Turkish Journal of Computer and Mathematics Education (TURCOMAT) ISSN: 3048-4855

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

Advanced Autonomous Surveillance Robot for Enhanced Monitoring and Individual Identification

Moeen Ul Islam, Debanjon Dutta Purkaystha, Antu Das Gupta, Sopan Saha, Durjoy Banik, Muhibul Haque Bhuyan

Department of Electrical and Electronic Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh

Email: muhibulhb@aiub.edu

How to Cite
Islam, M. U.., Purkaystha, D. D.., Gupta, A. D.., Saha, S.., Banik, D.., & Bhuyan, M. H. (2024). ADVANCED AUTONOMOUS SURVEILLANCE ROBOT FOR ENHANCED MONITORING AND INDIVIDUAL IDENTIFICATION. Turkish Journal of Computer and Mathematics Education (TURCOMAT),15(3), 25–34. https://doi.org/10.61841/turcomat.v15i3.14722

Abstract: The primary objective is to detect and identify suspicious activities and potential threats in a precise manner while prioritizing human safety leveraging surveillance technology and machine learning. The implementation of this system involves coding in Python using the OpenCV library. It utilizes Wi-Fi connectivity as a means of communication. The robot is equipped with a Raspberry Pi along with a USB web camera, which captures video footage and employs object detection algorithms to identify unknown individuals. When a person or an object is detected, the system sends an email to the dedicated email addresses including an image of the unrecognized individual. The proposed system is designed as a unified unit responsible for monitoring the environment for hazardous conditions and delivering real-time video feedback. The proposed system is simulated and tested in real-time to observe its functionality, and it is observed that the system works properly as per given input conditions.

Keywords: Surveillance Robot, OpenCV Library, Identification, Monitoring Environment, Autonomous Robot.

1. Introduction

The Internet of Things (IoT) is a kind of device that is linked to the internet connectivity through various computing devices both mechanical and digital, each assigned with a unique affiliation number and the capability to transmit data across the network autonomously, eliminating the necessity for direct man-to-man or man-to-computing machine communication. IoT devices are being employed in power systems monitoring systems (Talha, 2023), automatic solar panel maintenance systems (Biswas, 2023), health care systems (Bhuyan, 2021), fisheries systems (Bhuyan M. H., 2023), garbage monitoring and management systems (Paul, 2023), railway or road traffic monitoring and control systems (Bhuyan M. H., 2022), etc. In the past, robots were primarily controlled through wired networks (Madakam, 2015). However, recent advancements have made robots more user-friendly by enabling them to respond to user commands wirelessly, without any distance limitations (Adnan, 2023). This wireless connectivity allows robots to operate in various locations where a wireless network is available (Huang, 2019). Such technology has promising applications in security, particularly for gathering information in suspicious areas or about suspicious individuals. In contemporary security scenarios, surveillance plays a critical role, but the quality of surveillance often falls short of expectations. To enhance the quality of surveillance, there is a need for dynamic surveillance systems that can be deployed flexibly and effectively (Budiharto, 2015). These systems are equipped with computer vision algorithms that can interpret videos and extract valuable information, such as the identities of individuals, their movements, and the timing of events, from raw video data. Biometric applications, which require reliable and automated personal identification, are integral to the effectiveness of such systems (Yang, 2004). Facial recognition poses a complex challenge due to the variability in facial morphology caused by factors like lighting

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

and posture. Rather than exposing human personnel to dangerous situations, this paper presents the design of a robot capable of performing the same tasks (Wang, 2008).

The primary focus of this paper is the development of a mobile robot equipped with real-time image and video capture capabilities for surveillance purposes. The robot's primary function is to monitor a designated area continuously, ensuring safety and security by observing as well as acting as a surveillance tool, and identifying any suspicious individuals within its vicinity. Its capabilities are geared toward enhancing security and safety without compromising human lives. This versatile robot finds application in various contexts, including military scenarios. It can be deployed for monitoring specific individuals or areas of interest, providing a tactical advantage in potentially hostile environments or during hostage situations. These robots can be deployed beyond enemy lines to gather crucial information and secrets, providing tactical advantages to their operators. In situations involving hostages, where security cameras are often the first target, the development of mobile robots for real-time image and video capture becomes imperative. In summary of this paper, the IoT has been established for the creation of wireless, user-commanded robots for versatile surveillance applications. These robots are equipped with advanced computer vision capabilities, including facial recognition, to enhance the quality of surveillance and improve security in various scenarios.

