Design and Implementation of an IoT Based Patrol Robot

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***Abstract*—In this paper, a design was proposed and tested for the implementation of an auxiliary security system that is used along with the standard CCTV setup that is present in most commercial settings. The design mainly focuses on providing a layer of automation in a cost-effective manner. The bot, as a single unit or a team of up to 4 units, makes use of technologies like perception, path following, IoT-based Twitter alerts, and camouflage to patrol a typical commercial setting such as a retail store at night.**

***Index Terms*—IoT, Mobile Robotics, Path Follower, Surveillance, Automation**

I. Introduction

Security is a serious threat, In India alone, a survey puts the cost of retail crime loss at $2190 million. To combat these losses various advancements in Security technology have been made ranging from complex laser alarms to IoT systems. However, the drawback of these systems is their high cost, at a retail level the most common system used is still a 4 CCTV system. This system might be robust and effective but it is still subject to human error

A lot of systems suffer detrimental consequences of human error. These include but are not limited to nuclear energy systems, medical automation systems, and security systems. Despite all pros of automating a system, a completely automatic system is a huge risk to take because there are many errors that cannot be accounted for.

Taking into account the above points, The Patrol Bot is designed to act as a secondary security system and essentially as an alert system that is to be used in conjunction with a primary surveillance system such as CCTV.

This security system is an active system as opposed to a passive one, in which there are moving robots that can patrol the specified area and provide constant monitoring. The entire system consists of 1-4 bots; depending on the number of points of entry (doors, windows, vents, etc.), with each bot monitoring one side of a room and uploading alert data to a cloud IoT Platform known as ThingSpeak.

II. Literature Survey

The paper [1] talks about a different approach to path following which requires two cameras. While this does present ideas to improve the path following with the implementation of cameras, currently, a different approach was taken by using IR sensors instead as the implementation of cameras is going to increase the cost of the bot significantly.

In [2], the paper talks about the future scope that could be adopted and implemented into this bot. When adding a camera using a neural network with the YOLO algorithm in tandem will provide a smarter method of patrolling which will help in the identification of threats such as weapons and other elements which can disturb the harmony. While a camera can be added, it is counterintuitive to the original decision to make the bot cost-effective.

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The papers [3] and [4], talk about bots in neural networks that patrol the network for security measures. These measures of cybersecurity could be implemented in the future in a vision-based AI system that can be mounted on the design. However, it was decided not to use a vision-based system for perception as it is counter-intuitive to the goal of making the bot cost-effective.

The paper [5] helped gain an insight into usage and programming the NodeMCU effectively to be used in an alert system which helped set up the base for the IoT domain of the project. Although the NodeMCU was not used in the final project, this paper gave insights into working with an ESP8266 module, which was used.

The paper [6] talks about various parts required to make an optimum line follower, it also provides the sensor configuration and also provides good code structure. This paper inculcated an understanding of positioning the sensors to reduce the effect of ambient light and the various states of the motor while providing a good base to build the code.

The Paper [7] provides insights into the mapping of integration of multiple sensors and provides an understanding of how to use Wi-Fi to send data over to an aggregation point. It was also highly beneficial for the design stage as it provides a flowchart for the alarm system. Which was instrumental in understanding the working of the entire alert system.

The paper [8] suggested a new and efficient system instead of complex algorithms for motion detection. This paper also provides an innovative way for the movement algorithm for the patrol robot which allowed different options to program the patrol bot in case of any errors. This paper initially provided the idea of sending data over Wi-Fi to a smartphone and the successful implementation using Arduino and raspberry pi.

[9] talks about the viability of Thingspeak as an IoT server for small-scale projects and the process of IoT integration over Wi-Fi. It also introduced the MQTT protocol which was implemented successfully. This paper helped set the entire operation for the IoT protocol as it provides a description of how to use ThingSpeak and the usage of MQTT protocol to route to an app. This was implemented successfully. It further helped in the implementation by providing an entire flowchart for sending data collected from sensors to get alerts on a smartphone.

The Paper [10] facilitated a deeper understanding of ultrasonic sensors and the reason they are the backbone of this project. The entire system is based on the principle of echolocation used on ultrasonic wave radar, RF communication Infra-Red technology, This is separately controlled by different microcontroller boards which control the different sensors, motors line following robots according to the desire. This robot works on the principle of White or Black line Infra-Red Line Tracking. This paper presented the different applications depending upon the sensors such as accurate distance measurement, close-range device, level detection, vehicle detection, blind person Support, and robotics barrier.

