Secure Dual-mode Robotic Intrusion Detection System for Remote Surveillance

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Abstract

Remote video surveillance has become an integral part of premise monitoring in urban society, due to the menace of intruders. There have been various surveillance system implementations, but there is no one that fits all applications. Poor stream rate, security, and propriety issues are the major limitations of these systems. To this extent, a low complexity surveillance system that blends the three factors in a good mix is being presented in this work. A non-propriety, medium-rate MJPEG compression format was employed by the pi-camera to provide a good transmission rate and low storage requirement. The robot controller was linked to the monitoring web page through the Common Gateway Interface (CGI) protocol to provide a dynamic update of the page for real-time monitoring and analysis. The robotic movement of the system was achieved using two dc motors and a caster arranged as a differential wheel system. A combination of obstacle detection and avoidance system makes autonomous robot movement possible. The system test results show good robot navigation with obstacle avoidance and low-latency video streaming. The implemented secure shell protocol ensures secure video transmission.

Keywords: Video Surveillance, Live Streaming, Robotics, Security Camera, Obstacle Avoidance, MJPEG.

1. INTRODUCTION

Video surveillance is a growing topic with diverse application areas. There have been tremendous improvements in video surveillance technology since the introduction of first-generation or analog Closed-Circuit Television (CCTV) systems. These first-generations are inefficient as the analysis of the recorded or live video is done by humans, and the cameras are fixed type [1] - [3].

The second generation imbibed digital video techniques, thereby opening a new world of opportunities in processing and communications. It accommodates a large network of cameras that can be monitored remotely. With support for more sensors, it also multiplies data generated and drastically increased bandwidth requirements ([4], in press).

The necessity to manage a large volume of data effectively has led to the development of third-generation systems [2]. These are characterized by Internet compatibility and a distributed approach to computing. Their multisensory environment provides good scene capture; but also necessitates the introduction of artificial intelligence monitoring techniques. This enables the system to monitor an environment in real-time and provide the interpretation of scenes or predict an individual's action based on sensor data ([5], in press). Various algorithms and predictive models have been developed to detect, track, and analyze the behavior of targets, some of these can be found in [6] - [10]. An added feature of third-generation surveillance is improvement in video coding and compression techniques. This supports reduced data size, smaller storage requirements, low latency transmission, and a higher level of data security, such as can be found in [7] and [11] - [14]. This work draws upon advances made in third-generation video surveillance to develop indoor IOT enabled surveillance robot.

In section 2, some past related works on intrusion detection systems are discussed; it also enumerates justification for this work. Section 3 presents the hardware and software design of the proposed system. The results of the experimental analysis were presented in section 4 and the performance of the system was evaluated as well. Section 5 provides concluding remarks on the work.

2. RELATED WORKS

An outdoor surveillance robot was designed and implemented in [15]. It incorporates RFID to detect authorized people and a metal sensor to detect metal weapons. It provides 360˚ rotation of the camera and uses infrared detection for obstacle avoidance of the robot. Messages about human and metal detection are relayed through the GSM module. The use of infrared however makes detection to be susceptible to environmental conditions variation and there was no real-time remote monitoring. A robotic surveillance system was presented in [16], which utilizes a passive infrared (PIR) sensor for the detection of unauthorized human presence. Two transmit-receive infrared sensors were used to detect obstacles for robot navigation. The detection of human presence by the PIR will trigger the camera to capture an image or video and send it via a web server to a web page. One of the drawbacks is that there could be missed the event as the infrared operation is affected by weather conditions. A remote surveillance system that includes a face recognition feature was implemented in [17]. The camera continuously captures the environment scenes, while video analysis is performed to detect motion. When motion is detected, face recognition is done to ascertain identity. If an unauthorized face is detected, the video will be streamed to a web page. However, if authorized personnel is detected, the onboard voice assistant will start talking with the person. While the inclusion of face recognition might save cost in bandwidth and transmission requirements, it may compromise the security architecture if there are false positives. There is also the problem of false alarms if there are false negatives. A robotic surveillance system based on stereo-vision and artificial neural network was used in [16] to improve the pan, tilt, and zoom parameters, but the design was complex and expensive. A method to control robots by obtaining their location information using a map constructed by visual information from surveillance cameras installed indoors was presented in [18]. It makes use of several neighboring surveillance cameras to avoid occlusion. A two-dimensional map containing robot and object position information is constructed using images of the cameras. The mobile robot was able to maneuver to its destination using the two-dimensional map without the help of any other sensor. The construction of a navigational map may cause a delay that will make real-time monitoring difficult. An indoor robotic inspection system was proposed by [19], to primarily monitor industrial sites, structures, and infrastructure. The design of the hybrid mobile robot and sensors allows for multiple data acquisition and storage. This mechatronic solution is however complex in design, ineffective cost-wise and some of the components cannot withstand a harsh industrial environment. In this design, a simplistic approach was used to achieve low complexity and cost. The robot has autonomous operation capability, and real-time monitoring of the robot was facilitated through CGI connection of the robot to the Internet. The robot navigation was facilitated through obstacle detection and low latency of video transmission was achieved by the MJPEG compression format.

