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Efficient and Safe Wireless Multi-Sensor Landmine Detection System Using Image Fusion through SC-FDMA Transmission

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ABSTRACT

Landmines are one of the biggest problems affecting many counties in the world. As effectively finding a land mine using only one sensor is often impossible so we propose an efficient and safe wireless landmine detection system which uses various and complementary sensors which respond to different specific physical attributes in parallel connected to data logger and fuse their output images to have one image to decrease the false alarm rate as weaknesses of one sensor are compensated by inherent strengths of other sensors, resulting in good performance of the whole system. This wireless system is controlled remotely and collected data are transferred to the base station using SC-FDMA wireless communication system. The proposed system is not only make the landmine detection safe as it is controlled remotely and carried out by small aircraft to avoid detonating the land mines but also speed up the de-mining process as it can be used efficiently under huge variety of environmental conditions with high detection possibility rate.

Keywords: *Image Processing; Wireless Communication; Communication*

I. INTRODUCTION

According to estimates from The United Nations, there are approximately 60 to 70 million landmines polluting the environment in about 70 countries around the world (most polluted countries are illustrated in table 1). The number of polluting mines is still increasing because mine clearance operations proceed much more slowly than mine lying. These hidden killers maimed or killed approximately 26,000 civilians, the majority of whom are children [1].

Landmines can be easily manufactured. They are inexpensive and can be deployed with little effort. The main problem in eliminating these hidden killers from the earth is the clearance rate as the process of de-mining is slow, expensive and dangerous. At the present clearance rate it will take years to detect and neutralize the mines buried all over the world. The other requirements for an efficient landmine detection scheme are a low Probability of False Alarm (i.e., the probability of detecting a mine when the subsurface target is clutter) and a high Probability of Detection [1].

Originally, mines were detectable because of their metal content. Unfortunately, in the fast developing mine technologies, new materials that may last for many years, have made it possible to produce varieties of mines that are practically undetectable with the existing methods (metal detectors). With those methods it is still very difficult to make a distinction between the detection of a simple (metal) object and a landmine.

The most serious problem in mine detection applications is the ambiguity of the target signal. In order to overcome this ambiguity problem, most research has been conducted in two ways. Firstly, methods to extract multiple signals from a source or to enhance the ambiguous signal to a noticeable level have been studied. Secondly, many research groups have developed a new detection device with multiple sensors, called sensor fusion. Of course, the development of new kinds of sensors is another possibility.

II. UNMANNED MINE DETECTION MULTI-SENSOR SYSTEM

Wireless connection through SC-FDMA is proposed between the local controller on an aircraft and general controller (personal computer) that is installed at the outside of the minefield at the control room to handle the whole navigation procedure (see figure 1). The general controller is responsible for mapping the landmines and determining some general settings for local controller.

At the transmitter, the image is firstly converted to a binary form in the "Image Formatting" block suitable to be transmitted and processed by SC-FDMA System. The SC-FDMA transmitter starts by an encoder then modulating the input signal using binary Quadrature Phase Shift Keying (QPSK). The outputs are then mapped to M ($M > N$) orthogonal subcarriers followed by the M-points IDFT to convert to a time domain complex signal sequence. $M = QN$ is the output block size. Q is the maximum number of users that can transmit. The subcarrier mapping assigns frequency domain modulation symbols to sub-carriers. It also adds a set of symbols as cyclic prefix (CP) in order to provide a guard time to prevent inter-block interference due to multipath propagation. The cyclic prefix is a copy of the last part of the block. It is inserted at the start of each block. Then transmitted data propagates through the channel [4].

At the receiver, the CP is removed then the received signal is transformed into the frequency domain in order to recover sub-carriers. The de-mapping operation isolates the frequency domain samples of each source signal. Because SC-FDMA uses single carrier modulation .Then, the samples are passed through the Frequency Domain Equalizer (FDE). After that, the inverse transform at the receiver transforms equalized symbols back to the time domain. The demodulation process recovers the original data, which is passed through the decoder. The Image reconstruction used to convert the binary form to an image to recover the original image.