2. Literature Review

2.1. Earlier Research

The authors (Budiharto, 2015) have made an intelligent surveillance robot that can avoid any obstacles by utilizing the neural network. They used it in advanced surveillance and military capabilities through the development of a sophisticated remote-controlled robot. This robot is designed for tasks, such as rescue operations in hazardous environments and military applications, utilizing neural network technology for obstacle escaping and victim detection. However, they could integrate artificial intelligence (AI) recognition for the same purposes and could implement advanced power management in their system for enhanced durability and efficiency. Besides, they could combine remote control capabilities with real-time Closed Circuit Camera Television (CCTV) monitoring for comprehensive surveillance. They could also introduce automated alarms/alerts for immediate responses and could implement patrolling for continuous area coverage. This integrated system should ensure superior performance by reducing costs and enhancing security measures.

In another paper, the authors employed 30 standard images of different faces of human beings. The focusing regions of these face images are on the eyes as the templates that are matched and applied along with the two-dimensional principal component analysis (2DPCA) algorithm that was established by the authors (Yang, 2004) (Wang, 2008). Their experimental results identified faces so accurately within a very brief period.

2.2. Recent Research

The authors (Karishma, 2018) made a smart office surveillance robot based on face detection. The main purpose is to revolutionize surveillance with a robot featuring face recognition and remote control via Android. It offers heightened security, eliminating the need for proximity identification. However, he could include integrated patrolling capabilities for automated area coverage and combine real-time Closed Circuit Camera Television (CCTV) monitoring with AI recognition for enhanced threat detection enabling remote control and alarm generation for immediate responses by the user. This comprehensive system ensures efficient surveillance, reducing human errors, and thus providing timely alerts, significantly bolstering security measures.

In another work on the surveillance robot with face recognition using Raspberry Pi, it was found that the authors tried to revolutionize border security with an automated surveillance system using a sensor-equipped robot (Bhavyalakshmi, 2019). It aimed to address human limitations in continuous monitoring, ensuring uninterrupted and efficient protection. In our opinion, they could integrate AI recognition for accurate identification of known persons and use multi-sensor fusion for patrolling and detecting unusual events. In this work, they could also combine real-time Closed Circuit Camera Television (CCTV) monitoring with remote control for efficient surveillance and could introduce automated alert signal generation to reduce the response time of the users. This comprehensive system enhances security, reduces human error, and cuts operational costs.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

The primary objective of this current research initiative is to implement a surveillance system utilizing a robotic device connected through a Wi-Fi network. This surveillance system boasts several key features, including conference capabilities and remote control via a remote device through an internet connection. Additionally, it incorporates night vision technology for low-light environments and offers the ability to maneuver and orient itself in specific directions via a web application. To minimize the risk of data loss due to network failures, the system leverages onboard memory storage within the robot.

The potential applications for this system are diverse and extend to areas where individuals face life-threatening situations or a high risk of property loss. It also serves as a cost-effective alternative for enhancing security in various settings, such as companies, laboratories, and factories. By providing a simple and affordable security solution, this system empowers individuals and organizations to safeguard their well-being and assets effectively.

3. Methodology

To begin, we constructed a robot using a Raspberry Pi 4 along with Arduino Uno connected to different input/output devices and sensors for monitoring and surveillance. We integrated a USB camera with the Raspberry Pi 4 to enable live streaming of the camera feed over the internet by capturing images by the camera and processing the images by the Pi 4 to detect the captured images and sorting. A specifically designed Python-based application serves to control the robot's movements via remote access. Using applications, such as TeamViewer, we can access the operating computer over the internet.

The Raspberry Pi 4 is used as the processing unit of the robot. The processor uses an algorithm to detect whether the image captured by the camera is a person or an object. The serial communication protocols are used to communicate among the control units and the other peripherals. Surveillance, in this context, refers to an automated endeavor known as robotic surveillance. The initial surveillance robots were primarily designed for security purposes and operated through mobile applications. In this first-generation surveillance robot, the robot's tasks involve detecting and responding to commands via a remote access device. A surveillance robot is equipped with navigation, response mechanisms, cameras, ultrasonic sensors, and communication systems. Servo motors are employed for precise navigation of the robot.

There are several characteristics of a surveillance robot. Our implemented surveillance robot has the characteristics that are discussed in the following sub-sections.

3.1. Sensing

The robot can sense its surroundings using ultrasonic sensors and a camera feed. It moves in and around the given location on its steering wheels while avoiding objects, if necessary, with the help of the DC motor driver configured with object detection configurations.

