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IBOT SURVEILLANCE ROBOT

Prathyush Korisaliyil Bijukumar[1*], Arun Manickam R[2], Surya Balan S[3], Ravi Kumar S[4], Abhinav Singh Rawat[5]

[1]Mechatronics Engineering, Acharya Institute of Technology, prathyushd.22.bemt@acharya.ac.in*
[2]Mechatronics Engineering, Acharya Institute of Technology, arunr.22.bemt@acharya.ac.in
[3]Mechatronics Engineering Acharya Institute of Technology, Suryas.22.bemt@acharya.ac.in
[4]HOD of Mechatronics Engineering, Acharya Polytechnic, ravikumar@acharya.ac.in
[5]Mechatronics Engineering, Acharya Institute of Technology, abhinavd.22.bemt@acharya.ac.in

**Corresponding Author*
**Email id: prathyushd.22.bemt@acharya.ac.in*

Abstract—

In a time when security and surveillance are the new buzzword, the IBOT Surveillance Robot offers 'an innovative solution that unites robotics, artificial intelligence and IoT connectivity. Featuring an Arduino Nano microcontroller, an ESP32-CAM real-time video streaming processor, and advanced sensors such as PIR (for sound detection), gas, flame, accelerometer, noise cancellation; and environmental sensor arrays, this autonomous robotic system is designed for precise monitoring in military, industrial or domestic applications. It has been developed to meet demanding high-precision standards. Bluetooth and Wi-Fi are both used by the robot to enable remote operation as well as transmitting data. In this paper, the system's architecture, innovative design methodology and optimized energy management strategies are thoroughly analysed. Extensive experimental testing confirms the robot's suitability for different environments, demonstrating high accuracy in detecting threats, exceptional power efficiency, and reliable autonomous navigation. The IBOT Surveillance Robot's real-time data processing, security flaws, and power requirements are the key factors that set it apart from other autonomous surveillance systems. It is scalable to modern security infrastructures and will be an intelligent asset in future with improvements such as AI-led anomaly detection, navigation via SLAM on the cloud, or cloud-integrated remote monitoring.

"When intelligence meets motion, vigilance becomes seamless, and security transforms from a mere concept into an unwavering presence."

Keywords— *surveillance Robotics, Autonomous Security Systems, Wireless Communication, Arduino Nano, ESP32-CAM, Sensor Integration, IoT in Surveillance, Real-Time Video Streaming, AI in Surveillance, SLAM Navigation, Autonomous Navigation, Machine Learning for Threat Detection, Cybersecurity in Robotics, Power Management in Robotics, Embedded Systems for Surveillance.*

I. INTRODUCTION

This project aims to design and implement a feasible intelligent robotic surveillance system that autonomously collects real-time data to improve security supervision in response to the rising need of engineers and computerized surveillance. Traditional surveillance has become inept despite being human-controlled and entail possible costly misinterpretations. Just what is attributable to this? The development of these high autonomous surveillance robots is through integration of embedded systems technology, sensor-based automation, with both autonomous and remote-controlled capabilities, and wireless communication.

An Arduino Nano microcontroller, an ESP32-CAM real-time video broadcast software, motion detection, environmental control sensors, potential threat sensors, Bluetooth and Wi-Fi control, all integrated into the same system, are implemented by this IBOT surveillance robot. Easy deployment occurs in industrial, military, and residential areas, all of which are associated with high security risks. Made of lightweight yet strong material, the robot's base allows it to skip or climb different surfaces.

Detailed design, development and deployment of IBOT Surveillance Robot is included in this paper. Details of the hardware and software are described in methodology, with experimental results proving that the robot can operate in real life. The outcomes demonstrate the efficacy of sensor integration, power efficiency, and communication reliability in surveillance capabilities. Future enhancements are discussed, with a focus on AI-based anomaly detection, cloud storage for real-time data access, and SLAM-facilitated navigation techniques. [4], [14], [22]

II. CHALLENGES

The next issue was power management, as the robot had to manage several sensors, motors, and even a camera to keep energy consumption optimal. Balancing battery life against performance was a major consideration.

This is what rough terrain and lack of light caused hurdles to environmental adaptation. Sensors required proper calibration to ensure correct detection and relieve false triggers. The same on the sensors depended on integration adjustment, to not interfere with motion sensors, gas, and fire.

This caused difficulties in the video streaming process with bandwidth and latency issues that needed to be overcome to ensure steady transmission of good quality images. [11], [8], [19]

III. TECHNICAL ADVANCEMENTS

The IBOT Surveillance Robot is equipped with several technological advancements to improve security monitoring.... The integration of Bluetooth and Wi-Fi as dual wireless communications features, which allow for both short-range and remote-control capabilities, is one of the most important developments. This guarantees flexibility in operation across diverse environments.

Real-time video streaming capability through the ESP32-CAM module is another significant advancement. Low power consumption, efficient data transmission and live surveillance feeds are all achieved with this device.

Moreover, the project incorporates various sensors such as PIR motion detector and gas/fireball sensor in addition to other environmental Sensor Integration. Asynchronous sensors are responsible for providing real-time alerts to enhance security.