3. SYSTEM OVERVIEW

The design of the prototype wireless surveillance robot involves the mechanical construction of the robot, electronics that provides camera and robot movement, video processing, and transmission program modules. Raspberry pi-3 serves as the electronics core that provides an interface for drive control of dc motors; robot obstacle avoidance; servomotor for camera panning movement; camera module connection and a user-friendly graphical user interface to control the robot and view streamed video from the camera module. Figure 1 shows the block diagram of the system.

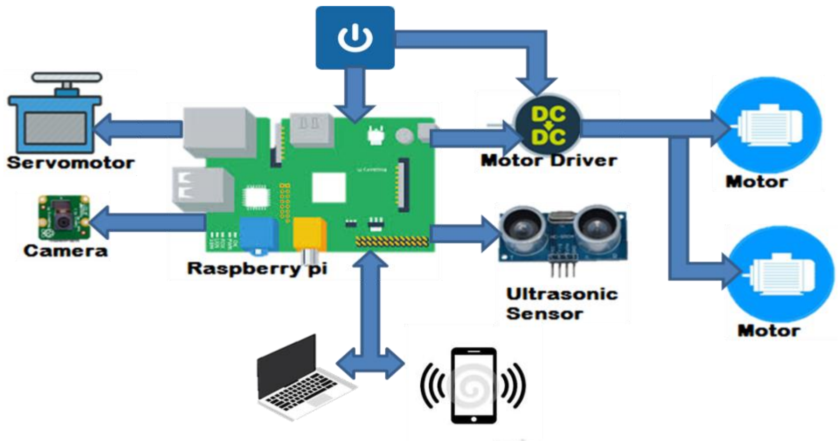

FIGURE 1: System schematic layout.

3.1 Raspberry pi Configuration

Raspbian buster operating system was installed on the SD card of the Raspberry pi 3- model B via the laptop. A secure shell (SSH) was set up on the SD card of the raspberry pi by creating an empty SSH file with no extension and a second configuration file as wpa_supplicant.conf. Important parameters such as network id and password are entered into the configuration file. The files were created using a notepad++ text editor. A headless connection between the raspberry pi and the laptop is thus established via SSH. The SSH provides strong password authentication, public key authentication, as well as encrypted data communications over the open-unsecured Internet. A command-line interface to interact with the raspberry pi was set up on the laptop by installing putty. Putty is a Windows terminal that allows direct communication with the command terminal of Linux devices from a pc connected to the same SSH network. This was accomplished by entering the IP address of the raspberry pi into the Hostname (IP address) feed and assigning 22 to the PC port. The Wi-Fi of the pc and the raspberry pi is connected to the same SSH network MobaXterm was installed to provide a pc-like graphical user interface on the raspberry pi, and set up in a similar way to putty.

3.2 Motor Circuit Design

The motors were driven using the L293D IC. This is a 16-pin dual H bridge motor driver IC. It can be configured to drive motors in the clockwise or anticlockwise direction. The device is suitable for driving inductive loads such as electric motors. Internally, it consists of four-channel current drivers which are paired up to form two pairs of drivers. The pairing of the channels allows for current flow to rotate the motor in either direction. The IC operates with a maximum input voltage of 7V to produce a maximum voltage of 36V. The WiringPi library that was written in C language was used to configure general-purpose input-output (GPIO) pins as an output port to power the IC. A CGI script was written in C language to configure the logic levels of the GPIO pins to yield motion in the forward, reverse, right turn, and left turn directions appropriately. The use of CGI allows the hypertext transfer protocol servers to render dynamic contents on the web page. While, the writing of the CGI script in C allows for seamless integration and interfacing with wiringPi library that was also written in C, and faster communication of the server with the CGI scripts, as C is a middle-level programming language. The motor control programs were written in python.

3.3 Setting Up The Camera Module

The camera captures the video as well as compresses the video signals. It has a resolution of 5 megapixels. It supports 1080p video recording at 30fps or 720p at 60fps and 640x480p at

60/90fps. A micro servomotor SG90 was used to achieve a precise angular displacement of the camera. It can turn through a total angle of 180 degrees, divided between five steps. The servo motor has three terminals, the power, the ground, and the data terminal. The data terminal of the servomotor was connected to GPIO.23 of the raspberry pi, which corresponds to physical pin 16. The control of the servomotor was made possible through the servo-blaster library that was installed on the raspberry pi. Manual control of the servomotor to pan the camera to the extreme-left, left, center, right, and extreme-right from the remote monitoring web page was provided as an added feature. By clicking the HTML buttons, a Javascript function is called, which invokes the CGI script that controls the servomotor through the apache server.