III. Design

The design of an individual bot broadly consists of hardware and software design. Wherein, the hardware design covers the mechanical and electronic systems and the software design covers the IoT alert system and the detection algorithm

A. Hardware Design Methodology

The Hardware design takes into consideration the various constraints as we look at the problem from a security perspective. The Patrol bot must be designed such that it is as inconspicuous as possible in its normal operation. It should also be able to operate for an 8-hour time period at night. These goals are reflected in the decisions taken for the mechanical and electronic systems.

B. Mechanical System

The main body of this bot is made using acrylic sheets joined by 50 mm spacers. Acrylic is cheap and durable enough for indoor applications. Additionally, it is transparent with a black tint which makes it very difficult to see at night.

The lower sheet houses the four battery-operated motors connected to a gearbox for extra torque. It also houses the common power and ground circuit, as well as the comparator circuit for the Infrared Sensors

The Upper sheet houses the microcontroller unit, the motor driver, and the battery. The microcontroller is on the top sheet because the design makes it easy to access and reprogram the controller with proper IoT Credentials and Wi-Fi SSID and password.

The selected battery is lithium-ion. It's high energy density is perfect for a compact bot such as this while providing the necessary charge. This battery is placed on top-front as it is the main weight component and therefore weight distribution of the patrol Bot is uniform. It is also placed at the top so it can easily be charged or replaced. The motor driver is put on top for the dissipation of heat effectively through the heat sink. This is one reason why a cover is not implemented.

Fig. 1. CAD Model

C. Electronic System

The microcontroller used is the modified version of the ATmega 2560 microcontroller. This modified board is similar to the Arduino mega in that it consists of 54 I/O pins. Although all the pins have not been used, the remaining pins may be used to implement more sensors in the future. This modified ATmega board also has an ESP8266 Wi-Fi module built-in and is connected internally via I2C serial communication protocol

The board also has a Ch340 USB TTL converter which allows the uploading of code directly via MicroUSB. The serial connection between these 3 vital components (CH340, ATmega 2560, ESP8266) can be configured via an 8-bit DIP switch. The switches may be configured in various ways to make only certain chips work together or all work independently. This means that it is possible to program the ESP8266 and the ATmega separately to run their own programs. This allows for a contingency code that can send a message in case the ATmega malfunctions.

There are two IR sensors that help the bot follow a path defined by a black line. To make the black line distinct in the dark at night, a standard white LED has been attached, which will supplement the line following the system. The final and most important part of the electronic system is the ultrasonic sensor detection algorithm. The ultrasonic sensors used are rated as having a max detection range of 4m. However, it was experimentally determined that the actual range of detection is 10m. The experiment results are presented in detail in section VI of this paper. All the wiring of the components is shown in figure 2.

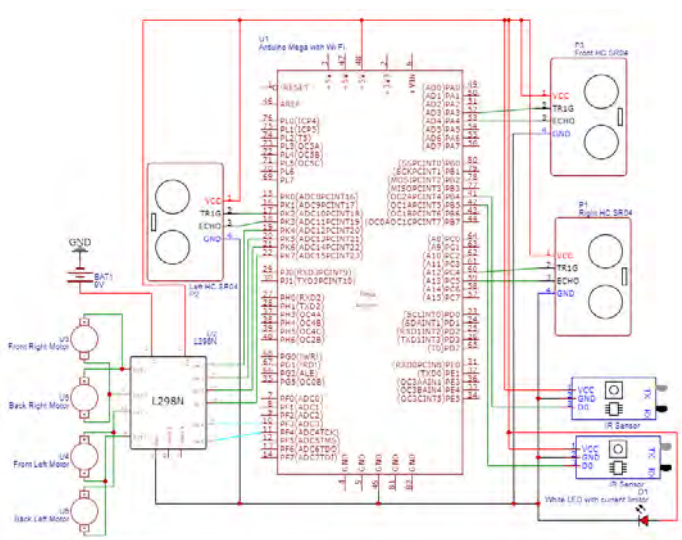

Fig. 2. Circuit Diagram

D. Software Design

The software is designed to intuitively navigate the bot around the room while simultaneously checking for intruders and raising alerts upon detection. The system was designed to keep the lowest response time (MQTT) and a level of redundancy (Multiple Alert Systems) while keeping the cost to a minimum.

