International Journal of Mechanical Engineering and Technology (IJMET)
Volume 10, Issue 01, January 2019, pp. 1672-1685, Article ID: IJMET_10_01_168
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=10&IType=01
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

DEVELOPMENT OF A SMART AUTONOMOUS MOBILE ROBOT FOR CAFETERIA MANAGEMENT

Ademola Abdulkareem* and Victoria Oguntosin
Department of Electrical and Information Engineering, College of Engineering, Covenant University, Ota, Nigeria.

Adeniran S. Afolalu
Department of Mechanical Engineering Department, College of Engineering, Covenant University, Ota, Nigeria

Adaobi Onyeakagbu[1]
Department of Electrical and Information Engineering, College of Engineering, Covenant University, Ota, Nigeria.

*corresponding author

ABSTRACT

The main aim of this work is to use a robot in a typical cafeteria environment to deliver food from the main counter to the customer's table, thereby acting as a mobile robot waiter. This study is essential in order to promote efficiency in serving food to customers. The robot uses an Arduino microcontroller to run a program with a combination of RFID technology, a line following module and an obstacle detecting system. The Radio Frequency Identification (RFID) reader is fixed on the robot itself, and reads the RFID passive tag which is placed under the serving tray. The RFID application allows the robot to identify the right table that is to be served and the robot moves to the respective table based on the tag. The uniqueness in the design of this serving robot is the application of the obstacle detection and collision avoidance, together with the integration of RFID technology. The findings from this research provide evidence that the robot is able to move according to the described path.

Keywords: Smart autonomous, Mobile robot, Cafeteria management, RFID technology, IR sensor module. Power converters,

Cite this Article: Ademola Abdulkareem, Victoria Oguntosin, Adeniran S. Afolalu and Adaobi Onyeakagbu, Development of a Smart Autonomous Mobile Robot for Cafeteria Management, International Journal of Mechanical Engineering and Technology, 10(01), 2019, pp.1672–1685
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=10&Type=01

1. INTRODUCTION

Food service industry is generally concerned with the quality preparation, presentation and delivering of foods usually for immediate consumption away from home [1]. The use of service robots for food delivery is growing rapidly in the industry especially in developed countries. The idea behind these robots is to deliver food from kitchen to where the customer is sitting. T-Bartender is one of the oldest food delivery robots and was implemented to improve on the preparation of Japanese green tea [2]. The Waiter Robot was developed in 2015 to take care of ordering and delivery. This robot, however, is not a fully autonomous system as it depends on external computing to tell it at what table to stop.

There are numerous researches on service delivery applications of robot but not without one challenge or the other [3]. For instance, a 7x5x2.5 electromechanical robot was designed to test out how much weight the robot can carry without affecting its line tracing capabilities; the application worked but not without challenge [4]. Warehouse navigation robot and food service system robot based on the ‘line following system’ were designed and implemented [5]. These applications worked fine, but ultimately lacked the ability to detect and avoid unexpected obstacles. Another application of line following robot is the library inventory management system (LIMS) designed to search through books on a rack and select the required one. Even though it was able to perform its required purpose, it could only search books at the bottom row of the rack due to height constraints and obstacle detecting sensors. [6]. the ultrasonic sensors are the most popular type of obstacle detecting sensors. They are mostly used because of their low cost and their inherent ability to achieve the goal. A tour guide robot called Central’s Automated Tour Experience (CATE) [7] was developed in 2012 to act as sonar guided robot at an unspecified higher institution. Majority of mobile robots used for food delivery operate on the basic principle of line following. Line following is based on Infrared Photoelectric (IR) technology. An IR sensor is used to ensure that the robot moves by tracking a line of white colour on a black surface or a black colour on a white surface. It is a feedback control system, which allows a corrective measure if the robot happens to move out of line. Moreover, RFID Technology has been applied to many kinds of robots, such as a Pick and Place robot designed to follow a line to move to a specific or required location [8]. Another RFID application of robot is the Warehouse robot; a variation of the Pick and Place robot, designed to resemble a forklift used in warehouses [9]. Also, the “ServingBot” robot combines RFID technology, line following module and a simple gripper and lifter mechanism to deliver food to tables by reading the tag which is placed under the serving tray [10].

