International Journal of Robotics and Automation (IJRA)
Vol. 2, No. 3, September 2013, pp. 83~92
ISSN: 2089-4856

Behavior-Based Approach for the Detection of Land Mines Utilizing off the Shelf Low Cost Autonomous Robot

Abdel Ilah Nour Alshbatat
Department of Electrical Engineering, Tafila Technical University, Tafila, Jordan

Article Info

Article history:

Received Dec 28, 2012
Revised Apr 2, 2013
Accepted Apr 28, 2013

Keyword:

Mobile Robots
Intelligent Controller
Landmine Detection

ABSTRACT

Several countries all of the world are affected by landmines. The presence of mines represents a major threat to lives and causes economic problems. Currently, detecting and clearing mines demand specific expertise with special equipment. In this context, this paper offers the design and development of an intelligent controller which can control and enable the robot to detect mines by means of sensors and of processing the fused information to guide soldiers when passing landmines. This is accomplished by broken down the overall system into two subsystems: sensor technologies and robotic device. Sensors devices include infrared distance sensor, metal detector, ultrasonic range finder, accelerometer sensor, while the structure of the robot in our case consists mainly of a commercial off-the-shelf parts which are available at low costs. The proposed controller is mainly based on creating fuzzy rules that reflect the behaviors of soldier beings in controlling a robot in a well known landmine. Simulation and experimental results are presented her to prove the efficiency of the proposed approach. The results show that the system is able to detect landmines and guide soldiers while crossing mines area.

Corresponding Author:

Abdel Ilah Nour Alshbatat,
Department of Electrical Engineering,
Tafila Technical University,
P.O.Box 179, Tafila, 66110, Jordan.
Email: a.alshabatat@ttu.edu.jo

1. INTRODUCTION

In recent years, landmines are one of the biggest problems that faced many countries throughout the world. The current solutions for detecting landmines are the use of a prodder, metal detector and remote sensing that are carried by human operators [1]. Those solutions expose a lot of risk to operators since a slight mistake may cause death. The risk accompanied with this solution is due to the fact that demining functions are boring and repetitive.

A metal detector is simply an electronic device that detects metal, mainly through the use of a coil that generates an electromagnetic field and measures the eddy currents induced by a metal object. These currents are interpreted by the circuitry of the metal detector and generates appropriate audible signal. The performance of a metal detector determined by several factors; including the scanning speed of the robot.

In prodding, a sharp stick is inserted into the ground to examine the existence of a buried object. In this technique, accidents are mainly caused by landmines that were moved away from their original position. Recently, In order to reduce risks; several attempts have been considered to mechanize prodding and to reduce the risk of such method. One method proposes the use of a robot to insert a series of ultrasonically vibrating probes into the soil to measure the stiffness of the soil and to examine the material used in landmines [2].

Remote sensing is the third method in which the presence of a buried object is examined using sensors such as electromagnetic induction sensors [3], [4] and ground penetrating radar [5]. Remote sensing or sometime what so called vehicle-mounted sensors is considered more appropriate for robotics applications because it is significantly safer, and more attainable. This method is usually used in military missions to provide a safe route to the solders through minefields.

From this perspective, it is desirable nowadays that landmines detecting is carried out by robot capable of autonomously manipulating a typical handheld detector for remote sensing of buried landmines in a manner similar to a human operator. Such robotic systems appear to have an important role in detecting landmines and may provide a safe alternative to extremely hazardous operations [6], [7]. Thus robots could be used instead of humans and may bring efficiency and safety to the whole process.

The problem of controlling a robot is very important and requires great attention. Obviously, all solutions proposed for the problem of landmines detecting required a construction of reliable robot that can operate in rough terrain with a good accuracy. The purpose of this paper is to design a sensory system to take readings from its surroundings and make the necessary decisions such as detecting landmines and guiding soldiers to cross a well known landmines field. This technique is specifically designed to be used when there is not a lot of time for the soldiers to clear minefields, and there is a need for a quick and efficient method with less chance of soldiers getting injured.

Several techniques such as neural networks, fuzzy logic and genetic algorithms can be applied to attach the previous problem. Amongst the three techniques, a new approach to the design of a simple fuzzy system is described. The suggested system has the advantage of planning the soldier's path among the known landmine, as well as local path planning for real-time obstacle avoidance. Moreover, the system tries to determine the position of the mine and consequently attempts to steer the robot around it.

The remainder of this paper is organized as follows: The next section will start with a survey of current research regarding the technologies that are employed with the aim of detecting mines and pin-pointing their locations efficiently. In Section 3, we explain the system architecture, hardware design, mine avoiding mechanism, and software design. In Section 4, we present the fuzzy controller and in Section 5, we present the simulation results then experimental results is presented in Section 6. Finally, we summarize the main results in Section 7.

