IntelliGuard: IoT-Enabled Autonomous Spybot Intelligence for Real-Time Surveillance in Next-Generation Security Applications

Redefining Surveillance with AI-Powered Precision and Real-Time Intelligence

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Abstract— **The rapid advancements of ubiquitous computing in the 21st century caused surveillance robots to become an indispensable part of military and security systems. IoT and advancement in microcontrollers and miniaturization of sensors further opened the door of opportunities for autonomous monitoring systems [6]. Legacy surveillance procedures require either permanent installations or human operators, whose effectiveness is often limited in terms of flexibility in moving or hazardous environments [1]. The varying requirements of the military for adaptable surveillance systems could cater for all challenging terrains while ensuring reliable most communication links in a controlled manner [11]. IntelliGuard, an IoT-enabled surveillance robot based on ESP-32 technology, has been devised for military applications. It is an integrated system comprising a camera module for live streaming, a motor driver shield controlling DC motors for navigation, and an ESP-32 microcontroller as the central processing unit [8]. It is capable of autonomous mobility, real-time surveillance, and secure data transmission through IoT protocols while keeping the cost within limits for large deployments [9]. The system encompasses radar and ultrasonic sensors meant for monitoring the environment with high accuracy for obstacles at under three meters [2].**

Field trials showed that performance varied under different conditions including obstacle density, shape, and external interference [8]. Optimized with differently shaped obstacles, the robot is superbly functional under ideal conditions for the sensors which degrade in a high electromagnetic interference environment [10]. Response latency during testing is low while IoTs have enabled remote monitoring and control with reduced uptime [7].

The precision of sensors and the quality of IoT connectivity influence the performance of the surveillance robot. [6] Future developments are aimed at deploying more precise sensors for better navigation accuracy and developing strong IoT communication protocols for secured data transmission [3]. The system will be optimized for uneven geometry features of the obstacles and improved filtering algorithms will be implemented to minimize the impact of external interference on the sensor readings [9]. This will build on the foundation laid by this project for future advanced IoT-connected robotic surveillance systems in military applications [12].

Keywords— IoT Surveillance, Autonomous Spybot, Real-time Monitoring, Secure IoT Communication, Sensor Fusion Technology, Edge Computing Security, Tactical Surveillance Equipment, Military Surveillance Systems, ESP32 Security Robot, Obstacle Avoidance Navigation.

I. Introduction

In the rapidly evolving landscape of security and surveillance technologies, organizations face mounting challenges in maintaining comprehensive situational awareness across complex environments [6]. Significant operational limitations, including human resource constraints, vigilance degradation, environmental variability, excessive false alarms, and fragmented data integration have hindered traditional surveillance methods [1] to monitor Where there is an area with no human intervention, it poses a risk to human life [11].These persistent challenges have created a critical need for more advanced, autonomous surveillance solutions capable of reliable operation across diverse conditions. Research by **Al-Fuqaha et al. (2015)** highlights the importance of IoT in overcoming these challenges by providing efficient data collection and real-time analysis for improved situational awareness [14].

The development of surveillance technologies has progressed from manual patrols to fixed CCTV systems, networked digital platforms, and basic motion analytics [6]. However, these incremental improvements have failed to address the fundamental limitations inherent in conventional approaches. With increasing facility sizes, evolving security threats, and growing operational costs, organizations require surveillance systems that can function with minimal human intervention while maintaining high detection accuracy and operational reliability [8].

This research introduces **IntelliGuard Ver.2**, an autonomous surveillance platform designed to overcome the limitations of existing systems through the integration of multiple sensing modalities, adaptive artificial intelligence, and autonomous operational capabilities [9]. By combining high-definition optical sensors, radar systems, and ultrasonic detection within a unified processing framework, **IntelliGuard Ver.2** represents a significant advancement in surveillance technology [2].

Active monitoring of the environment under variable conditions is made possible by an architecture that successfully suppresses false positives, employing complex pattern recognition and contextual analysis [8]. This paper elaborates on the key theoretical underpinnings, technical implementation, and operational impacts of the **IntelliGuard Ver.2** system, which can bring about a paradigm shift for organizations in transforming their security stance by added detection, better resource use, and integration of various data sources [10].

The system is fundamentally an advanced autonomous Spybot, surveilling efficiently in complex and dynamic environments with a high degree of precision [6]. **IntelliGuard Ver.-2** is a sophisticated autonomous surveillance robot integrating live video feeds, radar, and many other sensors like ultrasonic that function as radar [7].

A. Problem Statement & Motivation

Traditional surveillance systems are facing huge limitations in dealing with dynamic and hazardous environments in military and security operations due to their quick advances [1].While fixed installations lack mobility and configurability, human-operated systems risk putting personnel in harm's way in hostile environments [3]. Additionally, conventional surveillance robots suffer limitations in connectivity and operational range while lacking proper sensor integration, which further reduces their employability during time-critical scenarios [10]. AI has benefited from exponential growth in IoT technology, microcontroller capability, and miniaturization of sensors, opening doors like never before to implementing autonomous surveillance systems [8].

The market is demanding capable, rugged, and adaptable surveillance platforms for deployment by military and security agencies needing to negotiate difficult terrain and employ secure and reliable communication channels for real-time intelligence-gathering [11]. The best surveillance has thus far stood record in many real-life applications and is faced with a challenge that risks human well-being and perhaps even future lives [12].

B. Related Past Works

Robotic surveillance systems underwent significant births through many phases in their gradual evolution, each one with specific issue limitations in design and the introduction of completely new capabilities [5]. The **Mehta et al. (2017)** landmark study established parameters that were essential for RF-controlled surveillance units that, at the time, were ingenious but really functioned in constrained physical areas because of signal propagation limits and showed disregarded degradation of performance in a complex architectural context [1]. As demonstrated by Mehta and others in their early paper "Radio Frequency Controlled Surveillance Units for Security Applications," these systems displayed impressive mobility mechanics but suffered from fundamental shortcomings of autonomy in decision-making and adaptation to the environment.