3.2. Adaptability

The surveillance robot can perform numerous tasks simultaneously. Therefore, it needs to adapt according to the desired tasks at a given timeframe in the designated surveillance area, such as detecting persons, sounding alarms, and adjusting the speed of detection in a particular coverage area.

3.3. Durability

The designed surveillance robot must perform its actions in each coverage area successfully with its full strength at any given time. The compact and robust building of the robot ensures durability and effectiveness during its regular operations.

3.4. Intelligence

The usage of OpenCV and TensorFlow lite libraries ensures proper object detection. With the help of the pre-trained models, the detection of people in areas of surveillance is very effective. The complex yet sophisticated development of the application also ensures a comfortable user interface with proper and intelligent functionalities.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

4. Proposed System

In creating an intelligent surveillance robot system, we used a variety of components, such as a Raspberry Pi, an OpenCV Python library, a Global Positioning System (GPS), an Application Programming Interface (API), an ultrasonic sensor, a Logitech camera, an internet connection, and a motor with a motor driver circuit. This work integrates all these components with Artificial Intelligence (AI) algorithms to build a modern and capable intelligent robot. The block diagram of the proposed system architecture is shown in Fig. 1.

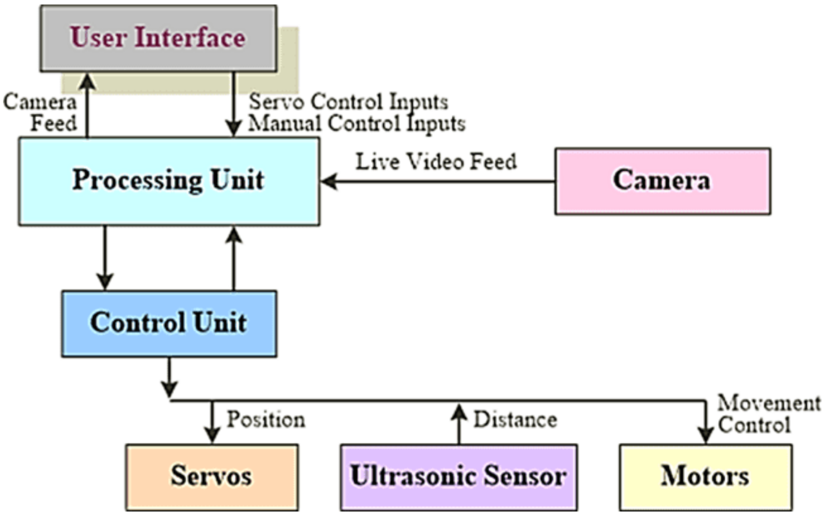

Figure. 1 Block diagram of the proposed system architecture.

4.1. Hardware Setup

One Raspberry Pi 4 and one Arduino Uno are used as the main processing and control unit, respectively. While 3 ultrasonic sensors are used to identify obstacles. Besides, an active buzzer and a few LEDs are used for the alarm generation and display system. A BTS7960 with four 30G motor is used for the high torque locomotion of the robot.

4.2. Software Setup

TensorFlow lite in Python is used for person detection. A graphical user interface (GUI) is created with Python for custom user applications. A serial communication protocol is used to link Arduino Uno and Raspberry Pi.

4.3. Object Detection and Tracking

Object detection algorithms are implemented using OpenCV, such as deep learning-based models, like TensorFlow lite. Besides, pre-trained models are used for developing algorithms to detect specific persons for surveillance, and the camera feed is employed to detect and implement person detection in real time. There are two types of detections, such as near zone and far zone detections. In the near zone detection, the panoramic mode while in the far zone detection, the Pan, Tilt, and Zoom (PTZ) patrolling mode is used to scan a wide and deep region.

4.4. Internet Connectivity

The internet connectivity is set up on the Raspberry Pi microcontroller to enable remote monitoring and controlling. In this regard, a secure communication protocol is implemented to protect data transmission processes.

4.5. Remote Control Monitoring

The internet connectivity on the Raspberry Pi is set up to enable remote monitoring and controlling via TeamViewer. As such, a secure communication protocol is implemented to protect data transmission processes.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

5. Result Analysis and Discussion

Analyzing the results of an intelligent surveillance robot for monitoring tasks involves assessing its performance, effectiveness, and the achievement of set goals of the intended work. The simulation results focus on an in-depth analysis of the simulation outcome obtained from the data analysis. The simulation path breaks out the difference from hardware result findings. In this analysis, the process of simulated results is thoroughly examined to identify irregularities, anomalies, and potential problems that may create malfunctioning of the system. Factors, such as several design considerations are considered for the applied model. We showed both simulation and experimental results in the next two sub-sections.

