ISSN 2229-5518

Wireless Robot for Personal Mine Detection and Extraction Equipped with a Wide Range Metal Detector Sensor

W.M.M. Seada, E. Kamal and M. A. Koutb

Abstract - This paper deals with design and implementation of a novel low cost- four wheels mine detection and extraction robot. The powering, driving and controlling circuits are illustrated. It is multitasks cooperative controlled robot for personal land-mine detection and extraction of the mines from the ground as a solution for the landmine detection and extraction problem. It is capable of operating very long time using a new mechanism for the mine detection and extraction. An efficient design of electromagnetic induction metal detector sensor is achieved. A distributed sensors fusion system that identifies the robot environment and operation is developed. The robot extracts the mine by drilling the soil, catching the mine and extracting it from the ground while enabling the operator to control the robot wirelessly from a safe distance. The robot Path planning and scanning process is carried out based upon a defined routine. The overall system has controlled using PICs 18F452 microcontroller circuits. A prototype is presented showing the illustrated design.

Keywords - Land Mines, Mine Detection, Mine Extraction and Wireless Robot

1 Introduction

According to current estimates, 100 million landmines, mostly antipersonnel mines laid in over 60 countries, kill over 20,000 persons a year. In recent years, many organizations and universities in different countries have increasingly recognized the significance of low cost and sustainable technologies for mine detection and extraction. The current solution for removing landmines from civilian areas is the use of trained technicians who manually search for buried objects using a metal detector. A human operator, on the other hand, sweeps a mine detector from side to side while moving forward to cover ground; this process is rather slow (20-50 square meters per hour). The operator can follow the ground profile with the detector head close to the ground without hitting the ground or any objects on it. The operator can also vary the width of sweep to suit a particular situation, and is usually not limited by terrain. However, the manual method is slow, hazardous, manpower-intensive and stressful. As a result, the operators can perform this task only for short periods. In addition, the task is monotonous and at times errors result due to operator inattentiveness. The humanitarian activity of removing antipersonnel land mines requires the use of robotic systems that put the operator at a distance to increase both operator's safety and the mine removal rate [1], [2]. Although efficient mobile robotic systems are required for such applications, adequate sensor heads must be investigated first. Sometimes mine detectors are one-point detectors and thus they must be moved over large areas of ground, normally with the use of scanning manipulators.

- *W.M.M. Seada, master degree Industrial Electronics and Control Eng. Department, Faculty of Electronic Engineering, Menoufia University, Egypt . seada_2410@yahoo.com*
- *E. Kamal Dr. degree Industrial Electronics and Control Eng. Department,Faculty of Electronic Engineering, Menoufia University*
- *M. A. Koutb Prof. degree Industrial Electronics and Control Eng. Department, Faculty of Electronic Engineering, Menoufia University.*

Thus, robotic mine detection regularly combines a mobile robot, a manipulator and a sensor head [3], [4], [5].

There has been a great activity in developing robotic systems for humanitarian de-mining for the last years. Many works have been devoted to the development of new sensors, detectors and include mobile robots (wheeled, tracked and legged robots), also investing in a mechanized solution will be effective on

both human and economic levels [6],[7]. Conventional vehicle-mounted mine detector systems employ an array of sensors elements to achieve a detection path typically 2~ 4 m wide. Some systems employ more than one type of sensor technology. These systems, while being very useful, are often expensive, complex and inflexible. The risk of mine clearance missions is primarily related to the lack of knowledge about the location of the mines, as well as the detection and extraction operations. When the mines are located, extraction may become a less hazardous procedure. However, the danger remains even if it is reduced but still there, since at the end of the day the mine must be extracted manually [9], [10]. The goal now is to develop a fully automated system that is capable of locating and extracting the mines with the most bottom interference from human side. Robot path planning is a critical problem. This problem addresses how to find a collision-free path for a mobile robot from a start position to a given goal position while avoiding any obstacles. The proposed robot is capable of autonomously moving a mine detection sensor over natural ground surfaces and extracts the mine. The system has an automated mechanized process for mines detection and extraction. Moreover, the robot is designed to operate remotely using transceiver radio frequency communication remote unit to communicate the robot for increasing the safety of the personnel performing mine detection [11], [12], [13]. This paper is organized as follows:

The robot characteristics and specifications are presented in Section 2. The robot sensors system and the mine discrimination process are illustrated in Section 3. Section 4 defines the relays and motors driving board. The control system and communication module are explained in Section 5. Section 6 describes the mines extraction mechanism. In Section 7 the robot path, planning and operation are explained. Section 8 shows the tests and the results. Section 9 presents the conclusions.

2 THE ROBOT SPECIFICATIONS AND CHARACTERISTICS.

2.1 The design specification of the main body of the robot as follows:

- Simple body structure moved on four-wheel driven by two motors using differential drive steering mechanism with climbing slope 40° capability.
- Durability and reliability test of the driving motors system, and axle fitted with a belt chain.
- It is remote reliable control, half-automatic and automatic mode robot .Using (y/ϕ) transceiver, and using handheld panel to control the robot.
- The full length of the body is 1.8 m. The sensor arm is lengthened vertically until reach distance above the ground of 5 cm. The width of vehicle is 1.1m including the tire. The height of vehicle is 1.3 m and 2.2 m with the solar electrical power system. The full weight is 150 kg including the compliance assembled robot arm.
- The driving system and electronic circuits are feed from two deep cycle recharged batteries of 100 ampere that, are charged from two axes solar tracking system [8].
- The robot mechanism has 8 DC motors with gearboxes of different ratios 1/20, 1/40 to achieve high starting torque to drive all parts distributed as follows:

1) Two main motors each has a power of 500 Watt for the vehicle driving, they rotate separately.
2) The left-hand side wheels (front, rear) and right-hand side wheels (front, rear) are controlled independently and driven by two separate motors and four rubber belts. By coordinating the two different motor speeds, one can cause the robot to spin in place, move in a straight line, move in a circular path, or follow any prescribed trajectory.
3) One motor of power 250 Watt, for moving the main arm horizontally left and right was selected to scan the field with arc of length 1.3 meter.
4) One motor of power 500 Watt for the digging mechanism rotation (rotary wheel) digs the ground by the fingers.
5) One motor of power 30 Watt is for moving the magnetic sensor up and down.
6) Two symmetric motors of power 30 Watt for opening and closing the fingers for digging, personal mine catching and picking it up.
7) One motor of power 30 Watt moves the vertical main head up and down.