E. Alert System

The alert system makes use of a free IoT platform called ThingSpeak.
ThingSpeak is open-source, and it was originally written in Ruby. This platform provides API keys to easily read and write data from fields specified in a particular channel. The reason this platform was preferred over other platforms is because of all the apps available on ThingSpeak.

It integrates very well with Twitter, which is the main alert medium for the IoT system because it is widely available on all platforms. In addition to that, ThingSpeak has integrated with MATLAB and can be used to implement a JSON payload system to push out email alerts. Up to 800 emails can be sent through ThingSpeak annually for free. This number is sufficient for the target application, as it translates to approximately 2 alerts per night, which should be good enough for an auxiliary alert system.

The last method of alerting is desktop alerts via the MQTT protocol. MQTT is an emerging technology that is very fast and seamless in connecting to a device. It is different from HTTP in the sense that a publisher and subscriber node in MQTT are always open to connection. This eliminates the delay in the request system present in HTTP. Moreover, MQTT minimizes data packets, so it works even in low connection. Finally, MQTT is very power efficient, which really helps the battery life of the patrol bot.

F. Detection Algorithm

The detection algorithm consists of 2 phases

- Calibration Phase : The bot at first needs to be placed at the starting black line facing the opposite wall, which also has a finishing black line. In this phase, the bot will determine its range of detection and the minimum distance for it to detect an intruder on the line. This is done by an algorithm that updates the maximum side detection range if it is less than the previous maximum detection range.

  If
  $Range = OldReading \ \& \ NewReadingReading$
  Then
  $Range = NewReading$

  This ensures that the bot does not mistake furniture for an intruder and sends an alert. After determining the maximum detection range and the minimum forward detection range, the calibration phase will end. A Flowchart of the calibration phase is present in Figure 5.

- Detection Phase : In this phase, the bot will continuously take distance measurements and compare them with the max detection distance and min forward distance determined in calibration. If any distance comes out to be less than calibrated distances, a flag message is triggered and sent to the ThingSpeak IoT Platform. The Flowchart for the detection phase is present in Figure 4.

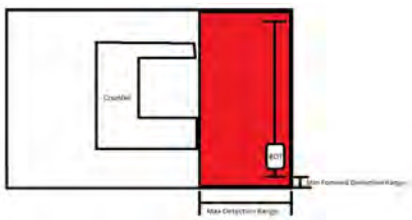

Fig. 3. Detection Area

After the patrol bot has entered the detection phase, it will continuously patrol the area. An illustration of the detection area after calibration is shown in Figure 3.