2. RELATED WORK

Different combinations of technologies are employed with the aim of detecting mines and pin-pointing their locations efficiently [1]. Some of these technologies have been explored by many researchers, while others have been received relatively little attention. The most commonly used technologies are metal detectors, electromagnetic, acoustic, and biological sensors [8]. At the present time, the effectiveness of the detection process depends mainly on the sensor technology and on the means for carrying these sensors. The system provided in this paper combined both methods and thus allowed the operator to stay at a safe distance during crossing minefield.

Technologies that are employed with the aim of detecting mines use different principles. The first principle is based on sending energy into the ground and reflecting off the land mine [9], [10]. The presence of a mine is detected from differences in the electromagnetic properties of the target. This approach is varying based on the wavelength used by the source and thus affecting the depth of penetration and resolution. Long wavelength allows better ground penetration but will suffer from poor spatial resolution. The poor spatial resolution resulting from the wavelength makes it difficult to distinguish between buried mines and other objects of a similar size and shape. On the other hand, shorter wavelength has greater resolution but have a corresponding loss of depth in penetration. However, the applicability of this approach is limited due to the wavelength, it will meet the mission of locating the position of a buried mine.

The second principle is based on receiving energy that is emitted by the explosive inside the land mine [11]-[15]. This approach works by projecting energy into the ground that reacts with the molecules of the explosive, which creates a detectable reaction with the explosive and then sends a signal that is received by the detector. As an example for this technology is a quadrupole resonance [16], [17]. In this technology, a pulse of long wavelength energy causes the nitrogen nuclei in the explosives to emit a pulse of energy that is characteristic of the molecule. One limitation with this approach is that the detector head must be close to the mine. Despite this limitation, quadrupole resonance approach increases the amount of information available to distinguish mine targets from the background.

The third technology is primarily not electromagnetic, but it is based on acoustic or seismic energy reflected off the target [18]-[20]. This approach operates by creating an acoustic or seismic wave in the ground through a loudspeaker or a seismic source coupled with the ground. A doppler radar or a microphone with a conditional circuit is used to receive and process the signal reflected off the mine. A major concern with these approaches is that interference from rocks and other naturally objects in the environment may alter the waves as they travel in the ground [21]. This problem requires an additional work from the researchers to be conducted to assess the limits of this technology for detecting land mines.

The effectiveness of any technology is often evaluated by minimizing accidents to the operators specifically to those landmines that for any reason were moved away from their original position. To solve this concern, some countries nowadays performed the detection of buried landmines using several other methods, such as using dogs that sniff the explosive contents of the mines. This method is close to the third technology mentioned above but it has significant limitations and cannot be regarded to as general purpose solutions.

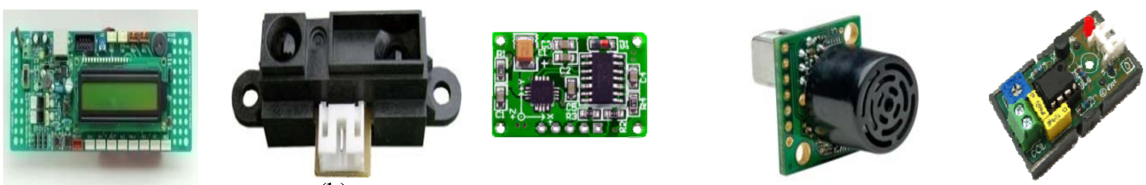
Several approachs for the detection of a small and shallow buried objects have been developed [22], [23]. A fuzzy logic based controller is used in the letruture to determine how the robot’s wheels velocities can be adjusted to keep the robot in a straight line and to set the robot to the correct direction. In [24], the auther proposed a new approach that emulates the driving behavior. The inputs to the system represent the readings of several sensors distriputed over the robot. The output of the system is the linear velocity needed to drive the robot safely on the path.

3. SYSTEM DESCRIPTION

3.1. Hardware Design

Figure 1 provides an overview of the hardware installed on the Robo-PICA kit. The hardware is designed to be as modular as to allow for ease of part replacement and also to ease hand-holding by the soldiers. As shown in Figure 1(a), RBX-877 provides a USB programmer and is considered as the main controller board for the robot. The heart of this controller board is the PIC16F887 microcontroller. The board contains a step-up switching power supply to maintain the +5V for microcontroller until battery voltage level down to 1.5V. Moreover, it contains LCD16x2 display, Piezo speaker, 9-Programmable multipurpose ports, L293D H-bridge motor driver for driving 2 channel DC motors, and two types of serial communication ports; UART and I2C bus. GP2D120, as shown in Figure 1(b), is an infrared distance sensor. The output voltage from this sensor will change according to the detection distance. With this module, distance measuring and obstacle detection using infrared light adds a good feature a head of the user.