Meanwhile, the use of autonomous service delivery robots in Nigeria and other developing countries is a potential goldmine. Furthermore, since the fast food industry in Nigeria has been a key contributor to the Nigerian economy, it is recommended that a system that could handle the high-volume traffic as well serve as a new customer attraction, be implemented. Therefore, this work aims to explore the application of autonomous robots with RFID tracking and an obstacle detection and avoidance system. This Smart autonomous mobile robot uses sensors for line following and obstacle detection, coupled with a RFID tracking system to enable it deliver food to customers in a typical indoor environment.Robots have increased in popularity due to a wide range of factors. These factors include better quality of product and cost reduction [11, 12], For this work, the passive RFID tag is used because of its cost effectiveness [13]. The outcome of the work can be implemented in a typical Nigerian cafeteria or restaurant to eliminate cost of human error and would inevitably boost customer patronage.

2. SYSTEM DESIGN AND ANALYSIS

In building this autonomous robot, various suitable platforms are considered in order to build a reliable and flexible system. The development and construction of the autonomous robot are functionally divided into hardware and software designs.

2.1. Hardware Analysis

Differential drive robots have two wheels which can turn at different rates so that the robot moves around. For differential drive robots, we have the right and left wheel velocities which are controlled independently. If both wheels have the same velocity, the robot is moving straight; if one wheel has a velocity lower than the other, the robot moves in the direction of the wheel with lower speed. To develop a model for the differential drive robot, two parameters are specified: L is the distance between the two wheels; while$R$ is the radius of the wheel. The control parameters are the speed of the right wheel, v_r, and the speed of the left wheel, v_l. The position of the robot is given by (x, y) and it has an orientation angle specified by φ.A schematic diagram showing parameters of a differential drive robot is shown in Figure 2.1

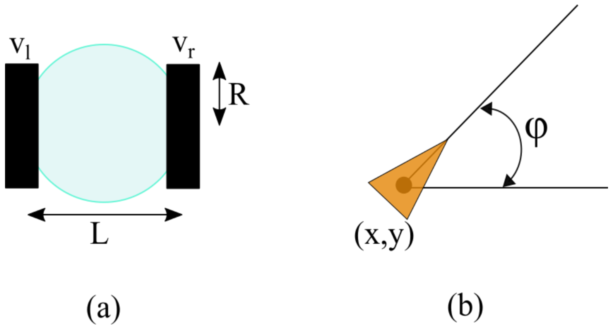


Figure. 2.1 Schematic diagram showing parameters of a differential drive robot

The differential drive robot model specified in terms R and L is given by:

$$\dot{x} = \frac{R}{2}(v_r + v_l)\cos\emptyset \tag{2.1}$$

$$\dot{y} = \frac{R}{2}(v_r + v_l)\sin\emptyset \tag{2.2}$$

$$\dot{\emptyset} = \frac{R}{L}(v_r - v_l) \tag{2.3}$$

The dynamics of the differential drive robot specified in terms of its position and orientation is given as:

$$\dot{x} = v\cos\emptyset \tag{2.4}$$

$$\dot{y} = v\sin\emptyset \tag{2.5}$$

$$\dot{\emptyset} = \omega \tag{2.6}$$

Where v and ω are the translational speed and angular velocity respectively

The hardware design of the robot basically consists of the mechanical structure and the electronic circuit design of the circuit. Figure 2.2 gives an illustration of the hardware design of the entire system.

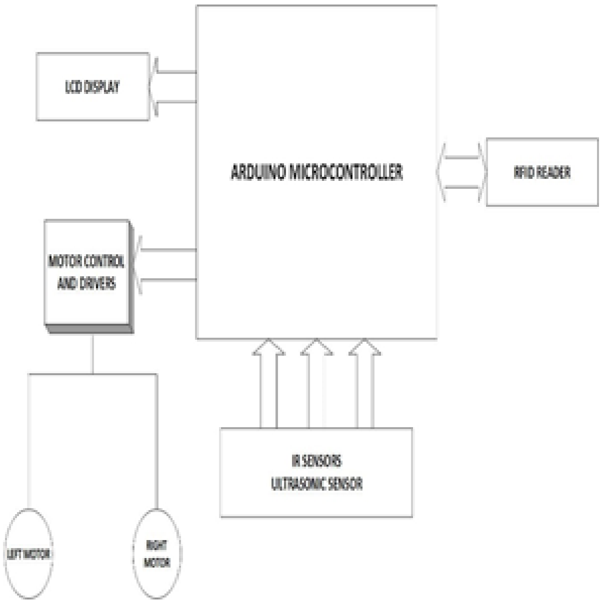


Figure. 2.2 System hardware design

2.2. Mechanical Structure

The mechanical structure of the robot consists of the chassis as shown in Figure 2.3. It is the body of the robot, the lifter system and the actuators. The chassis is made with strong clear acrylic material with maximum length of 25.4 cm and maximum width of 152.4 cm. The Chassis is coupled with a 4-wheel drive system with 4-DC geared motors controlling each 68mm wheel. Figure 2.3 illustrates the fundamental design of the robot, indicating the chassis and the 4 wheels.