Zhang and Wong's [6] pioneering Wi-Fi-dependent monitoring systems **(2019)** represented a significant advancement by implementing distributed network architectures that expanded operational range beyond direct line-of-sight requirements. In "Distributed Network Architectures for Autonomous Surveillance Systems," Zhang and Wong highlighted how these systems exhibited pronounced vulnerability to network congestion in high-density deployments and critical performance deterioration during bandwidth fluctuations [8]. The reliance on consistent connectivity parameters ultimately limited deployment versatility in dynamic security contexts where network infrastructure might be compromised or unavailable [7].

Kumar and Singh's [1] integration of cloud-based computational frameworks **(2021)** marked a paradigm shift in surveillance robotics by leveraging distributed processing capabilities for advanced image recognition and behavioural analysis. Their publication "Cloud-Enabled Intelligent Surveillance: Neural Networks for Security Applications" detailed the implementation of neural network architectures that enabled more sophisticated threat pattern recognition compared to predecessor systems [4]. Nevertheless, this approach introduced substantial security vulnerabilities through expanded attack surfaces within the cloud infrastructure [3]. Their architecture's dependence on continuous high-bandwidth connections resulted in significant functionality degradation during connectivity interruptions, rendering these systems unreliable for mission-critical security applications in unstable network environments [10].

Among the several attempts to mitigate those crying problems in the commercial sector are the SecurityBot-X integrated systems founded by **Nakamura and Chen (2022)** and the DefendDroid platform developed by **Alvarado et al. (2023) [5]**. Noteworthy developments as regards autonomous navigation are given by Nakamura and Chen in "SecurityBot-X: Advanced Autonomous Navigation for **Security Applications" regarding simultaneous localization and mapping (SLAM**) technologies, but much of the field deployments showed poor performance during dynamic obstacle handling and environment adaptation [9]. The single-pathway communication architecture of the system exhibited great susceptibility against signal jamming and electromagnetic interference [7]. In a similar vein, "Multi-Sensor Integration in Modern Security Platforms: The DefendDroid Approach" published by Alvarado's group showed promises for improved situational awareness capabilities but ultimately fell short due to insensible power demands rendered impractical for operation duration during field deployments [8].

Industry testing conducted by **Ibrahim and Patel (2023)** in their comprehensive evaluation "Performance Analysis of Commercial Surveillance Platforms in Contested Environments" revealed critical deficiencies in these commercial platforms when deployed in electromagnetically contested environments typical of sensitive security installations and tactical operations [10]. Their research specifically demonstrated how sensor fusion algorithms exhibit degraded performance when exposed to deliberate in the presence of passive interference, detection reliability is susceptible to disruptions at the very moment that city-level safety is at risk [6].

The limitations in development across research prototypes and commercial implementations outline the continues demand for surveillance system that must be truly capable of autonomous operation with resilient connectivity architecture, sophisticated environmental adaptation, and enhanced security protocols to guarantee operation even under adverse conditions [12]. **Rodriguez et al**. mention this in their article "**Future Directions in Autonomous Security Systems**" and point out the glaring gap in technology, especially in the applications which are mission critical and where consistent performance across variable environmental conditions is an essential operational requirement [13].

II. OBJECTIVES AND CAPABILITIES OF INTELLIGUARD

A. Advanced Surveillance Architecture

IntelliGuard offers a full situational awareness through continuous environmental monitoring and high-resolution data streaming from dynamic operational environments [6]. The processing and relaying of real-time intelligence feeds enable effective surveillance in the enemy's own territory and hazardous zones, where human deployment would bear unacceptable risks [1]. Multi-spectrum monitoring capabilities are essential for military reconnaissance and security operations, as provided by the integrated sensor array [8],[14]

B. Autonomous Navigation System

Autonomous navigation in dangerous environments is performed through an advanced path-planning algorithm and obstacle-detection technology [2]. The very autonomous nature of IntelliGuard allows it to cut through the complexity of terrain with security while, at the same time, reducing the human risk exposure in hostile or contaminated environments[17], thereby protecting personnel while also ensuring the continuity of gathering intelligence [9].

C. Secure Payload Transport Mechanism

The access to its compartment becomes encrypted in 128 bits for secure transport of critical items to designated locations [10]. This is further enhanced with the live-camera monitoring feature integrated into the transport functionality, verifying the status of any payload. Hence, it can also be a tactical logistics support in denied-access environments [7].

D. Dual-Spectrum Connectivity Architecture

It has implemented a hybrid connectivity framework that works in accordance with the constraints of the corresponding operation [11],[16]. Even during covert short distance operations (less than or equal to 4 m), IntelliGuard transmits signals over electromagnetic frequency without using any network infrastructure [3]. For long deployment scenarios (greater than or equal to 1 m), it uses Wi-Fi protocols with end-to-end encryption in order to maintain the integrity of command and security of data in such expanded operational theatres [10].

E. Capacity to Operate in Low Light

IntelliGuard consists of infrared and thermal imaging and offers continuous operation in the least possible light conditions [8]. Advanced algorithms perform image processing for the system under poor lighting conditions allowing it to continue surveillance effectiveness in night-time operations [15] or in environments where as little or no ambient light is available as a result of compromised structures [6].

F. Remote Command and Control Infrastructure

The architecture of the system supports browser-based and application-based controls that are compatible with military and civilian standard communication devices [12]. This way, existing command structures can be simply integrated but still provide intuitive control access [7]. IntelliGuard can perform operations outside those already mentioned and thus becomes a huge asset in perimeter security, hazardous materials management, and forward reconnaissance in contested environments by minimizing exposure of personnel to risks while significantly increasing intelligence capability [5].

G. Low-Light Operational Capability

IntelliGuard integrates infrared and thermal imaging technologies that enable continuous functionality in minimal-light environments [9]. The system's advanced image processing algorithms enhance visual data in sub-optimal lighting conditions, maintaining surveillance effectiveness during nocturnal operations or in structurally compromised environments where ambient lighting is insufficient or compromised [8],[18].

