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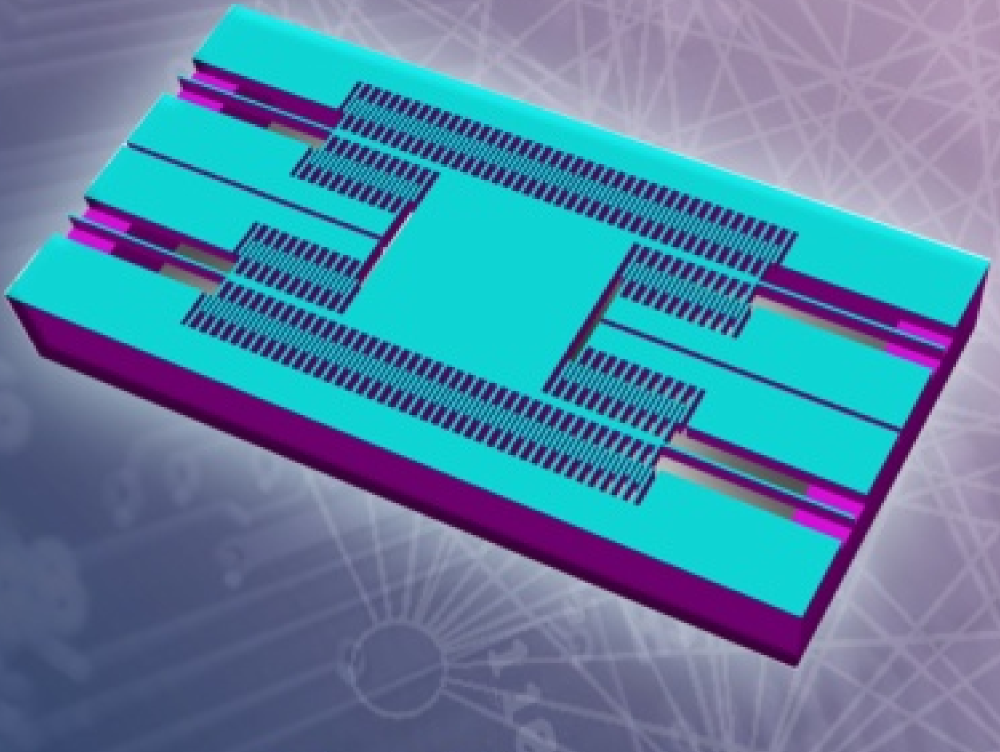

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# Microcontroller Based Neural Network for Landmine Detection Using Magnetic Gradient Data

**[1] Mohamed Elkattan, [2] Ahmed Salem, [1] Fouad Solima, [3] Aladin Kamel and [3] Hadia El-Hennawy**
[1] Nuclear Materials Authority, Cairo, Egypt
[2] GETECH, University of Leeds, Leeds, UK
[3]Ain shams University, Electronics and Communication Department, Cairo, Egypt
E-mail: emtiazegf@hotmail.com

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**Abstract:** Landmines are affecting the live and livelihood of millions of people around the world. In this paper, we have developed a new method for detection of landmines using Hopfield neural network as applied to gradiometer magnetic data. The Hopfield Neural Network is used to optimize the magnetic moment of dipole source representing the landmine at regular locations. For each location, Hopfield neural network reaches its stable energy state. The location of the landmine corresponds to the location yielding the minimum Hopfield energy. Output results include position in two dimensions, *horizontal location and depth* of the landmine. Furthermore, the proposed algorithm was implemented on a microcontroller, to be suitable for real time detection. Theoretical and actual field examples prove the effectiveness of using the microcontroller based Hopfield neural network as an objective tool for detection of landmines. *Copyright © 2012 IFSA.*

**Keywords:** Vertical magnetic gradient, Magnetic moment, Microcontroller, Hopfield neural network, Landmine.

## 1. Introduction

Landmines have been used during warfare for a long time. Unlike conventional weapons, buried landmines, if not removed, remain a threat. Hence, landmine detection is a very important issue, not only in military operation but also in humanitarian concerns. Research conducted in the areas of landmine detection and classification is voluminous encompassing diverse groups of researches and techniques. Several techniques are introduced for landmine detection like nuclear quadruple resonance [1], thermal neutron activation [2], thermal imaging, electro optical sensors [3, 4], and chemical sensors [5]. Current demining efforts are heavily reliant on metal detectors and prodders. In many circumstances, the prodder is the first, and in all cases, the last resort. The advent of nondisturbance fused mines makes prodding a dangerous operation. Mechanical devices such as ploughs, rollers, and flails are usually followed by manual demining to obtain the desired level of clearance. These machines are expensive for developing countries. Dogs are good when they work but can only operate for limited periods and must be acclimatized.

