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Embedded Design and Implementation of Mobile Robot for Surveillance Applications

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ABSTRACT

The surveillance and security of areas such as home, laboratory, office, factory, and airports, are important to prevent any threatening to human lives. Mobile robots are proven their effectiveness in a large number of applications, especially in hazardous areas where they can be remotely controlled by humans to accomplish certain tasks. This research paper presents a design and implementation of a mobile robot for surveillance and security applications. The main objective of the design is to lower the cost and the power consumption of the mobile robot which accomplish using low-cost open-source hardware such as Arduino and Raspberry Pi. The robot is connected wirelessly via a low-power ZigBee module to the control station to allow the operator for controlling the mobile robot motions and monitoring the physical events in the environment where the robot is used. Sensors such as camera, temperature, and range are embedded in the robot to sense and monitor human motion, the room temperature, and the distance of the surrounding obstacles. The testing of the implemented mobile robot shows that it can run continuously for approximately 6.5 hours at a motor shaft speed 25 rpm of unlit the need to recharge the battery.

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1. INTRODUCTION

In practice, robots are electromechanical systems that have sensors to control their environment, process units that process the information from these sensors and produce results, and motion mechanisms that can transfer the results of the process to the output. Robots can be divided into two main parts as mobile and non-mobile robots (Humaidi *et al*., 2019). If the working volume of a robot does not move according to a reference coordinate system, this robot is called a non-mobile robot, if it is moving, this robot is called a mobile robot (Chen *et al*., 2018).

Mobile robots can be used in many areas such as the cleaning of toxic and nuclear wastes, the disposal of explosives, the transportation of biological wastes, as a service robot in quarantined environments, cleaning the outer windows of high buildings, locating and removing and transporting mines, construction of space stations, underwater search and rescue, human rescue in earthquakes and part transportation in factory production lines (Ajeil *et al*., 2020a, Humaidi ., 2018). Another important area of using mobile robots is surveillance and security applications of indoor environments, such as warehouses, airports, and production plants. In such applications, the mobile robot can interact with humans and other robots to monitor the environment and trigger an alarm when an abnormal event is occurred (Park *et al*., 2018).

The aim of this research paper is to design and implement a cost-effective and easy-to-use wirelessly controlled embedded mobile robot suitable for remote surveillance and security applications. The paper is organized as follows: Section 2 provides a brief literature review of the mobile robot and its applications. Section 3 describes the mobile robot design presented by this paper in both hardware and software aspects. Section 4 includes the testing results of the robot and the conclusion

2. LITERATURE REVIEW

The are many studies in the literature considering the design of mobile robots for different applications, some of these studies are summarized as follows.

Raj *et al*., 2018 discussed safety precautions in fire accidents in areas such as laboratory, home, office, factory, and building. They emphasized that since explosive or flammable materials may be found in these places which can lead to fire accidents, these accidents can be prevented by taking safety measures. Robots are considered as one of the best and effective ways to take these safety measures. So, they developed a rescue robot to detect fire using a camera sensor and Image processing.

Liu *et al*., 2017 studied how much improvement the error rate of data obtained from multiple sensors in multi-mobile robot patrol observation systems in a simulated environment. The robots are interconnected wirelessly. They used a different combination of laser, ultrasonic, and camera sensors, to collect the data from the environment which simulated using Microsoft Robotics Development Studio.

In the study carried out by (Nasrinahar *et al*., 2018), an obstacle avoidance approach is considered for mobile robots for hazard areas that not accessible by humans. In these areas where people cannot enter, it is possible for robots to easily move and perform any task, by reaching the desired places without hitting any obstacles in that area. A search algorithm is considered to find the optimal path for the mobile robot to reach without hitting the obstacles in the environment (Ajeil *et al*., 2020b).

Boufera *et al*., 2018 proposed a hybrid approach with fuzzy logic to overcome the obstacles of mobile robots in an undetermined environment. The basic limit conversion method has been developed to achieve safe and flexible navigation. By

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reducing the number of direction changes during avoidance, can make the avoidance more flexible (Azar *et al.*, 2021). The proposed algorithm has been successfully tested in different configurations on the simulation.

López *et al.*, 2016 presented an open-source, low-cost (35 euro), modular and expandable mobile robot. open-source devices and software such as Android and Arduino-based are used to design the robot. The mobile robot is designed to be used in distance education and large open online courses as an alternative to traditional visual laboratories where it can be used in classroom environments or laboratories.