One of most important function of this intelligent robot is to interface the sensors; that are capable for guiding the soldiers to their targets, to the RBX-877. The prototype of this intelligent system is shown in Figure 2. The system comprises of four major components, namely; robot, a data processing unit, a mine detection unit and additional sensors to control the movement of the soldiers. A variety of sensors are mounted on the robot, including ultrasonic sensors, accelerometers, metal locator, and sensors for avoiding obstacles. As shown in Figure 1(c), three-axis accelerometer sensor is selected for tilt detection. The sensor provides information about robot motion orientation. On the other hand, Figure 1(d) shows an ultrasonic sensor. This sensor is added to measure the distance between the robot and the soldier. Figure 1(e) shows the metal detector dedicated for this system and it consists mainly of a metal coil which creates an electric field around the mine. This electric field is used to detect any presence of conductive materials nearby. Upon sensing the mine under the robot, the system will alert the soldier and it will steer the robot around the mine and resume motion toward the soldier target.



(a) (b) (c) (d) (e)

Figure 1. Overview of the hardware installed on the Robo-PICA kit: (a) RBX-877 PIC Robot Board, (b) GP2D120, (c) Three-axis accelerometer board, (d) Ultrasonic Range Finder, and (e) ZX-METAL board

In this paper we considered two key operational parameters for our intelligent system: speed of advance, which is necessary for time critical missions and standoff. The ability of a Robo-PICA robot to keep up with the required rate of advance is dependent on two factors: the time to search a given area for mines and the number of times a sensor indicates the presence of a mine where one does not exist. The standoff, which is the distance a soldier can be from a mine. The maximum standoff for this system is the actual range for the ultrasonic sensor, which is about 6 meters. To keep the distance fixed between the robot and the soldier, this distance is maintained as the speed of the soldier increases by accelerating the robot.

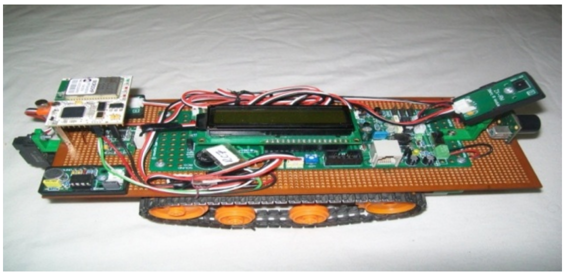


Figure 2. The photo of the mobile robot

3.2. Mine Avoiding Mechanism

The first priority of this system is to expose the location of the buried object. The movement of robot is initially random. RBX-877 controller board, which installed on the robot, will receive the data from the sensors. The data will be then processed and redistributed based on the proposed approach to the respective mechanisms to carry out the required processes. Mainly, the robot is intended to detect the buried mines, inform the soldier and then continue looking for another mine. As shown in Figure 3, after the location of a land mine has been exposed, it is required to warn the marching troops. Simply, the detector which is located between the wheels of the robot will scan the path ahead of the soldier. The ultrasonic sensors are continuously sampled while the robot is moving. If the driver stayed within the predefined maximum range limit of 6 meters, the robot would move forward, otherwise it stopped. To control the speed of a mobile robot, the driver steers the robot such as the movement of the soldier is set proportional to the magnitude of the distance measured between the robot and the soldiers. Thus, if the distance decreased, the robot would move ahead at its maximum speed. With this technique, the robot will run at its maximum speed to maintain a 6 meters space between the driver and the sensor. However, in the presence of mines, the robot's speed will reduce to a certain level that permits the robot to turn around the mine. Subsequently, the robot resumes its normal mode, and heads toward its destination.

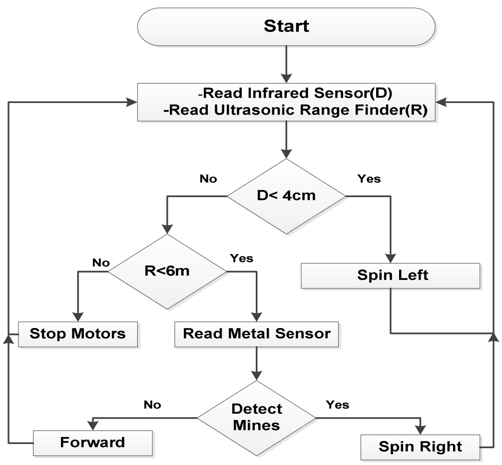


Figure 3. Algorithm of the processing unit

3.3. Software Architecture

The philosophy behind our software design is to implement the mine avoiding mechanism using C language. As shown in Figure 4, the code is used to connect a number of modules to the PICA robot, such as: the ultrasonic module, tilt module, and detector modules. Additionally, we are implementing the proposed fuzzy controller based on mine detection and sensors data.