Table 1: Quantity of Landmine Distribution in Various Countries and Clearance Performance [2, 3]

Countries	Mines (million)		Cleared Mines	Mined Area (km^2)	Cleared Area (km^2)	Casualties
	UN	USSD				
Afghanistan	10	7	158,000	550~780	202	300~360/month
Angola	15	15	10,000	Unknown	2.4	120~200/month
Bosnia	3	1	49,010	300	84	50/month
Cambodia	6	6	83,000	3,000	73.3	38,786 or 100/month
Croatia	3	0.4	8,000	11,910	30	677
Egypt	23	22.5	11,000,000	3,910	924	8,301
Eritrea	1	1	Unknown	Unknown	2.48	2,000
Iran	16	16	200,000	40,000	0	6,000
Iraq	20	10	37,000	Unknown	1.25	6,715
Laos	NA	NA	251	43,098	Unknown	10,649 or 16~18/month
Mozambique	3	1	58,000	Unknown	28	1,759
Somalia	1	1	32,511	Unknown	127	4,500
Sudan	1	1	Unknown	800,000	0	700,000
Vietnam	3.5	3.5	58,747	Unknown	65	180/month

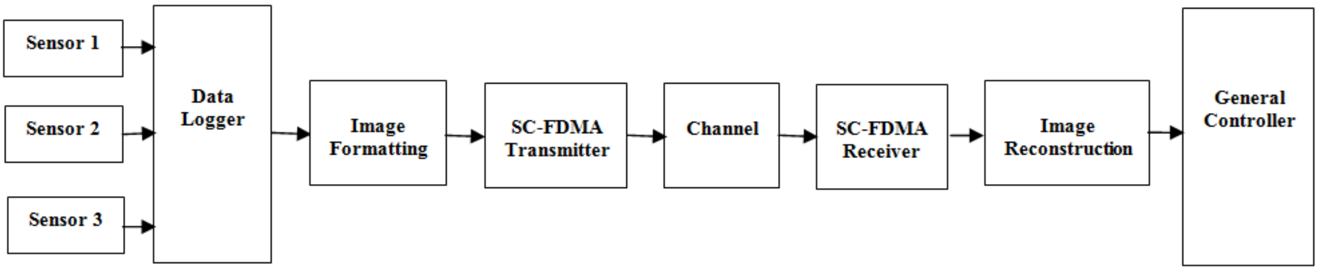

Fig. 1: Proposed Wireless System

A. *The Proposed Sensors*

Effectively finding a land mine using only one sensor which illustrated in figure 2 is most often impossible so it is better to use several sensors which respond to different specific physical attributes [1, 5, 6].

In our proposed de–mining system we propose to use three different types of sensors to improve the performance such as nuclear radiation sensor, metal detector, Infrared camera and ground penetrating radar.

A.1 Metal Detector

Mines had a significant amount of metal content in them. Therefore, metal detectors based on the principle of Electro Magnetic Induction (EMI) were developed to detect the presence of metal in the mines. The advantage of using the metal detector is its compact structure and a relatively simple principle of operation.

Metal detectors are inexpensive, light weight and easy-to-use tools, but the main problem with the metal detector is the high false-alarm rate because there are many other metallic objects, like bullet casings or shrapnel under the ground in the minefields that can also be detected as mines. Moreover, this technique cannot detect landmines with a small metal content such as the modern plastic landmines. It cannot discriminate between landmines and metal debris, which causes high false alarm rates [5, 6].