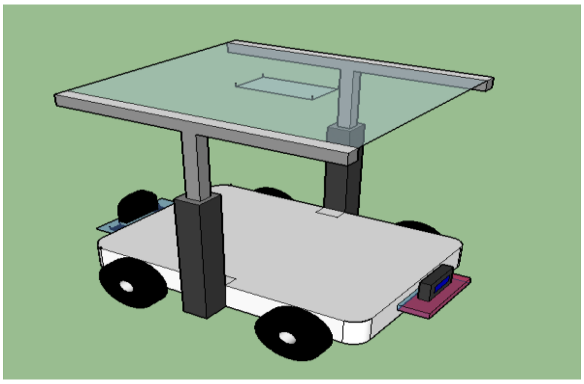


Figure. 2.3 Fundamental design of the robot

There are also 2 load bars connected to the chassis to enable a clear plastic to be attached. This serves as the platform where the tray of food will be placed. Figure 2.4 is the proposed bottom view of the robot, showing the 4-DC Geared motors that are used for driving the wheels. The clear plastic will enable the RFID reader, which is attached under, to read each RFID tag on the trays.

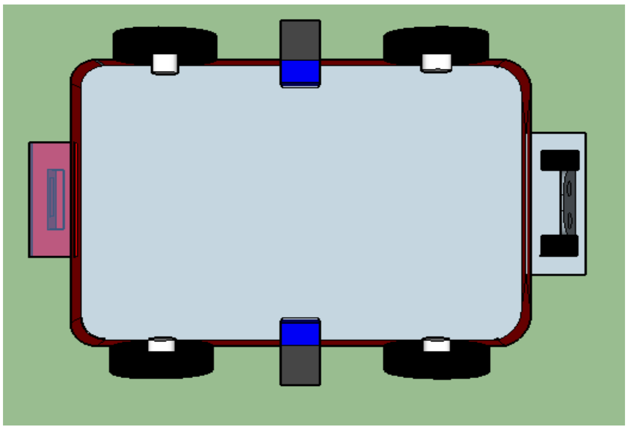


Figure. 2.4 Proposed bottom view of the robot

2.3. Circuitry Design

The circuitry consists of the control module, the input and the output devices. The circuitry shown in Figure 2.5 was designed, illustrated and simulated using the Proteus software. The major components used are the Arduino Mega microcontroller, the 2 Infrared sensors, the Ultrasonic sensor, the RFID module, the display, the servo motor, the motor driver and the powering circuit. The circuit diagram for the service robot is shown in Figure 2.6.

The Arduino Mega board has 54 digital input/output pins with 15 pins having the additional function of pulse width modulation outputs, 16 analog pins, a 16-MHz ceramic resonator/crystal oscillator, an ICSP (In-circuit Serial Programming) header, 4 UARTs (hardware serial ports), a USB connection, a power jack, and a reset button. It is based on the ATmega2560 processor programmed as a USB-to-serial converter. The operating voltage is 5V while the recommended input voltage ranges from 7V to 12V with limits of 6V minimum and 20V maximum. The DC current per I/O Pin is 40mA while the DC current for 3.3V Pin is 50 mA. Its clock speed is the same as that of the UNO board but it is chosen over the UNO board because of its additional number of digital and PWM pins.