3.4 Collision Avoidance

Collision with obstacles when the robot moves in the reverse direction were prevented through sensing for obstacles at a distance and providing adequate instructions to the robot to avoid them. HC-SR04 ultrasonic transceiver sensors were used, because of their resilience against weather conditions. The transmitter sends out 40kHz sound waves at regular intervals and the time taken for the signal to be reflected was measured. From this, the distance was calculated as:

$$s = \frac{t \times v}{2}$$

where *s* is the obstacle distance, v is the speed of sound in the air and t is the time taken for the reflected waves to be received. The echo pin of the sensor was connected to the raspberry pi through a voltage divider circuit, to step its 5V output voltage down to the raspberry pi rated 3.3V.

3.5 Power Supply

The raspberry pi requires a USB supply of 5V. The 8,500mAh power bank was used to power the raspberry pi. The power bank has two USB ports rated 5V, 2.1A. The second power bank port was used for the motor driver IC.

3.6 Web Interface

The web application was designed using HTML, styled with CSS, made responsive with Javascript, and information was fed from the server using XmlHTTP through CGI. The web page was hosted locally on the raspberry pi using the apache server. Navigation buttons were created on the web page to navigate the robot or to turn the camera. The web page also features a window for viewing the video captured by the camera. Access restriction to the web page was provided through authentication and login credentials encryption. Through XmlHTTP and CGI, the web page can fetch information from the server without the need to reload the whole page; this is essential in terms of speed and timing.

3.7 Localhost with Apache Webserver

Apache server was well integrated with the raspberry pi as the hosting software. The server also allows the interaction of the web page with the backend code stored on the raspberry pi through the CGI without having to reload the page on each button click. This is essential for speed because each page reload will increase the lag or delay in the system's response.

3.8 Robot Assemblage

The robot's chassis consists of an acrylic frame with a pair of 5V dc motors and a caster serving as the wheels. Connecting wires were soldered to the leads of the dc motors, before inserting firmly into the gearbox. The mounting brackets were used to mount the gearboxes onto the robotic frame, while ultrasonic sensor holders were fixed onto the robot's chassis, as well as the power bank. The raspberry-pi sits on top of the power bank, after attaching the raspberry-pi camera to the servomotor. The servomotor was then attached to the raspberry pi case. The completed robot is as shown in Figure 2. In the manual mode, a user controls the robot by using the control buttons on the web page. But in the autonomous mode, a routine in Python was written for the obstacle detector output to navigate the robot.

3.9 Video Streaming

Motion Joint Photographic Group (MJPEG) video streaming engine was installed on the raspberry pi to stream video captured by the robot. MJPEG streams frames of JPEGs at a rate of about 30 frames per second. The frames are transmitted through HTTP to the web page from where the stream is viewed. MJPEG-streamer is a command-line application that copies JPEG frames from one or more input plugins to multiple output plugins. It can support various types of browsers and a variety of different input devices, with added support for the Raspberry Pi camera via the input_raspicam plugin. It was originally written for embedded devices with very limited resources in terms of RAM and CPU. The SSH connection provides robust security for the video streams. The web page for the video streams is as shown in Figure 3.

4. RESULTS AND DISCUSSIONS

The live feed of the surveillance robot can be accessed through the IP-controlled web interface. An authentication page as shown in Figure 4 pops up when the correct IP address was entered into a browser. If incorrect credentials were entered as the username and password, the page returns “Restricted Content”, otherwise the video stream page loads. The use of login credentials provides an additional level of security to safeguard against unauthorized access to the network. The robot is normally driven in the autonomous mode, but manual mode serves as an alternate option as well as operational changes purpose. Obstacles or objects within a minimum distance of 2cm and a maximum distance of 4m and placed in the range of 15˚ from the perpendicular direction to the ultrasonic sensor, can be detected and avoided by the robot, as shown by Tables 1 and 2. This obstacle detection range is suitable enough to navigate the robot successfully without collision. Reflection of the ultrasonic waves from the transmitter of the ultrasonic sensor module varies with the texture of different objects. Measurement of distance from the object was more accurate with objects that have a hard-reflective surface than with objects with a soft or padded reflective surface as shown in Table 3. It can be seen in table 4 that vertically upright objects were more accurately measured than objects that were slanted at an angle. Additional different types of sensors can be used to enhance the detection of slanted or soft padded objects. While Table 5 shows the calculated latency per line for corresponding video rates and size of the camera. The average overall latency of 19.7ms was measured from the timestamp of transmitted and received video, which accounts for all the delays in the buffers. This value is well below 100, which is considered the benchmark for low latency.