The LiPo battery system was refined, and power management strategies were employed to improve power efficiency, resulting in extended operational life without excessive energy consumption.

Through the use of CAD modeling and material selection methods, mechanical and structural improvements were made to create a chassis that is both lightweight and robust, with an emphasis on improving mobility and durability in different terrains. [3], [7], [15]

IV. QUALITY METRICS

Key quality metrics were used to evaluate the operational reliability and efficiency of the IBOT Surveillance Robot. Those results were unveiled later. This was mainly focused on the precision of motion detection sensors, gas detection detectors and fire detection systems. While the PIR motion sensor was sensitive and not falsely positive, gas and flame sensors were run in simulated hazardous environments to guarantee timely and dependable notifications. The fundamental feature for the assessment of video quality streaming was the frame rate, which was subsequently considered in the context of latency and resolution. Taking advantage of the ESP32-CAM module optimization, streaming progressed smoothly in real-time, whereby clarity and reduced consuming power were worked on. POS functionalities being monitored included power efficiency through battery usage monitoring over an extended period of operation, during which advanced power management techniques were employed to sustain prolonged uptime without comprising performance. Reliability of communication was tested by examining the range and stability of its dual-mode Bluetooth and Wi-Fi system that enhances seamless remote control throughout various operation locations while also minimizing connection drop-offs. Through terrain tests, the lightweight yet sturdy chassis was combined with an optimized motor control system to enable smooth operations when crossing rough terrains. The robot was also tested under various lighting and temperature conditions to verify performance of the detected sensors without influence requiring calibration for accuracy. [6], [10], [18]

V. METHODOLOGY

A. Introduction:

The IBOT Surveillance Robot underwent a systematic process that included hardware selection, software development and system design. The initial step involved conceptualizing and analysing requirements, which established the primary goals for monitoring and identified the necessary components. They conducted a feasibility study to ascertain the most suitable combination of microcontrollers, sensors, communication modules, and power supply for operation.[2],[9],[16]

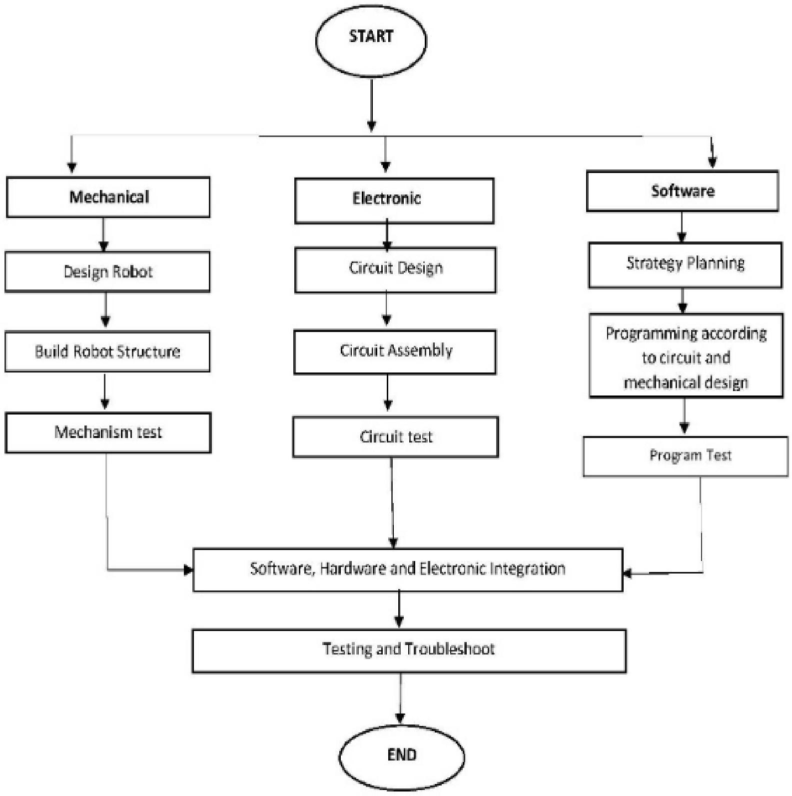

Fig.1 - Methodology

B. Circuiting:

Its integrated circuitry will provide live monitoring and communication instantaneously, as well as manage power consumption efficiently. The circuit's microcontroller is an Arduino Nano, which manages sensor inputs and door motors. The ESP32-CAM module will use solid power and data connections to cast live Streaming Video. The HC-05 Bluetooth module is available for wireless communication with the main ESP32, through which advanced remote control and exchange of data are facilitated. The Arduino interfaces with a PIR motion sensor, MQ4 gas sensor (UO2), and controls such as an RF thermometer and indicator code to facilitate real-time monitoring of environmental parameters. By controlling power to the DC motors, the L298N motor driver makes it possible for them to run smoothly with obstacle avoidance. Included with that is a relay module which would extend the control to other security features like turning on lights or sirens. Getting its power from a LiPo battery, it has regulated voltage so that power will not leak out from any components. Good grounding and noise isolation however was ensured for maximum reliability of the system against signal interference. Finalization of the circuit design was realized, making sure to propose a very low power use system with maximum operational efficiency.