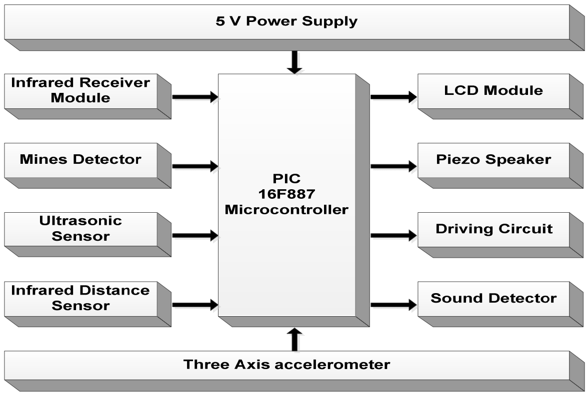


Figure 4. Block diagram of system

4. FUZZY CONTROLLER

The intelligent system proposed in this paper utilizes the theory of fuzzy sets to guide soldiers while crossing landmines. The proposed approach is mainly based on creating fuzzy rules that reflect the behaviors of soldier and sensors beings in controlling a robot in a well known landmine. The structure of the proposed fuzzy system is shown in Figure 5. As seen in the figure, the system consists of four subsystems. Each is responsible for an independent decision and attached to a single sensor. The main function of these subsystems is to generate a weighting factor (wi) that represents the degree of robot orientation. Weighting factors are then attached to the engine (defuzzifier) for the purpose of creating the fuzzy values to steer the robot to the desired location. The Center of Area method is used her by the engine to obtain the final crisp value for the steering angle of the robot (θ). The same method is also used to obtain the final crisp value for the speed of the robot (v). The whole system is responsible for guiding the driver safely from one location to another in the given area that contained a random number of mines.

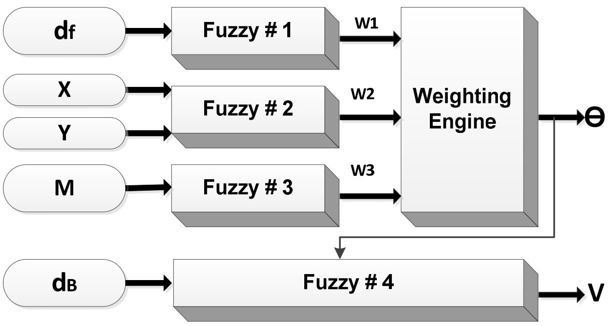


Figure 5. Structure of the proposed fuzzy controller

The reaction of the robot can be inferred from the movement of the driver and sensing data. The system named behavior-based approach is responsible for generating decisions that result in robust real-time reaction that is capable of reducing injury to all drivers. Based on Figure 6, the robot should behave according to four elements: behavior of the driver, sensor data, metal locator and accelerometer. As show in Figure 7, each element is represented as a simple fuzzy system and is responsible for generating an independent decision in which the final decision is generated as a result of combining all previous decisions. The fuzzy system has four main components: knowledge-Base which holds the information in the form of a set of rules. The decision making logic or the inference engine evaluates which control rules are relevant at the current time and then decides what the input to the robot should be. Fuzzification is the process of converting a set of crisp data into a set of fuzzy variables using the membership functions. Finally the defuzzification which is the process of converting fuzzy rules into a crisp output.

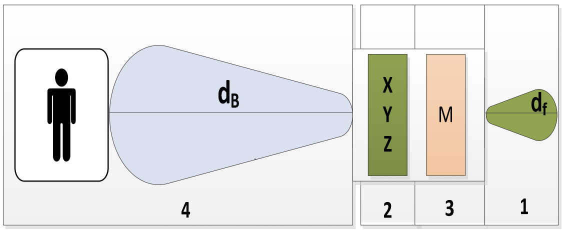


Figure 6. Elements of the proposed controller

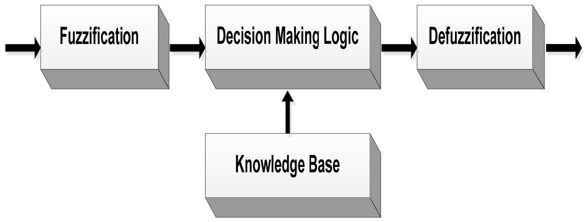


Figure 7. Element-Bases fuzzy controller block diagram

As shown in Figure 8 which represent the behavior of the driver, the input d_B to the subsystem is mainly representing the distance between the soldier and the robot with respect to the maximum distance of sensor. This distance is measured by an ultrasonic sensor whose maximum range is 6 m. the membership functions that represent this input variables are shown in Figure 9(a). The second input to this subsystem is the absolute value of the steering angle $|\theta|$, where the membership functions for this variable are shown in Figure 9(b). The output of this subsystem is the speed of the robot (v), where the membership functions for this variable are also shown in Figure 9(c). For the proposed fuzzy controller number four, the input variables for the soldier distances d_B are simply expressed using five linguistic labels: very near (VN), near (N), medium (M), far (F), and very far (VF). The second input variables for the absolute value of the steering angle $|\theta|$ are expressed using three linguistic labels: small (S), medium (M), and big (B). The fuzzy sets for the output variables are expressed using five linguistic labels: stop (ST), slow (S), medium (M), fast (F), and very fast (VF). Table 1 shows the if-then rules that are needed to define the fuzzy algorithm of the inference engine for this subsystem.

