An Anti Personal Landmine Detection Scheme Based on Microwave Imaging

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***Abstract* — In this paper, an intelligent anti-personnel landmine detection system is proposed. The system generates continues electromagnetic waves in the (2-8GHz) range through a wave guide and analyzes the reflected signal to decide on the presence of a landmine under the ground. A multi-layer model to represent the interaction of the signal with the soil and landmine is developed. Simulation results are presented to find the optimum operating frequency for improved detection of the landmine. Furthermore, an experimental set up is built to validate the operation of the system. The results indicate that accurate detection of the presence of landmine is feasible.**

***Index Terms* — Landmine detection, imaging system, microwaves.**

I. INTRODUCTION

Landmines became a serious problem for humanity, and have received considerable public exposure in the past few years, especially anti-personnel (AP) landmines. According to the International Campaign to Ban Landmines, they have estimated that 15,000 - 20,000 people are injured or killed by landmines each year [1]-[2]. The United Nations Children's Fund (UNICEF) has estimated that around 30-40 percent of mine victims are children under 15 years old. Several landmines ban programs have been launched, several countries refuse to stop the production of antipersonnel land mines including the United States [3]-[7]. AP Landmines cost only $3 for production, while the cost of extracting it is about $1000 per mine [8].

Worldwide, in most humanitarian de-mining operations, man used only hand-held metal detectors. The metal detector is extremely reliable, but it only detects metal mines, extremely slow and produces several false alarms [9]. In addition, most of the new AP landmines are non-metallic and can not being detected. Numerous research studies have been done to detect AP landmines, metallic or non-metallic, and without any direct contact to the ground surface. One of the solutions is the Ground Penetrating Radar (GPR) system that is used for detection. However, a the system is costly, has high power utilization and hard to generate due to the fact that it uses wideband antennas to generate a short pulse or a pure sine wave covering large and continuously varying frequencies at the high range [10]. Another solution for AP landmine detection is based on using infrared sensors. The problem is that infrared sensors are highly dependant on environmental conditions (heat variations) and the time needed to detect these environmental variations is usually difficult to control by the observer. Thus, the use of infrared sensors is limited.

In this paper, an AP landmine detection system using wireless technology will be designed, simulated, and implemented. The system will have the capability to detect non-metallic landmines buried within sand layer using the 2 – 8 GHz frequency range. The system will be based on the concept of reflection coefficient change due to the unique permittivity of each material, and the detection will operate on the optimum frequency that has the best detection of the landmine. This frequency will be chosen by simulation and some experimental results.

II. SYSTEM DESIGN AND MODEL

The proposed system is mainly targeted towards detecting a nonmetallic landmine buried under the surface of the ground without direct contact with the ground surface. As it was said earlier, the system is designed to do so using electromagnetic waves. In this section, the system will be briefly explained along with the mathematical model behind it.

A. Mathematical Model of a Multilayer System

Microwave techniques are applied in either far-field approach or in the near-field approach. The proposed microwave nondestructive non-invasive testing technique utilizes an open-ended waveguide operating in the near-field region. This system can be effectively utilized for AP landmine detection. Some of the advantages of the near-field technique are:

- The spatial resolution, when operating in this region, is significantly influenced by the scanning probe dimensions rather than the operating wavelength. Therefore, much finer spatial resolutions may be obtained [11][14].
- Contact as well as non-contact modes of measurements are possible.

There are many open-ended probes that may be used; such are open-ended rectangular waveguides, open-ended circular waveguides, open-ended waveguides of other aperture geometry, open-ended coaxial lines, open cavity resonators, microstrip patches, small horn antennas as long as one is operating in their near-field regions. Each of these probes possesses its own distinctive features that may yield valuable information about a structure [15][17].

- The distance between the probe and the material under inspection, commonly referred to as the liftoff or standoff distance, may be used as an optimization parameter for increased detection sensitivity. This is an important feature which makes near-field techniques much more desirable than far-field techniques.
- The frequency of operation may also be used as an optimization parameter.
- The required microwave power associated with these inspection systems is in the milliwatt range. Therefore, this inspection system is harmless.