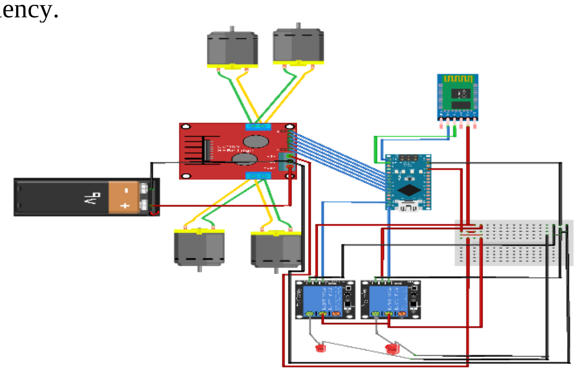

Fig.2 - Circuit for the movement of IBOT

At the time of designing the hardware and integrating it, the decision was made to use an Arduino Nano as the central processing unit because of its low power consumption and ability to process real-time data. For real-time video streaming, the ESP32–CAM module was included, and various sensors were placed in sequence: PIR for motion detection, MQ4 for gas sensing (ambient light emission), IR flame detection (high intensity low intensity) with DHT11 designed to provide full coverage. High-torque DC motors were controlled using a L298N driver, resulting in smooth operation even under rough terrain. The chassis was fabricated using CAD modeling to ensure its strength and weight.

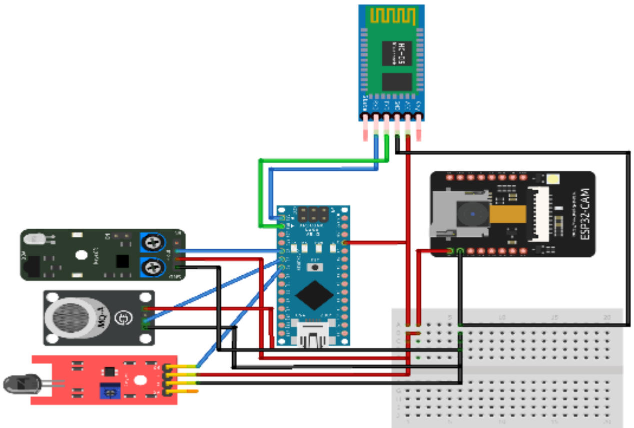

Fig.3- Circuit for the sensor's unit

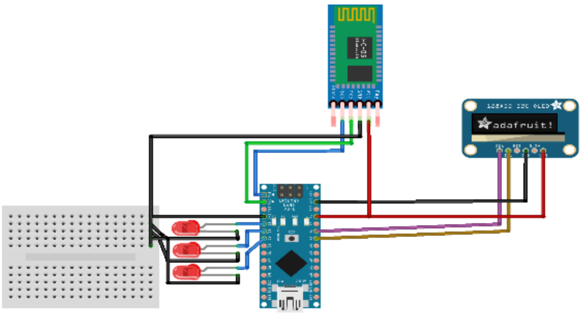

Fig.4- Circuit for the receiving unit

During the software development process, the Arduino IDE was utilized to write and enhance firmware that allows for easy access to sensor data, motor operation, and wireless communication. By means of Bluetooth and Wi-Fi protocol, it became possible to be operated remotely and thus receive data in real-time while allowing for latency optimization. A customized control interface offered ease in operating mobile apps.

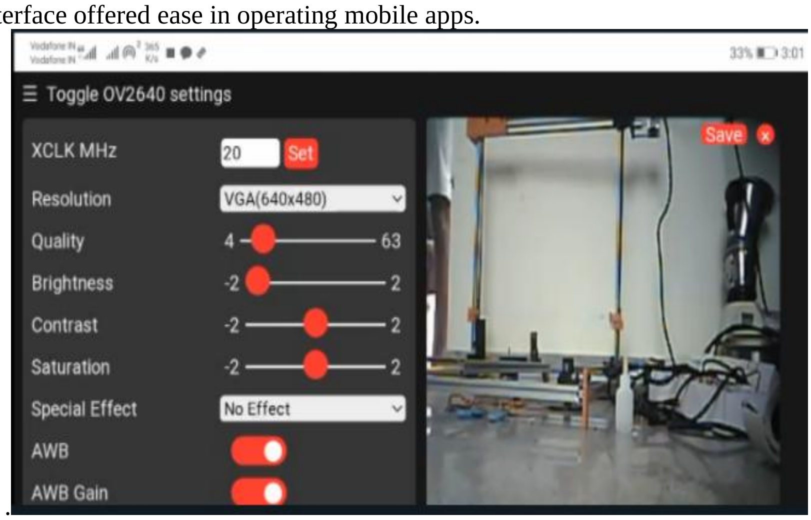

Fig.5- Software implementation

A rigorous testing and calibration process was adopted to help enhance the operational precision of the sensor and power efficiency. Besides testing for its surveillance accuracy and mobility, field tests were also carried out in order to see how stable it would be while attaining communication with other units. This iterative process guarantees the debugging and enhancement of the hardware as well as certain software bugs.