Magnetic detection is one of the standard methods of environmental investigations used in locating ferro-metallic objects, especially when the signal-to-noise ratio of the magnetic anomalies is high. Measurement of perturbations in the direction and/or strength of the Earth's magnetic field are used to locate underground ferro-magnetic objects. Gradient of the perturbations were also used for the detection. An advantage of the gradient measurements is that it removes to some extent the undesirable influence of disturbing fields, compensates for the influence of the regional field and does not depend on diurnal variations in the Earth's magnetic field. Recent development of magnetic survey systems has made it possible to rapidly detect much smaller objects using magnetic surveys, than it was possible before [6]. However, these advantages produce a large amount of data that need an automatic interpretation technique that can help in real time detection of landmines. This technique may be found in the field of artificial neural network. A Hopfield model is one type of these neural networks that does not require training for operation. This network is considered as good tool for solving optimization problems. In this paper, we extend the work of Salem et al. [7] to the detection of landmines from magnetic gradient data. Advances of using gradient data are first enhancing the resolution of shallow ferro-metallic objects. Second, unlike the total magnetic field data used in [7], magnetic gradient data do not require base station magnetometer. Thus it is more suitable for real time detection. Not only extension to magnetic gradient data, we also present a hardware implementation for the method using an inexpensive microcontroller chip that can be installed along with a magnetometer for real time detection.

## 2. Extension to Vertical Gradient

For landmine detection, a proper method of forward modeling of the magnetic signature of the landmine should be selected to build a cost function similar to the energy of the Hopfield neural network. The magnetic signatures of ferro-metallic objects can be simulated using one of two methods. In a simple simulation, a ferro-metallic by an equivalent source such as point source, or a vertical or horizontal line of sources. Alternatively, we can represent the object by a model that accounts for the shape and orientation effects [8]. Although there may be significant variations from one object to another, it is best to model magnetic signatures of ferro-metallic objects in a mathematical best fit sense [9]. For ferro-metallic objects such as landmines, we can simulate their magnetic signatures using equivalent dipole sources. The total field magnetic anomaly produced by a diploe source "i.e. Landmine" can be written as:

$$\Delta T = K\frac{3D^2 - r^2}{r^5}, \tag{1}$$

where $K$ is the dipole moment and $r$ is the distance from the dipole ($x_0, y_0, z_0$) to the observation point ($x, y, z$), and can be described as

$$r = [(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2]^{\frac{1}{2}} \tag{2}$$

and D is the quantity related to the magnetization direction of the dipole source, and can be described as:

$$D = lr_x + mr_y + nr_z\,, \tag{3}$$

where $r_x$, $r_y$, and $r_z$ are the components of r in *x, y,* and *z* directions. *l, m,* and *n* are also quantities related to the magnetization direction of the dipole source. If *a* is the angle between the geographic north, and the magnetic north “i.e. magnetic inclination” , and *b* is the angle between the horizontal component and the geographic north ‘ i.e. magnetic declination”, these quantities are defined as:

$$\begin{aligned} l &= cos(a)cos(b) \\ m &= cos(a)sin(b) \\ n &= sin(a) \end{aligned} \tag{4}$$

The gradient of the total field anomaly $\Delta T$ with respect to the depth *z* can be defined as follows:

$$\frac{\partial T}{\partial z} = 3K\frac{2r^2Dn - 5D^2r_z + r^2r_z}{r^7} \tag{5}$$

Solving (5) for both location and magnetization parameters is a non-linear problem. In this paper, we use the Hopfield neural network to estimate the magnetic moment of a dipole source located at a set of regular locations. At each location, the Hopfield network reaches its stability at different energy level. The location having minimum energy is selected to indicate the location of the source.