Open-ended rectangular waveguide probes have been used in most of the investigations that deals with nondestructive noninvasive inspections. Fig. 1 shows such an open-ended waveguide probe radiating into a stratified dielectric layered media made of any number of layers backed by an infinite half-space of material (ground). Considering the dominant TE_{10} mode incident on the waveguide aperture, the terminating admittance of the waveguide can be written as [12-15]:

$$Y = G + jB = \frac{\iint_{aperture}\left[\bar{E}(x,y,0)\times\bar{W}(x,y,0)\right]\hat{a}_z\,dxdy}{\left[\iint_{aperture}\bar{E}(x,y,0).\bar{e}_o(x,y)dxdy\right]^2} \qquad (1)$$

Where

$$\bar{W}(x,y) = \bar{H}(x,y,0) + \sum_{n=o}^{\infty} Y_n\bar{h}_n(x,y)\iint_{aperture}\bar{E}(\eta,\xi,0).\bar{e}_n(\eta,\xi)d\eta d\xi \qquad (2)$$

where ***E**(x, y, 0)* and ***H**(x, y, 0)* are the electric and magnetic aperture field distributions, respectively. The admittance expression is constructed using transverse vector mode functions and their orthogonal properties. The n^{th} vector mode functions are $\boldsymbol{e_n}$, and $\boldsymbol{h_n}$, and Y_n is the characteristic admittance of the waveguide for the n^{th} mode. Additionally, *a* and *b* are the broad and narrow dimensions of the waveguide. Hence, the TE_{10} mode aperture field distribution is given by

$$E_y(x,y,0) = \bar{e}_0(x,y) = \begin{cases}\sqrt{\dfrac{2}{ab}}\cos(\dfrac{\pi x}{a}) & (x,y)\in aperture\\ 0 & (x,y)\notin aperture\end{cases} \qquad (3)$$

The complex reflection coefficient at the aperture of the waveguide, Γ, is related to the terminating admittance of the waveguide, Y, by

$$\Gamma = |\Gamma|e^{j\phi} = \frac{1-Y}{1+Y} \qquad (4)$$

This is a complex quantity whose phase and magnitude variations can be calculated and measured for optimization, testing and assessment.

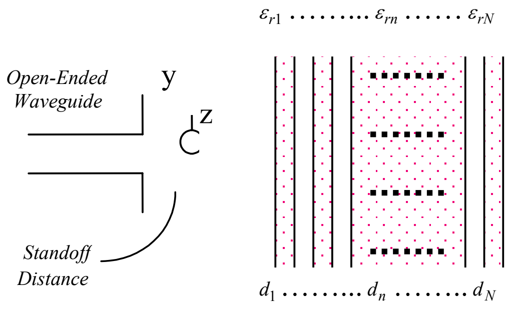

Fig. 1. Cross-section of an open-ended rectangular waveguide radiating into an N-layer structure backed by free-space.

A Matlab code was utilized in order to calculate the effective reflection coefficient for the two cases with and without a landmine. The frequency of operation and the standoff distance were used as optimization parameters to maximize variation in the reflection coefficient parameters calculated theoretically. The inputs to the code are the number of layers, their dielectric properties, their thicknesses, and the frequency of operation. The results of the theoretical optimization were used to build the experimental system.

B. Landmine Detection System

The system is composed of two main parts: a scanning station and a controlling and computing Station The details of these two parts are illustrated on Fig 2. A continues wave signal is generated by the sweeper. The signal propagates through the air layer between the sensor and the ground. Upon interaction with the soil and its contents, part of the signal is reflected back towards the radiating sensor, another part continue propagating through the soil layer above the landmine and gets reflected once it touches the landmine surface and its content. The reflected signal is received by the sensor and passed through a circulator to isolate it from the transmitted signal and then passed to a PIN diode detector to measure the signal strength. The output signal (voltage variations) is converted into digital format and stored in the PC for farther processing.

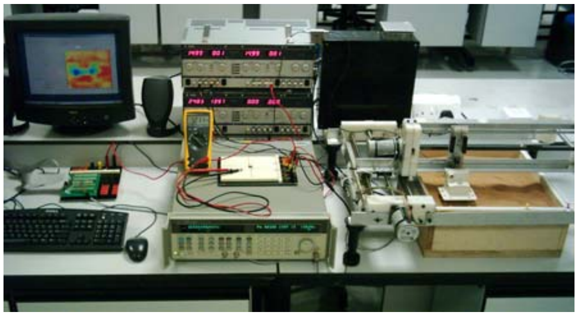

Fig. 2. Overall picture of the system.