Finally, a phase of performance analysis and validation was carried out, in which the experimental data were validated against prescribed benchmarks

C. CAD design of the Ibot Surveillance:

During its design phase the IBOT Surveillance Robot was designed in CAD to ensure an optimal combination of structural orientation, component placement and mobility. The chassis, motor mounts, and sensor enclosures were modelled in SolidWorks for this purpose. Its basis structure, which considered material choice, weight distribution and stability, was the starting point of its development. A lightweight and sturdy frame was chosen for mobility without compromising-strength.

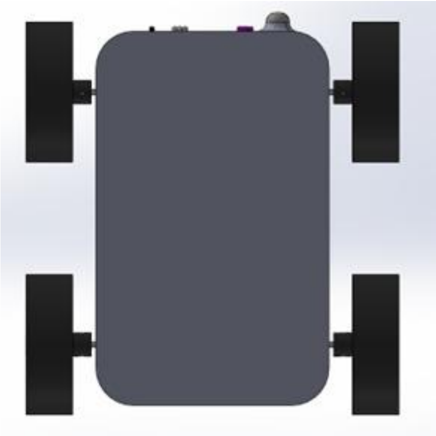

Fig.6- Top View

The slender design of the Arduino Nano, ESP32-CAM, sensor equipment, motor driver L298N, and battery pack allowed them to fit into the enclosure. Ventilators were designed to cool the installed electronics.

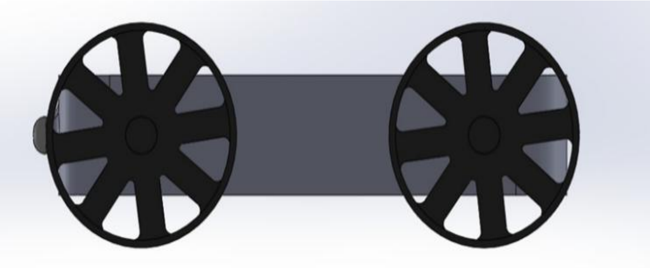

Fig.7- Side view

The motors and wheels were set such that regardless of terrain it would give optimum stability with a good weight distribution system. The sensors and cameras were positioned on brackets that guaranteed the maximum field of detection and field of view. Finally, structural integrity was evaluated with the help of 3D simulation and stress analysis in various applications.

Fig.8- Front View

The CAD designs were passed on to "workshop-ready" drawings, whereby physical assembly could be executed accurately and electronic components integrated into the circuitry. Through these CAD-based solutions, the overall efficiency, durability, and functionality of the IBOT surveillance robot were enhanced.

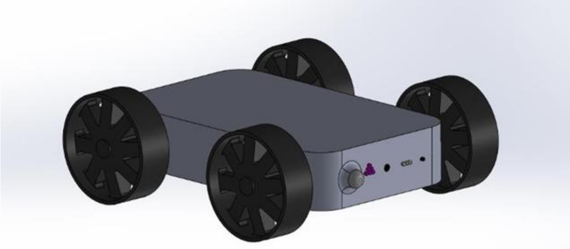

Fig.9- Full Model

VI. MECHANISM

A. Introduction:

DC motors power the IBOT Surveillance Robot's differential drive to provide it with smooth and precise movement. The motion control is controlled by an L298N motor driver that responds to user commands or autonomous navigation logic and controls speed and direction. Users can easily connect PIR motion sensors, gas detectors, flame sensors and temperature sensors to the Arduino Nano microcontroller, allowing for automatic decision making for real-time environmental monitoring. The ESP32-CAM module enables real-time video streaming by a surveillance mechanism and dual-mode Bluetooth and Wi-Fi for remote control. This arrangement and mechanism can help to develop good navigation skills, threat identification and remote data transfer, these features make a great asset for security.[5],[12],[20]

B. Working Principle:

The IBOT Surveillance Robot is a wheeled mobile robot system practicing sensor-based automation, motor-driven mobility, and wireless control for efficient surveillance. This is a locomotion mechanism with four DC motors being driven by an L298N motor driver and executes very easily clean velocity and direction. This mechanism uses differential drive for motion and makes it possible for it to slowly turn and operate over various terrains.

This is controlled by the ESP32-CAM module that is the heart and soul of the entire surveillance system, which streams live video. The camera has a large viewing angle, permitting effective monitoring of the situation at hand. Its sensor system was developed to detect threats and hazards in the surrounding environment using PIR motion sensors, gas sensors (infrared radiation), and others. The microcontroller receives the data via Arduino Nano and processes the information.

Bluetooth (HC-05 module) and Wi-Fi (ESP32 module) make dual-mode communication of the IBOT Surveillance Robot capable of short-distance control and communication. The robot can be controlled and operated by the operator according to pre-programmed logic to move around or detect threats activated by directional sensors.