## 3. Magnetic Moment Estimation

Following [10], if we have M vertical magnetic gradient data points measured over a dipole source of unknown magnetic moment m, located at the center of cell l (see Fig. 1). To estimate the unknown magnetic moment, we build a cost function between the measured and the calculated magnetic anomaly of the dipole source. The theoretical magnetic anomaly at a measurement point K can be written as:

$$d_k^c = G_{lk}m\,, \tag{6}$$

where m is the dipole moment and $G_{lk}$ represents the geometric relation between the center of cell l and the observation point K. $d_k^c$ represents the calculated vertical magnetic gradient anomaly. In the case of inexact data, due to noise and other sources of error, the magnetic moment can be approximated in a least-square sense by a solution that minimizes a cost function between the measured and calculated data.

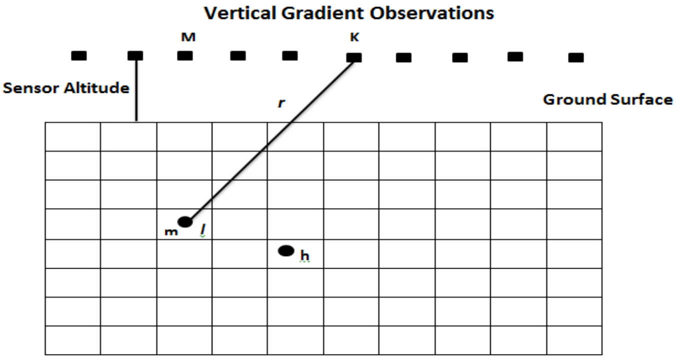


**Fig. 1.** A region consisting of square cells under a magnetic profile.

We define a cost function C in terms of the sum of squares of the differences between the measured and calculated anomalies, i.e.

$$C = \frac{1}{2}\sum_{k=1}^{M}(d_k - d_k^c)^2 = \frac{1}{2}\sum_{k=1}^{M}(d_k - G_{lk}m)^2 \tag{7}$$

where $d_k$ represents the measured magnetic anomaly.

Furthermore, the magnetic moment m must be represented in a system consistent with the output of the Hopfield neural network, where a typical output can be one or zero. Then the magnetic moment can be expressed as:

$$m = \sum_{i=1}^{n=D+U+1} 2^{(i-D-1)} b_i \,, \tag{8}$$

where $b_i$ equals to 0 or 1; D and U are the integer numbers that depend on the precision and magnitude of the magnetic moment, respectively. Thus, (8) can be viewed as a binary representation of the moment m with n bits. Substituting (8), into (7), expanding and regrouping, gives:

$$\begin{aligned} C = -\frac{1}{2}\sum_{i=1}^{n}\sum_{j\neq i=1}^{n}[-\sum_{k=1}^{M} 2^{(i+j-2D-2)}(G_{lk})^2]b_i b_j - \sum_{i=1}^{n}[-\frac{1}{2}\sum_{k=1}^{M} 2^{(i-D-1)} G_{lk})^2 b_i + \\ + \sum_{k=1}^{M}(2^{(i-D-1)} G_{lk})d_k]b_i + \frac{1}{2}\sum_{k=1}^{N}(d_k)^2 \end{aligned} \tag{9}$$

and for the particular model of Hopfield neural network, which is known as the discrete or classical Hopfield model [11], the energy function of this model may be defined as:

$$E(v) = -\tfrac{1}{2}\sum_{i=1}^{n}\sum_{j\neq i=1}^{n} w_{ij} v_i v_j - \sum_{i=1}^{n} I_i v_i \,, \tag{10}$$

where $w_{ij}$ is the connection weight between neuron i and neuron j. $I_i$ and $v_i$ is the input and output of neuron i respectively. It can be shown from (9), and (10), that the cost function and the energy function have the same form except for the constant term $\tfrac{1}{2}\sum_{k=1}^{N}(d_k)^2$ , which disappears upon differentiation with respect to the moment elements.