5.1. Simulation Results

This simulation setup involves the use of Proteus 8 simulation software (Bhuyan M. H., 2020) to mimic the behavior of a robot. Within this setup, a serial input emulator is employed to simulate data transmission from a Raspberry Pi. This emulator is connected to a virtual port generated by virtual serial port software. Data transmission through this port is simulated using Tera Term software, enabling real-time input via the device keyboard. The Arduino serial monitor is utilized to monitor and read the serial output from an Arduino Uno as shown in Fig. 2.

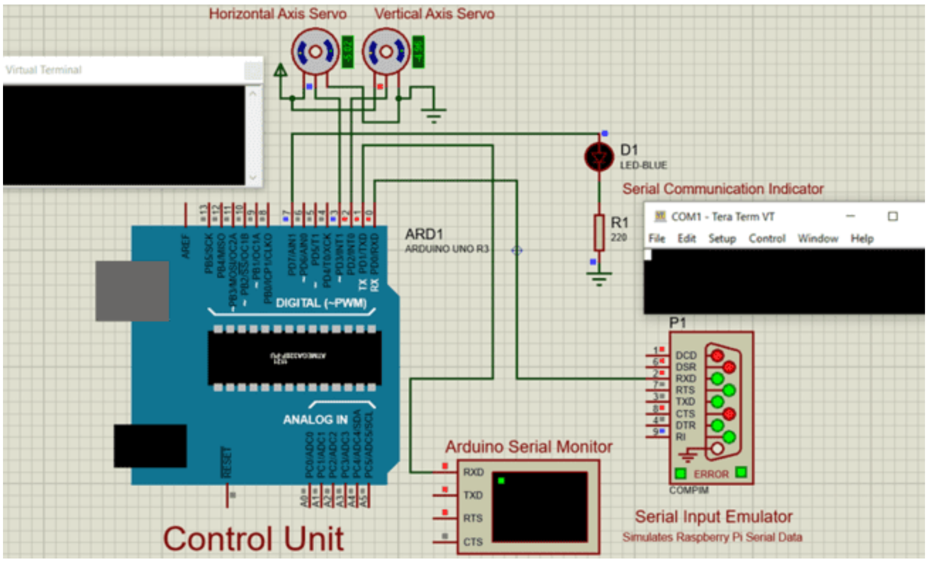

Figure. 2 Robot setup (AI) using Proteus software.

During the simulation, each operational function is represented by the corresponding action written in the form of a Serial.Print() command. A blue LED serves as an indicator of successful serial communication between the Arduino and Raspberry Pi. When this blue LED illuminates, it signifies that the communication between these two devices is successful as shown in Fig. 3. At first, we simulated the robot setup process.

This simulation showcases the camera's motion in response to communication between the Raspberry Pi 4 and the control unit. At the outset, both servos are in an idle state, positioned at 0 degrees. As depicted, when the Raspberry Pi transmits the command 'W', the vertical-axis servo swiftly adjusts to 90 degrees counterclockwise, causing the camera to tilt upwards. Conversely, when the command 'X' is issued, the vertical-axis servo promptly shifts to 90 degrees clockwise, resulting in a downward motion of the camera. These are shown in Fig. 3.

When a robot identifies a person, it signals the Arduino Uno through serial communication by sending the letter 'Z'. The Arduino then activates a system to sound an alarm for person detection. This system includes a buzzer and LEDs that flash simultaneously with the message 'Person Detection! Alarm Going Off' is displayed on the Arduino UNO's serial monitor as shown in Fig. 3. To prevent excessive current draw and potential damage to the Arduino pin, a MOSFET is employed as a switch to ensure the system functions efficiently and safely.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