Power management is not releasing energy. The device as a whole runs on a LiPo battery supplying regulated voltage to sensors motors and the communication modules. [1], [13], [21]

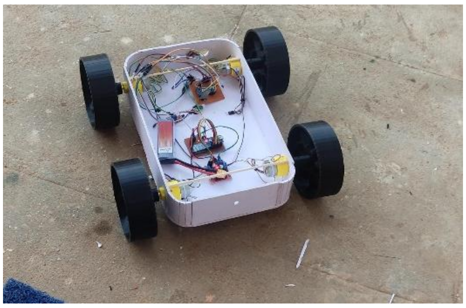

Fig.10- Working principle

Fig.11- Testing phase

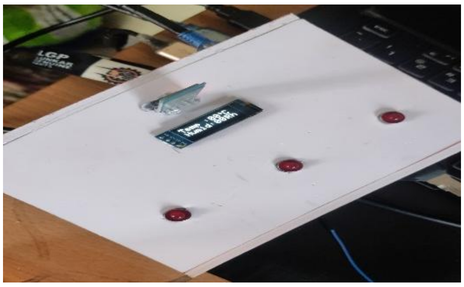

Fig.12- Temp & Humidity reading

VII. BLOCK DIAGRAM

Block Diagram Explanation:

At the centre of the IBOT control system is an Arduino microcontroller, which will receive and carry out the commands given. All demanded features are, thus, fed from a regulated power supply, capable of making sufficient, steady power available for proper working of all components. Communication will occur with the assistance of a Bluetooth module, which will transmit the necessary commands to the Arduino, giving ability for remote operation. After the commands have been transmitted, the Arduino now receives input and produces control signals which run various subsystems. Within a motor control subsystem, the system shall utilize the motor driver module, which will amplify low-power control signals from the Arduino for driving motors effectively, allowing the IBOT to conduct its movements precisely. A relay module represents an electronic switch that controls various external devices such as LED indicators. An LED has become a status indicator displaying, in real-time, the current activities of the IBOT. This structured approach promotes perfect communication, efficient motor control, and an automated response mechanism, and permits the IBOT to adjust to a huge number of application setups.

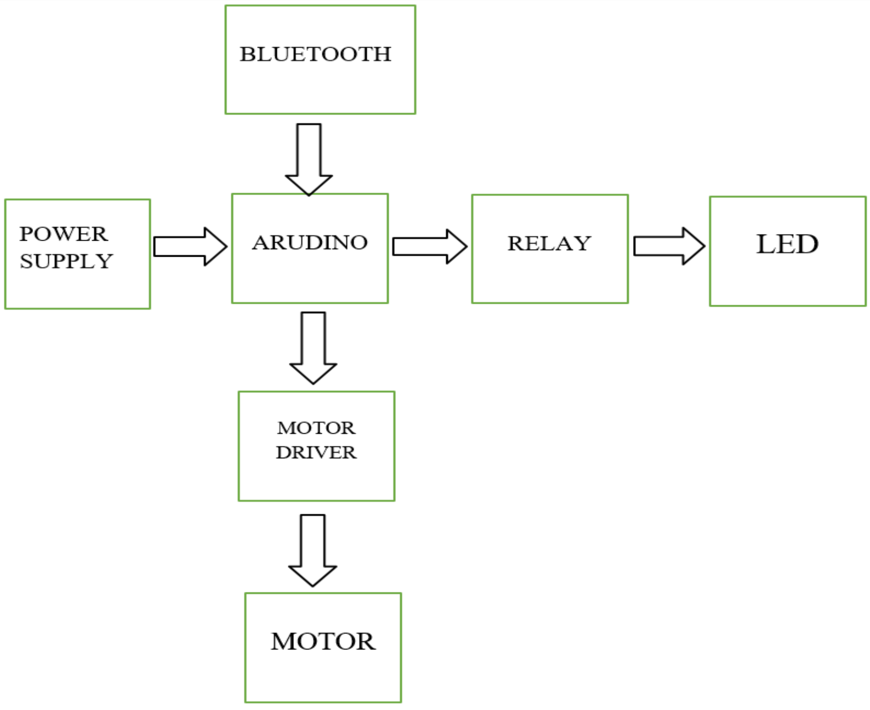

Fig.13- Block diagram of control

The data slave module of the IBOT model is the major receiver and responder of commands in the network. It is therefore made of an Arduino microcontroller that functions as the processing unit interpreting all the commands it receives through a Bluetooth module. The Bluetooth module sets up a wireless communication link that allows a master control unit to send the data remotely. The power supply is regulated so as to provide stable voltage levels for smooth operations without the interference of fluctuations in the performance. After receiving control signals via Bluetooth, the Arduino acknowledges the input and turns on the indication lamp as immediate visual feedback for the execution of commands. In this way, the organization works to guarantee an efficient wireless communication system, exact implementation of command received, and meaningful feedback, making the data slave a consequential feature in IBOT's distributed control architecture.