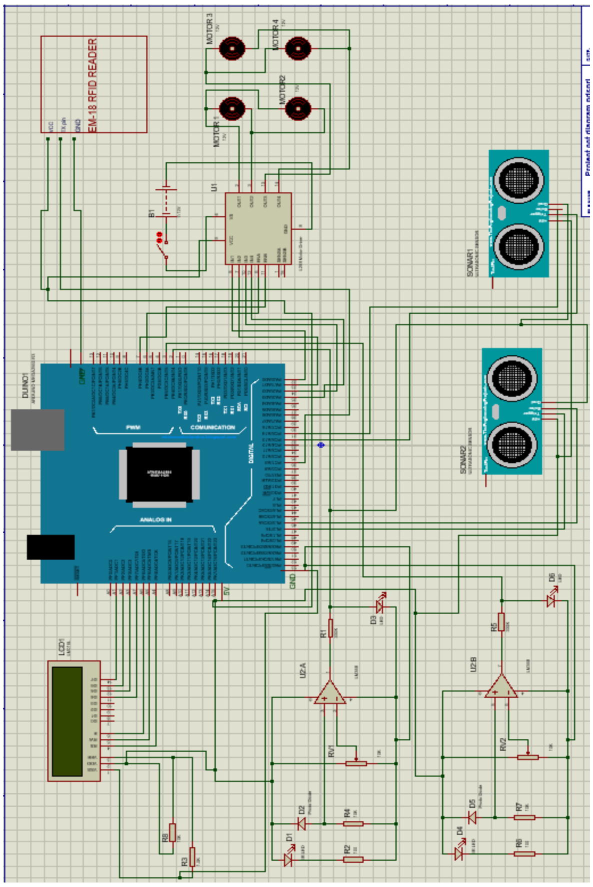
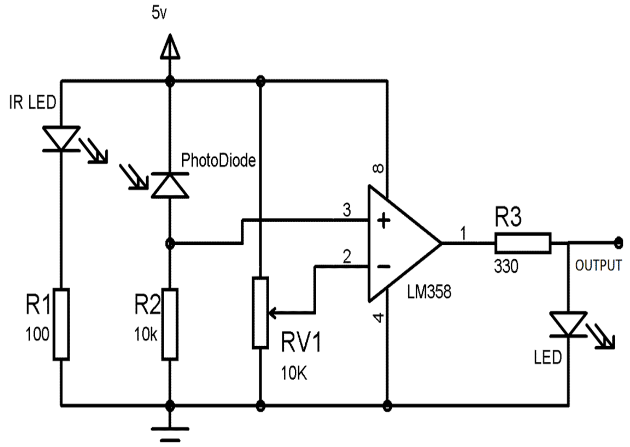


Figure 2.5 The circuitry of the robot

2.3.1. Infrared sensor (IR)

The IR Sensor Module is a circuit consisting of sensorswhich include an IR LED or photodiode pair, a potentiometer, an LM358 operational amplifier, resistors and LED. IR sensor transmits Infrared light and photo diode receives the infrared light. The behaviour of light varies from surface to surface. Since this robotwill be tracking black lines on a white surface, the behaviour of light on black and white surfaces is considered. When light falls on a white surface it is almost fully reflected while in the case of black surface, light is completely absorbed. The LM358 is a dual Op amp that acts as a comparator in the circuit. The potentiometer is used to set the reference voltage at the LM358'sfirst terminal while the IR sensors are used to sense the line and provide a change in voltage at comparator's second terminal. Then comparator compares both voltages and it generates a digital signal at the output. When the sensor senses a white surface, the microcontroller receives a"1" as input and when it senses black surface (black line), the Arduino gets "0" as input. Figure 2.7 shows the basic circuitry for an IR sensor module.



Figurr 2.6 Circuit diagram of the service rotor

2.3.2. The Ultrasonic sensor

The Ultrasonic sensor provides the robot with the ability to virtually see and recognize object, avoid obstacles and measure distance. It also provides exact, non-contact separation estimations within 2cm to 3m. Its measuring angle is 30˚ but its effectual angle is less than 15˚. The ultrasonic sensor emits short and high frequency signals propagating in air at the velocity of sound. The ultrasonic sensor consists of a multi vibrator, fixed to the base. The multi vibrator is a combination of a resonator and vibrator. The resonator delivers ultrasonic wave generated by the vibration. The ultrasonic sensor actually consists of two parts: the emitter which produces a 40-kHz sound wave and the detector which detects it and sends electrical signal back to the microcontroller. Whenever any obstacle comes ahead of the ultrasonic sensor, the sound waves will reflect back in the form of echo and generates an electric pulse. The time of return of the echo is measured to determine the distance of objects. It is placed at the front of the robot to detect any moving obstacles, for instance an approaching human, and sends a signal to the Arduino which causes the robot to stop and this averts collisions.