Ibari *et al.*, 2016 designed different algorithms for mobile robot navigation systems. Fuzzy logic and genetic algorithms are used in some algorithms. Lightweight Telepresence robots require simpler and more intensive computational algorithms (Najm *et al.*, 2020). Especially the odometry algorithm has been preferred to meet this need. The anti-barrier feature is designed to improve the algorithm. Arduino UNO, two DC motors, and an ultrasonic sensor have been used to prototype the mobile robot.

One of the important areas of using mobile robots it is surveillance and security applications. In Lopez *et al.*, (2017), a mobile robot called Airport Night Surveillance Expert Robot (ANSER) is designed to use in surveillance applications in civilian airports and similar wide areas. The robot can be controlled by a human operator in a fixed supervision station to monitor the activities and the events in these areas.

Trovato *et al.*, 2017 designed a mobile Robotic Security Guard and implemented it for remote indoor security applications. The robot is used to patrol the environment and watch valuable objects, to recognize people and to provide the operator with a detailed analysis of captured data.

Another example of a security robot is called MARVIN (Mobile Autonomous Robotic Vehicle for Indoor Navigation) is designed as an indoor security agent. The robot is equipped with speech synthesis and speech recognition and conveys emotional states in order to intact with humans (Carnegie *et al.*, 2004).

Following this trend of mobile robot applications, a low-cost low power consumption wirelessly controlled mobile robot is designed in the current research paper for surveillance and security applications.

3. MOBILE ROBOT DESIGN

The design of the mobile robot presented in this paper is divided into two parts. The first part covers the hardware design of the robot, and the second part covers the software development for controlling the robot.

3.1. Hardware Design

The hardware used to design the mobile robot in this paper consists of the following components:

Robot Driver Unit, ZigBee wireless module, Sensors, Camera Module, Microcomputer and Micro-controller (Raspberry Pi and Arduino) and PC. The details for each part used in designing the mobile robot is described as follows;

3.1.1. Robot Driver Unit

The robot driver unit is responsible for robot movement in the x-axis and y-axis. The robot consists of four wheels to help to manoeuvre over slant and level terrains. Each wheel is driven independently by its own DC motor which is used to control the movement direction of the robot as illustrated in **Figure 1**. The speed and the rotation direction of each 12-V Dc motor are control via L293D motor driver IC. The maximum speed of each motor is 95 rpm (Cardeira *et al.*, 2005).

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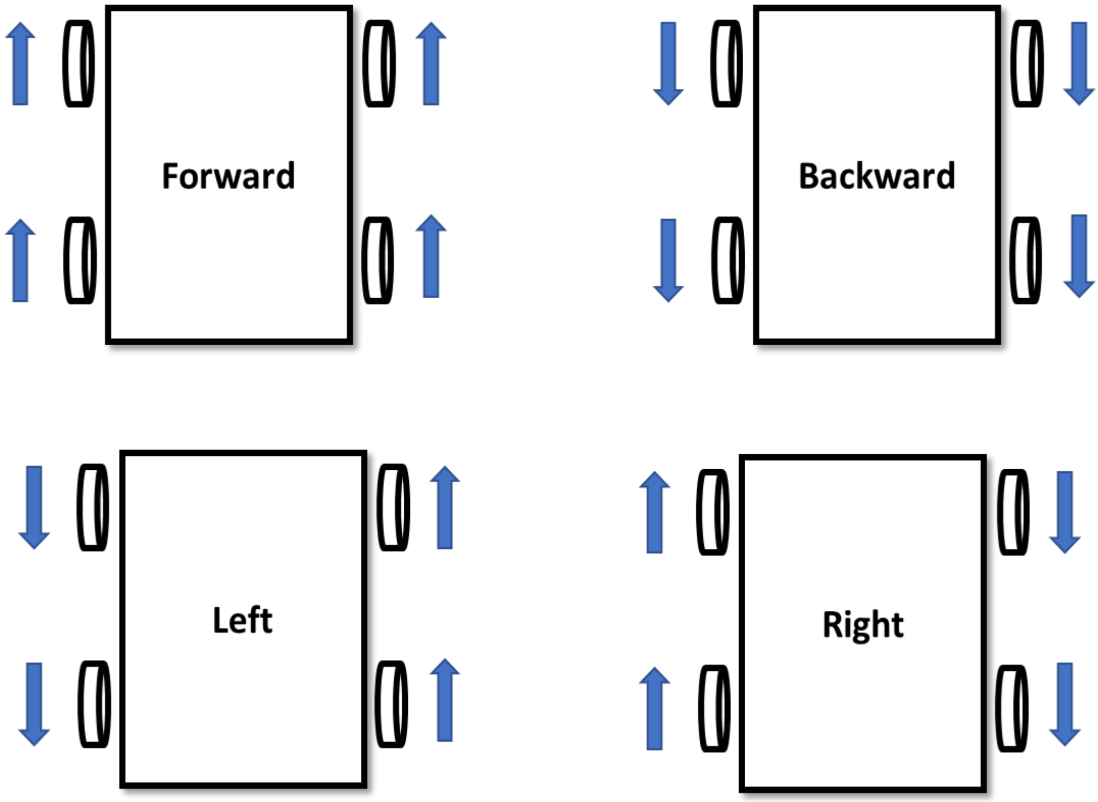

Figure 1. Robot movement direction based on the motor movement of each wheel.