From the previous analogy, we can derive the connection weight at cell l to be:

$$w_{l_{ij}} = [-\sum_{k=1}^{M}(2^{(i+j+D-i)}(G_{lk})^2)] \tag{11}$$

and the input of the same cell to be:

$$I_{l_i} = [-\tfrac{1}{2}\sum_{k=1}^{M}(2^{(i-D-1)} G_{lk})^2 b_i + \sum_{k=1}^{M} 2^{(i-D-1)} G_{lk} d_k] \tag{12}$$

Substituting (11) and (12) into (10), we can say that the Hopfield energy to estimate the magnetic moment of dipole source (i.e. landmine) at the center of cell l becomes:

$$E_l(b) = -\tfrac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} w_{l_{ij}} b_i b_j - \sum_{i=1}^{n} I_{l_i} b_i \tag{13}$$

## 4. Magnetic Detection Using Gradient Data

To describe the idea of detection, let us consider the same dipole source (i.e. landmine), located at the center of cell *l*. However, this time, we estimate the magnetic moment using the Hopfield network at a wrong cell, for example at cell *h* (see Fig. 1). The energy function corresponding to cell *h* can be written as:

$$E_h(b) = -\tfrac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} w_{h_{ij}} b_i b_j - \sum_{i=1}^{n} I_{h_i} b_i \,, \tag{14}$$

where $w_{h_{ij}}$ and $I_{h_i}$ are the connection weights and inputs corresponding to cell h, respectively. We can express them in relation to those of the correct cell *l* as:

$$w_{h_{ij}} = w_{l_{ij}} + \Delta w_{ij} \ \mathit{and}\ I_{h_{ij}} = I_{l_{ij}} + \Delta I_{ij} \,, \tag{15}$$

where $\Delta w_{ij}$ and $\Delta I_{ij}$ are the difference in the connection weights and the inputs between cell *h* and *l*. Substituting (15) into (14), the energy function corresponding to cell *h* becomes:

$$E_h(b) = E_l(b) - \tfrac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \Delta w_{h_{ij}} b_i b_j - \sum_{i=1}^{n} \Delta I_{h_{ij}} b_i$$

or

$$E_h(b) = E_l(b) + \Delta E_h(b) \,, \tag{16}$$

where $\Delta E_h(b)$ is the shift in the energy function of the Hopfield network due to the geometric shift from cell *h* to the correct cell *l*. Equation (16) indicates that if we apply the Hopfield network to estimate the magnetic moment at a set of regular cells representing the region of interest, we will obtain the least energy at the correct location where the shift in the energy is equal to zero. To provide a meaningful probabilistic measure of the source location, we introduce the following weighted energy $E_{hw}(b)$ to express the energy of cell h to the measured data as:

$$E_{hw}(b) = \left[ -\frac{E_h(b)}{\tfrac{1}{2}\sum_{k=1}^{M} d_k^2} \right] \times 100 \,. \tag{17}$$

With this change, the maximum weighted energy $E_{hw}(b)$ will indicate the location of the target.

## 5. Microcontroller Implementation

To implement the Hopfield neural network detector, we propose the following scheme:

1) Divide the subsurface region of interest under the magnetic profile in a set of cells.

2) For each cell:
a) Assume that the center of this cell is the target location;
b) Use all the profile data to calculate both the connection weights, and the inputs of the Hopfield network;
c) Iterate the Hopfield network using the stochastic update rule, until the steady state is reached;

d) Calculate the weighted Hopfield energy for each cell, and store the resultant moment and energy.

3) After scanning the whole cells under the desired subsurface, display the obtained energies in a cross-sectional form to determine the location of maximum weighted Hopfield energy; this location indicates the target location.

The used Hopfield model is a single layer feedback neural network. Fig. 2 indicates the hardware diagram of the Hopfield neural network. The applied Hopfield Neural Network, using 14 neuron outputs, with U = 7, and D =7. The Hopfield network output here is equivalent to an A/D converter, which estimates the magnetic moment "digital", of a buried landmine, from its magnetic signatures "Analog". Neuron *I* is represented by a rectangle, and is characterized by the input current $I_i$, and a connection weight to the j$^{th}$ neuron $w_{ij}$ denoted by a small solid square. The net output amplifier is represented by a triangle, and the output voltage by $v_i$. The network is symmetric $w_{ij}=w_{ji}$, and incorporates feedback into a neuron from all neurons except itself (e.g. $j \neq i$), to avoid a permanent feedback of its own state value.