2.3.3. Wheel Motor

The DC motors are freewheeling 12-V motors running at approximately 200RPM and are used to power the wheels of the robot. Its speed is controlled using pulse width modulation. This refers to the process of controlling the motor's power level by strobing the power on and off. It makes use of the principle of duty cycle, that is, the percentage of on-time to off-time. The L298N H-bridge module shown in Figure 2.7 enables the control of the speed and direction of DC motors. It has a current consuming capacity of 4A and can be used to drive 7V to 12V DC motors at a maximum of 2A per channel with PWM. The Arduino board does not supply sufficient voltage and current to power the motor. Therefore, the motor driver is used to provide the required voltage. Figure 2.7 shows the connection of the motor driver to the 4 motors.

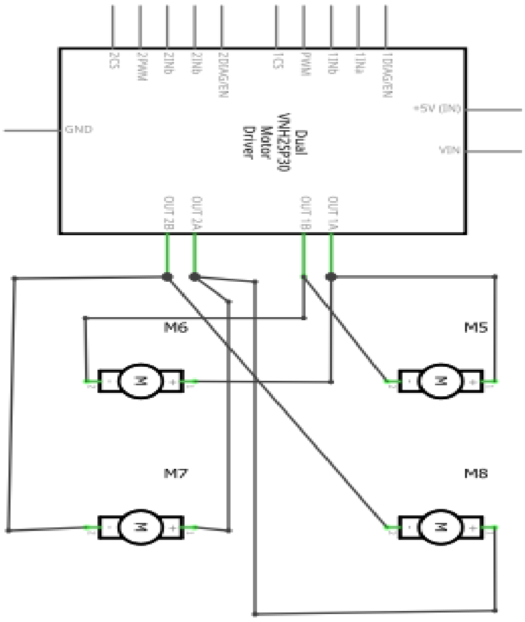


Figure 2.7 Circuitry of an IR Sensor

2.3.4. The RFID reader

The EM18 RFID reader is used for this project because it is a highly-integrated reader applied for a 125-KHz contactless communication. It has a data transfer rate of 9,600bps and an operating voltage of 5V that is required, in order to be powered by the Arduino board. The passive RFID used for this work is of low cost, current consumption of less than 50mA, small form factor and easy to use. When a tag, which is attached to a tray, is sensed by the reader, the ID is read and a pulse is sent to the Arduino for the corresponding action. The power circuitry consists of a Lithium-ion polymer (LiPo) battery. It is a rechargeable battery of lithium-ion technology in a pouch format. They work with the principle of intercalation and de-intercalation of lithium ions from a positive electrode material and a negative electrode material, with the liquid electrolyte providing a conductive medium. They are light and can be charged, discharged into a load and recharged many times. Four 3.4-V, 2000-mAH LiPo batteries are connected in series to give a voltage of 14.8V. This is used to power the Arduino and motor driver at the same time. Due to its heavy-duty feature, it is able to last for long periods of time and can be recharged when discharged.

2.4. Software Implementation

The software methodology is illustrated as in the flowcharts shown in Figure 2.8. Arduino Integrated Development Environment (IDE) is the programming software used in programming the Arduino microcontroller which in turn, controls the motor driver, LCD, RFID module, Infrared sensors and Ultrasonic sensor. C++ is used as the programming language to program the robot. Figure 2.8 illustrates the autonomous process of the system in a simple flowchart.