3.1.2. Arduino Microcontroller

Arduino is a physical programming platform consisting of an I/O board and development environment that includes an implementation of the Processing/Wiring language. Arduino can be used to develop stand-alone interactive objects or can be connected to software running on the computer (such as Macromedia Flash, Processing, Max/MSP, Pure Data, SuperCollider). Ready-made cards can be purchased, or information on hardware design is available for those who want to produce them themselves.

In terms of hardware, the Arduino cards consist of an Atmel AVR microcontroller (ATmega8 or ATmega168 in the old cards, ATmega328 in the new ones) and the side elements required for programming and connection to other circuits. Each card has at least a 5-volt regulated IC and a 16 MHz crystal oscillator. Since a bootloader program is pre-written to the microcontroller, no external programmer is required for programming.

In terms of software, Arduino IDE is an application written in Java programming language that acts as a code editor and compiler, can also load the compiled program to the card, and can work on any platform. The development environment was developed based on the Processing software developed to introduce artists to programming (Araújo *et al*., 2015).

In the context of the robot design in this work, the Arduino microcontroller is used to retrieve the robot movement command sent by the operator and transit it into signals used to drive robot motors. **Figure 2** shows the schematic diagram of using Arduino to drive the robot motors.

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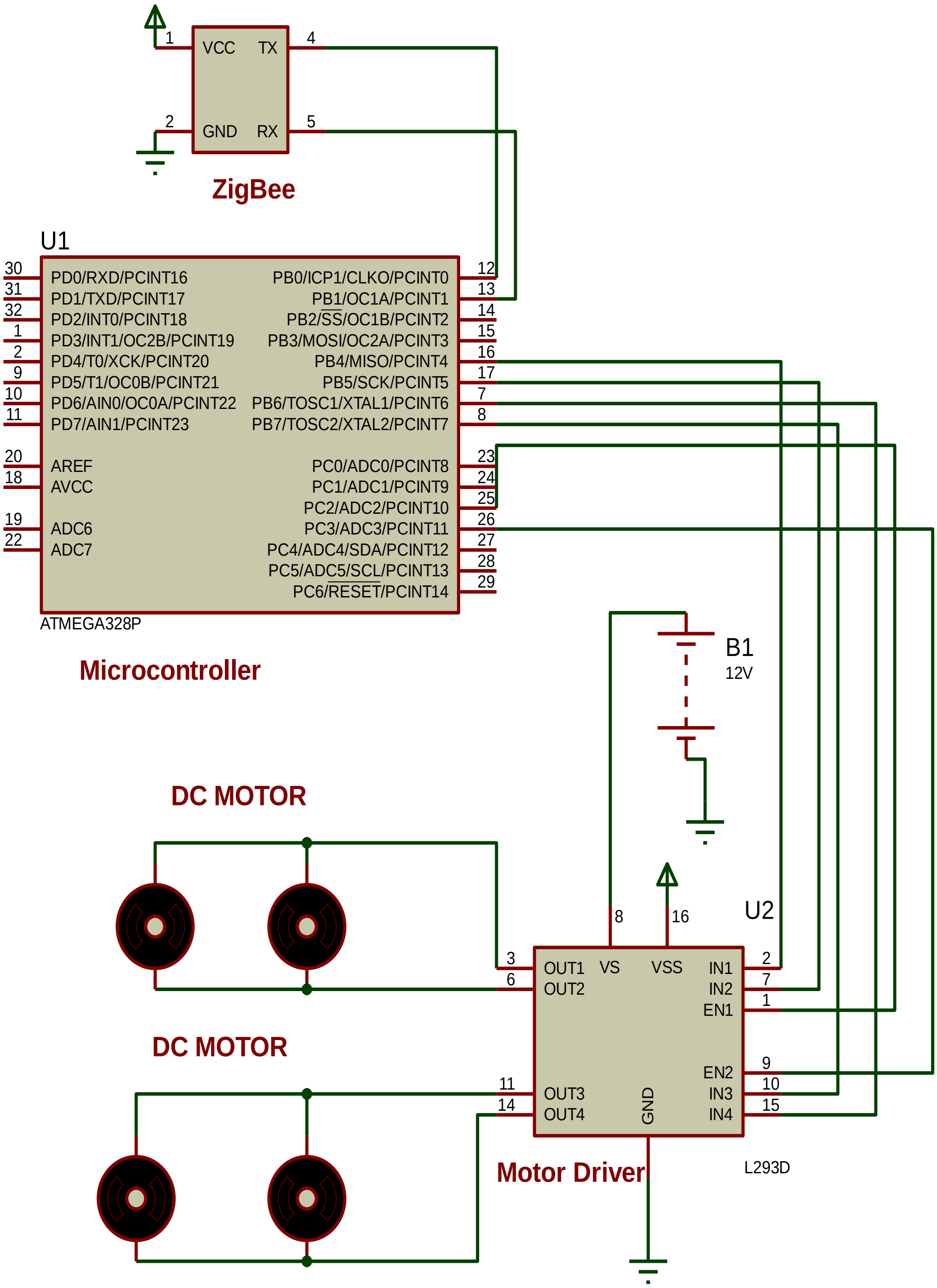