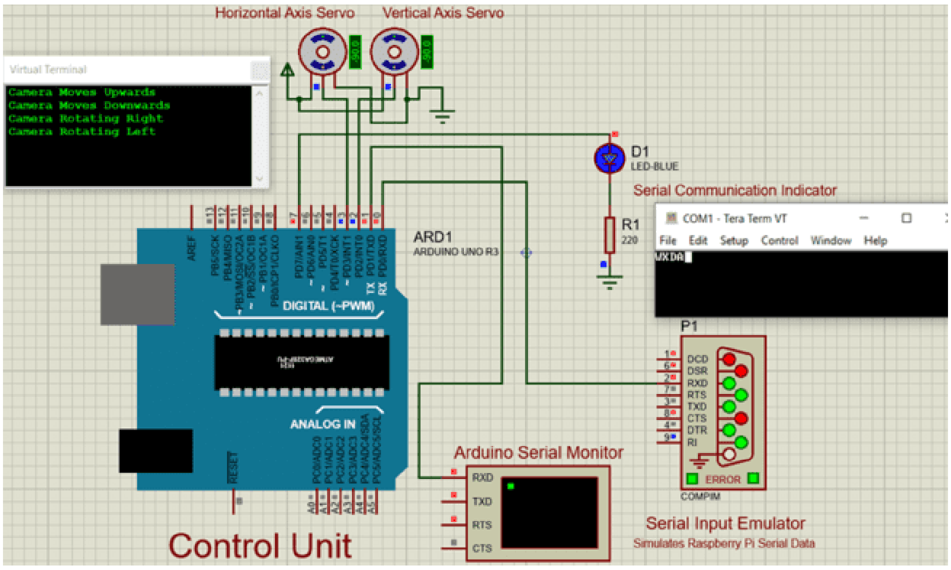

Figure. 3 Camera movement simulation in Proteus simulator.

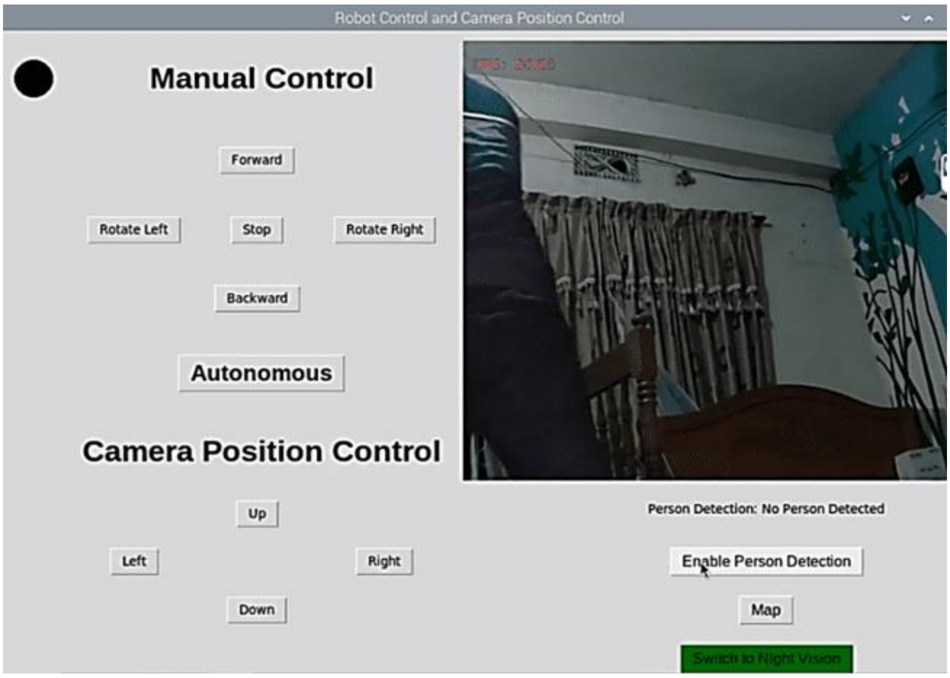

Figure. 4 GPU App interface.

The GUI app interface displayed is designed for manual control of a robot's movement and camera positioning as per the operator's choice as shown in Fig. 4. It also provides a live camera feed from the robot and an option to view the robot's current location on Google Maps. This section of the app interface handles the robot's movement. When the toggle button is in 'Manual Control' mode, the operator can use the application's control buttons to direct the robot's motion. The 'Forward' button moves the robot forward, the 'Backward' button moves it in the reverse, 'Rotate Left' and 'Rotate Right' buttons turn the robot in the left and right directions, respectively. The 'Stop' button halts the robot, putting it in an idle position as shown in the upper left corner of Fig. 4.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

When person detection is active, the camera display highlights detected individuals with a square box and alerts the operator as shown in Fig. 5. Additionally, an email is sent to predefined recipients, sharing the coordinates derived from a freely available third-party Application Programming Interface (API) that determines the device's location based on its IP address and online presence.