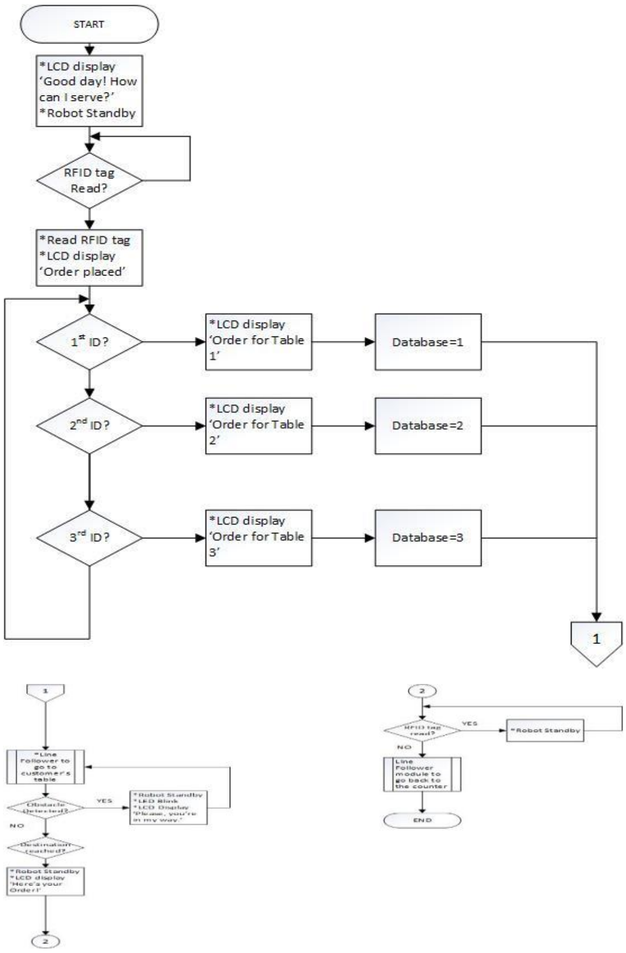


Figure. 2.8 Flow chart of software methodology

3. SYSTEM TESTING AND IMPLEMENTATION

In this section, tests conducted on the individual components and the entire system are shown and discussed. These include the RFID reader, LCD screen, Servomotor, IR sensors, DC motors and the line following module. Also, all modifications done to ensure smooth operation and interfacing are discussed.

3.1. Mechanical Implementation

First, the base of the acrylic chassis was coupled with the use of screws, nuts and bolts to the four motors and their respective wheels. The platform for the tray was then attached to the base with screw. The bars used in holding the transparent plastic in place were 4, 6-inch screws that were fixed with the aid of nuts as shown in Figure 3.1.

Figure. 3.1 Transparent Plastic

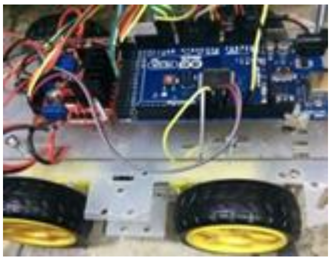


Figure.3.2 Electrical sub-circuit of plastic wheel

3.2. Electrical Implementation

For the implementation of the electrical circuit design, complex electrical circuits were treated as individual circuits. The electrical sub circuit integration of transparent plastic wheels is as presented in Figure 2.2. The software design was also implemented simultaneously as this is a necessity to test the operation of the system. The Individual circuit is described in detail in the following subsections:

3.2.1. The Arduino Microcontroller

The control circuit of the robot which consists of the Arduino Mega and the motor driver was fixed firmly to the coupled chassis. The microcontroller which serves as the brain-box of the circuit and receives the sensor signals from the 2 ultrasonic sensors, 2 infrared sensors and RFID reader as input signals, also sends control signals as outputs to the actuators and the LCD. The motor driver was incorporated into the circuit with a DC supply connected to the power input.

3.2.2. Integrating the Motor Driver

The motor driver was used to drive the motors with enough current as is required. The four output terminals were connected to the positive and negative terminals of the four motors. The four motors were connected to the driver in such a way that two motors on each side act as one. The polarities of the motors were unclear so the direction of the motors was controlled using trial-and-error method. The Motor driver also controls the forward and the reverse movements using the Enable terminals.

3.2.3. Integrating the Infrared sensors

The two Infrared sensors were attached to the front of the chassis and connected to the Arduino mega board. The sensitivity of the sensors was tested using different black materials to assure optimum absorption. The sensitivity was calibrated by tuning the potentiometer accordingly. The sensor positions are adjustable but the distance between the two sensors ranges between 2.5 and 5cm. This is to ensure that the sensors do not touch the black line or disrupt the movement of the robot. The distance between each sensor and the ground is approximately 1cm.

3.2.4. Integrating the RFID reader

The EM18 RFID has only the RX pin because it can only perform the READ function. This makes it an input device to the Arduino. Initially, the tags are tested against the reader in order to get their Unique Identification (UID) number. This is done by isolating the RFID and checking the Serial Monitor as the tags are placed within reach. The Unique Identification (UID) is then incorporated into the code and stored in a character array of not more than 13-character capacity. The code for the reading of the tags is then compiled to compare the tag read with the tags stored.