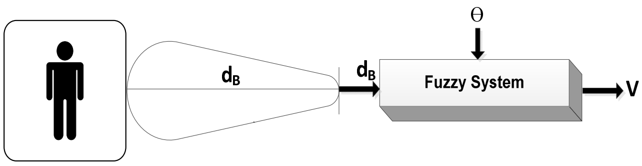
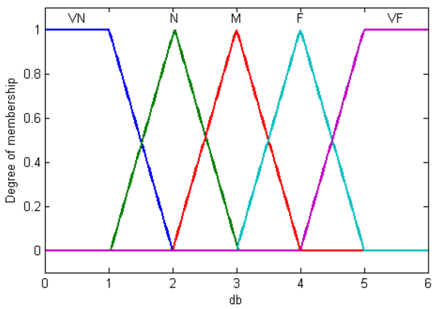
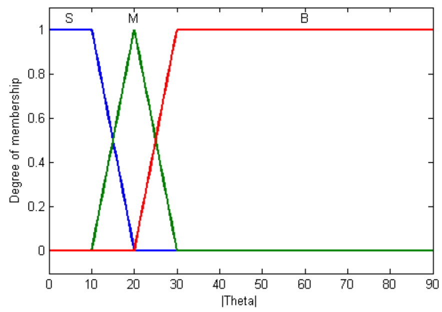


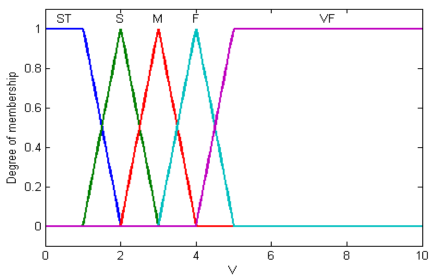
Figure 8. Behavior of the driver



(a)



(b)



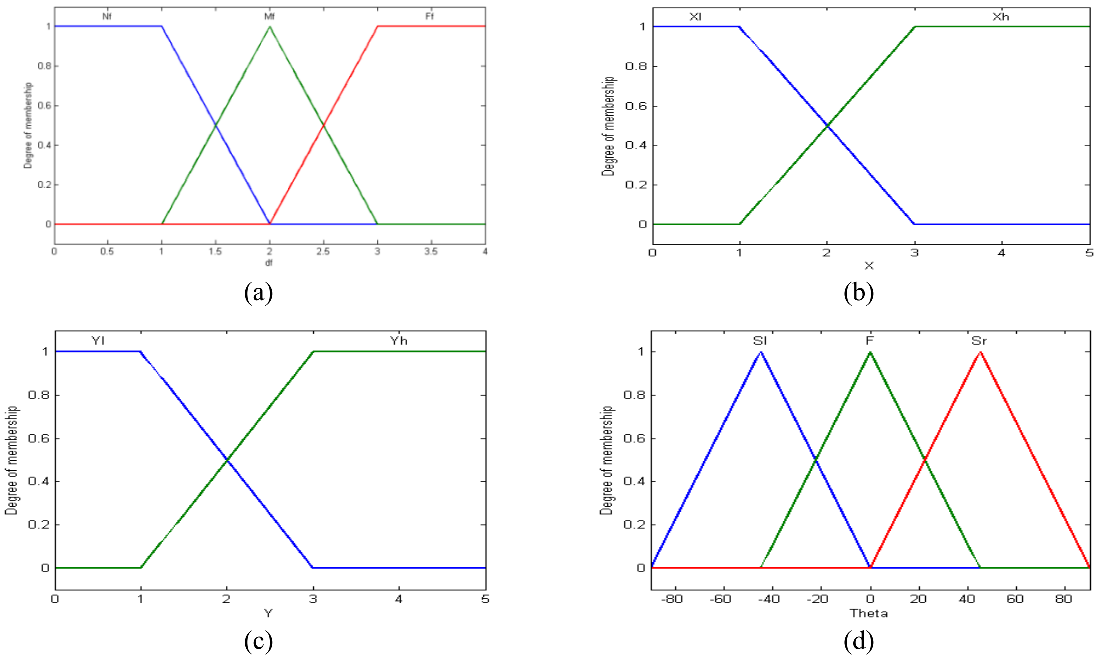
(c)

Figure 9. Fuzzy set definition for the input and output variables: (a) d_B, (b) $|\theta|$, and (c) V

Table 1. The fuzzy rule base

If (dB is VN and |θ| is S) then V is VF.
If (dB is N and |θ| is S) then V is F.
If (dB is M and |θ| is M) then V is M.
If (dB is F and |θ| is M) then V is S.
If (dB is VF and |θ| is B) then V is ST.