2.2 Robot characteristics

- The robot is able to detect 90% of landmines by using metal detector (Anti-personnel mines and Anti-tank mines), extracts only the anti-personal mines. It has a new mine extraction mechanism extracting one mine in 90-second duration.
- For the safety of the operator, the designed robot operates remotely and equipped with wireless data transmitting capabilities.
- The robot travels in a straight-line path, steered using a differential drive steering type, detecting the possible buried mines, clearing 1.3-meter wide lanes in one pass. The robot can scan an area of 200 meter square per hour.
- The robot platform is designed to be versatile enough to work with any detectors installed onto it and equipped with a solar power energy system to provide with electrical energy during working in the field [8].

3 THE ROBOT SENSORS SYSTEMS.

The robot is equipped with two main system sensors as follows:

3.1 The main controlled mine detection sensor

The metal detector sensor is an electromagnetic induction sensor for detecting the mine in the ground. Worked by sending out magnetic fields and detecting the response from the electric eddy currents generated when the field interacts with a metallic target. The metal detector sensors are considered the most reliable sensors for mine detection work. However, landmine detection performance of metal detectors is highly dependent on the distance between the sensor heads and the buried landmines. Therefore, the main target was designing very sensitive metal detector with accepted range which is in our case is one meter range based on electromagnetic induction theory [14], [15], [16], [17]. The diameter of the coil is 25 cm and can be modified to 30 cm based on the maximum detection distance wanted. The detection sequence is made by feeding a signal with frequency fo = 20 KHZ through the onboard microcontroller PIC18 F452. An inductance capacitance combination LCt form a resonator, where L is the sensor coil inductance and C_t is the total parallel tank capacitance. The total capacitance is given by :

$$C_t = C_o + C_{comp} + C_{cal} \quad (1)$$

Where, Co is the resonant capacitance, Ccomp compensation capacitance and Ccal is the changeable calibration capacitance. The resonant frequency is related Ct such a way that:

$$f_o = \frac{1}{2\pi\sqrt{L\,C_t}} \quad (2)$$

The output signal is taken to a multistage buffers and amplifiers before it goes back to the on board 10 bit analog to digital converter inside the controller for processing. However, the input impendence of the used microcontroller is said to be infinity but the loading effect has a serious impact on the performance of the coil [17]. That is why the signal must go through the multistage filters, buffers and amplifiers to control the output voltage according to the detection depth and metal area. The detection circuit block diagram is shown in fig. 1. The metal detector sensor is installed at a separated mechanism moving down at scanning operation with gap of 5 cm from the ground and up at extraction operation. The whole mechanism is fixed at the front head and main arm, the sensor head accurately follows the ground surface the using ultrasonic sensor.

- Mine detector schematic

The sensor detection circuit schematic diagram shown in fig. 2, consists of PIC18F452 responsible for producing the 20KHZ square wave to the coil through 4N35 opto-coupler, where the signal output from the coil to the amplification circuit going back again to the on-board analog to digital converter to convert to digital signal. The variable frequency signal drives the sensor coil to set up the magnetic field around it. Then the output voltage of the LC, which is changed due to the target nature and area, is buffered and amplified. Then, it reaches the zero crossing detectors to detect the occurrence of the zero crossing, which is changed in case of detecting a mine. The sampling and holding circuit senses the crossing time and the voltage amplitude.

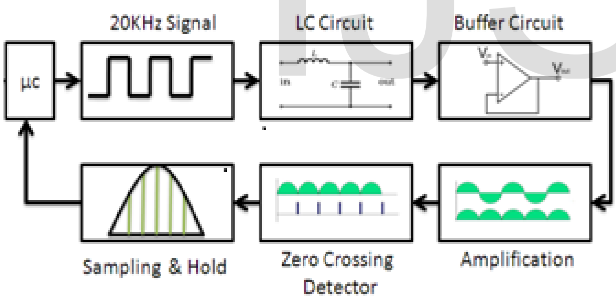


Fig. 1. The block diagram of the detection circuit

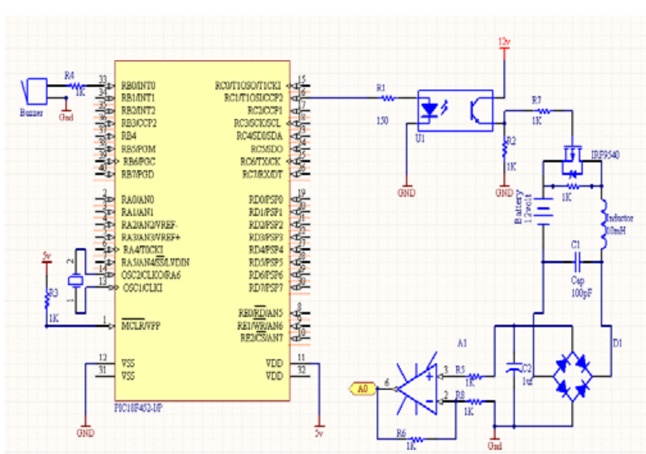
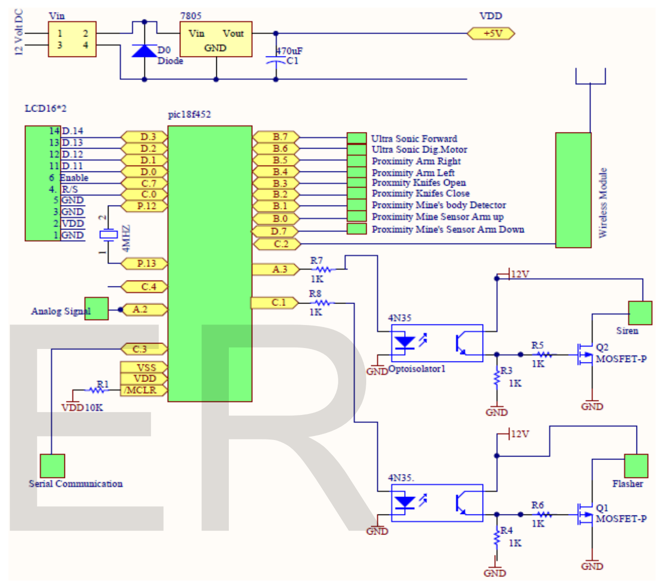