Figure 2. Motor driving using a microcontroller.

3.1.3. Sensors

A sensor electronic device is used to convert a physical quantity into a signal which can be read by an instrument or by a monitoring device. Two sensors are used in the current design. The first sensor is the Ultrasonic sensor which is described as follows. In the classification of sound waves, sound signals in the range of 20 kHz - 1GHz are defined as ultrasonic sound. Many ultrasonic sensors produce ultrasonic sounds at a frequency of 40 kHz. The important factor here is the frequency that determines the loudness of the sound. If the sound is high, it is louder in frequency. Human ears cannot detect ultrasonic sound signals. The transducer transmits the ultrasonic pulse. The impact is reflected from the deflection and received by the transducer. The travel time of the impact is proportional to the distance of the deflection from the sensor. This sensor is used to detect the distance between the robot and obstacles in front of the robot.

The second sensor is the temperature sensor and its described as follows. A temperature sensor (DS18B20) is a digital sensor with a single line (1-Wire) interface that has a 64-bit serial code. It can measure temperatures from -55 °C to + 125 °C with a 9-bit - 12-bit resolution. The maximum measurement and cycle time for 12-bit is 750 ms. It is used for fire detection in an area where the robot is moving (Bhatia *et al*., 2011).

3.1.4. Raspberry Pi Minicomputer

The Raspberry Pi circuit board used in this design is the only credit card-sized card computer developed by the Raspberry Pi Foundation in the UK to teach computer science in schools. The Raspberry Pi, which is mostly used in embedded system applications and applications requiring an operating system, is frequently preferred because it can be developed independently from a computer and easily portable systems. Raspberry Pi is released in various models with some hardware changes.

The B+ model of the Raspberry Pi circuit board, whose hardware units operate based on Broadcom BCM2835 SoC (System on Chip - System on Chip), includes a single-core ARM1176JZ-F 700 MHz processor unit with ARMv6 architecture. With the VideoCore IV graphics processing unit in Broadcom BCM2835 SoC and this Raspberry Pi card with 512 MB RAM, most operations can be performed on a normal computer, including high-resolution video playback, can be performed. There is no internal hard disk on which the operating system can be installed, and data can be stored on this board, which can be used as a mini-computer by connecting a keyboard, mouse, and display. For this, the operating system can be installed after the memory card is inserted into the microSD card slot on the card and the desired data storage operation can be performed. Raspberry Pi B + model cannot run Windows operating systems since it has ARMv6 architecture. For this, Linux operating systems designed for Raspberry Pi should be downloaded from the website of the manufacturer foundation and installed on the memory card. The Foundation's website has Linux operating systems such as Raspbian (based on Debian Wheezy) and Pidora (based on Fedora) (Bokade *et al*., 2016).

In the robot design, the Raspberry Pi is used as the main processing unit which connected the sensors of the robot as shown in **Figure 3**. The Raspberry Pi also interfaced with the ZigBee wireless module to provide comminution between the robot and the controlling device. In addition, the camera module with 5MP resolution, designed to be directly connected to the CSI connector on the Raspberry Pi circuit board, and it used to capture live video of the environment and steams it to the controlling device.