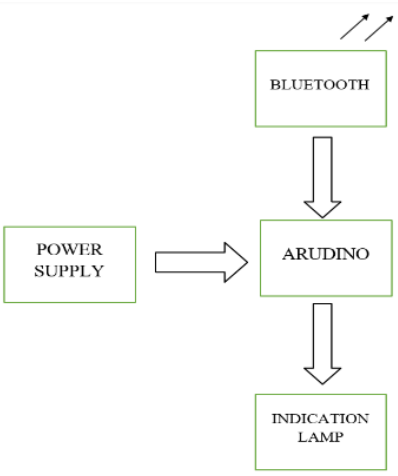

Fig.14- Block diagram of Slave data

The data master module of the IBOT system is the main control and data acquisition unit, which oversees sensor data collection and wireless transmission. The module includes an Arduino microcontroller, which acts as the central processing unit that interfaces with the sensor for acquisition of data regarding the environment or system in real time. A regulated power supply to the Arduino and sensor ensures proper operation by delivering needed voltage. As soon as the sensor gathers data of interest, it is sent to the Arduino for processing and wireless transmission through a Bluetooth module to the IBOT network. This arrangement allows data acquisition, processing, and monitoring to be done remotely so the master module can send all the necessary information for further analysis and decision-making within IBOT.

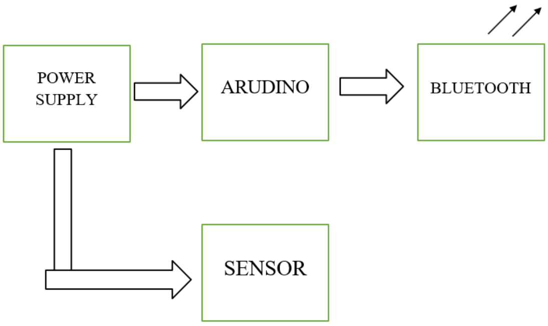

Fig.15- Block diagram of Master data

VIII.HARDWARE SPECIFICATIONS

The IBOT system is basically the combination of some hardware, built for optimally operating such an acquisition, processing, and communication system. In this case, the main processing unit is an Arduino microcontroller (could be an Uno, Nano, or Mega) built around the ATmega328P or ATmega2560 with a 16 MHz clock speed, powered with many GPIO pins for interfacing with peripherals. It is powered on 7-12V DC power source, which is regulated to 5V and 3.3V for proper operation of the device. A sensor module collects real-time data from its place, interfacing directly with the microcontroller for onboard processing. Communication is done via Bluetooth, allowing data to be sent wirelessly. In addition, an indicator lamp gives a visual indication by means of system activity. All this hardware together makes IBOT operate as an intelligent and responsive system. [17], [23], [25]

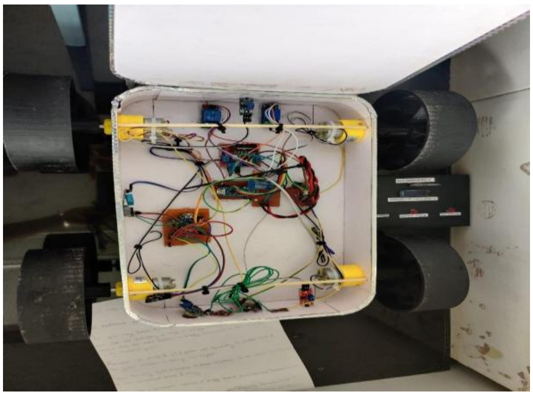

Fig.16- Hardware placement

Arduino-Nano:

The prime microcontroller unit of the IBOT is an Arduino Nano. It processes sensor data and provides commands to other devices using GPIOs. The ATmega328P microcontroller processes commands at 16 MHz, having some GPIO pins for the link to a sensor and actuator. Its small size makes it a good choice for embedded systems like IBOT, allowing real-time data processing and decision-making.

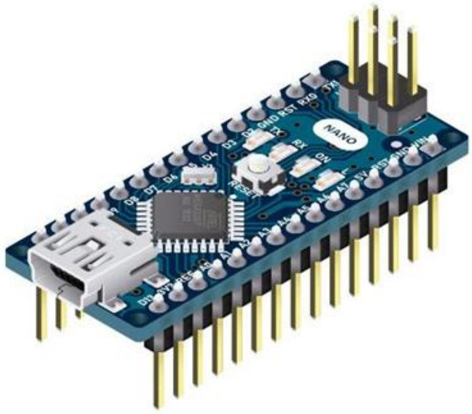

Fig.17- Arduino Nano

A. DC Gear Motors:

The movement control mechanism of IBOT uses DC geared motors to bring about precise and efficient movements. They are modules geared down to produce high torque with a slow speed that provides good mobility and navigation control for the robot. The motor's other speed and direction were controlled from the driver unit.

Fig.18- DC Gear Motor

The performance curve of IBOT gearbox reveals the relation of torque (T), speed (N), current (I), power (P), and efficiency (η). As torque increases, speed goes down, while current increases. Power increases with an increase in torque up to a peak and then decreases; efficiency works in a similar fashion but reaches its peak earlier. One should always run near the maximal power point, which, in conjunction with the mid-torque range, would ensure regaling efficiency. Running the motor at stall torque, or maximum load, is inefficient, may cause overheating, and puts individual switches at risk of injury. The result should yield a curve from the data that facilitates the optimization of speed, power, and energy efficiency within an IBOT.