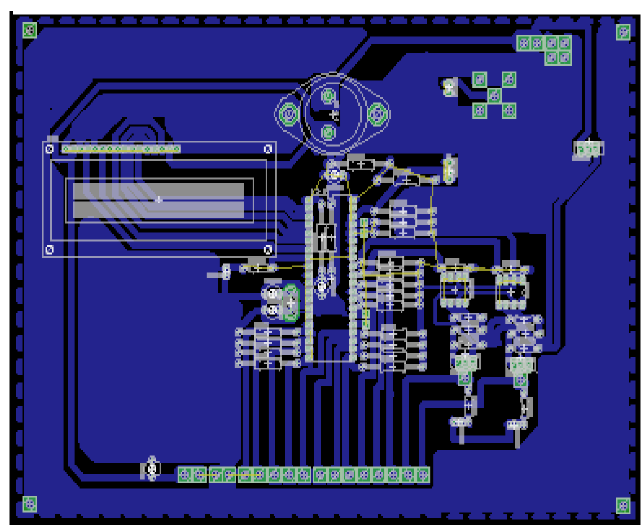
Fig. 2. schematic diagram of the metal detector sensor

3.2 Ultrasonic and proximity sensors

A group of signals is produced from 9 sensors, two ultrasonic and seven proximity sensors. The signals are processed in the main PCB as shown in fig. 3. The Main PCB represents the brain for the whole system. The ultrasonic sensors (Obstacle sensor - Digging front head sensor) give signals proportional to the distance of the object surface in front of them. They have specified operational range of 4-100 cm and require a voltage supply of 5V DC at about 40 mA. The analogue output signal of the sensor is converted to digital signal in the PIC A/D converter that samples the distance in a periodic cycle of about 40 ms. The onboard sensors installed as follows:



(a)



(b)

Fig.3. The main circuit (a) schematic diagram (b) circuit PCB

ISSN 2229-5518

- Main arm sensors

There are 2 proximity sensors on the way of the arm movement responsible for controlling the arm sweeping area and ending range (left & right).

- Fingers sensors

There are 2 proximity sensors installed on the fingers controlling its opening and closing angle range for extraction operation with a maximum right (90 degree) angle at opening and (30 degree) at closing.

- Mine detector holder arm sensors

There are 2 proximity sensors installed on the arm holding the detection coil of the mine detection sensor for controlling and adjusting the movement of the mine detection sensor arm (up & down) in order to keep the direction of a mine detection sensor parallel to the ground.

- Digging front head sensor

Ultrasonic sensor installed perpendicular to ground responsible for controlling the movement of the Digging head distance from the ground (up & down).

- Mine protection sensor

A proximity sensor is installed inside the rotary wheel to help identifying the gap of the mine while digging with 1cm range, preventing the rotary wheel from hitting the mine, and explode during the motion of the fingers.

- Obstacle sensor

Ultrasonic sensor installed on the front head of the robot body for identifying any obstacle in front of the robot and safe the robot from accident.

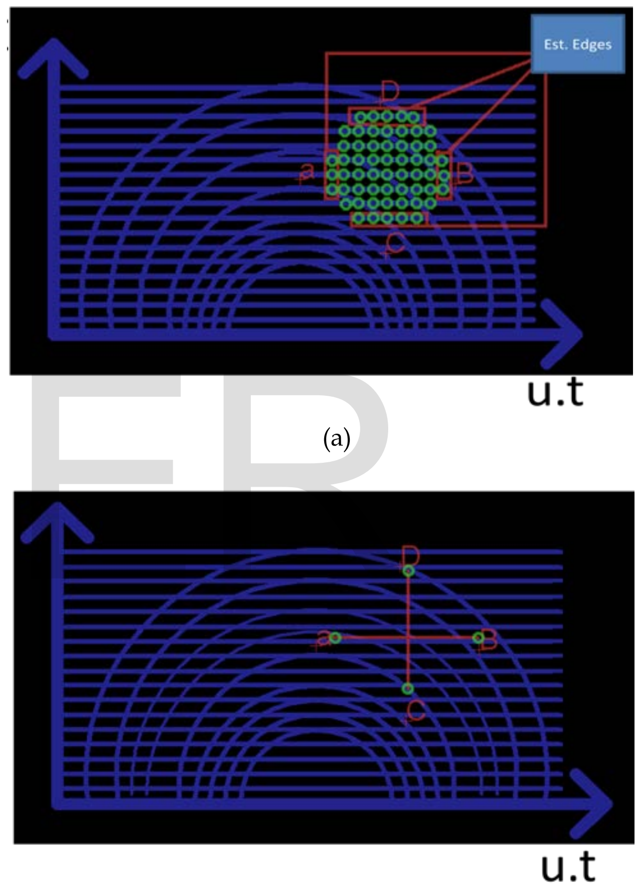
3.3 Mines discrimination and position estimating

The discrimination is done by identifying the size and the position of the found object, which is very useful in the extraction process [15]. In addition, it can be used to estimate the density of the metal in the object.