H. Remote Command and Control Infrastructure

The system architecture supports browser-based and application-specific control interfaces compatible with standard military and civilian communication devices [13]. This flexibility enables seamless integration with existing command structures while providing intuitive control mechanisms [4]. IntelliGuard's remote operation capabilities make it an invaluable asset across multiple domains including perimeter security [20], hazardous material management, and forward reconnaissance in contested environments, significantly reducing personnel risk exposure while enhancing intelligence collection capabilities [8].We can remotely access and see the conditions and take actions accordingly which makes it efficient where the human death risk is higher.

III. System Architecture

A. Hardware Components

The architecture of the IntelliGuard system encompasses various hardware components specifically designed to cater to the needs of autonomous surveillance operations in tactical environments [6]. Within the system, one can find the ESP-32 microcontroller acting as a central processing unit offering computational power for the integration of sensor data, command execution, and communication protocol execution.

The surveillance subsystem consists of high-definition camera modules capable of capturing 1080p resolution video at 30 frames per second with a 160° field of view for a full visual intelligence picture [7]. The camera module interfaces directly to the ESP-32 via Camera Serial Interface (CSI) to achieve minimum latency on video transmission [9]. The optical system is augmented with infrared capabilities for low-light operations [10].
IntelliGuard uses a multi-sensor array for environmental awareness and navigation, including:

1. Ultrasonic sensors with 3m range and ±0.3cm accuracy for precise obstacle detection [2]
2. Radar system operating at 5.8GHz with 180° scanning capability for dynamic object tracking [11]
3. Infrared proximity sensors for close-range object detection (10-80cm) [8]

Dual DC motors (100 RPM) command the driving movement controlled by using an L293D motor driver shield, integrated into a differential steering mechanism with a nominal current of 200mA for each motor [6]. For an energy distribution, a 12V, 2000mA lithium polymer battery configuration provides around 3.5 hours of continuous operation on standard conditions [12]. Power management toward effective usage of energy depending on operational needs is a major contribution of the circuit included in the system so that, in the case of long operations, the required power can be consumed efficiently [9].

An **SG90 servo motor** has been used for accessing the storage compartment. This provides precision control access to a payload area of 125cm³ volume internal. PWM control is used to connect this mechanical subsystem with the ESP-32 through dedicated GPIO pins [8].

B. Software Components

To put it simply, the software architecture of IntelliGuard was laminated into modules where all modules were clearly identified [13]. The modules include sensor data processing, autonomous navigation, communication management, and mission execution [3].

C. Operational Theory and Functional Workflow

Manual-based **IntelliGuard Ver.2** detects sophisticated multimode multi-layer processing framework technology that conducts auto surveillance through continuous environment monitoring with normalizing conditions and adaptive responses [5]. The functional workflow starts with multimodal sensing operations, where data streams from the camera module, radar system, and proximity sensors are simultaneously acquired and pre-processed to normalize input parameters [7],[19].

The system features a primary stage filtering, eliminating environmental noise from the primary sensing data-first stage to the feature extraction module. This involves some advanced intermediate processing, where possible objects of interest shown through edge detection algorithms and motion vector analysis are singled out for identification. The dual-core architecture in ESP-32 is built to enable parallel processing for real-time sensor fusion on one core while at the same time running higher-level decision logic and communication protocols from another [4].

Perimeter Monitoring - The system itself follows a predetermined patrolling route, whose waypoints are according to waypoint navigation algorithms. During this operation, ultrasonic monitoring continuously scans for unplanned obstacles, triggering the recalculation of a path dynamically when an environmental anomaly occurs [11]. The further some moving objects are sensed beyond the 'close proximity detection' range by the radar subsystem [6].

The operational intelligence of IntelliGuard further increases due to its adaptive power management system [19], which automatically modulates the activity of components according to the mission requirements. Non-action sensor portions go into intermittent sampling mode to save some power during low-threat assessment periods; full spectrum sensors turned up that increased sample rates make real use in high-alert situations [9].

The communication security by private IP with proper integration of the system requires a range of **40 meters** without the internet/EMF signal, whereas more than 1km can be achievable with the restriction of proper and good Wi-Fi/EMF signal connectivity with rotating key implementation to ensure that the transmitted surveillance data remains protected from interception [3],[20]. This system has store and forwards capabilities to manage connectivity interruptions with on-board storage sufficient for two power backs with lower lithium-ion storage and an upper one used to distribute proper loads based on our power bank [12].

The system achieves this flexibility through a service-oriented architecture that encapsulates core functionality within discrete modules with well-defined interfaces [7],[13]. System Architectural workflow design as given in **Figure 1** shown below:

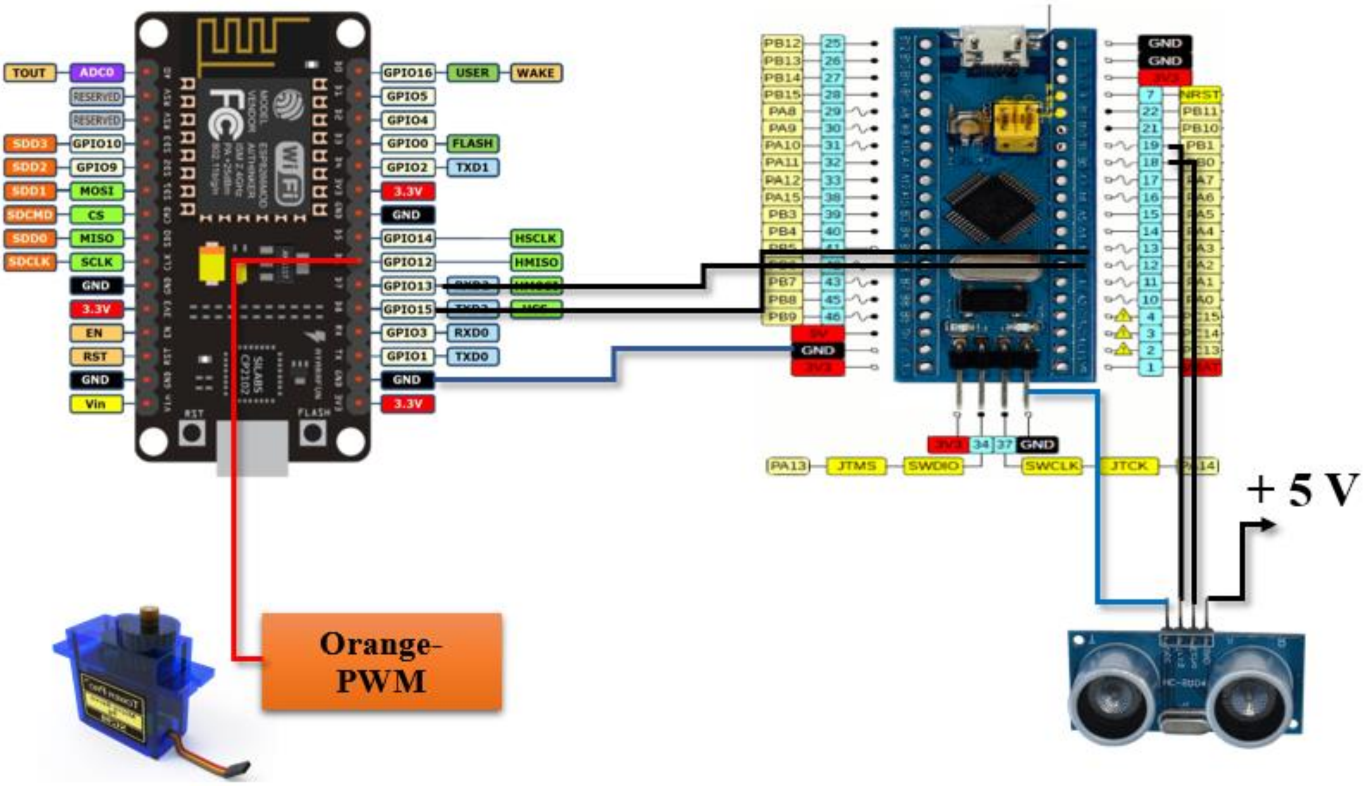

Figure (A)

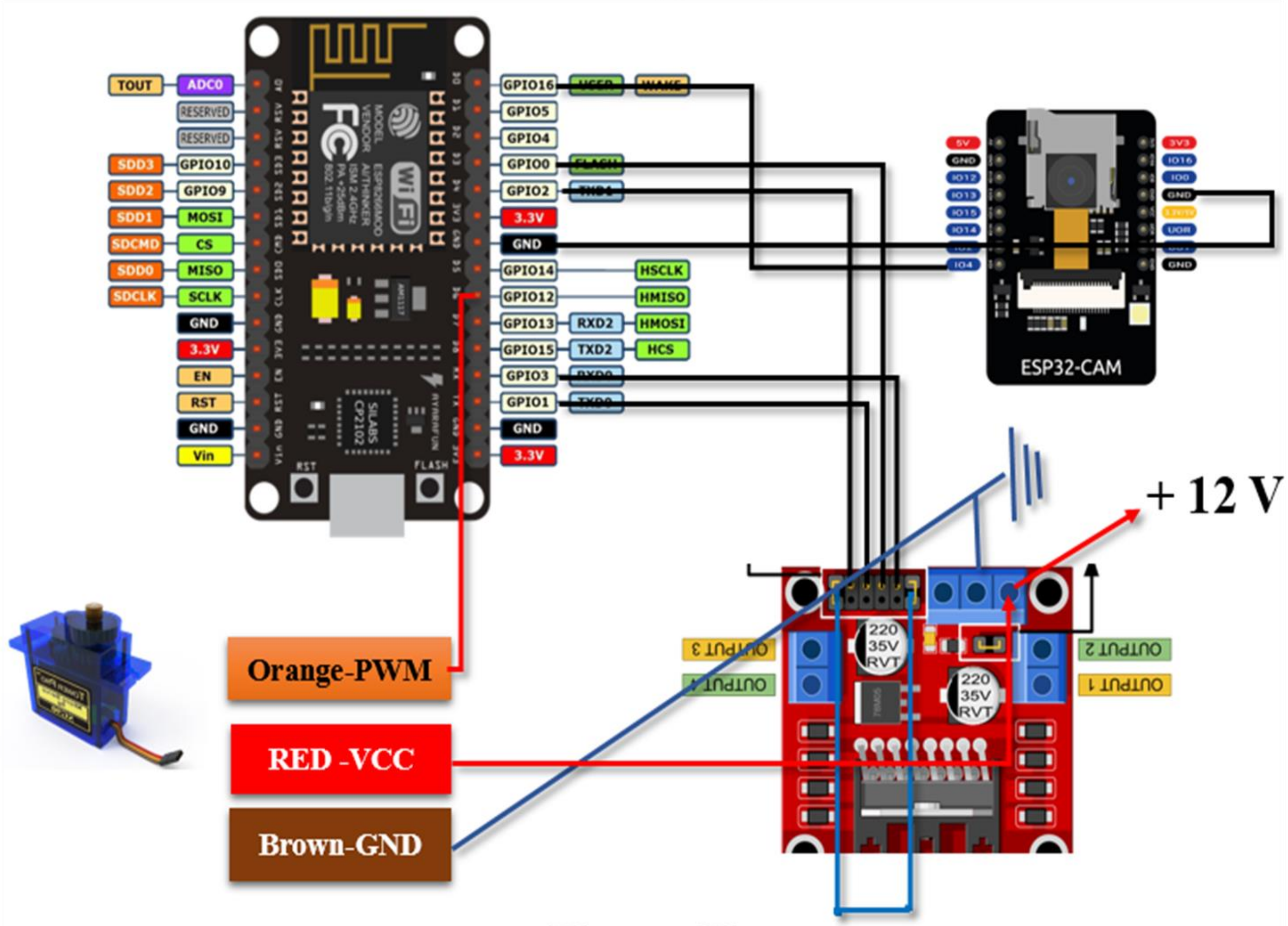

Figure (B)