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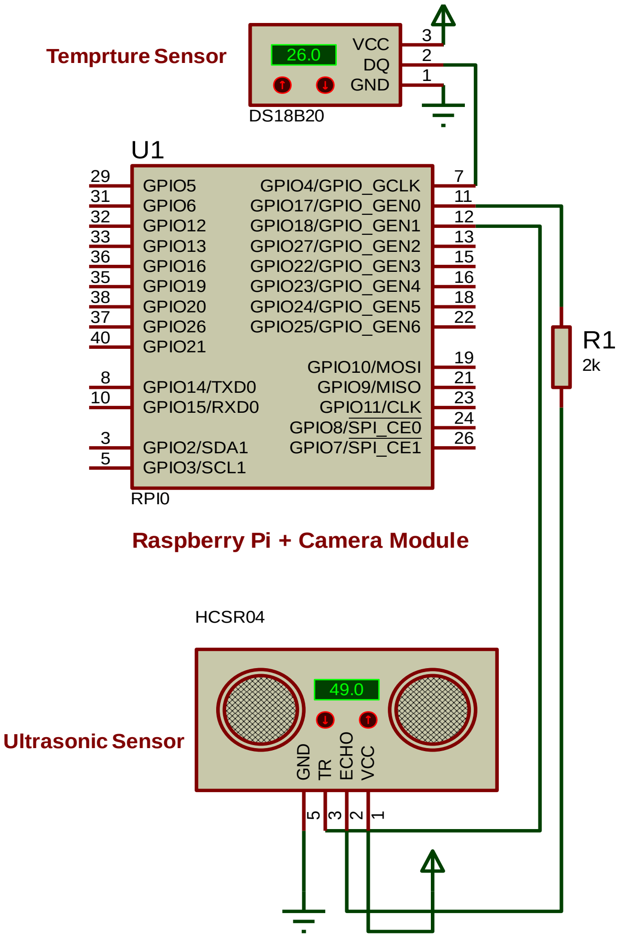

Figure 3. Raspberry pi connections with temperature and ultrasonic sensors.

3.1.5. Wireless ZigBee

ZigBee networks consist of standards consisting of IEEE 802.15.4 standard-based wireless short-range, a set of communication protocols providing low-speed data communication. ZigBee gets its name from the complex zig-zag movement that bees make as they move between flowers. This zig-zag structure symbolizes communication between nodes in the communication network. The organization called ZigBee Alliance, which formed ZigBee, is an association formed by global technology companies such as Philips, Motorola, and Intel in 2002. ZigBee-based wireless devices operate at frequencies of 868 MHz, 915 MHz, and 2.4 GHz. The highest data rate that can be reached is 250 kB/s. ZigBee generally targets battery-based applications based on low speed, low cost, and long battery life. In many applications, the activities of ZigBee equipment are very limited. Equipment generally operates in a low power consumption mode, also known as sleep mode. Therefore, ZigBee equipment is capable of working for years without the need for a battery change (Bharathi *et al.*, 2013).

Based on the advantages of the ZigBee of low power consumption, wide range, and speed, it is utilized for providing the remote controlling and monitoring capability for the robot design. **Figure 4** shows a block diagram of using ZigBee to provide the communication between the robot and the controlling device wirelessly.

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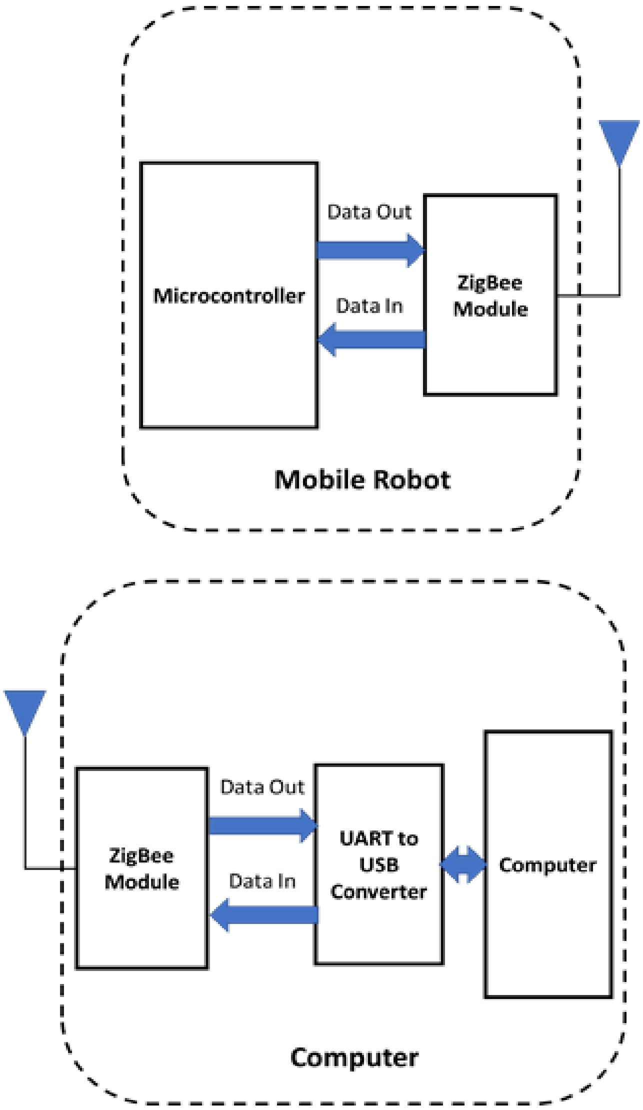