- Discrimination and identifying the size

The discrimination process for the land mine is based on the detection of the size of the metal parts in the mine. As the sensor detects a target a sequence of scanning process is executed as follows:

1) The arm holding the detector moves left and right in the X- axis, the robot moves forth, and rear in the Y-axis to scan the neighbor area of the target sensing the power of the reflected signal from target edges as shown in fig. 4.
2) The arm motors attached encoders define the velocity and position of the arm during scanning process.
3) Once the velocity is known the distance between farthest points measured by the sensor can be found with respect to time.
4) The A/D converter in the PIC receives the output reflected power signal from the detection circuit and the PIC recording and comparing all incoming signals (A/D converter – encoders signals) of the found object. An estimated edge identifier and areas detection program is used to identify the edges and areas of the found object.
5) The PIC is programmed using 23 different detection cases for corresponding three different metal areas and different depths in the ground (steps of every 5 cm). This program is executed as changing in the voltage of the incoming signal is noticed by the A/D converter.
6) The estimated size and edges plus a safety factor feed to the extractor routine in order to adjust the extraction position with a maximum diameter 20 cm, which can be extended by increasing the diameter of extraction rotary wheel [17].



(b)

Fig. 4 Discrimination and position estimating (a) position estimating (b) Edge Identifier Routine

- Estimation of the position

This section shows the method of estimating the position, confined to the case of the detection area with only one buried landmine. The detection circuit used in this research can detect the change of zero crossing time of the output signal (zero crossing detection), which changes after the detection of the mine. The microcontroller processes and detects the output signal amplitude and zero crossing points. As the detector scans right and left, the output signal from the metal detector is converted to a negative value, when a landmine exists on

the right side from the center of the sensor head along the X-axis.
When a landmine exists on the left side, the signal converted to positive value. As the robot moves forth, and rear in the Y- axis to scan the target, the value and sign of output signal changes also. The position of the buried landmine is estimated from the processing of the output signals of the metal detector in the X- axis, Y- axis. The sensor head scans the mine X- axis and Y- axis N times, as show in fig. 5. The output voltage value of the detection circuit depends on the depth of the target and its metal area. From the output voltage value, the PIC program can estimate the position in z direction, which highly depends upon the total distance of the target from the coil. The magnetic field decreases very quickly with increasing the total distance between the transmitting - receiving coil and target. The total distance represent the target depth in the ground and the sensor height above the ground, that is installed about 50mm above ground to avoid the surface irregularity from all the previous the target position is identified.