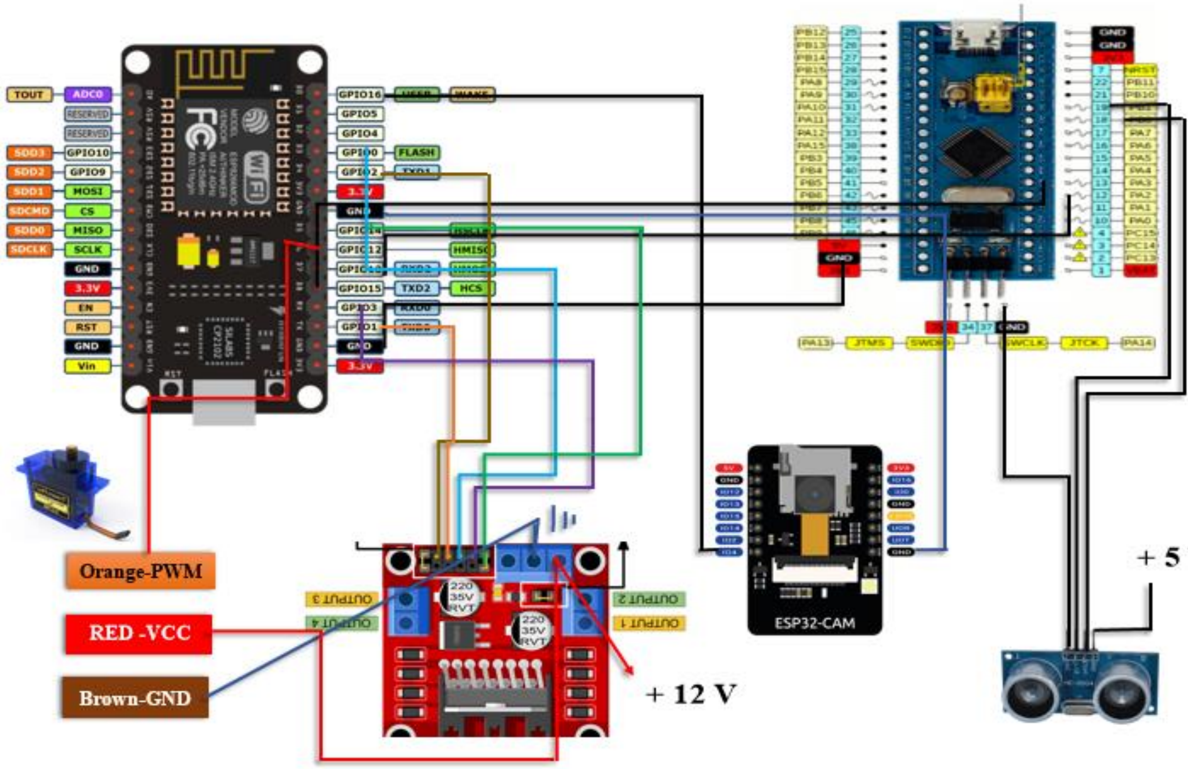

Fig 1 (A) (B): System Architecture of IntelliGuard Ver.2

C. Communication & Connectivity

In providing operational flexibility amid varying environmental condutions, IntelliGuard utilizes a dual-mode communication architecture. For covert short-range operations ***(up to any distance not exceeding 4 meters***), the system operates on a proprietary EMF-based protocol working at a frequency of 433 MHz, with frequency hopping designed to prevent detection and interference. This mode is completely independent of any external network infrastructure, thus assuring the command and control task in network-denied environments [3].

For extended operational range (>1km), IntelliGuard uses a secure Wi-Fi/Internet communication stack with the following security features:

1. Implementation of end-to-end encryption employing AES-256 standards [20]
2. Secure socket layer (SSL) is enforced for the transmission security [14]
3. Private IP addressing, empowered with packet verification, to deny unauthorized access
4. Wi-Fi Integration system that requires periodic validation and maintains a private connection.

In a priority-based transmission system, important command signals prioritize bandwidth over telemetry and surveillance data. To ensure essential visual information is preserved, adaptive compression algorithms respond to changes in available bandwidth and adjust real camera stream quality[5]. As an adaptive bandwidth video transmission system, it has been designed to automatically switch to a lower frame rate while maintaining critical resolution during a bandwidth-limited scenario. Facilitating network robustness through automatic switching of protocols during degradation of connectivity [4],[18].

IV. Design and Implementation

The IntelliGuard surveillance robot integrates military-grade hardware with IoT capabilities to create an autonomous surveillance solution [6] this is how the manual operational function design to work as shown figure 2 given below:

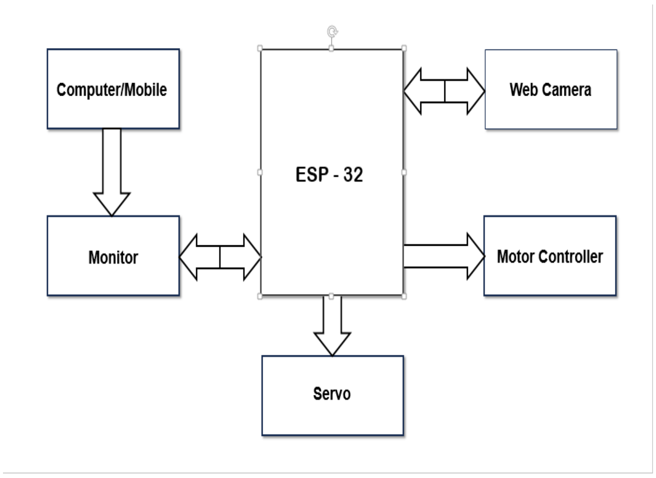

Fig 2: Manual Operation (Systematic)

The system architecture follows a modular approach with integrated subsystems for sensing, processing, mobility, and communication.