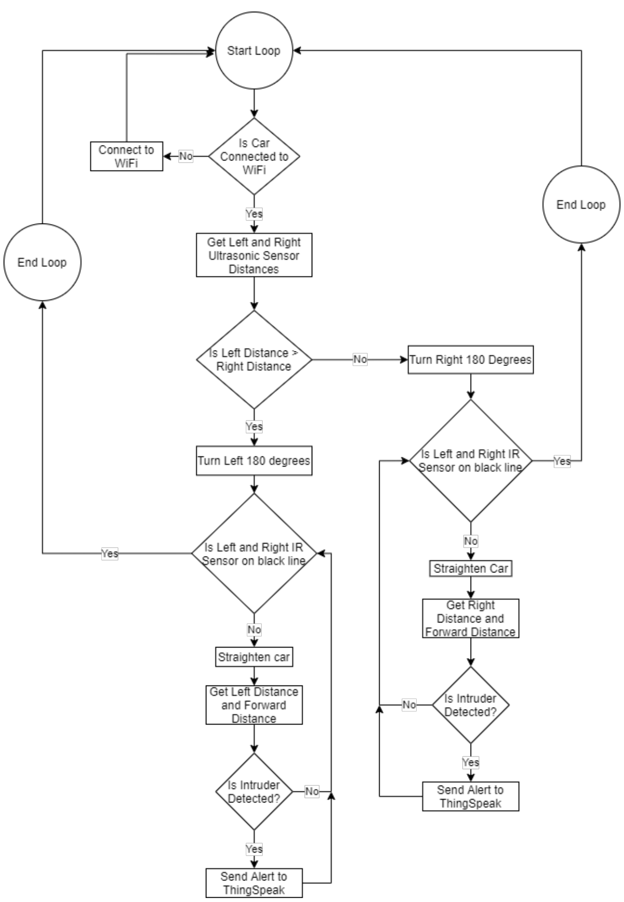

Fig. 4. Detection Phase

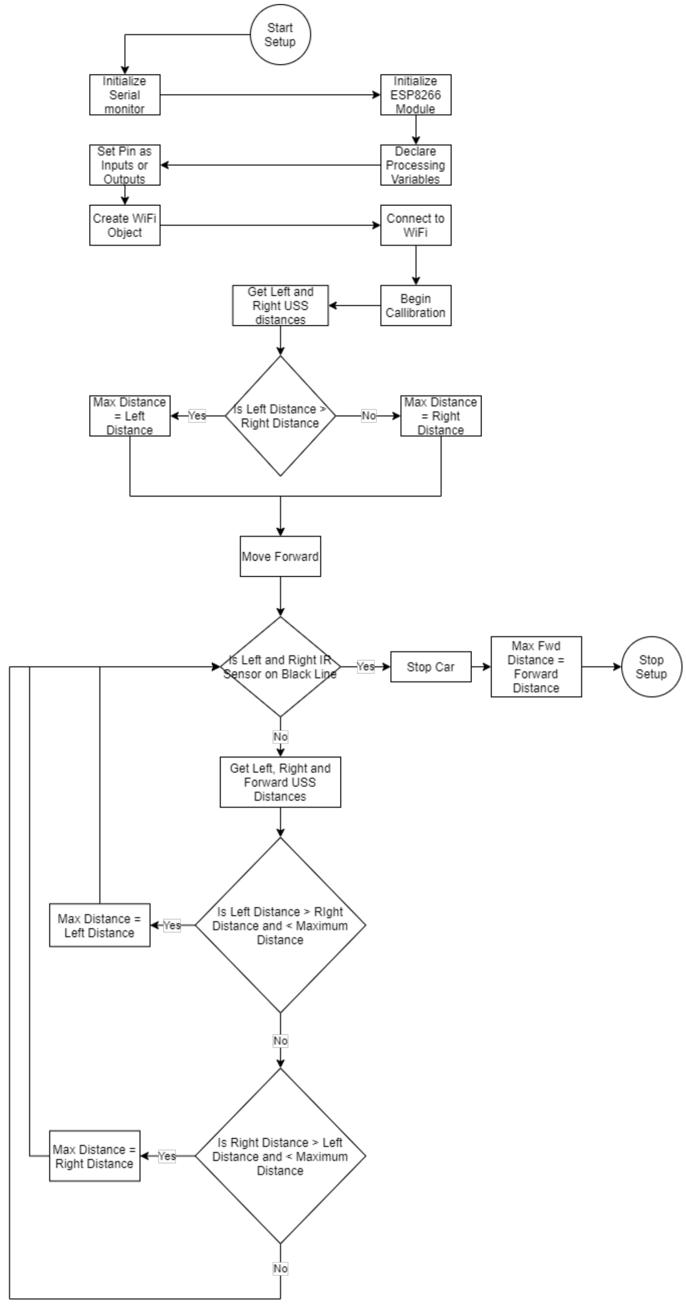

Fig. 5. Calibration Phase

IV. Limitations

- The range of the Patrol Bot decreases as the distance from the furniture/objects decreases i.e. extruding parts of the room will decrease the overall range of the bot
- The battery life of the patrol robot is limited as it works on a rechargeable lithium-ion battery and therefore has to be charged before every patrol session and works on a limited timeline
- The alert system heavily relies on Internet service and Wi-Fi connection to send alerts across all its platforms and therefore becomes handicapped during connection issues

- If there is a lighting issue in the path it can lead to pathway errors as it will not be able to distinguish between different shades of black and therefore stray off the path
- If it is knocked off course by a manual or natural phenomenon it will be immobilized until human intervention due to its natural code
- There is a limitation to the number of alerts it can send at a certain time therefore in case of alerts extending the threshold it will cease to send alerts

V. Results

The Patrol Bot uses ultrasonic sensors to generate a detection zone and make a map of objects lying in it. To do this the range of ultrasonic sensors and the accuracy of detection with various ranges have to be determined. The equipment for the test was an HC-SR04 ultrasonic sensor connected to an Arduino board

The Ultrasonic sensor retains an accuracy of 98.54% at 10 meters as seen in Table 1, and the accuracy gets better with the decrease in distance. A large contributor to the errors in the calculations done by the microcontroller which is programmed to take the speed of sound as 340m/s.