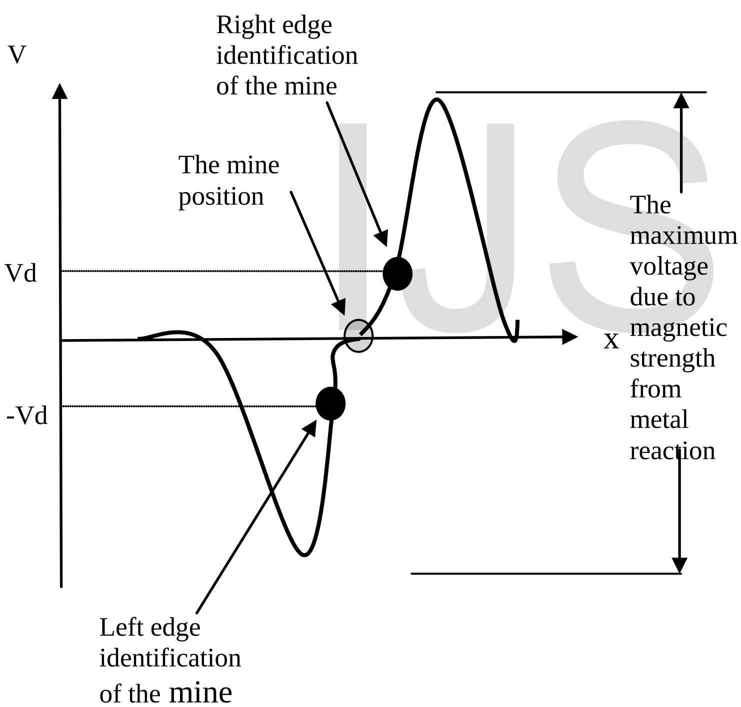


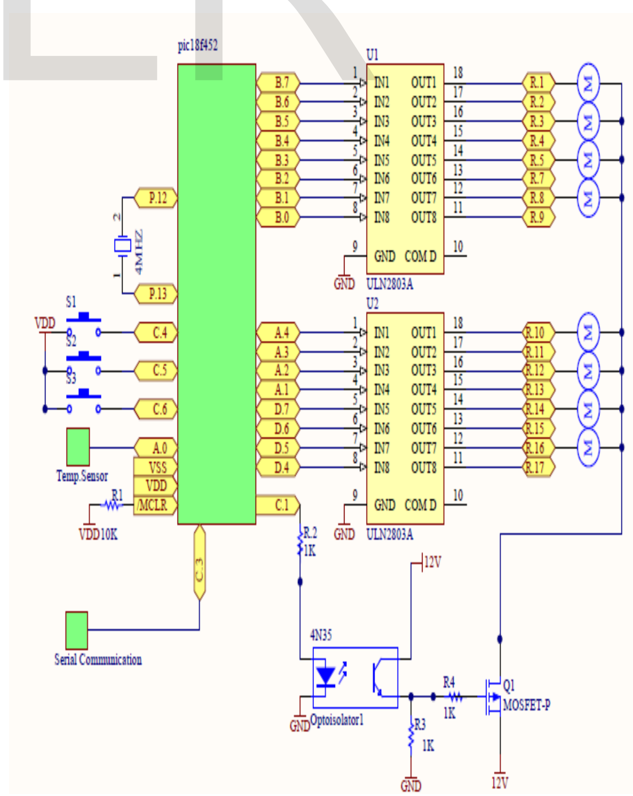
Fig.5 Definitions of the mine position

4 RELAYS AND MOTORS DRIVING BOARD

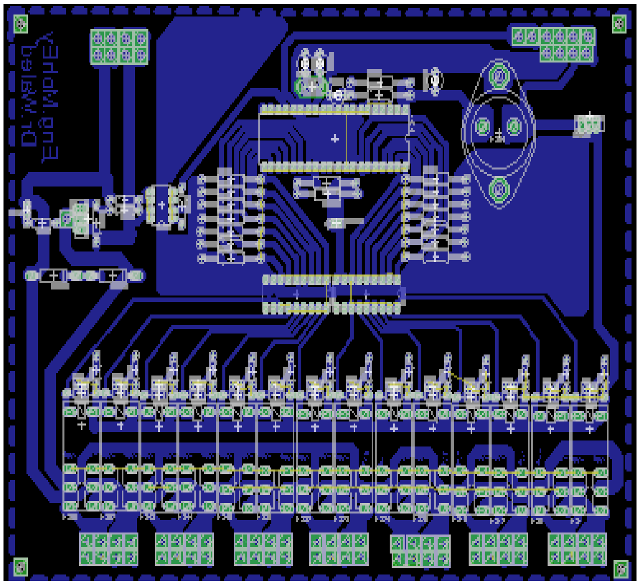
This board consists of 16 high current relays responsible for controlling the direction of motors, two ULN2803 and the microcontroller circuit. The microcontroller circuit receives the commands from the main board in order to control the motors status, through built in serial communication module. The motors are connected in such a way that the ground rails are connected through a ULN2803 that guarantees each motor controlled separately.
The + 24 volt rail is connected through the transistor IRF9530 which is controlled by the PWM signals coming from the microcontroller to control the speed of any of the attached motors based upon the given duty cycle. two PIC controls 9 DC motors through 9 sensors as shown in fig. 6.

5 CONTROL SYSTEM OF THE ROBOT

The objective of this work is to control the movements and operation sequence of the robot wirelessly. The control strategy and the design method is carried out using open loop control technique in order to synchronize the movements of the mechanisms to perform the mine detection and then extraction operations. This objective is achieved using two PICs microcontrollers that have the capability to monitor and drive eight DC motors, handling the signals of 9 sensors, rotary encoders, two LCDs, 2 flashers, sound alarm, transmitting-receiving wireless module and the signal from the metal detector sensor. A wireless hand-held device that controls the robot modes of operation, functions and movements as the operator wants to do in the field with a wireless range up to 150 m.
The hand-held remote control has onboard PIC microcontroller that, handles the wireless communication operations, command signals and modes of operations between the hand-held device and the rest of the robot electronic circuits through wireless (wifi) antenna system.



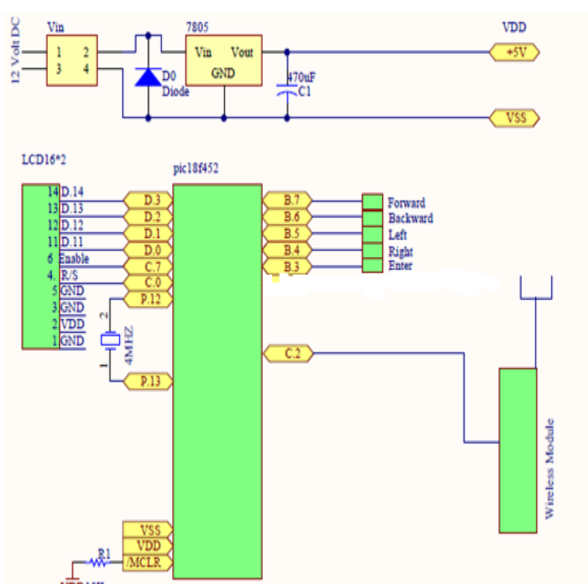
(a)



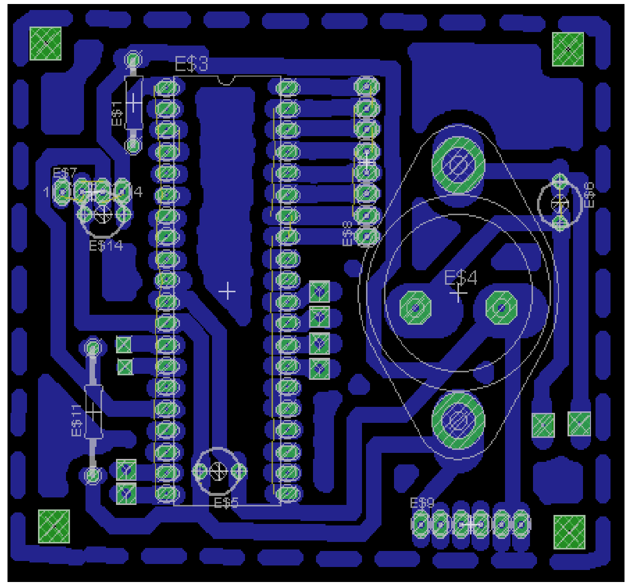
(b)

Fig.6. Relays and motors driving circuit Board (a) The schematic diagram (b) the PCB

The control heart of the hand-held device is the PIC18F452 microcontroller interfaced with the KST-TX01 wireless module. It is a transmitter-receiver pair used to transmit and receive serial digital data streams with maximum 20 Kbps rate. The hand- held schematic diagram and the PCB are shown in fig. 7. The analog signals coming from the mine detector PCB. The main PCB and the relays PCB are controlled serially through serial communication between them via the onboard PIC18F452. The PIC18F452 microcontroller circuit has two channels of up/down counters for processing the motors rotary encoders signals to control the robot movements according to the applied programs.



(a)



(b)

Fig. 7. The handheld circuit (a) schematic diagrams (b) PCB.

The data memory map is divided into 16 banks that contain 256 bytes each and Analog-to-Digital Converter module (A/D) with fast sampling rate to deal with the analog signals of encoders, proximity and ultrasonic sensors. The robot programs are executed at high speed, through communication between the two PICs. fig. 8 shows the flow chart of the robot system.

6 MINES EXTRACTION MECHANISM

6.1The mechanical structure of the extraction mechanism as shown in fig.9 is composed of the following parts:

- A rotary wheel with 25 cm radius coupled with a motor has 500-watt electric power with a gear box 1/20 producing a final 200 revolution per minute. The PIC microcontroller controls the speed and torque of the wheel during the digging operation.
- Four moving hard steel fingers derived from two DC vertical motors attached to four steel bars bolted with caged overhead conveyor bearing to translate the rotary motion of the motors to line motion used for opening the fingers to take the digging position and closing it to pick up the personal mine.
- Two ultrasonic sensors to measure the distance from the detector sensor and fingers position to the ground and a magnetic proximity sensor to sense the gap distance from the mine to inside the rotary wheel during digging and catching it.