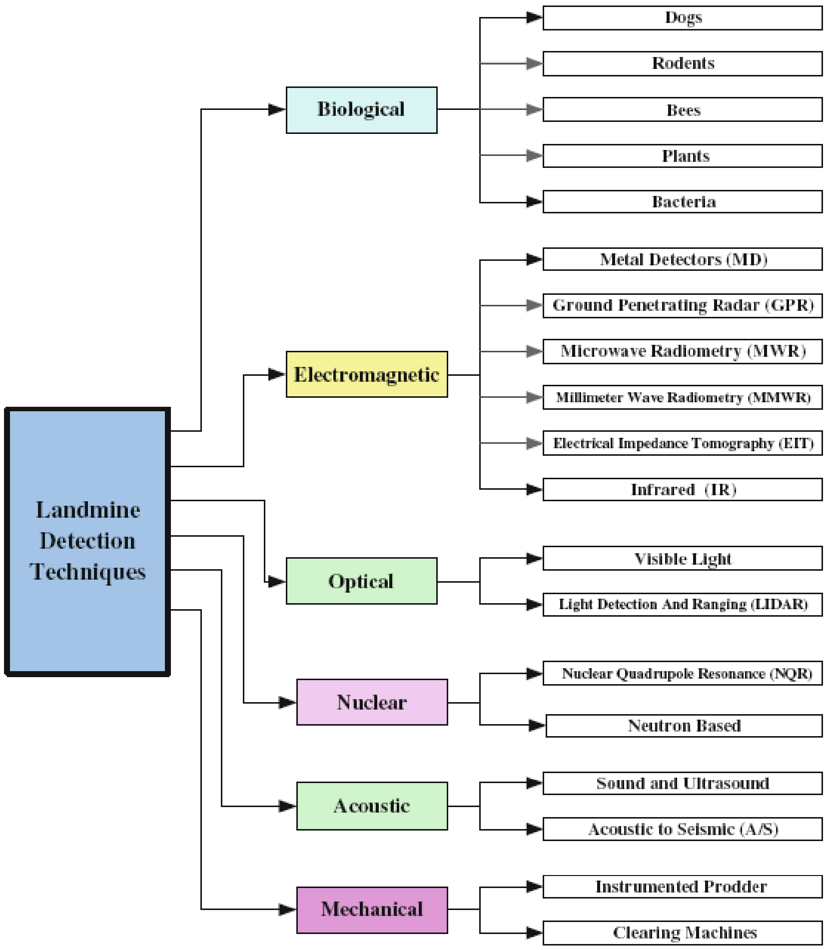

Fig. 2: Landmine Detection Techniques

A.2 Ground Penetrating Radar (GPR)

GPR transmits short pulses of high frequency electromagnetic energy into the ground from a transmitting antenna. These waves propagate into the ground with a velocity that depends on the dielectric property of the medium. If the waves encounter an interface between two materials with different refractive indices, some of the wave energy is reflected back and the rest continues to propagate to create further reflections. A receiver picks up these reflections and processes them to create an image as shown in Figure 3. The type of material in which the waves of the GPR propagate has a strong effect on the signal penetration and the clarity of the received wave [1, 2, 3, 5].

Ground Penetrating Radar (GPR) can be used for imaging tool due to its high resolution; therefore it would be quite ideal for identification of buried objects that most metal detectors cannot achieve. However, imaging by GPR is very difficult in strongly inhomogeneous material due to strong clutter.

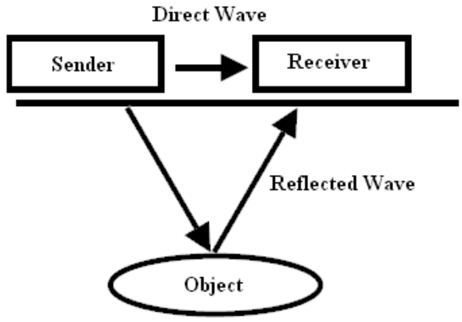

Fig. 3: Image Creation

A.3 Infrared Camera

Landmines are of different shapes and sizes that cause them to have different thermal radiation patterns. Infrared detectors use this property of thermal radiation to differentiate between a mine and clutter. If a certain level of thermal radiation of the soil without the presence of a target is obtained by measurements, then changes in thermal radiation measurement from that obtained from the soil indicate some subsurface target. But it has been proved that soil moisture can produce variations in thermal radiation, which means the difference in thermal radiation detected might not only be because of some subsurface targets. This leads to a significant false-alarm rate. Moreover, the detection of mines is also dependent on the weather conditions, type of soil and the size and shape of the mine as shown in Table 2 which shows a qualitative comparison between landmine detection techniques from the points of view of cost, complexity, speed, safety, false alarm rate and the effect of environmental conditions. IR sensors have difficulty in detecting objects buried deeply [2, 5].