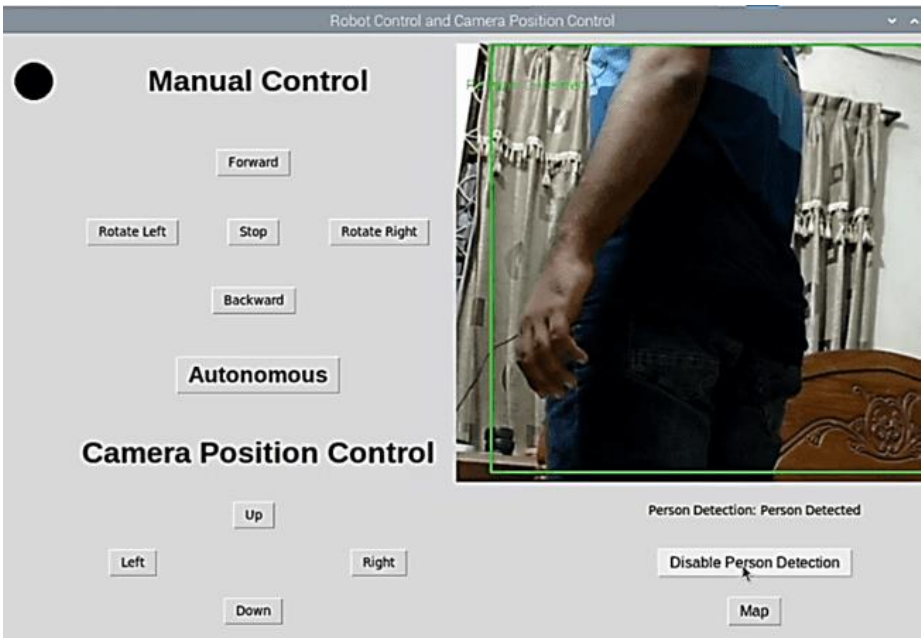

Figure. 5 Robot camera control App.

If the link in the email is clicked, the coordinate is shown in a Google Map specifically. If the application operator wishes to view the map manually without an email, the 'Map' button in the bottom right corner of the application (as in Fig. 5) is used to open a browser to show the coordinates in Google Maps as shown in Fig. 6. The accuracy of the map is average as the used GPS API is open source and is not as reliable as the paid APIs like Google.

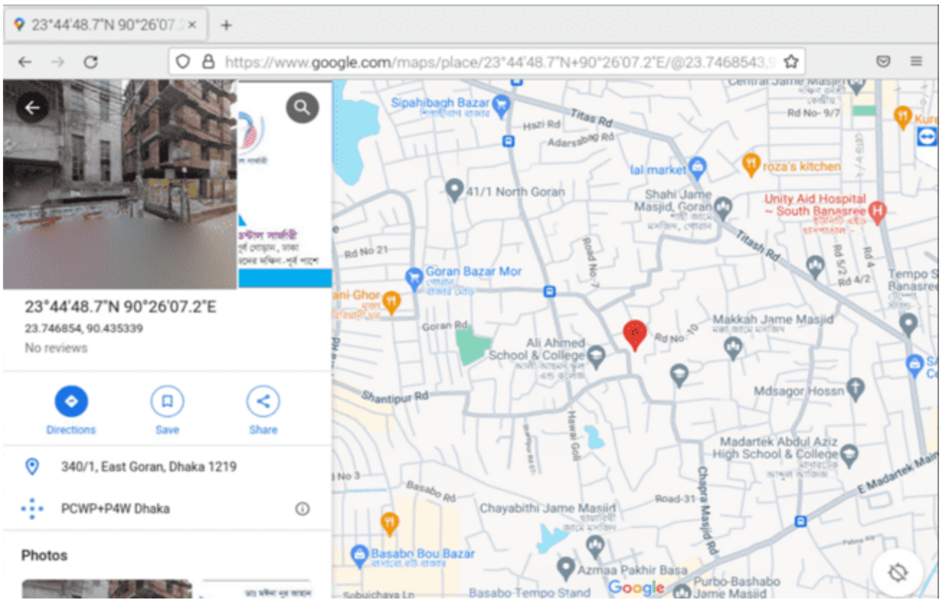

Figure. 6 Robot locomotion library setup.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

Table 1 shows the accuracy of the robot's person detection system. The data demonstrates that the robot can successfully identify a person 17 times out of 20 attempts and thus has an accuracy rate of 85%. The pre-trained model used for this algorithm is a bit outdated but still applicable. Using a better model for the object detection algorithm can improve the accuracy to a very high standard level.