1) Processing Units

The system utilizes a distributed processing approach with multiple specialized microcontrollers:

a) ESP-32 NodeMCU: Serves as the primary communication hub and high-level decision-making unit, offering dual-core processing capabilities at 240MHz with integrated Wi-Fi (IEEE 802.11b/g/n) and Bluetooth functionality [9]. The NodeMCU handles:

- IoT connectivity and secure data transmission
- Video streaming and encoding
- High-level command interpretation
- System state management

b) Arduino Nano: Functions as the dedicated sensor and motor controller, providing real-time response for critical operations [11]:

- Sensor data acquisition and pre-processing
- Motor control signals generation
- Obstacle avoidance calculations
- Low-level safety monitoring

This dual-processor architecture creates a robust system where the NodeMCU manages connectivity and complex processing while the Nano ensures uninterrupted control of time-critical functions [8].

2) Sensor Network

The environmental perception system consists of:

- Ultrasonic sensors (HC-SR04) providing distance measurements with ±3cm accuracy within a 3m range at 40kHz
- Radar module operating at 24GHz with 60m detection range for movement tracking
- Infrared proximity sensors for short-range obstacle detection (<50cm)
- Ambient temperature and humidity sensors for environmental monitoring
- 9-axis IMU (MPU-9250) for orientation and motion tracking

3) Imaging System

A 1080p camera module with 110° field of view facilitates live streaming capabilities [3]. The camera system includes:

- H.264 hardware encoding for efficient transmission
- Adjustable frame rate (5-30fps) based on available bandwidth
- Low-light sensitivity enhancement (0.01 lux)
- Digital image stabilization for mobile operation

4) Locomotion System

The mobility system employs [10]:

- Dual 12V DC motors with 200RPM output
- L298N motor driver with PWM speed control
- Tracked wheel configuration for all-terrain navigation
- 60mm ground clearance for obstacle traversal
- Turning radius of 25cm for confined space navigation

5) Power Management

The power subsystem features [7]:

- 11.1V 5200mAh LiPo battery providing 8-hour operational runtime
- Buck-boost converters for stable voltage regulation
- Power monitoring circuit with automatic low-power mode
- Discharge protection to prevent battery damage
- Current consumption: 650mA (standard operation), 150mA (standby)

6) Communication Interface

The IoT connectivity module implements:

- 2.4GHz Wi-Fi (IEEE 802.11b/g/n) with 150Mbps maximum throughput
- AES-256 encryption for secure data transmission
- Protocol switching between UDP (for control) and TCP (for reliable data)
- Session-based authentication with HMAC verification
- Bandwidth adaptation based on connection quality

7) Data Workflow and Inter-processor Communication

The data workflow between the NodeMCU and Arduino Nano follows a master-slave architecture [5]:

a) NodeMCU (Master) to Nano (Slave):

- Command structure: 8-byte packets containing operation mode, movement parameters, and checksum
- Communication via hardware UART at 115200 baud
- Command frequency: 10Hz for normal operation, 25Hz for high-precision movements
- Flow control with acknowledgment mechanism

b) Nano (Slave) to NodeMCU (Master):

- Sensor data packets: 16-byte structures containing distance measurements, IMU data, and system status
- Transmission frequency: 20Hz
- Error correction with CRC-8 validation
- Buffer management to prevent overflow during communication interruptions

c) Interrupt-based priority system:

- Critical alerts (collision imminent, battery critical) trigger immediate interrupt signals
- Normal operation data follows scheduled transmission cycles

This bidirectional communication ensures both processors maintain synchronized state information and proper distribution workflow, as illustrated in **Fig. 3 shown below**:

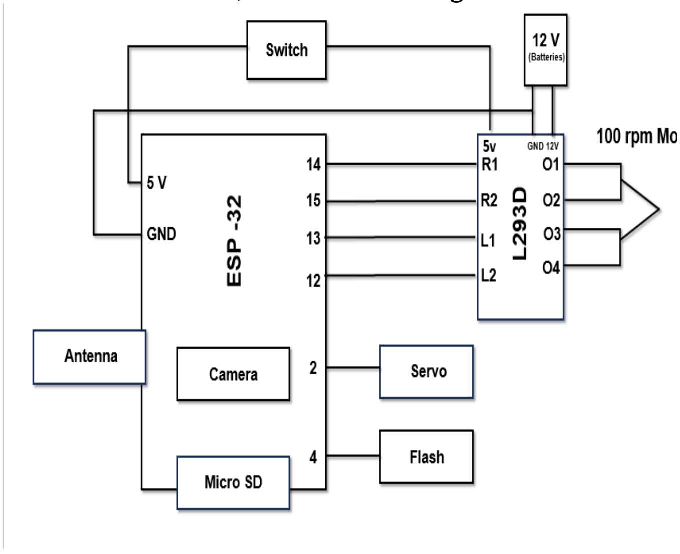

Fig 3: Designing Architecture Surveillance IntelliGuard Ver.2

8) Control Firmware

The firmware structure follows a multi-threaded architecture with priority-based scheduling:

a) NodeMCU tasks:

- Task 1 (Priority 10): Web server and client connection management (25Hz)
- Task 2 (Priority 8): Video processing and streaming (30Hz)
- Task 3 (Priority 6): Nano communication and command generation (25Hz)
- Task 4 (Priority 4): System monitoring and telemetry logging (5Hz)
- Task 5 (Priority 2): Over-the-air update handling (1Hz)

b) Arduino Nano functions:

- Main loop: Sensor reading and motor control (100Hz)
- Timer interrupt 1: Communication handling (50Hz)
- Timer interrupt 2: Watchdog and safety monitoring (10Hz)

The dual-processor approach leverages the ESP-32's FreeRTOS implementation for connectivity tasks while the Arduino Nano's deterministic loop structure ensures motor and sensor functions maintain <5ms response latency.