Figure 4. ZigBee wireless commutation for the robot and the controlling device.

The general block diagram of mobile robot design based on the ATmega328 microcontroller and Raspberry Pi is shown in **Figure 5**.

The operation of each part used in the mobile robot design is described as follows:

- The robot monitoring the temperature and the ultrasonic sensors and in case of discovering any anomalies the robot sends an alarm signal from the Raspberry Pi to the master controlling computer.
- The Raspberry Pi captures the video from the camera and streams it to the master controlling computer to allow the operator to monitor the environment.
- On the remote side (PC) the controlling software allows the operator to control the movement of the robot via sending a set of commands to enable or disable the motors on the robot.
- On the remote side (PC) the controlling software allows the operator to monitor the environment via the received live video from the robot's camera.
- The communication between the robot and the controlling and monitoring device is established wirelessly via ZigBee.

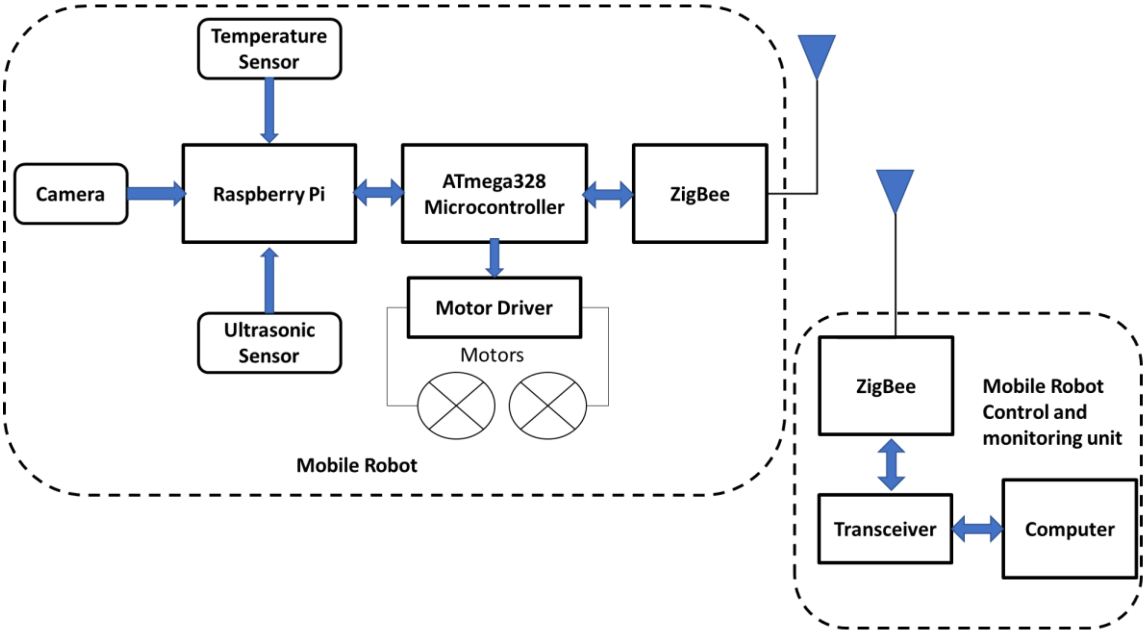

Figure 5. The general block diagram of the robot design.

3.2. Robot Software Development

The software used to control the robot is divide into two parts robot side software and remote controller side software.

3.2.1. Robot Side Software

The robot side software is responsible for the following tasks:

- Reads the sensors that are connected to the robot and reports its values to the control software at the operator's side.
- Captures live video for the environment from the camera that is mounted on the robot and streams it to the monitoring software at the operator's side.
- Receives the movement commands from the control software at the operator's side and translates them into a motion in the robot's motors.

The flow diagram for the robot-side software is shown in **Figure 6**.