3.2.5. Integrating the Ultrasonic sensors

The Ultrasonic sensors also serve as inputs to the microcontroller. When the robot is in motion in either direction, or the sensors approach an obstacle within its ping distance, it sends a signal to the microcontroller. The microcontroller then gives the command to the motors to stop and for the LCD to display that there is an obstacle. The ping distance for the project was set at less than 20cm.

3.2.6. Integrating the LCD

In this system, the LCD describes most of the process. Initially, the LCD was tested using a Parallel to Serial interface but then the interface was discarded due to the sufficient number of pins on the Arduino Mega. To control the contrast of the LCD, 1-kΩ and 10-kΩ resistors based on design, were connected in parallel to the V0 pin of the LCD. The other terminal of the 10-kΩ resistor is also connected to the VDD terminal of the LCD while the other terminal of the 1-kΩ resistor is connected to the VSS terminal of the LCD. Figure 3.3 shows the initialization message of the system displayed by the LCD

Figure. 3.3 Initialization Message displayed on the LCD

3.2.7. Power Supply

The power supply was a DC supply from four rechargeable 3.4-V batteries connected in series. This is calculated to be sufficient to power the Arduino and the motor driver simultaneously.

3.3. System Test

The testing of the system was done using a bottom-up approach as indicated in the previous sections. This implies that the subsystems discussed above were individually tested. The process of testing led to various adjustments made to the entire robot system for optimum performance. One of the adjustments was to increase the sensitivity of the IR sensors according to the tested response to various materials. Response of DC Motor with respect to IR sensor input signal is as presented in Table 3.1. The distance between the sensors was also adjusted according to the width of the black line used for testing. Figure 3.4 shows the adjustable IR sensors placed in position.

Table 3.1: Response of DC Motor with respect to IR Sensor Input Signal

IR Sensor Input		PWM Value of DC Motor				Response of DC motor
Left IR	Right IR	Left Front Motor	Right Front Moto	Left Rear Motor	Right Rear Motor	
1	1	High	High	Low	Low	Forward
0	1	Low	High	High	Low	Turned Left
1	0	High	Low	Low	High	Turned Right
0	0	Low	Low	Low	Low	Stopped

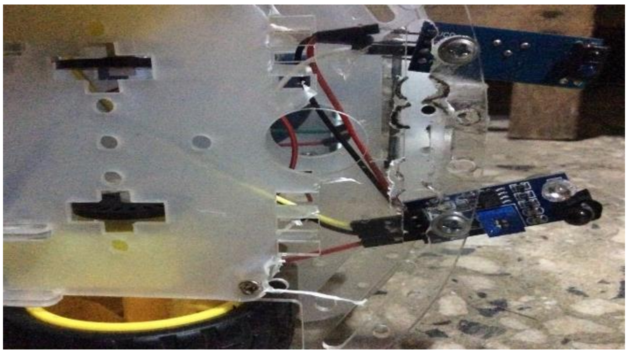


Figure. 3.4 Adjustable IR Sensors

Another adjustment made was to the speed of the motors. The initial forward PWM speed was 50 while the turning speed was 80. This was reduced to 40 for both movements. Figure 3.5 shows the robot during testing.

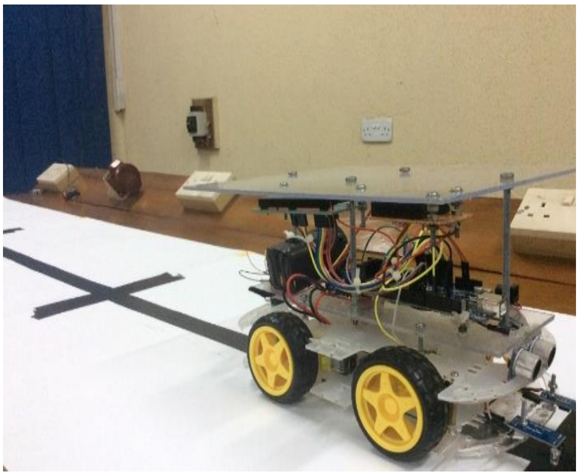


Figure. 3.5 Diagram of the robot during test

4. CONCLUSION

This work attempts to bring forward the prominent procedures concerning analysis, design and development of an autonomous robot that solves some challenges posed in a typical cafeteria environment. The test carried out on the complete assembly shows that the autonomous mobile robot is able to read data from the prescribed RFID tags and can deliver order to corresponding tables. The robot is completely autonomous, i.e. it moves by itself to reach the customer's table by following the prescribed path on the ground.It can also function efficiently on level ground but is not optimized for rough.The fully functional robot has a maximum weight of 2.2kg; height of 20cm and possesses eyes in front and back.However, to obtain an optimum performance, the height of the robot should not be less than 75cm, corresponding to the approximate height of cafeteria tables.Besides, an ordering system may be incorporated in the customer's tables and to the robot to further improve the efficiency. All the proposed objectives are attained and with due consideration, the same ideas can be generalized for other applications, such as in a book-keeping robot, tagging robot, etc.