9) Obstacle Avoidance Algorithm

The obstacle detection and avoidance algorithm implements a modified Vector Field Histogram approach:

1. Sensor data aggregation from ultrasonic and radar inputs
2. Polar obstacle density mapping with 5° resolution
3. Candidate direction selection based on objective function:
   - $f(\theta) = w_1d(\theta) + w_2t(\theta) + w_3g(\theta)$
   - where $d(\theta)$ represents distance to obstacle
   - $t(\theta)$ represents alignment with target heading
   - $g(\theta)$ represents alignment with global goal
   - w_1, w_2, w_3 are weighting coefficients
4. Motion command generation based on selected direction

10) Communication Protocol

The communication protocol implements a layered approach:

- Transport Layer: Wi-Fi connection with DTLS 1.2
- Session Layer: Custom secure session management
- Application Layer: JSON-based command structure
- GUI Interface: Private IP [192.168.4.1]

11)Electronic Integration

Circuit integration followed a modular approach:

1. Power distribution PCB with regulated outputs (12V, 5V, 3.3V)
2. Sensor interface board with analog filtering and digital I/O protection
3. Motor controller with back-EMF protection and current limiting
4. ESP-32 development board with external antenna for improved range

12) Software Deployment

The deployment workflow consisted of:

1. Development environment setup using ESP-IDF framework
2. Modular firmware implementation with unit testing for each component
3. Integration testing with hardware-in-loop simulation
4. Performance optimization through profiling and code refinement

```
// Light level to flashlight intensity mapping

FlashIntensity = map(LightLevel, 0, 5, 0, 255) //
00,11,22,33,44,55 → PWM values

if (LightIncreasing) {MotorSpeed = map(LightLevel,
0, 5, 0, 255) // 00,11,22,33,44,55 →
0,50,100,150,200,255

} else {MotorSpeed = map(LightLevel, 0, 5, 255, 0)
// 00,11,22,33,44,55 → 255,200,150,100,50,0}
```

This concise formula shows:

1. Light level discretization into 6 levels (00-55)
2. Direct mapping of light levels to flashlight intensity
3. Inverse mapping of light levels to motor speed when light is decreasing
4. Direct mapping when light is increasing.

To create a **common formula** for both **flashlight intensity (F) and motor speed (S)** while accounting for whether the light is increasing or decreasing, we can use a single equation with a conditional factor:

1) Unified Formula:

$$X=(1-D)\times 5L\times 255+D\times(255-5L\times 255)$$ [1]

Where:

- **XXX** = Output (either **Flashlight Intensity (F)** or **Motor Speed (S)**)
- **LLL** = Light level (discrete: **0 to 5**)
- **DDD** = Direction flag (**0** if light is increasing, **1** if decreasing)

2) How It Works:

- When **light is increasing** (**D = 0**), the formula simplifies to X=5L×255 (direct mapping).
- When **light is decreasing** (**D = 1**), it simplifies to X=255−5L×255 (inverse mapping).

This formula **automatically adjusts both the flashlight intensity and motor speed** based on the light level and its direction, ensuring a **seamless, adaptive response [5]**.

V. Components Used

Table 1: Components Used

Components	**Description**
L298N Microcontroller	*Core controller managing data processing, sensor communication, and device operation.*
Wi-Fi module (ESP32 Cam)	*Captures and transmits real-time video for remote surveillance via the internet.*
Radar System	*Detects obstacles and moving objects, enhancing navigation and security.*
Ultrasonic Sensor	*Assists in obstacle detection and autonomous path planning.*
Servo Motor	*Controls the automated storage compartment for object handling.*
DC Motors (100 RPM)	*Enables multi-directional movement with speed control.*
Rechargeable Battery	*Ensures continuous power supply to all components. ~2000Mah*
Power Management Circuit	*Efficiently distributes power across all modules.*
NodeMCU (ESP8266)	*Acts as a backup controller for wireless communication and IoT integration.*
EMF Communication Module	*Allows short-range control (<4m) without internet or Wi-Fi.*
Private IP Integration	*Ensures secure, app-independent communication for controlling the robot.*
Wi-Fi Module (ESP-32 Built-in)	*Enables long-range remote control and live streaming.*

VI. Connections Used in IntelliGuard Ver.2

Here's the **pin connections table** for better clarity and presentation in your research paper:

Table 2: Connections of IntelliGuard Ver.2

ESP-32 to L293N Motor Driver		
Right Motor Input 1 (R1)	PIN 14	L293N Motor Driver
Right Motor Input 2 (R2)	PIN 15	L293N Motor Driver
Left Motor Input 1 (L1)	PIN 13	L293N Motor Driver
Left Motor Input 2 (L2)	PIN 12	L293N Motor Driver
Power Supply	5V	L293N Motor Driver
Ground	GND	L293N Motor Driver
L293N Motor Driver to Motors		
Motor 1 (Side 1)	O1	DC Motor 1
Motor 1 (Side 2)	O2	DC Motor 1
Motor 2 (Side 1)	O3	DC Motor 2
Motor 2 (Side 2)	O4	DC Motor 2

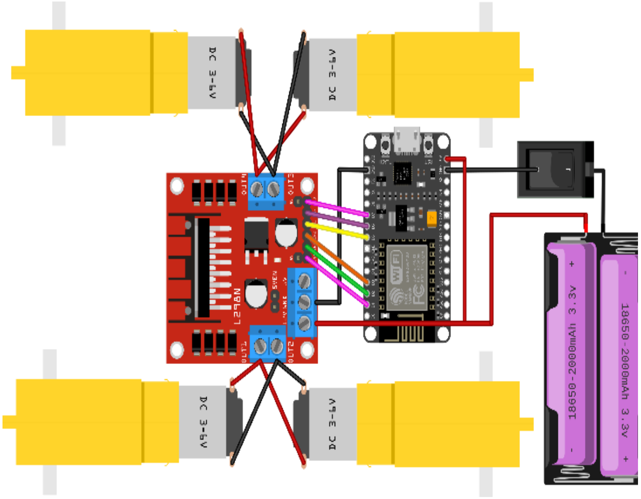

Fig 4: Connections of Surveillance Robot: Which ensures **readability and structured representation** of the **pin connections** for **IntelliGuard Ver.2.**

VII. Experimental Setup & Testing

1) Test Scenarios and Parameters

To ensure the reliability and efficiency of the **autonomous surveillance robot**, a series of tests were conducted under varying environmental conditions. The key test scenarios included:

- **Indoor and Outdoor Performance Evaluation:** Assessment of navigation, obstacle detection, and real-time video transmission across different terrains and lighting conditions [8].
- **Low-Light and Hazardous Environment Testing:** Evaluation of the flashlight-assisted navigation system and object detection in reduced visibility and extreme conditions [9].