For each cell, the net output $D_i(t)$ for a neuron *I* at time *t* is given by:

$$D_i(t) = \sum_{j \neq i = 1}^{n} w_{ij} v_i + I_i \tag{18}$$

and a simple threshold function is applied to the net input to obtain the new output

$$v_i(t+1) = \begin{cases} 1, & if\ D_i(t) > 0 \\ 0, & if\ D_i(t) \leq 0 \end{cases} \tag{19}$$

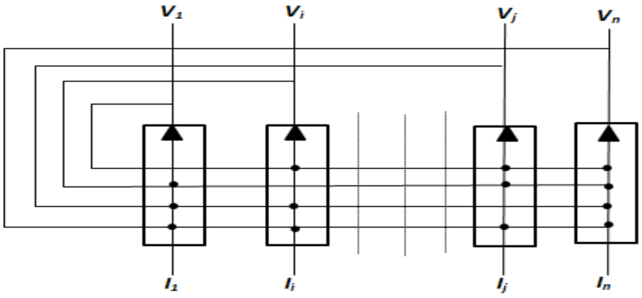


**Fig. 2.** Hardware diagram of the Hopfield neural network.

Neural networks hardware implementations are generally classified as neurochips or neurocomputers. In many applications, Microcontroller based neural network realizations are perfectly suitable and inexpensive solutions [12]. In this paper, the Hopfield neural network is embedded on EASYPIC v7 Kit, 40 MHz osc./clock input, with PIC 18F452 Microcontroller, used for implementation "see Fig. 3". The microchip has 1536 bytes of RAM, and 32 Kbyte flash memory used as a central processing unit to acquire data from the magnetometer sensor through the PC, process the data with the Hopfield neural network, calculate the energy at each cell, compare, finding the cell corresponding to the maximum energy, and generate the horizontal location, and the depth of the landmine, present it on the text LCD. The algorithm consumes 49 % of the available RAM, and 63 % of the flash memory. The Kit uses 5 volts as a processing power, and produces the landmine position in around 10 seconds, from acquiring the data, which makes the proposed approach more suitable for the real time application.

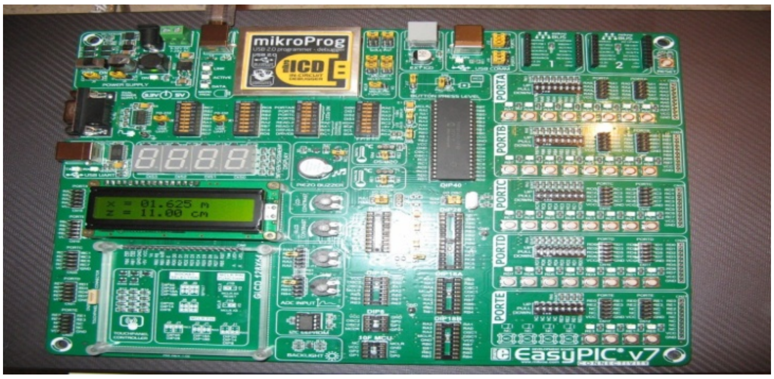


**Fig. 3.** EASYPIC v7 Kit, with PIC 18F452 Microcontroller, used for implementation.

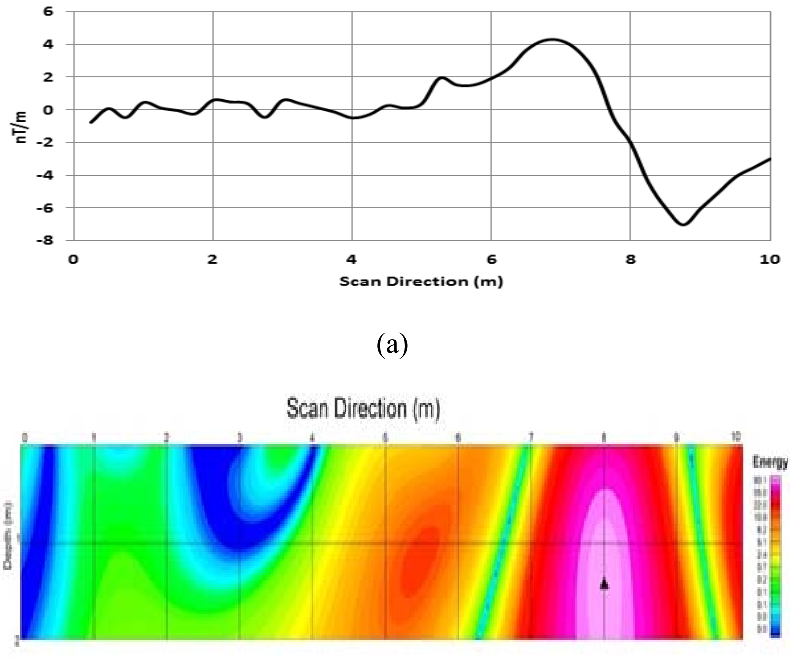
## 6. Simulation and Experimental Results