3.2.2. Control Device-Side Software

The controller side software is responsible for the following tasks:

- Receives sensors values the acquired by the robot and display it to the operator.
- Receives live video of the environment that the robot in and displays it to the operator.
- Sends movement commands to the robot based on the operator controlling as showing in **Figure 7**.

The flow diagram for the robot-side software is shown in **Figure 8**.

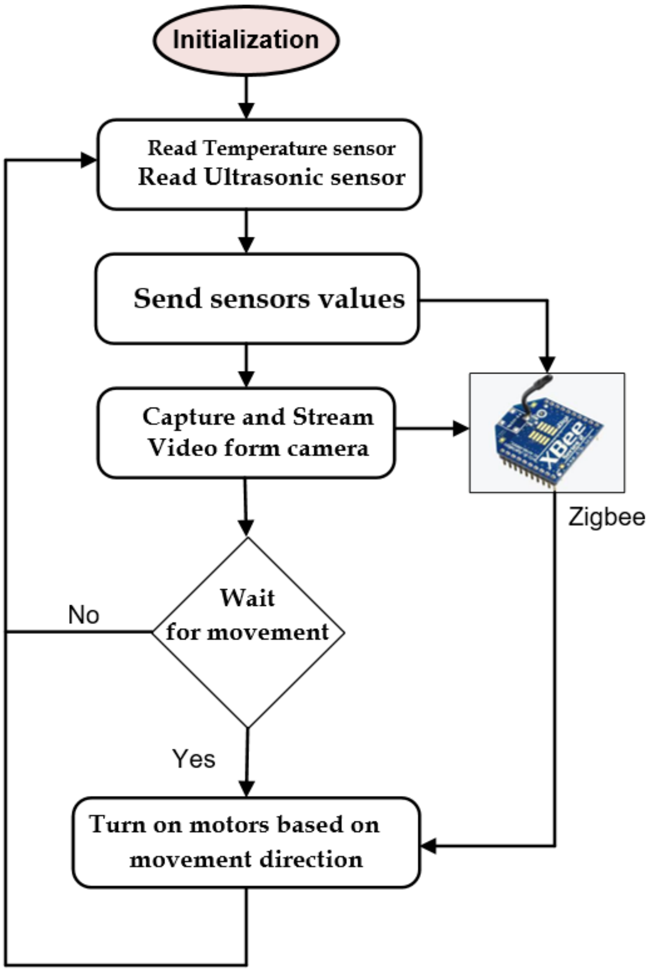

Figure 6. The flow diagram for software inside the robot.

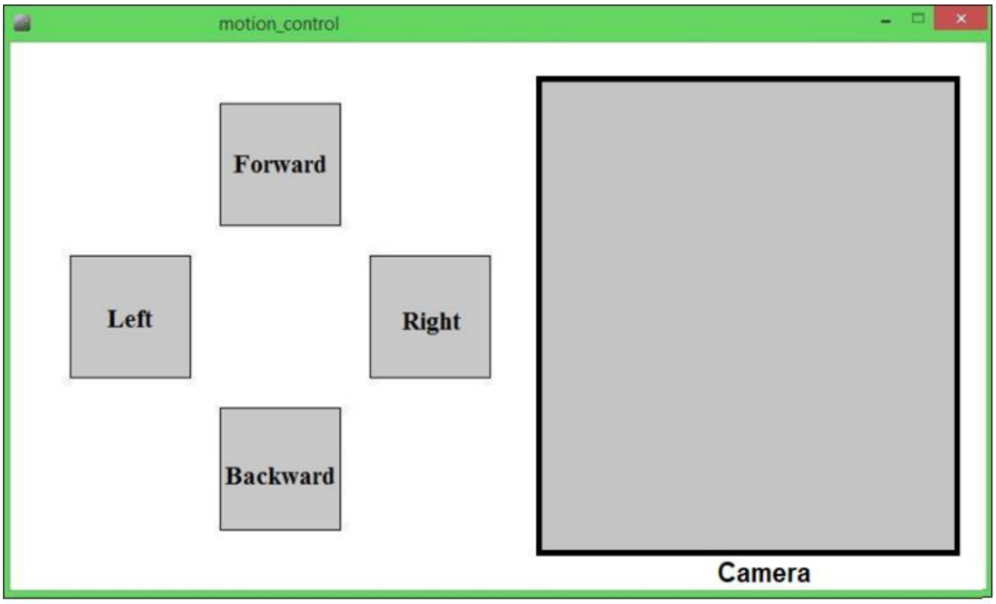

Figure 7. Mobile Robot control software from PC.