Again as shown in Figure 5, the input d_f to the subsystem number one is mainly representing the distance between all front obstacles and robot. This distance is measured by an infrared sensor whose maximum range is 4cm. The membership functions that represent this input variable are shown in Figure 7(a). Fuzzy subsystem number two is mainly representing the tilt in the x and y direction. The membership functions that represent this input variable are shown in Figure 7(b) and Figure 7(c) respectively. Finally, Fuzzy subsystem number three is representing the metal sensor dedicated for this system. The membership functions that represent this input variable are not shown her. Linguistic variables OFF and ON are taken for the membership functions that represent metal variable. ON indicates that mine is detected, and OFF indicates that mine is not detected. Linguistic variables like near (Nf), medium (Mf), and far (Ff) are taken for the membership functions that represent d_f variables, while X_h, X_l,Y_h, and Y_l are taken for the membership functions that represent tilt variables. The output from the three subsystems is the weighting factors (ω_i) that represent the degree of robot orientation (0.0, 0.25, 0.50, 0.75, 1). The weighting factors are then defuzzified to get the output (θ). The membership functions that represent this output variable are shown in Figure 7(d) and the linguistic variables like spin right (S_R), forward (F), and spin left (S_L) are taken for the membership function. Table 2 shows the if-then rules that are needed to define the fuzzy algorithm of the inference engine for the three subsystems.



(a) (b) (c) (d)

Figure 10. Fuzzy set definition for the input and output variables: (a) d_f , (b) X, (c) Y, and (d) θ

Table 2. The fuzzy rule base

If d_f is Nf then W1 is 0.00
If d_f is Mf then W1 is 0.50
If d_f is Ff then W1 is 1.00
If(X is Xl and Y is Yl) then W2 is 0.00
If(X is Xl and Y is Yh) then W2 is 0.25
If(X is Xh and Y is Yl) then W2 is 0.50
If(X is Xh and Y is Yh) then W2 is 1.00
If M is OFF then W3 is 0.00
If M is ON then W3 is 1.00

5. SIMULATION RESULTS

In this section, the proposed fuzzy controller is applied to the Robo-PICA robot for simulation purpose. Simulations were conducted using the MatLab protyping language. As shown in Figure 11, two different simulation cases are presented her to analyze the reaction behaviors of the Robo-PICA in detection and avoiding fifteen mines placed randomly in the simulation area. In the two cases the robot is assumed to be initially moving with full speed and its relative steering angle is assumed to be zero. We investigated the performance of the fuzzy controller for two behaviors: landmines detection and landmines avoidance. Figure 11(a), and (b) show landmines detection, while Figure 11(c), and (d) show landmines avoidance. The analysis of the reaction behaviors of the robot is based on the variation of the distance measured between the robot and the soldier, metal location, robot orientation and any obstacle a head of the robot.