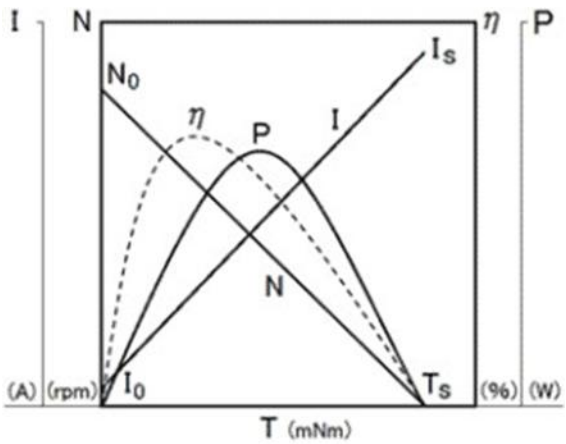

Fig.19- Performance curve

B. L298N Motor Driver Module:

The L298N is a dual H-bridge motor driver for controlling the geared DC motors used in the IBOT. Steering can be bidirectional, with speed variations under PWM signals from the Arduino. It works from 5V to 35V, thus helping motors work efficiently without heating them up.

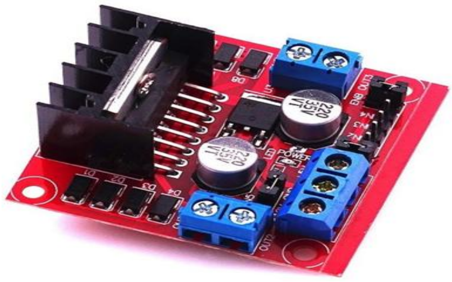

Fig.20- L298N Motor Driver Module

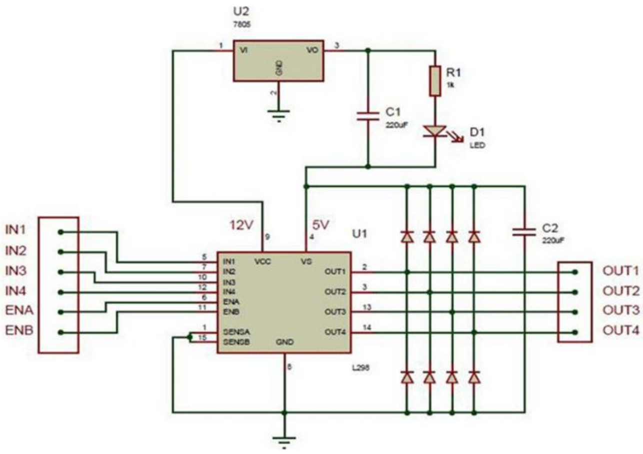

Fig.21- L298N Driver Modue layout

C. ESP32-CAM:

The ESP32-CAM Module gives IBOT the capability to take control of video materials throughout real-time conditions to monitor the environment. It comprises a 2MP OV2640 camera, Wi-Fi capability, an ESP32 microcontroller on-board, which makes it suitable for wireless visual data transmission and AI-based object detection.

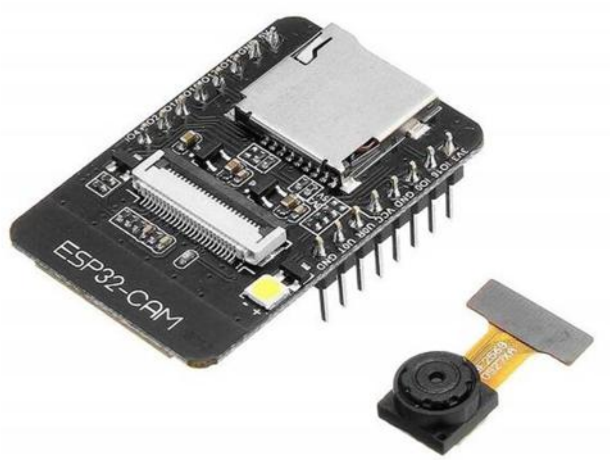

Fig.22-ESP32-CAM

D. Bluetooth module:

Bluetooth module (HC-05 or HC-06) enables a wireless connection on IBOT with other external devices such as a smartphone or a computer. It will allow remote control and monitoring through transmitting the sensor data and receiving of commands, operating at a frequency range of 2.4 GHz.

Fig.23- Bluetooth Module

E. Temperature and Humidity Sensor:

The temperature-humidity sensor-type sensor in IBOT is DHT11/MHT22 for environmental monitoring. It gives instant readings of ambient conditions that can be used in applications including climate control, fire detection or hazardous environment assessments.

Fig.24- Dc Motor.

F. Flame Sensor:

A flame sensor operates on the principle of detecting flame and relatively high heat through infrared radiation. The sensor is, therefore, incorporated into IBOT for applications in fire safety where it would trigger alarms or fire suppression mechanisms upon detection of flame.