A.4 Nuclear Quadrupole Resonance

The NQR technique is a radio frequency technique, in which the observed frequencies depend on the interaction between the electric quadrupole moment of the nucleus and the electric field gradient generated at the nuclear site by external charges. All common high explosives contain a quadrupole nucleus, which generates three sets of resonance frequencies, providing an unequivocal method for detecting and identifying the explosive. This technique is a derivative of the nuclear magnetic resonance, which is used without the need for an external magnetic field. It can be highly compound specific (each explosive has a unique signature). It is potentially a very low false alarm rate technique. The presence of metallic objects (in particular those containing explosives) can be detected by the detuning effect on the NQR probe. No nuclear radiation is involved. It is impossible to detect substances fully screened by metallic enclosures. The NQR signature of TNT is much stronger than that from a similar amount of RDX [5, 6].

III. DE-MINING SENSORS IMAGE FUSION

Effectively finding a landmine using only one sensor is often impossible so it is better to use various and complementary sensors which respond to different specific physical attributes in parallel and fuse their output images to have one image to decrease the false alarm rate as weaknesses of one sensor are compensated by inherent strengths of other sensors, resulting in good performance of the whole system. In this paper sensors output images are fused either by averaging method or using discrete cosine transform [7, 8, 9,10, 11].

A. Image Fusion Using Averaging

This technique is a basic and straight forward technique to simply combine two images into a single image and fusion could be achieved by simple averaging corresponding pixels intensity in each input image using the following equation [10]:

$$I(a,b) = \frac{I1(a,b) + I2(a,b)}{2}$$

Where I1, I2 and I represent the two inputs and fused images respectively. The fused image is at most equal to but not greater than the contrast of the optical image.

Image averaging is the most commonly used method as it significantly more computationally efficient than most other fusion systems.

B. Image Fusion Based on Discrete Cosine Transform (DCT):

In DCT image fusion scheme, the source images I1(a, b) and I2(a, b) are transferred to frequency domain using DCT then DCT coefficients of both images are combined using fusion rule. The fusion rule used is simply averages the DCT coefficients. The fused image could be obtained by taking the inverse discrete cosine transform (IDCT) [12].

$$I(a,b) = \frac{DCT\{I1(a,b)\} + DCT\{I2(a,b)\}}{2}$$

The 2-dimensional DCT is defined to be [13, 14]

$$Y = C.X\,.\,C^T$$

Where X is an NxN input data, Y contains the NxN DCT coefficients, and C is an NxN matrix defined as:

$$C_{mn}=\text{Cos}[(2m+1)*n*\Pi/2*N]$$

The top-left function is the basis function of the "DC" coefficient and represents zero spatial frequency. Along the top row the basis functions have increasing horizontal spatial frequency content. Down the left column the functions have increasing vertical spatial frequency content [13, 14].

For a "typical" block, most of the DCT coefficients will be near zero. The larger DCT coefficients will be clustered around the DC value (the top-left basis function) i.e. they will be low spatial frequency coefficients.

IV. EXPERIMENTAL RESULTS

The simulation of de-mining process is done in a MATLAB environment and the results are shown in figures 4, 5, 6 and 7. Figure 4 shows candidates of each different sensor and figure 5 shows the output of pre-processing stage, Figure 6 shows the output of the fusion stage using averaging method which contains the most important information. It contains the candidates which only exist at the approximate location in all input images. The fused output image using DCT is shown in figure 7. The simulation of de-mining process is repeated for different groups of sensors output and another results are shown in figure 8, 9, 10 and 11.

V. CONCLUSIONS

An effective landmine detection system is presented. This proposed system uses various and complementary sensors which respond to different physical attributes in parallel and fuse their output images.

This wireless system is controlled remotely and collected data are transferred to the base station using SC-FDMA wireless communication system. The experimental results approved the efficiency of the proposed system and it is not only make the landmine detection safe as it is controlled remotely but enhances the landmine detection probability to be close to one and reduces the false alarm rate which also reduces the de-mining cost therefore results in acceleration of the de-mining operation.