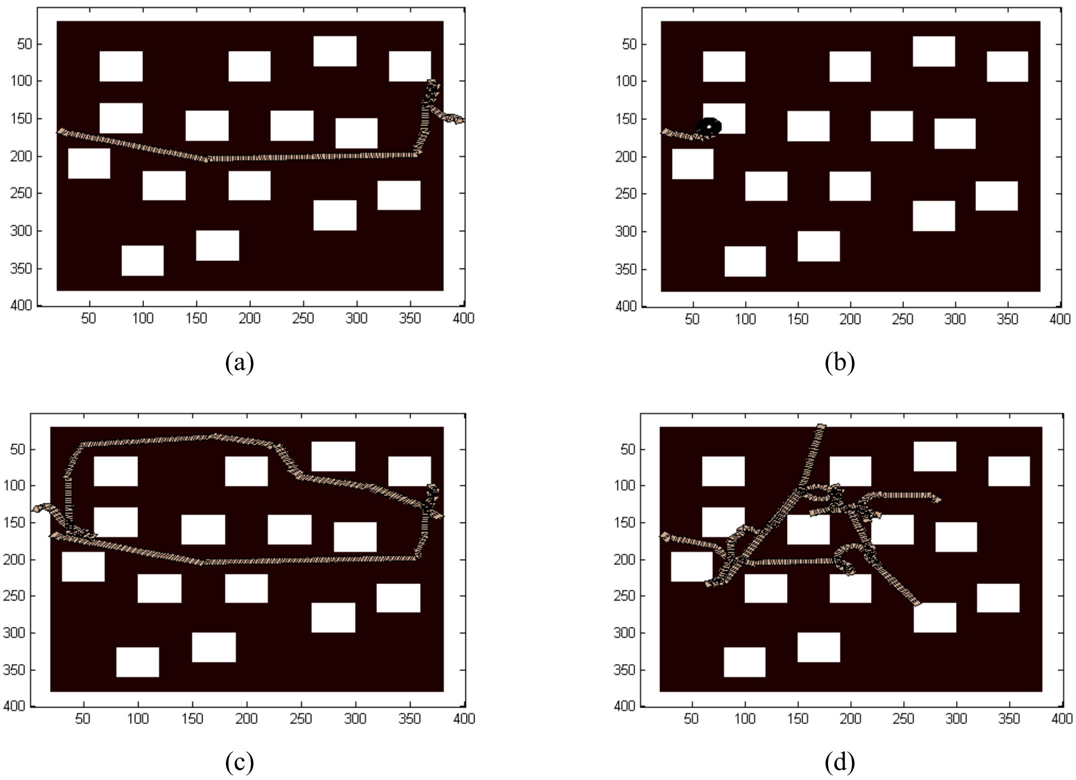


Figure 11. Robot path during simulation, (a) Variation of weighting factors, (b) Variation of mine location, (c) Variation of steering angle, (d) Variation of the distance measured between the robot and the soldier

6. EXPERIMENTAL RESULTS

The mobile robot used in all experiments is commercially available (Robo-PICA robot). To satisfy the purpose of this paper, additional sensors were added to the original hardware. The Robo-PICA robot has a maximum travel speed of V = 10m/min. This platform has a track wheels that permits omnidirectional steering, and it is driven by a geared PWM DC motors. The motion control of the two PWM DC motors is accomplished by a RBX-877 V2.0 controller board. The heart of this controller board is the PIC16F887 microcontroller. Our mobile platform has been equipped with a set of sensors and has been mentioned previously. A number of simple experimental tests were performed on the robot to test the validity of the proposed strategy. Figure 12, provides a snapshot for the robot during its navigation in one of the area that has mines.

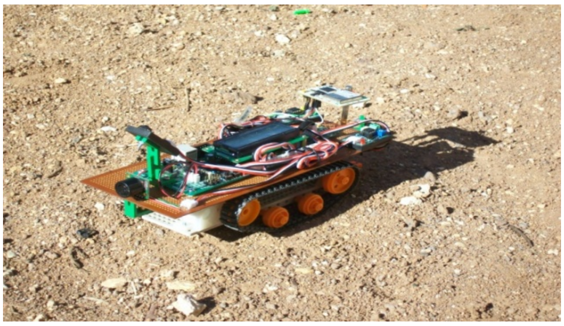


Figure 12. Snapshot for the robot during its navigation in one of the area that has mines.

7. CONCLUSION

In this paper, we have addressed the design and programming a robot that is capable of detecting mines with the aim of reducing risks to human operators and guiding soldiers when passing mines area. The paper describes the main features of the overall system, which consists mainly of sensor technologies and robotic device. The whole system has been configured to work in an autonomous mode with various kinds of sensors that allow the operator to stay away at safe distance and enabling him to control the movement of the robot using the ultrasonic sensor. The proposed fuzzy controller was simulated to confirm the operation of the land mine detection and then implemented on a Robo-PICA robot. The system has been thoroughly tested in several field and the results indicate that the system can improve the probability of detection landmines and reduce risks to soldiers.