For the validation of the proposed algorithm, a simulation model was generated to present a magnetic gradient profile measured over a landmine “i.e. dipole source”. The dipole source has “12 Am$^2$” Magnetic moment and the profile was designed to be 10 meters long. The vertical gradient observations were measured every 0.25 meter, and the landmine located at a horizontal distance $x = 8$ meters, and buried at depth $z = 1.5$ meters from the surface. Since in real field measurements, the magnetic data usually suffers from different types of noise resulting from different sources in the surrounding environment, an additive Gaussian pseudo-random noise with zero mean, and standard deviation of 0.75 nT/m was added over the generated data. Fig. 4a shows the theoretical magnetic gradient data of the simulation model. Fig. 4b shows the results of the algorithm in the form of energy contour maps, representing the weighted Hopfield energy at the center of each cell. The black triangle on the figure indicates the maximum energy position that corresponds to the Target position. It can be seen that even with the existence of noise, the target location suffers only from a very slight variation that cannot be even noticed.

The proposed technique was also tested with actual field data conducted at Anshas Area, East Cairo, using T-71 Antitank mine “see Fig. 5”. With dimensions 31.5 cm × 10 cm. The magnetic profile was conducted to be 3.5 meters long, and the measurements were taken every 0.25 cm. The magnetic instrument used in this experiment is a proton gradiometer with resolution of 0.01 nT. This device uses two sensors to measure either vertical or horizontal gradient of the magnetic field. In this test, the instrument was used to measure the vertical gradient, and the distance between the two sensors was 60 cm. The distance between the lower sensor and the ground level was 60 cm, making the measurement level from the ground to be 90 cm.

The measurements were made over the antitank landmine buried at sand soil at depths of 20 cm, and 45 cm. Fig. 6a, shows the vertical magnetic gradient data measured at the above depths. For applying the proposed algorithm, the subsurface under the profile was divided into 1 cm × 1 cm cells. The moment at the center of each cell was calculated, along with the minimum Hopfield energy.

Fig. 6*b,* and *c,* shows the weighted Hopfield energy contour maps, representing the maximum Hopfield energy at the center of each cell for the antitank landmine at depths 20, and 45 cm respectively. The black triangle on the figure indicates the maximum Hopfield energy position, while the black circle indicates the real location of the landmine.



(a)

(b)

**Fig. 4.** (a) Theoretical magnetic gradient data, and (b) its weighted energy contour map, over dipole source at horizontal location of x= 8 m and depth z =1.5 m. The data were contaminated with background noise with zero mean and standard deviation of 0.75 nT/m.

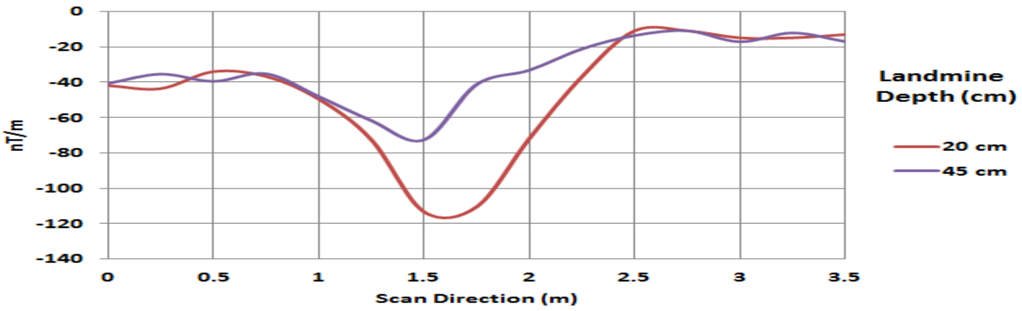
**Fig. 5.** T-71 Anti-Tank Landmine used in the experiment.

The illustrated results of the field test shows an error of 20, and 19 cm in the Horizontal location, and 4, and 1 cm in the depth of the antitank landmine buried at 20, and 45 cm respectively. However this error can be acceptable, if we consider the antitank diameter “31.5 cm”, and that the maximum Hopfield energy is at the center of the landmine.