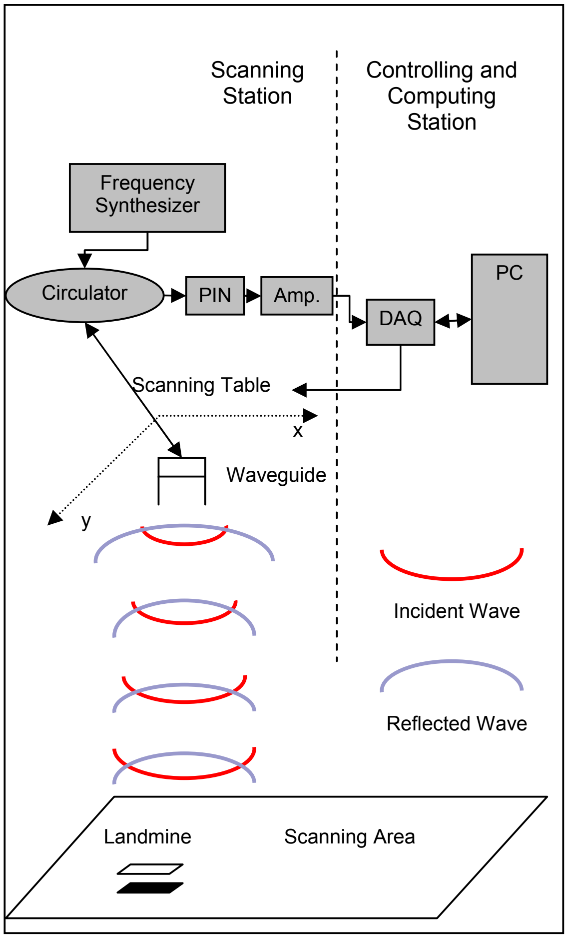

Fig. 3. Simplified system block diagram.

A rectangular waveguide, which acts as the sensor, will be used to transmit and receive the electromagnetic waves during the detection process. The detection process will take place by scanning the proposed area in the *X* and *Y* directions as illustrated in Fig. 3. It will be carried in the near field with continuous electromagnetic waves being transmitted at the lower GHz frequency range. The sensor will receive a reflection of the waves it sends based on the Multilayer concept which will be explained more in the next part of the section. The reflected waves will then be received and utilized to draw images for the subsurface of the scanned area.

The main idea is to utilize two cases, one with sand alone which will be used a reference and other case in which landmine is present. The difference between the reflection coefficients in the two cases will indicate the dielectric properties of a landmine.

III. SIMULATION AND EXPERIMENTAL RESULTS

With the system design model in hand, the system has been built accordingly.

A. Simulation Results

The simulation conducted was in two parts: the first part which was basically to increment the frequency over the range (2.6-8GHz) for the two cases and then calculate the effective reflection coefficient and plot it against the frequency range for different thicknesses of the air layer. Fig. 4 shows the change of reflection coefficient. Based on the results of this part, the frequency for which maximum change in reflection coefficient was obtained.

The second part of simulation was to get a simulated 2D and 3D images of the scanned area with the landmine by using the following inputs: the number of layers, their dielectric properties, their thicknesses, frequency of operation, size of scanning area and coordinates of the landmine. Figure 5 shows the image of the magnitude of the reflection coefficient.

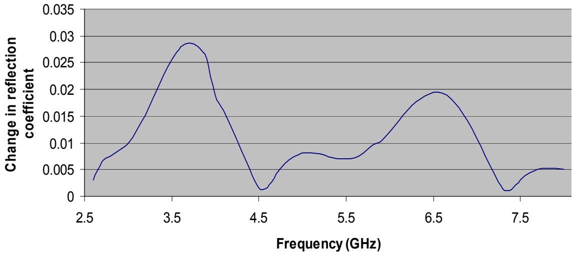

Fig. 4. Change in reflection coefficient against frequency at standoff distance of 1.7 cm.

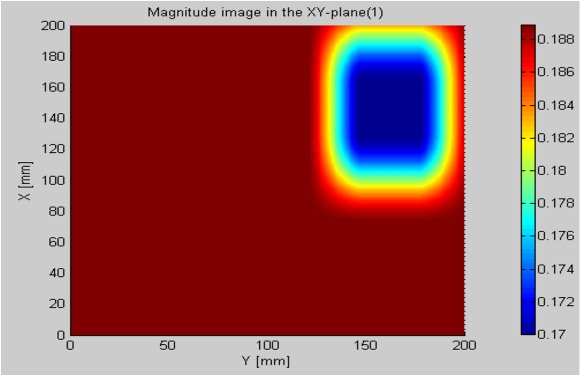

Fig. 5. An image of the scanned area at standoff distance of 1.7 cm and 3.6 GHz frequency.

B. Experimental Results

There are many different kinds of AP landmines planted all over the world. For simplicity, only one prototype of a landmine was considered while testing the system. The prototype (dummy) includes materials that are similar to those in the real landmines with similar percentages.

As a matter of fact, AP landmines that are buried with depth more than 5 cm will not be triggered with normal human step on them. For simplicity, the dummy landmine was buried under 1 cm of soil.