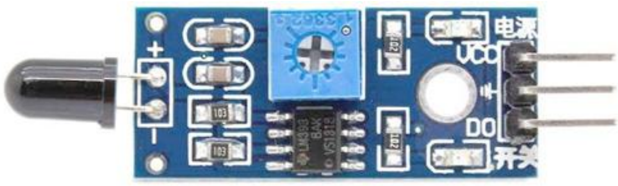

Fig.25- Flame sensor

G. MQ-4 gas sensor:

The MQ-4 gas sensor is used for the detection of methane (CH_4) and combustibles, allowing its application for leak detection for both aggregates and residential use. A selective sensing film can again respond with a change in conductivity, producing an analogue or digital output to show the results real-time.

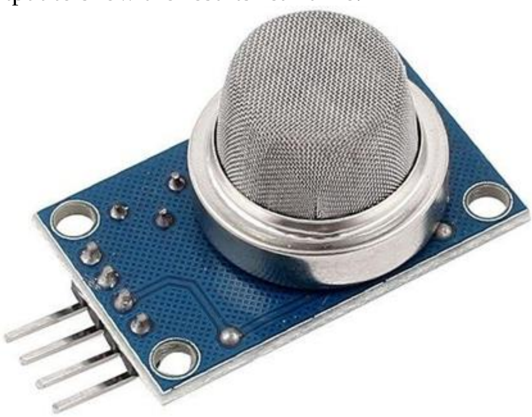

Fig.26- MQ-4 gas sensor

H. Passive Infrared (PIR) Sensor:

An infrared passive infra-red motion sensor is used for motion sensing with the unit IBOT. Infrared radiation emitted from humans or animals makes it possible for the sensor to pick them up. This becomes an important element in a security or intruder detection system and can likewise be used as an automatic lighting system.

Fig.27- PIR sensor

I. Relay Module:

The relay module allows IBOT to operate high-powered electrical devices such that lights, alarms, or actuators may be controlled. A low-voltage trigger sent from the Arduino to the relay can turn on or off a higher voltage device for automation.

Fig.28- Relay module

J. Infrared (IR) LED Light:

The IR LED light is utilized for night vision and object recognition in IBOT. When fused with the ESP32-CAM, it provides increased visibility in low-light conditions helping IBOT to perform adequately in dark environments. Furthermore, this device may be utilized in IR-based obstacle-detection systems.

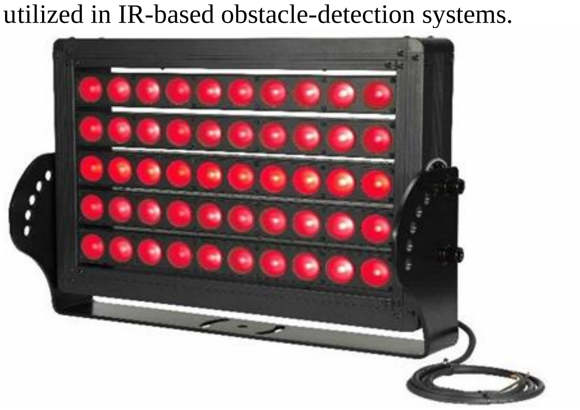

Fig.29- IR LED Light

K. Lithium-Polymer battery:

The IBOT is powered by a Lithium-Polymer battery which provides a stable power source of high-energy density. LiPo batteries are generally rated to provide from 7.4V to 12V so that they achieve a long operational duration in light and small devices, making them a perfect power source for mobile robotics

Fig.30- LIPO battery

These hardware components, therefore, permit IBOT to function as a smart, autonomous robotic system for monitoring the environment, surveillance, safety detection, and remote operation.

IX. PROJECT OVERVIEW

Fig.31- Isometric (View Front)

Fig.32- Front View

Fig.33- Isometric View (Back)

X. OUTCOME

In essence, hybrid industrial robotic system has been docked with a great variety of sensing devices and motors into one compact whole. It accomplishes blend and robust controls through Arduino Nano, ESP32-CAM and Bluetooth module making straightforward the transmission and reception of the entire system controls. Specific sensors include temperature and humidity sensors, gas and flame sensors, and motion detectors allowing real-time data logging and hazard detection. The mobility system features complete motorized control with smooth navigation based on the DC gear motors where control is executed using an L298N motor driver. Incorporating the LiPo battery handles the power supply. All in all, the IBOT is a truly stable and sufficiently versatile robotic platform for application in safety, security, and smart automation.

Fig.34-Result

XI. Conclusion

This will imply that IBOT is a working and efficient system used for real-time surveillance, hazard detection, and automation. IBOT, in addition, can navigate and respond to environmental conditions both safely and easily, making use of multiple sensors, wireless communication modules, and powering mobility systems. It does enable intelligent processing and remote surveillance through Arduino Nano and ESP32-CAM, for the field of security, safety and industry. Capable of recording temperature variations, leakage of gas, flames and human or animal motion, IBOT raises situational awareness while reducing risks. The project demonstrates an amalgamation of robotics and IoT for smart surveillance set for further advancements in autonomous security systems.

XII. References

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