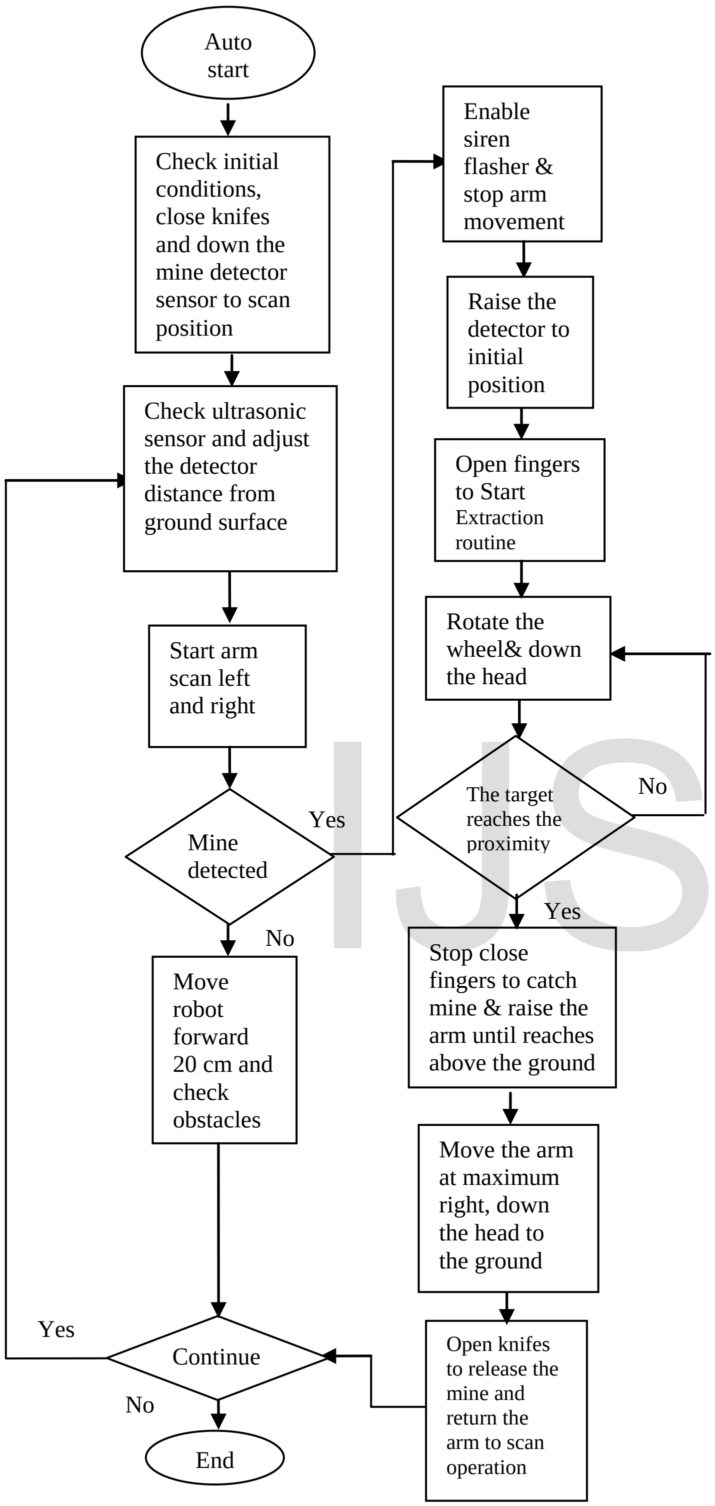


Fig.8. The flow chart of the robot system

Fig. 9. The anti-personal mine extraction structure.

6.2 Automatic extraction operation

As the magnetic metal detector detects a mine in the ground at distance (z) a sound and lighting alarm are released. The microcontroller begins the steps of mine extraction as follows:

- Raising the metal detector sensor holder to the up position, then opening the fingers to the right angle with respect to the ground.
- The ultrasonic sensor measuring the vertical distance to the ground (x) when the front head goes up or down, the microcontroller calculates the distance (y) needed to move the head down to pick up the mine as $y = z - x$.
- The rotating wheel begins to rotate right and left directions with ascending speed (v) and torque (T) touching the soil sensing the nature and strength of the soil by measuring the instantaneous voltage equation of the brushless DC motor and then increase or decrease the torque and speed to achieve a certain digging operation.
- The completely digging front head begins to go down directed to the ground and the fingers begin to dig the soil gradually, the microcontroller receives the proximity sensor signal to decide to stop or continue of digging operation.
- At reaching and sensing the mine, the fingers begin to close to catch the mine, the whole head goes up to 30 cm distance above the ground and the main arm moves to right far away from the robot path.
- The whole head moves down to the ground, the fingers are opened to let the mine and then the robot moves ahead to complete the scan mission.

ISSN 2229-5518

- The operator can monitor the extraction process through the on board wireless camera, located above the digging head. Once the operator visualizes the mine, he can readjust the robot position using the hand held remote control order to pick up the mine accurately.

7 Robot Path planning and operation

To scan a certain area, the mine detection and extraction robot applies a scanning routine as follows:

- Starting from the origin point A, the robot travels in a straight-line path in steps of 30 cm, then stops, scans and moves forward 30 cm repeating the same manner until reaching the end of the determined path.
- Turning to the left and returning to the opposite direction using the differential drive steering (stopping the wheel left driving motor and rotating the right motor) to scan the remaining area in zigzag style until reaching to the end point B of the specified area with overlap distance of 20 cm and so on as shown in fig. 10.
- Once the magnetic sensor detects a mine, the sensor will stop scanning and then the robot comes to a standstill and sends out signals to the operator by both illuminating the red flasher as well as beeping. The Metal detector coil sensor moves up to the extraction position and the automatic extraction operation begins.