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Table 2: Comparison between the Landmine Detection Techniques [6]

Technique	Sensor	Complexity	Cost	Speed	Safety	Environment effect	False alarm
Biological detection	Dogs	Low	Medium	Medium	Medium	Medium	Medium
	Rodents	Low	Low	Low	High	High	High
	Bees	Low	Medium	Low	High	High	High
	Plants	Medium	Medium	Low	High	High	High
	Bacteria	Medium	Medium	High	Low	High	Low
Electro magnetic detection	MD	Low	Low	Low	High	Low	High
	GPR	Medium	High	Medium	High	Medium	Low
	MWR	Medium	Medium	Low	High	Medium	Medium
	MMWR	High	Medium	Low	High	Medium	Medium
	EIT	Low	Low	Medium	High	High	Medium
	IR	Medium	High	Medium	Medium	High	Medium
Optical detection	Light	Low	Low	Medium	High	High	High
	LIDAR	High	High	Medium	High	Low	Medium
Nuclear detection	NQR	High	Medium	Medium	Medium	High	Low
	Neutron	High	High	High	Low	Low	Medium
Acoustic detection	A/S	Medium	High	Medium	High	Low	Low
	US	Medium	Medium	Low	High	Medium	High
Mechanical detection	Prodders	Low	Low	Medium	Low	Low	High
	Clearing machines	Medium	Low	High	Low	Low	High

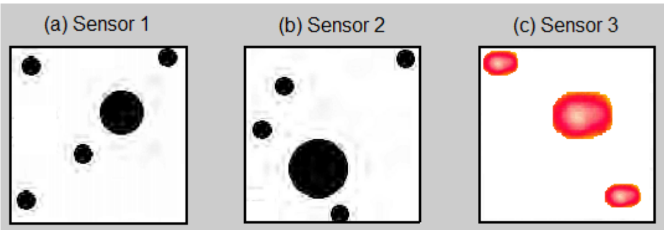

Figure 4: Sensors Data at SC-FDMA Receiver at Control Room; (a) Candidates from First Sensor Image, (b) Candidates from Second Sensor Image, (c) Candidates from Third Sensor Image

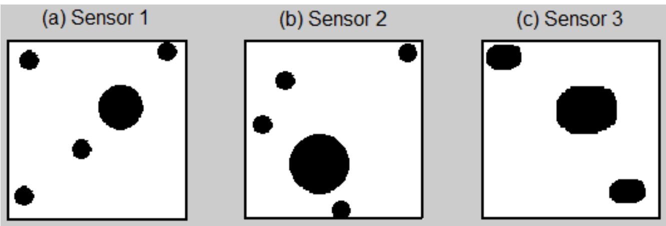

Figure 5: Sensors Data at Control Room after Pre-Processing

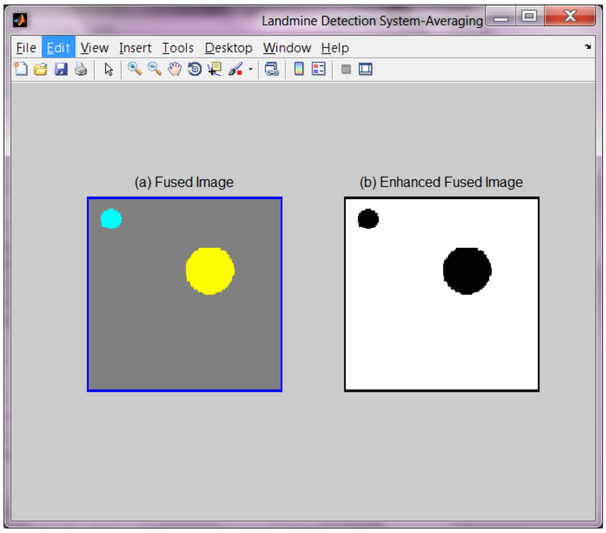

Figure 6: (a) Fused Image of Received Sensors Output Using Averaging Method and (b) Enhanced Fused Image

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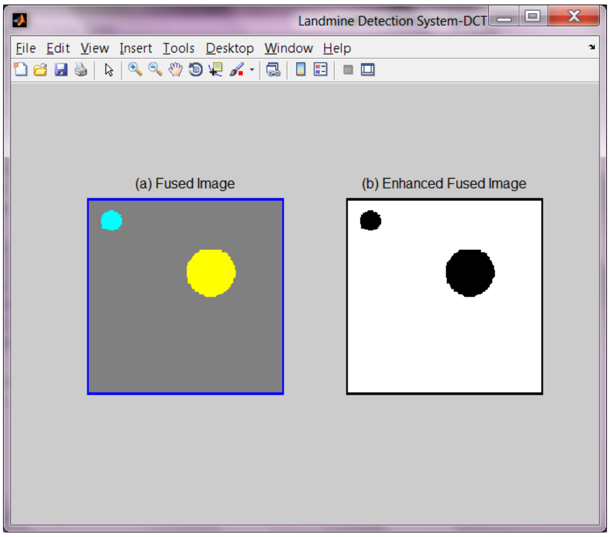