Table 1. Person detection by the Robot**.**

Sl #	Detected Object	Detected Successfully?
1	Person	Yes
2	Person	Yes
3	Person	Yes
4	Person	Yes
5	Person	Yes
6	Bottle	No
7	Person	Yes
9	Person	Yes
10	Cloth	No
11	Person	Yes
12	Person	Yes
13	Person	Yes
14	Person	Yes
15	Person	Yes
16	Chair	No
17	Person	Yes
18	Person	Yes
19	Person	Yes
20	Person	Yes
	The total number of persons detected	**17**

5.2. Experimental Results

The hardware consists of three major parts. Firstly, the robot's locomotive components consist of 4 G30 gear motors which are powered by two BTS7960 motor divers that can handle a high amount of current. It is essential for rough terrains and overcoming obstacles. The large wheels are designed for this kind of purpose.

The second major part of the hardware architecture is the control unit, which is the heart of the developed system. The Arduino Uno is situated on a PCB, designed specifically for connecting all the components to the Arduino Uno. There is also the main processing unit, which is the Raspberry Pi 4. The Raspberry Pi 4 has its case with a built-in cooling unit for a higher workload. The Raspberry Pi is attached to the Arduino Uno and the Webcam.

Finally, the important input/output device is the camera which is placed at a higher position than the rest of the components for a better view of the horizon. Not only that but there are also three ultrasonic sensors at the front as the input device. They are separated by a small distance from one another; hence they can cover a wide range of object detection areas. The corner sensors are also responsible for determining the direction of rotation of the robot when there is an object in front of the robot. Besides, the servos are mounted inside the 3D-printed dual-axis camera

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

mount to move the camera at various angles. An alarm system consisting of several bright LEDs and a buzzer is at the front of the robot for alert signal display.

There is a dedicated buck converter for powering the Raspberry Pi 4 module. The overall power comes from a 3-cell 4200 mAh battery that can provide a power backup for longer periods. There is a switch to connect and disconnect the power as well. While the robot operates in the wild, a pocket router is used to provide a flawless Wi-Fi internet connection to the robot thus ensuring proper remote access. Different views of the hardware of the prototype system are shown in Figs. 7-9.

Figure. 7 Top view of the Robot.

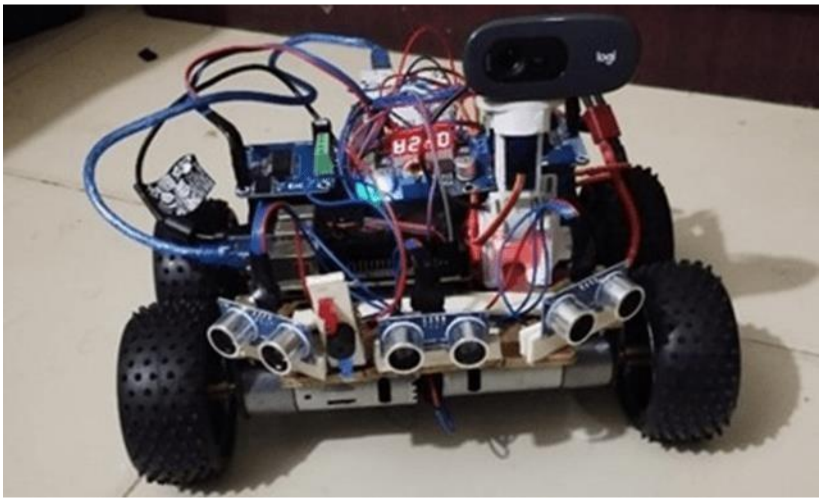

Figure. 8 Front view of the Robot.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

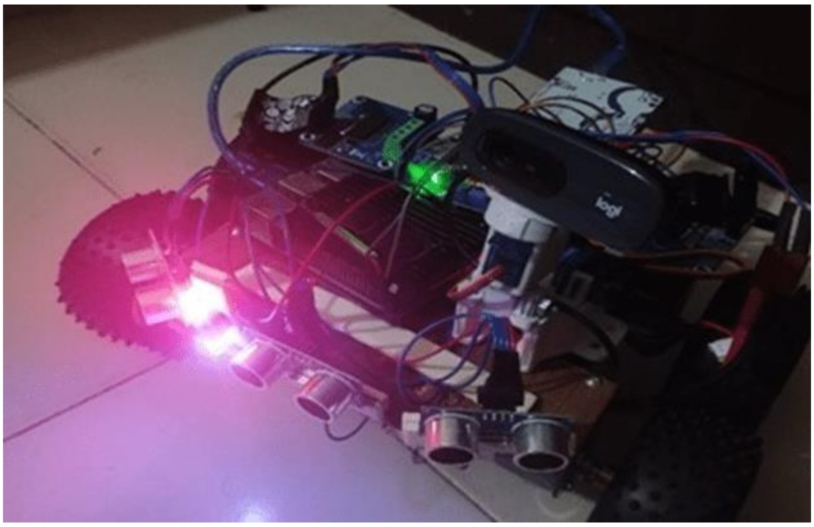

Figure. 9 Alarm system during person detection.