REFERENCES

[1] C Bruschini, B Gros. A Survey of Current Sensor Technology Research for the Detection of Landmines. *International Workshop on Sustainable Humanitarian Demining (SusDem'97).* Zagreb, Croatia. 1997; 6.18-6.27.
[2] Y Bar-Cohen. Detecting Landmines. *NDT Update*. 2001.
[3] P Gao, LM Collins, N Geng, L Carin. Classification of Buried Metal Objects using Wideband Frequency-domain Electromagnetic Induction Responses: A Comparison of Optimal and Sub-optimal Processors. *IEEE International Geosceince and Remote Sensing Symposium,* IGARSS. 1999.
[4] P Gao, S Tantum, LM Collins. *Single Sensor Processing and Sensor Fusion of GPR and EMI Data for Landmine Detection.* Proceedings of SPIE, The International Society for Optical Engineering. 1999; 3710: 1139-1148.
[5] PD Gader, M Mystkowski, Z Yunxin. Landmine Detection with Ground Penetrating Radar using Hidden Markov Models. *IEEE Transaction on Geosceince and Remote Sensing*. 2001; 39: 1231-1244.
[6] R Cassinis, G Bianco, A Cavagnini, P Ransenigo. *Strategies for Navigation of Robot Swarms to Be Used in Landmine Detection.* Third European Workshop on Advanced Mobile Robots (Eurobot'99). Proceedings IEEE, 1999; 211-218.
[7] J Trevelyan. Robots and Landmines. 1997; 24(2): 114-125.
[8] C Gooneratne, SC Mukhopadhyay, G Sen Gupta. *A review of Sensing Technologies for Landmine Detection: Unmanned Vehicle Based Approach.* Proceedings of The second International Conference on Autonomous Robots and Agents, Palmerston North, New Zealand. 401-407.
[9] KC Ho, Paul D Gader. A Linear Prediction Land Mine Detection Algorithm for Hand-Held Ground Penetrating Radar. *IEEE Transactions on Geoscience and Remote Sensing*. 2002; 40(6).
[10] KC Ho, PD Gader, JN Wilson. *Improving Landmine Detection Using Frequency Domain Features from Ground Penetrating Radar*. Proc. of IEEE International Symposium on Geoscience and Remote Sensing (IGARSS'04). 2004.
[11] JC Kapoor, GK Kannan. Landmine Detection Technologies to Trace Explosive Vapour Detection Techniques. *Defence Science Journal*. 2007; 57(6): 797-810.
[12] RA McGill, TE Mlsna, R Chug , VK Ngyuen, J Stepnowski, MH Abraham, P Kobrin. *Detection and remediation technologies for mines and mine like targets III.* Proceedings SPIE. 1998; 3392: 384-89.
[13] DL Patel. *Mine explosive compounds.* Proceeding of Biological and Trace Gas Sensor Workshop. Ft, Belvoir, VA. 1996.
[14] V George, TF Jenkins, DC Leggett, JH Cragin, J Phelan, J Oxley, J Pennington. *Progress on determining the vapour signature of a buried landmine.* Proceedings SPIE. 1999; 3710: 258-69.
[15] GK Kannan, Bhalla Rashmi, JC Kapoor, AT Nimal, U Mittal, RDS Yadava. Detection of landmine signature using SAW-based polymer-coated chemical sensor. *Def. Sci. J.,* 2004; 54: 309-15.
[16] AN Garroway, ML Buess, JB Miller, BH Suits, AD Hibbs, GA Barrall, R Matthews, LJ Burnett. Remote sensing by nuclear quadrupole resonance. *IEEE Trans. Geosci. Remote Sens.,* 2001; 39: 1108-1118.

[17] AN Garroway, ML Buess, JP Yesinow-ski, JB Miller, RA Krauss. *Explosives detection by nuclear quadrupole resonance (NQR)*. Proceedings of SPIE. 2276: 139–149.
[18] N Xiang, JM Sabatier. An experimental study on anti-personnel landmine detection using acoustic-to- seismic coupling. ***J. Acoust. Soc. Am.,*** 2003; 113: 1333-1341.
[19] D Donskoy, A Ekimov, N Sedunov, M. Tsionskiy. Nonlinear seismo-acoustic land mine detection and discrimination. ***J. Acoust. Soc. Am.,*** 2002; 111(6): 2705-2714.
[20] G Montaldo, P Roux, A Derode, C Negreira, M Fink. Generation of very high pressure pulses with 1-bit time reversal in a solid waveguide. ***J. Acoust. Soc. Am.,*** 2001; 110(6): 2849-2857.
[21] D Gregg, GD Larson, JS Martina, PH Rogersa, WR Scott, GS McCall. Impact of nonlinear effects on a high-frequency seismic landmine detection system, *The Fifth International Symposium on Technology and the Mine Problem Naval Postgraduate School in Monterey*. CA. 2002.
[22] PD Gader, BN Nelson, H Frigui, G Vaillette, JM Keller. Fuzzy Logic Detection of Land Mines with Ground Penetrating Radar. *Signal Processing, Spec. Issue Fuzzy Logic Signal Processing (Invited Paper)*. 2000; 80(6): 1069-1084.
[23] H Frigui, PD Gader, JM Keller. *Fuzzy Clustering for Land Mine Detection.* Proceedings of NAFIPS'98, Pensacola FL. 1998: 261-265.
[24] G Antonelli, S Chiaverini, G Fusco. A Fuzzy-Logic-Based Approach for Mobile Robot Path Tracking. *IEEE Transactions on Fuzzy Systems*. 15: 211-221.

BIOGRAPHY OF AUTHOR

Dr. Abdel Ilah Nour Alshbatat was born in Tafila, Jordan, in 1968. He received the B.S. degree in Electrical Engineering/Communications from Mutah Universty/Jordan in 1991, and the M.S. degree in Computer Engineering/Embedded System from Yarmouk University/Jordan in 2004, and the Ph.D. in Electrical and Computer Engineering/Networks from Western Michigan University/USA in 2010. In 1991, he joined Royal Jordanian Air Force (RJAF) and served in the Directorate of communication & electronics ground communication branch, during which, he was responsible for the wireless communication and digital microwave sections. In 2010, he joined the faculty of Tafila Technical University and is currently assistant professor in the Department of Electrical Engineering. His current research interests include computer networks, wireless networks, embedded systems, UAV (unmanned aerial vehicle) and communication systems.