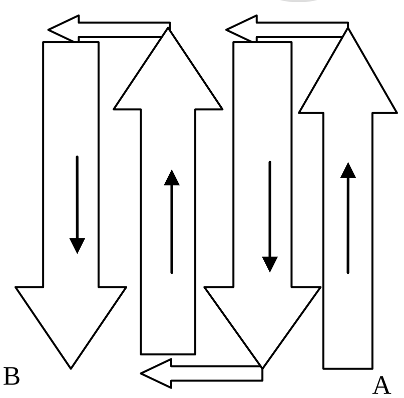


Fig.10. The robot path routine

- After finishing the extraction process then, the scanner will restart its scanning sequence and the robot would move forward again with no detection of mine. This scanning routine will continue until the scanner detects another mine.

8 Tests and results

The performance of the mine detection sensor is evaluated experimentally by measuring the output voltage of the detection circuit at different cases of targets. The results corresponding to the different cases of depths and areas of the target are shown in fig. 11. That results show the variation of the output voltage of the detection circuit against the depth of the target for three values of the metal areas (9 cm2, 6.25 cm2, 4 cm2) respectively. The robot complete structure is shown in fig.12. The experimental results of the prototype mine detector and extractor robot show that the designed robot is able to detect and extract the personal mines. The whole system can follow the designed path and terrain irregularities. The tests are carried out with the prototype assures the success of the robot design. However, in order to make the rotary wheel be able to extract mines of different sizes, it is necessary to introduce an adaptive capability for varying the size of the rotary wheel in accordance to the size of buried mine.

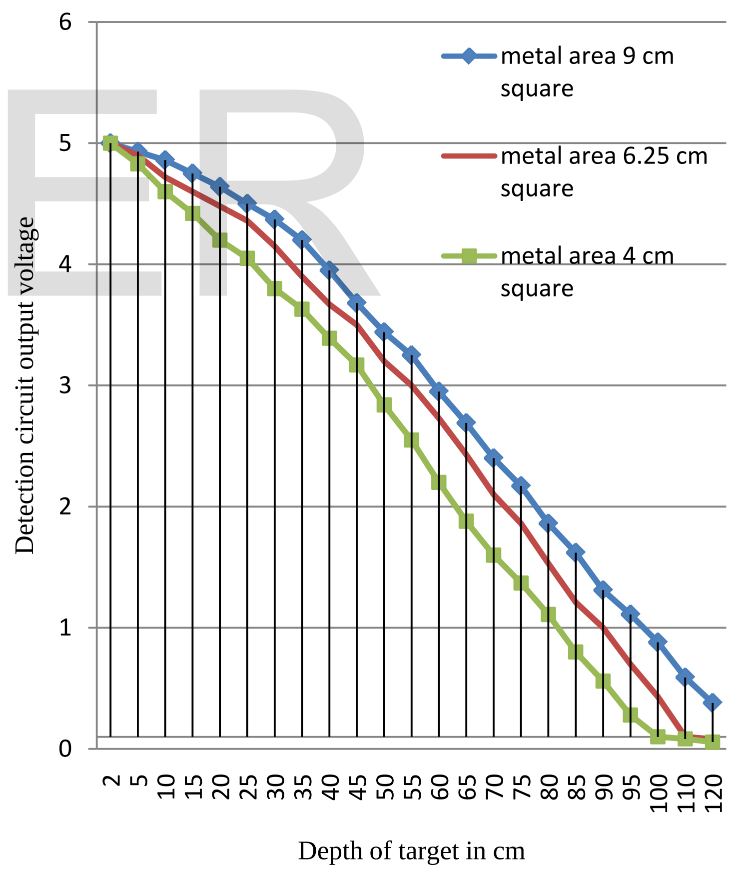
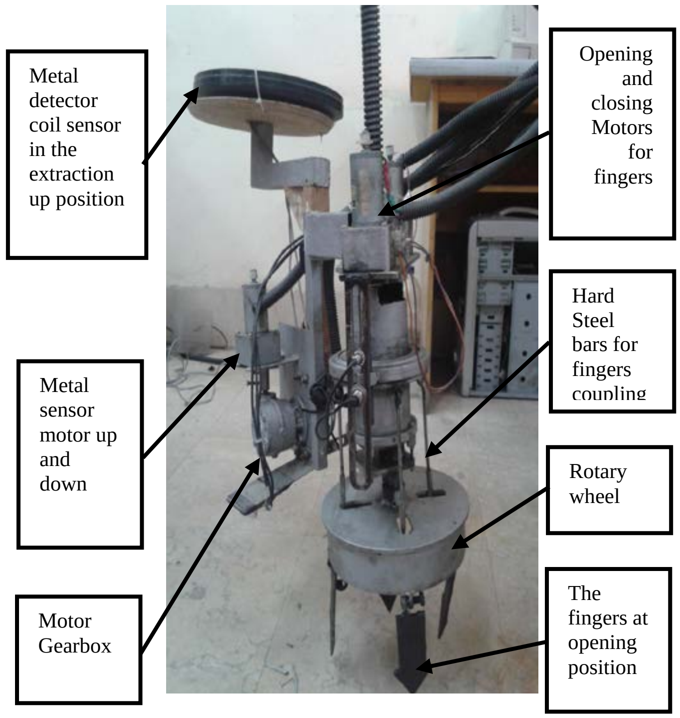
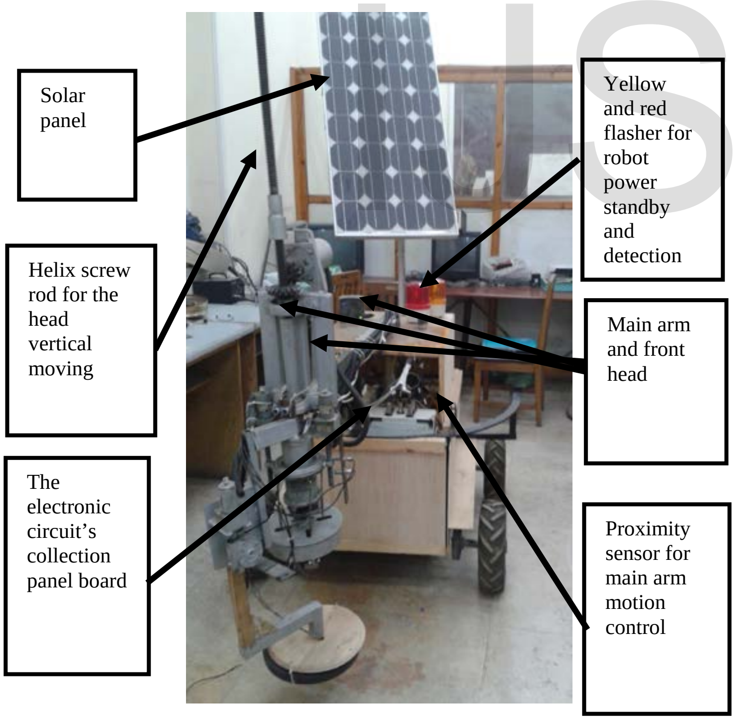


