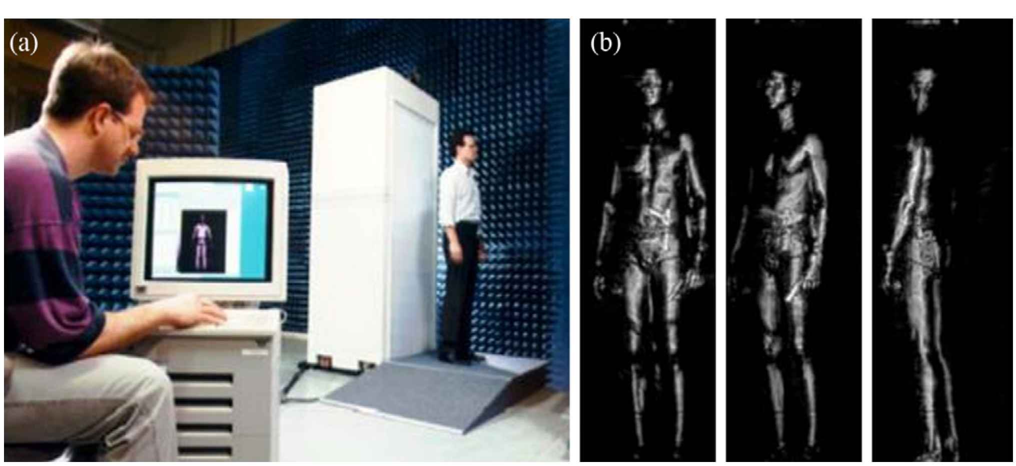

Fig. 3. A microwave imager for body inspection: (a) the inspection system, and (b) microwave images of a person carrying two concealed guns [12].