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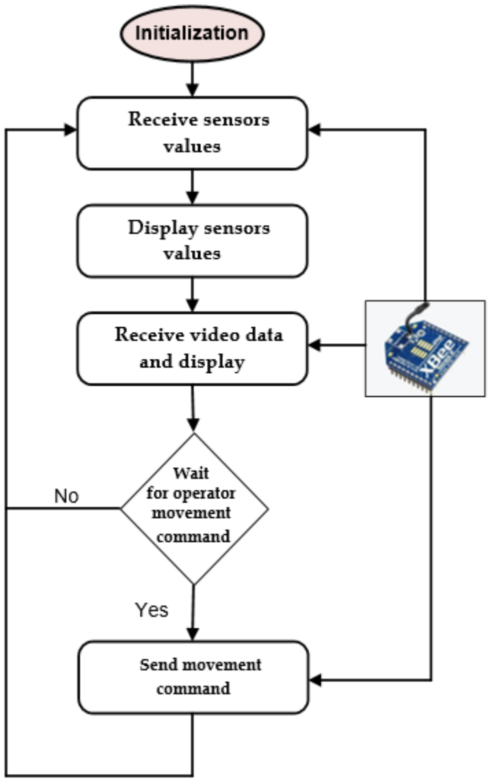

Figure 8. The flow diagram for software inside the controlling device for the robot.

4. RESULTS AND CONCLUSION

Based on the design proposed by this research paper, the mobile robot is practically built and implemented. After building the mobile robot it was tested in the environment practically. **Figure 9** shows the robot in action when it is controlled wirelessly by the operator.

During the test, the robot is powered by a 12V lithium polymer LiPo battery pack with a capacity of 6000 mAh and based on the motor shaft speed the robot running time is calculated as shown in **Table 1**.

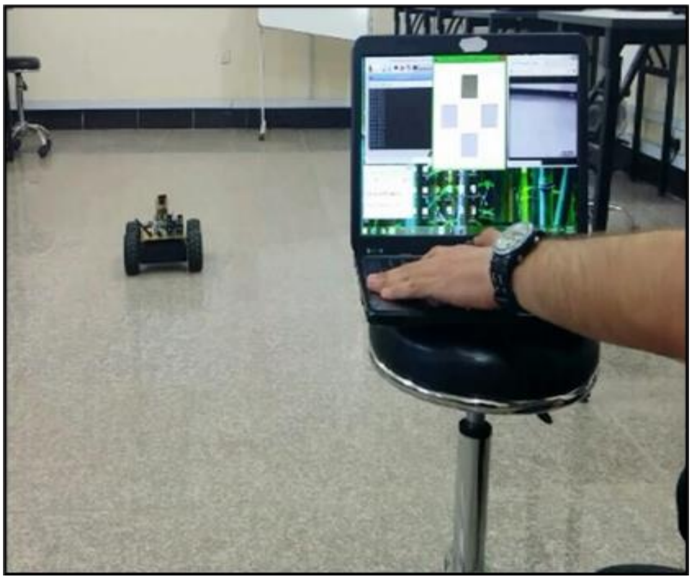

Figure 9. The robot and control operator in action.

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Table 1. Robot running time based on the motor's speed.

Motor Speed (rpm)	Motor current (A)	Raspberry Pi current (A)	Total current (4* Motor current+ Raspberry Pi current) (A)	Approximated Full-Running time (Hours)
95	0.7	0.25	3.05	2
45	0.35	0.25	1.65	3.6
25	0.17	0.25	0.93	6.5
10	0.1	0.25	0.65	9

From testing results in **Table 1**, it is shown that mobile robot can run for a reasonable time at medium and low motor shaft speeds before it needs recharging. The speed of the robot itself can be increased using a gearbox to ensure low power consumption and increase the run time. Noting that, due to the very low current consumption of the other component such as sensors and ZigBee, it was not taken into considerations when calculating the total current consumption of the robot. This paper presented the design and implementation of a wirelessly controlled mobile robot for security and surveillance applications. The goal of the design is to achieve a lower cost and power efficiency. The objective is achieved by designing the robot using easy-to-find low-cost open-source components as well as selecting a wireless communication module (ZigBee) with very low power consumption. The robot is implemented and tested partially. This study can be extended to apply advanced control and optimization techniques to enhance the tracking performance of mobile robot or to improve the path planning performance of mobile robot (Ajeil *et al*., 2020c, Ibraheem *et al*., 2020). In addition, the navigation of mobile robot can be developed by including the technology of FPGA instead of Raspberry (Humaidi *et al*., 2020).

5. AUTHOR'S NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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