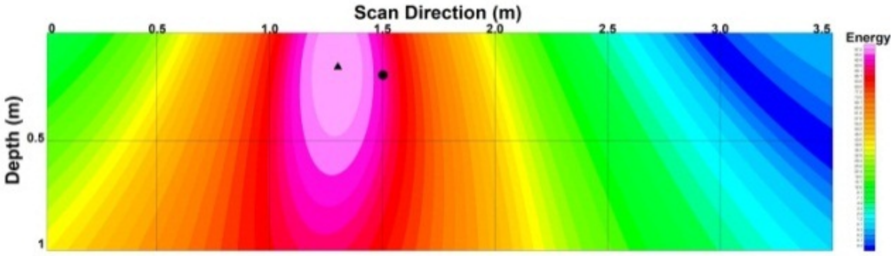
## 7. Conclusion

In magnetic data interpretation, The Hopfield neural network can be used as analogous to the conventional inversion techniques such as least-square method. However, inversion of potential field data in general is not a simple task. The main fundamental difficulties are the problem of non uniqueness and instability in the solutions. In this paper, the Hopfield neural network is not charged to do a classical inversion of magnetic data. Instead of that, the region under the magnetic profile is categorized into square cells. At the center of each cell, Hopfield neural network is used to estimate the magnetic moment of a dipole source “i.e. landmine”, located at the center of the cell. At each cell

Hopfield network reaches its stable state at a different energy level. The position having the lowest energy corresponds to the target location. The proposed method was implemented on an inexpensive microcontroller chip that has low power consumption. The algorithm was tested over both theoretical and real field data, and shows an acceptable accuracy in detecting the horizontal location, and the depth of the landmine in a few seconds, using low memory requirement. This accuracy, along with small detecting time makes the suggested approach suitable for real time detection of buried landmines.



(a)



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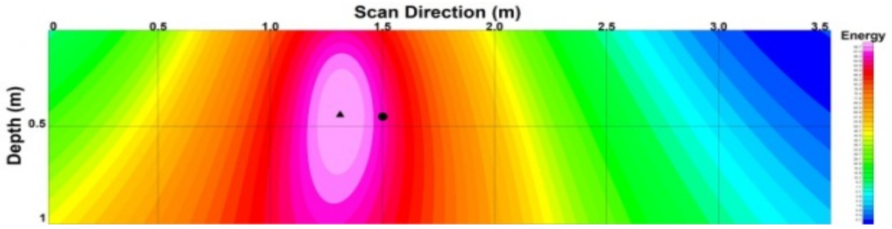

(c)

**Fig. 6.** (a) Field magnetic gradient data over T-71 Antitank landmine at depths 20, and 45 cm respectively, and their weighted energy contour map, over at depths (b) 20 cm, and (c) 45 cm.

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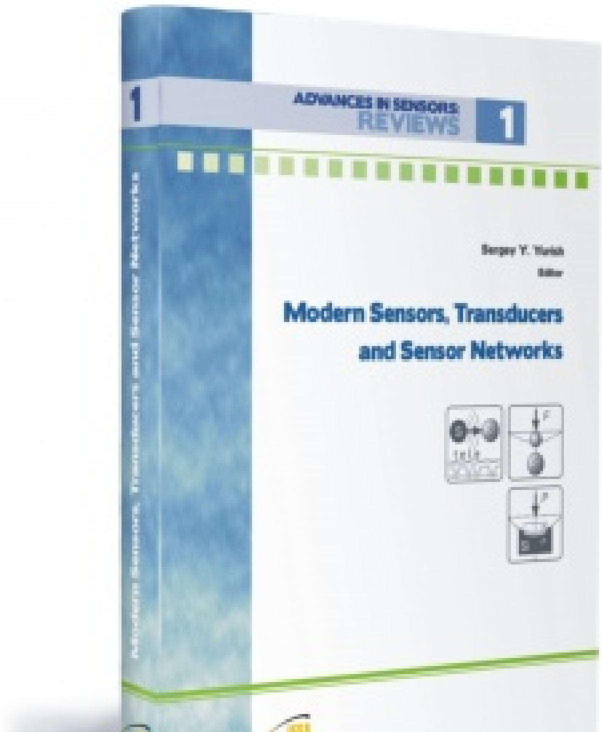
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