ACKNOWLEDGMENTS

The author is highly indebted to the management of Covenant University, Ota, Nigeria, for the financial support fund.

REFERENCES

[1] E. O. P. Oni, J. P. Adefila and A. Dauda, "Small and Medium scale business (Restaurant): A career opportunity for Nigerian youths," *Arabian Journal of Business and Management Review (OMAN Chapter),* vol. I, no. 10, pp. 28-44, May 2012.

[2] M. Tadashi, and D. Misaki. "Development of Japanese green tea serving robot" T-Bartender"." In Mechatronics and Automation, 2005 IEEE International Conference, vol. 2, pp. 1069-1074. IEEE, 2005.

[3] X. Chen, Y. Chen and J. Chase, "Mobile Robots- Past, Present and Future," in Mobile Robots-State of the Art in Land, Sea, Air, and Collaborative Missions, Croatia, Intech Education and Publishing, 2009, pp. 1-32.

[4] M. Islam and M. Rahman, "Design and Fabrication of Line Follower robot," Asian journal of Applied Science and Engineering, vol. II, no. 2, pp. 27-32, 2013.

[5] A. M. Rokonuzzaman, S. R. M.D and M. H. Mim, "Automated Restaurant Food Service Management system using a Line Follower Robot," in International Conference on Mechanical, Industrial and Energy Engineering, Bangladesh, 2014.

[6] H. D. Chon, S. Jun, H. Jung and S. W. An, "Using RFID for Accurate Positioning," Journal of Global Positioning Systems, vol. III, no. 1-2, pp. 32-39, 2004.

[7] K. Yelamarthi, S. Sherbrook, J. Beckwith, M. Williams and R. Lefief, "An RFID Based Autonomous Indoor Tour Guide Robot," in Midwest Symposium on Circuits and Systems, Michigan, 2012.

[8] S. H. Reddy, B. Vangipuram and G. Vishal, "Line Tracking Pick and Place Robot Using RFID Technology," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 4, no. 10, pp. 8059-8063, 2015.

[9] L. P. Chuan, A. Johari, M. H. A. Wahab, D. M. Nor, N. S. A. M. Taujuddin and M. E. Ayob, "An RFID Warehouse Robot," in International Conference on Intelligent and Advanced Systems, Malaysia, 2007.

[10] T. B. Huang, "An RFID Based Serving Robot," Faculty of Electrical Engineering, University of Technology Malaysia, Malaysia, 2012.

[11] A. Abdulkareem, C. O. A. Awosope, S. A. Daramola and E. C. Nnorom, "Development of a programable Mobile Robot", International Journals of Applied Engineering Research, vol. 11, no. 4, pp. 2314-2320, 2016. V. O. Matthew, S. I. Popoola, E. Adetiba, A. A.

[12] Atayero, "Cost-Effective Medical RoboticTelepresence Solution using PlasticMannequin", International Journal of Electrical and Computer Science, vol. 7, no. 3, pp. 1212 1218.

[13] S. Smiley, "Active RFID vs. Passive RFID," RFIDInsider, 4 March 2016. [Online]. Available: www.rfidinsider.com. [Accessed 8 October 2016].

[14] Mukul Anand Pathak, Kshitij Kamlakar, Shwetant Mohapatra, Prof. Uma Nagaraj, Development of Control Software For Stair Detection In A Mobile Robot Using Artificial Intelligence and Image Processing, International Journal of Computer Engineering and Technology, 7(3), 2016, pp. 93–98.

[15] Ashwani Kumar Aggarwal. Machine Vision Based SelfPosition Estimation of Mobile Robots, International Journal of Electronics and Communication Engineering & Technology, 6(10), 2015, pp. 20-29.

[16] A. Mubashira Anjum, Multifunction Mobile Robot-Virtual Human. International Journal of Mechanical Engineering and Technology, 8(7), 2017, pp. 742– 749.