Experimental results proved that scanning with frequencies 3.6 and 3.7 the images are becoming clear over all other frequencies in the range from 3.5 to 3.8. This just supports the simulation results given in the previous part. As a result, for landmine imaging, the frequency kept at 3.6 GHz. In Fig. 6, two different images where taken for a landmine in different heights from the surface of the soil (air layer thickness).

For testing the efficiency of the system; two other objects were considered: a rock and a flattened can. For every object, three images were taken with different heights from the surface of the soil: 9 mm, 11 mm, and 13 mm.

The dummy landmine was internally designed to be with a shape of the English letter "H". Also, there where a tiny piece of metal attached to one of its sides, as illustrated in Fig. 7.

A surface plot of the image shows the internal content of the landmine dummy as shown in Fig. 6. The figure shows two blue dips and one red mounting next to them. Obviously, the free space and the piece of metal produce these characteristic features in the image.

C. System Evaluation

For evaluating the system performance, two important errors should be carefully measured: the false-positive and the false-negative. The false-positive (or type I error) is the error of rejecting a null hypothesis when it is actually true. In other wards, it is the error of indicating a landmine is present where in fact there is no landmine. This type of error is not dangerous; however, it is always preferable to keep it as low as possible. The second type which is the false-negative (or type II error) is the error of accepting a null hypothesis when the alternative hypothesis is the true state of nature. In other words, it is the error of indicating that the area is clear where in fact there is a landmine present. This type of error is dangerous. It must be as small as possible (ideally zero); otherwise, the system will not be safe to use in the real world.

The system should be able to decide the presence of the landmine with its location. One approach to be considered is by using an Artificial Neural Network (ANN). The system will be able to make decisions with different objects buried and different surface conditions. The main propose of the ANN is to minimize the false-positive probability while keeping the false-negative probability to zero. This would be a future work to be done for improving the system.

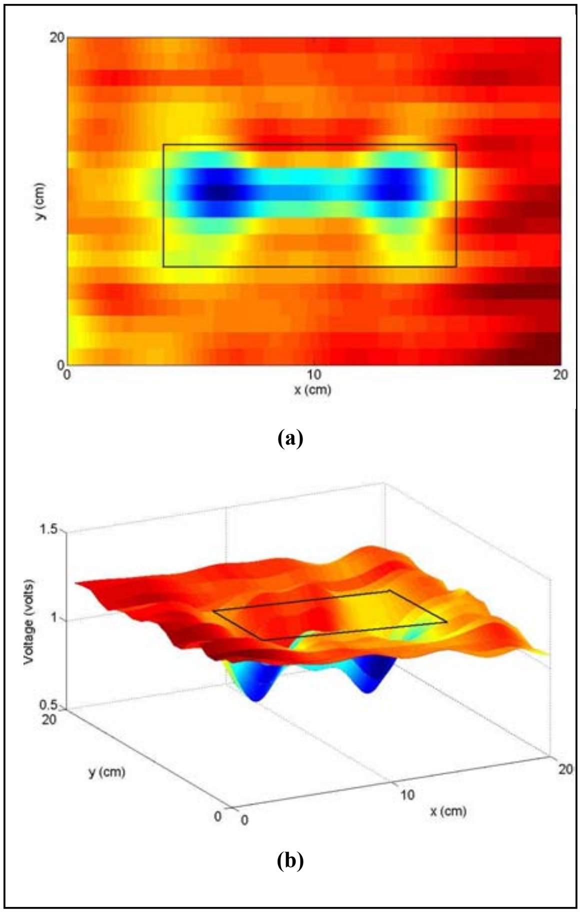

Fig. 6. (a) A 2D image after scanning indicating the location of the landmine by a black rectangle (b) a 3D plot of the same image in (a).

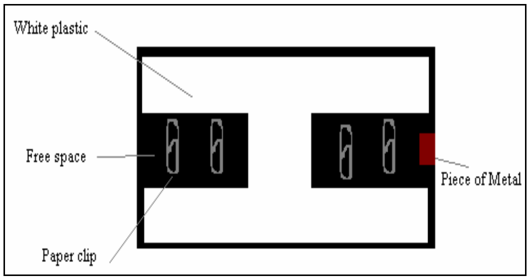

Fig. 7. A dummy block diagram.

IV. CONCLUSION

In this paper, an anti-personnel landmine detection system was proposed, modeled and implemented. Non-metallic mine detection without direct contact with the surface was based on observing changes in the measured signal that represent the reflected wave properties. An electromagnetic sensor which is a rectangular waveguide transition was used in the scanning process. The scanning process was carried in the near field with continuous electromagnetic waves being transmitted at lower GHz frequency range. The reflected signals are detected and utilized to build images for the scanned area and show the presence of the landmine.

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