Figure 7: (a) Fused Image of Received Sensors Output Using DCT Method and (b) Enhanced Fused Image

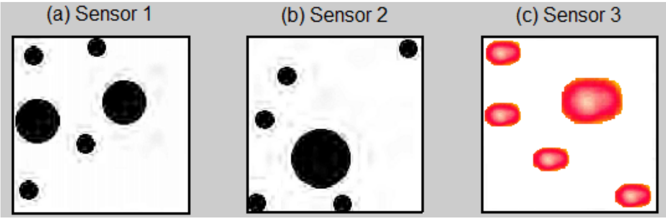

Figure 8: Sensors Data at SC-FDMA Receiver at Control Room; (a) Candidates from First Sensor Image, (b) Candidates from Second Sensor Image, (c) Candidates from Third Sensor Image

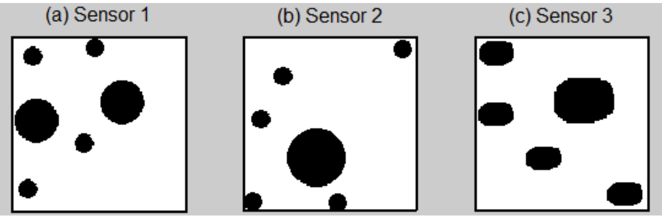

Figure 9: Sensors Data at Control Room after Pre-Processing

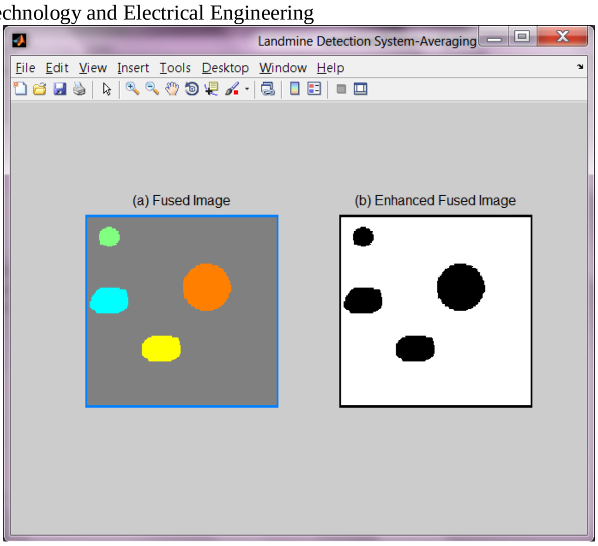

Figure 10: (a) Fused Image of Received Sensors Output Using Averaging Method and (b) Enhanced Fused Image

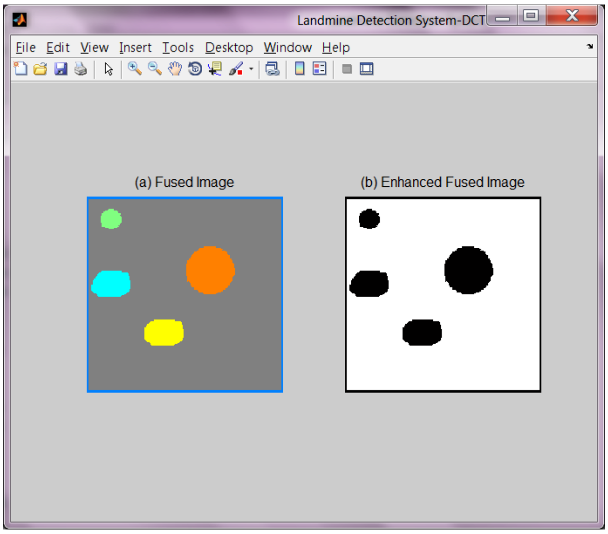

Figure 11: (a) Fused Image of Received Sensors Output Using DCT Method and (b) Enhanced Fused Image