Theoretical (cm)	1st (cm)	2nd (cm)	3rd (cm)	Average (cm)
100.3	99.2	99.17	99.21	99.19
200.3	197.80	198.0	197.7	197.83
301.3	297.33	297.46	298.1	297.63
400.6	395.27	395.31	395.29	395.29
500.5	493.74	493.82	494.2	493.92
600.2	591.86	591.6	592.1	591.85
700.0	690.13	689.87	690.22	690.07
800.3	788.94	788.3	789.18	788.80
900.8	887.74	886.94	888.13	887.60
1000.5	985.90	986.22	986.12	986.08

TABLE I
Observation of range of Ultrasonic sensors

A. Alert Examples

Figures 6,7,8 and 9 show the results with respect to the alerts sent. Figure 6 shows the serial monitor which confirms that an alert flag was sent to the ThingSpeak server.

Figure 7 shows the alert sent by email. It was received in Gmail. This method only allows an alert to be sent once every 10 minutes due to Gmail's spam protection. The message itself is sent via simple mail transfer protocol (SMTP) using a MATLAB script written in ThingSpeak.

Actual (cm)	Average (cm)	Error (cm)	Error Percentage
100.3	99.19	01.11	1.11
200.3	197.83	02.47	1.23
301.3	297.63	03.67	1.22
400.6	395.29	05.31	1.33
500.5	493.92	06.58	1.31
600.2	591.85	8.34	1.39
700.0	690.07	9.93	1.41
800.3	788.80	11.49	1.43
900.8	887.60	13.2	1.46
1000.5	986.08	14.42	1.44

TABLE II
Calculation of Error Percentage of Ultrasonic sensors

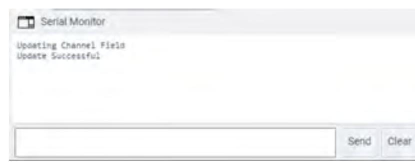

Fig. 6. Code Sent from microprocessor

Fig. 7. Email Alert

Figure 8 shows the alert sent by Twitter. ThingSpeak has integration with the Twitter API, which is used to post tweets on a particular feed. This allows the user to make an Alert account, follow it and keep its tweets on priority. This particular method is useful if the user does not want to install an app dedicated to alerts, but still wants alerts on their phone. The only drawback of this is that Twitter has spam protection and won't let you post the same tweet twice. A workaround for this would be to delete the tweet after getting the alert.

Figure 9 shows the alert sent by the MQTTX desktop app. ThingSpeak has MQTT integration, which uses the protocol of the same name. MQTT protocol works on a publisher-subscriber basis, which completely bypasses the need to send a GET request to the server and wait for the server to respond with OK. It is the fastest way of sending alerts, and it does it even with low-strength Wi-Fi. This method does not handle traffic very well, so it is not advisable to connect many computers to the same server.

Fig. 8. Twitter Alert

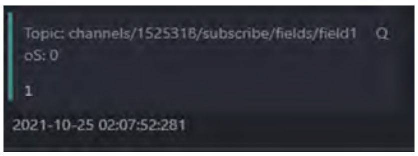

Fig. 9. MQTT Alert

VI. Future Scope

The robot requires an initial setup of a line, this could be aesthetically counter-productive to retail shops or workplaces. This could be solved by following the walls. However, that kind of algorithm tends to be jerky but can be solved by PID control as observed in [13].

Another approach to navigating could be the implementation of SLAM navigation. This is traditionally expensive due to the requirement of Lidar. But an ultrasonic sensor can be used as observed in [11] and [12].

A blind spot is created by the ultrasonic sensor detection algorithm for concave objects. This system can be overhauled by using cheap thermal imaging as seen in [16].

If the BO, motors are replaced by other motors, silencing techniques as seen in [14] and [15] could be tested

VII. Conclusion

The IoT Patrol Bot proved to be an effective solution to the proposed problem. It can patrol a room up to 20 meters in length and breadth. Depending on the number of points of entry, the system can use from 1-4 units. It is cost-effective since the system with the maximum number of units costs around the same as the most basic CCTV systems in the market. This is because it uses a cost-effective ultrasonic sensor which proved to be accurate up to 10 meters as compared to the rated range of 4 meters. This fact was verified experimentally, in which the sensor was shown to be 98.54% accurate with calculation error.

The IoT system was also successful in sending alerts in 3 different ways. The evident problem in this system was the spam protection from Twitter and Gmail which only allows the alert to be sent less frequently. This problem was not there in the MQTT system. The use of ThingSpeak as the IoT platform leaves room for the implementation of an app for sending alerts.

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