6. Conclusion

In this research activity, we focused on developing an economical and highly effective surveillance robotic system for wide open areas. It showcases an intelligent solution for surveillance and security integrating robotic technology and computer vision. The utilization of robots aims to minimize the risks for humans. This initiative addresses the concern of replacing human surveillance with robotic counterparts, ultimately reducing potential harm to human resources. One significant advantage of employing robots is their enhanced flexibility, enabling them to perform a wide range of applications and tasks. Robots exhibit superior accuracy and consistency when compared to human workers. Additionally, robots contribute to increased productivity and profit margins by efficiently completing tasks in less time. The comprehensive study emphasizes the various approaches undertaken to enhance the quality of video transmission and maximize the efficiency of the person detection algorithm.

References

Adnan, A. H. (2023). Design, Simulation, and Implementation of a Surveillance Robot System. Proceedings of the International Conference on Electronics and Informatics (p. 98). Dhaka: Bangladesh Electronics and Informatics Society.

Bhavyalakshmi, R. H. (2019). Surveillance robot with face recognition using Raspberry Pi. International Journal of Engineering Research and Technology (IJERT), 8(12), 648-652.

Bhuyan, M. H. (2020, October). Design and Simulation of Heartbeat Measurement System using Arduino Microcontroller in Proteus. International Journal of Biomedical and Biological Engineering, 41(10), 350-357.

Bhuyan, M. H. (2021, September-October). Designing, Implementing, and Testing a Microcontroller and IoT-based Pulse Oximeter Device. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 16(5), 38-48.

Bhuyan, M. H. (2022, March-April). Design and Simulation of a PLC and IoT-based Railway Level Crossing Gate Control and Track Monitoring System using LOGO. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 17(2), 13-23.

Bhuyan, M. H. (2023, January). Design and Implementation of Solar Power and an IoT-Based Pisciculture Management System. Journal of Engineering Research and Reports, 24(2), 15-27.

Biswas, S. B. (2023, September). IoT-based Automated Solar Panel Cleaning and Monitoring Technique. Journal of Engineering Research and Reports, 25(8), 56-69. doi:https://doi.org/10.9734/jerr/2023/v25i8959.

Budiharto, W. (2015). Intelligent surveillance robot with obstacle avoidance capabilities using neural network. Computational intelligence and neuroscience, 52.

Huang, H. S. (2019, January). Mobile robots in wireless sensor networks: A survey on tasks. Computer Networks, 148, 1–19. doi:https://doi.org/10.1016/j.comnet.2018.10.018.

Vol.15 No.3(2024),25-35
https://doi.org/10.61841/turcomat.v15i3.14722

Karishma, A. A. (2018, June). Smart office surveillance robot using face recognition. International Journal of Mechanical and Production Engineering Research and Development, 8(3), 725-734.

Madakam, S. R. (2015). Internet of Things (IoT): A Literature Review. Journal of Computer and Communications, 3(5), 164–173. doi:https://doi.org/10.4236/jcc.2015.35021.

Paul, N. K. (2023, April). Smart Trash Collection System – An IoT and Microcontroller-Based Scheme. Journal of Engineering Research and Reports, 24(11), 1-13.

Talha, M. A. (2023). IoT-Based Real Time Monitoring and Control System for Distribution Substation. Proceedings of the 10th International Conference on Power Systems (ICPS). 10, pp. 1-6. Cox's Bazar: IEEE. doi:https://doi.org/10.1109/ICPS60393.2023.10428721.

Wang, J. Y. (2008). Face detection based on template matching and 2DPCA algorithm. IEEE Congress on Image and Signal Processing (pp. 575-579). Sanya, China: IEEE. Retrieved from https://doi.org/10.1109/CISP.2008.270

Yang, J. Z. (2004). Two-dimensional PCA: A new approach to appearance-based face representation and recognition. IEEE Transactions on Pattern Analysis and Machine Intelligence, 26(1), 131-137.