Fig.11. The output voltage Variation of the detection circuit against the target depth.

ISSN 2229-5518



(a)



(b)

Fig.12 The robot complete structure (a) The robot head (b) The complete structure

9 Conclusions

A new development of mine detection and extraction wireless robot is introduced. The detection mines process is carried out using a metal detector sensor that operates based upon electromagnetic induction EMI. Mines discrimination and position estimation are done by identifying the size and the horizontal dimensions of the found object, which is very useful in the extraction process. The extraction process starts as soon as mine discrimination satisfaction has ensured. The operation of the robot combines the flexibility of manual and automatic modes of operation with rapid and safer mechanized scanning and extraction operations. The introduced robot has the advantage of reduced cost, size and reduced overall system complexity. The experimental results shows a high accuracy for gripping the detected mines, also detector experimental results shows that the detection and discrimination processes offers high sensitivity with one-meter range.

REFERENCES

[1] Kenzo Nonami, Yayoi-cho and Inage-ku, "Development of a Mine Detection Robot Mine Hunter Vehicle (MHV), Controlled Metal Detector and Multifunctional Hydraulic Manipulator." nonami@faculty.chiba-u.jp, pp 123- 143, 2008.

[2] H. Najjaran, N. Kircanski and A. A. Goldenberg "Landmine detection using an autonomous terrain scanning robot." NRCC-46424, 2003.

[3] Nyein Chann "Landmine detection and marking robot." Department of mechanical engineering national university of singapore Pp 01- 39, 2006/2007.

[4] Hajime Aoyama, Kazuyoshi Ishikawa, Junya Seki, Mitsuo Okamura, Saori Ishimura and Yuichi Satsumi "Development of Mine Detection Robot System." International Journal of Advanced Robotic Systems, Vol. 4, No.2 pp 229 – 236, 2007.

[5] Liu Gangfeng, Zhu Lei, Han Zhenfeng, and Zhao Jie, "Distribution and Communication of Multi-robot System for Detection in the Underground Mine Disasters." Proceedings of the IEEE International Conference on Robotics and Biomimetics December 19 -23, 2009.

[6] K. Vidyasagar, U. Nageswar Rao, K. Suresh and MD. Abdul Farooq," Landmine Detection Robot Using Radio Frequency Communication." Journal of Academia and Industrial Research (JAIR) Volume 4, Issue 2 July 2015.

[7] Nobuhiro Shimoi and Yoshihiro Takita, "Remote Mine Sensing Technology Using a Mobile Wheeled Robot." International Conference on Control, Automation and Systems. in KINTEX, Gyeonggi-do, Korea Oct. 27-30, 2010.

[8] Walid Mohamed Mostafa, Adle Ezzat Elhenawy and Magdy A. koutb, "Two Axes Automatic Solar Panel Sun Tracking System For Supplying Power To Mine Detection Robot." 9th International conference on electrical engineering Egyptian military technical college (ICEENG) 2014.

[9] Roger Achkar and Michel Owayjan , "Implementation of a vision system for a landmine detecting robot using artificial neural network International." Journal of Artificial Intelligence & Applications (IJAIA), Vol.3, No.5, September 2012

[10] E. E. Cepolina and M. Zoppi, "Cost-effective robots for mine detection in thick vegetation.", Sixth International Conference on Climbing and Walking Robots, CLAWAR03, Catania, Italy, 17-19 September 2003.

[11] Farhad Aghili, and Jean-Claude Piedboeæuf , "Emulation of Robots Interacting With Environment." IEEE/ASME Transactions on mechatronics, Vol. 11, No. 1, February 2006.

[12] R. Ponticelli, E. Garcia, P. Gonzalez de Santos and M. Armada, " A scanning robotic system for humanitarian de-mining activities."

Industrial Automation Institute, adrid, Spain Industrial Robot: An International Journal, Vol. 35/2 PP 133–142, 2008.

[13] Achkar, R. and Owayjan, M. "Implementation of a vision system for a landmine detecting robot using artificial neural network." Int. J. Artificial Intellig. Appl. 3(5): 73-92-2012.

[14] Guoqiang Wu, Dehui Xu, Bin Xiong, Duan Feng, and Yuelin Wang, "Resonant Magnetic Field Sensor With Capacitive Driving and Electromagnetic Induction Sensing." MARCH 2013.

[15] Kenzo Nonami, Yayoi-cho and Inage-ku, "Development of a Mine Detection Robot Mine Hunter Vehicle (MHV), Controlled Metal Detector and Multifunctional Hydraulic Manipulator." nonami@faculty.chiba-u.jp, pp 123- 143, 2008.

[16] Hajime Aoyama, Kazuyoshi Ishikawa, Junya Seki, Mitsuo Okamura, Saori Ishimura and Yuichi Satsumi, " Development of Mine Detection Robot System." International Journal of Advanced Robotic Systems, Vol. 4, No.2 pp 229 – 236, 2007.

[17] Slawomir Tumanski , "Induction coil sensors." Warsaw, Poland, 7 November 2006.

[18] Joonki Paik, Cheolha P. Lee, and Mongi A. Abidi, "Image Processing-Based Mine Detection." The University of Tennessee Knoxville, February 8, 2002.