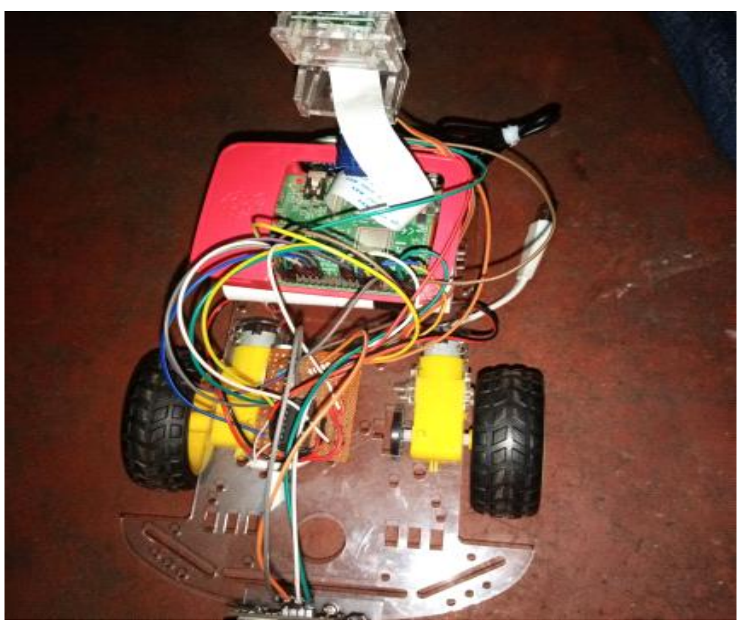

FIGURE 2: Pi-3 Robot.

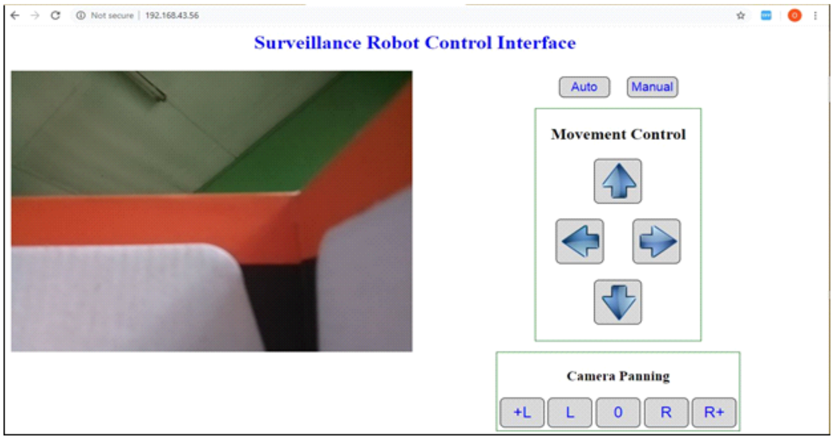

FIGURE 3: Surveillance Robot Web Interface.

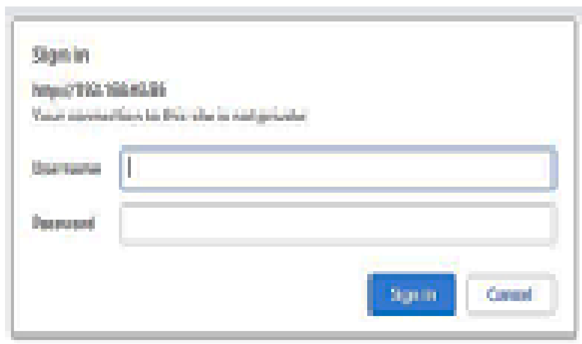

FIGURE 4: Authentication Page.

Distance	Detection
2cm to 400cm	High
Outside range	Low

TABLE 1: Effect of distance on detection.

Angular range	Detection
Within 15° direct distance	High
Outside 15°direct distance	Low

TABLE 2: Effect of angular range on detection.

Surface type	Detection
Hard reflective	High
Soft or padded	Low

TABLE 3: Effect of surface type on detection.

Orientation	Detection
Vertical	High
Slanted	Low

TABLE 4: Effect of orientation on detection.

Frame rate	Frame size		
	1080p	720p	640p
30fps	0.31µs	-	-
60fps	-	0.23µs	0.35µs
90fps	-	-	0.17µs

TABLE 5: Latency per line for corresponding recorded video frame size and frame rate.

5. CONCLUSION

In this work, simple architecture of a surveillance system to monitor indoor environment scenes has been presented. The obstacle detection method for the navigation of the robot was effective and was not affected by environmental factors. The compression scheme for the video was not propriety-based and therefore compatible with most web browsers. It offers an advantage overtemporal compression in frame-by-frame compression when there is a lot of motion in the scene or when the background is changing. The implementation of the CGI as part of the webserver enables dynamic updating of the monitoring web page. The choice of the compression scheme and the CGI adds up to provide low latency of the video stream.

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