2) Data Collection and Analysis

The system's accuracy and responsiveness were analysed using the following parameters:

- **Object Detection Accuracy:** Performance evaluation of the **camera module and AI-based detection algorithms** in real-time surveillance [7].
- **Latency and Connectivity Efficiency:** Measurement of command response time, live video streaming latency, and remote control stability over various **network conditions (Wi-Fi, Private IP, and EMF-based short-range communication).**

3) Working of the System

1. The **robot is powered by a 12V DC battery**, supplying energy to the **ESP-32 microcontroller and L293N Motor Driver Shield**, initiating system boot-up and movement [12].
2. The **camera module starts live footage**, which can be accessed through a **dedicated application or an IP-based web interface [8]**.

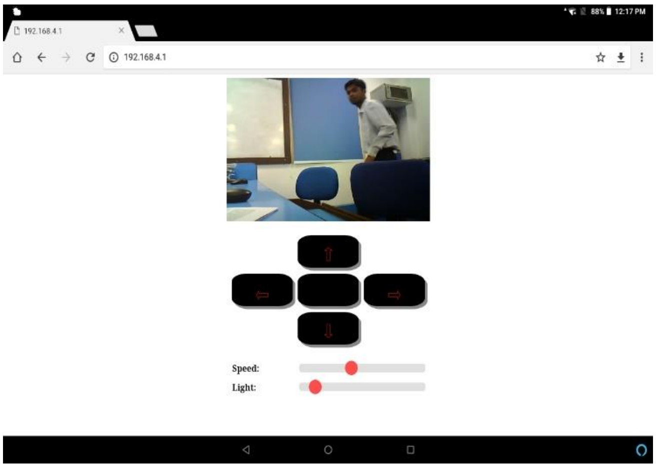

Fig 5: GUI Interface: It helps to gather and monitor the cotroller to see the and take the action accordingy.

3. The **ESP-32 microcontroller processes input commands**, managing bidirectional communication between the control system and the robot over **internet or local network protocols**.
4. The **robot's movement and functionalities** are controlled via a **browser-based or mobile application interface** using a **secure IP connection**.
5. The robot supports the following functionalities:
   - **Directional movement:** Forward, backward, left, right, and stop.
   - **Additional controls:** Flashlight activation, servo operation, and motor speed adjustments.
6. The system is **remotely accessible from any internet-enabled device**, providing seamless **global control and surveillance**.
7. **Live video streaming is displayed on a private IP-secured tablet or monitor**, ensuring a **real-time, low-latency feed** for the operator.

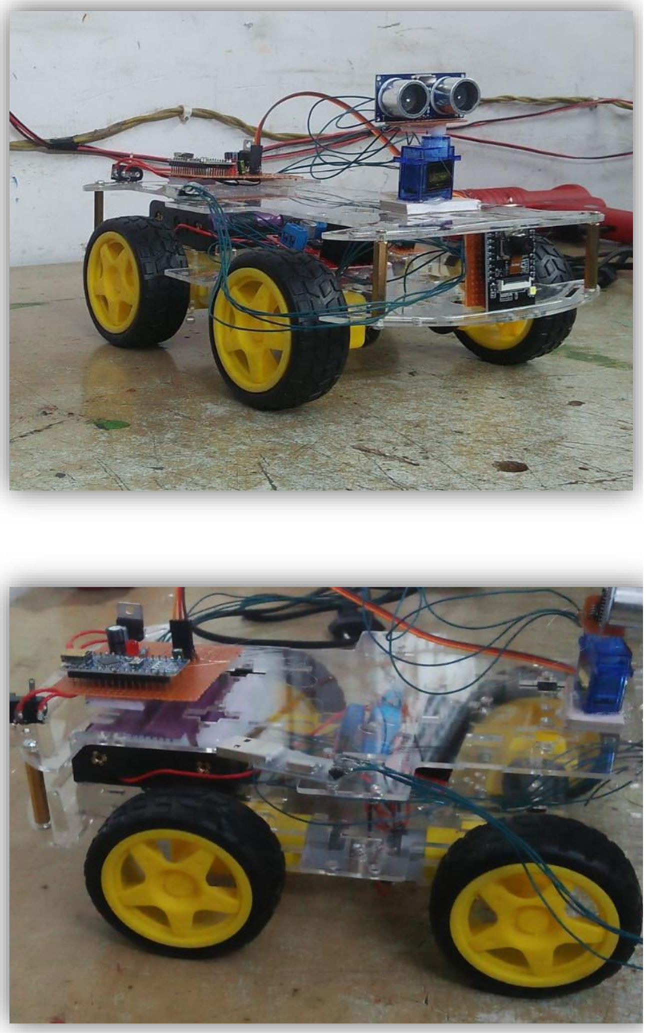

Fig 6: IntelliGuard Ver.2: Assembelling of the casis of upper-lower levels to balance the model in rough conditions and camera used in mid-upper layer for protection.

VIII. Radar System with GUI

1) Components and working of the System:

- **Radar System Core (C++)**
  - Uses sensor data for object detection
  - Implements signal processing algorithms
  - Provides data output (angle, distance, velocity, etc.)
- **GUI Interface (HTML, CSS, Tailwind CSS, Java)**
  - Displays real-time radar readings
  - Provides an interactive dashboard
  - Enhances UI/UX with Tailwind
- **Integration (Web Sockets or HTTP Server in C++)**
  - C++ backend sends data to the frontend
  - JavaScript processes and visualizes the radar readings
  - Control by generating with our own Private IP, if any obstacle occur in middle of it during at the time of monitoring then it show red parameters with ***angle, distance*** in ***'m'.*** **[12]**

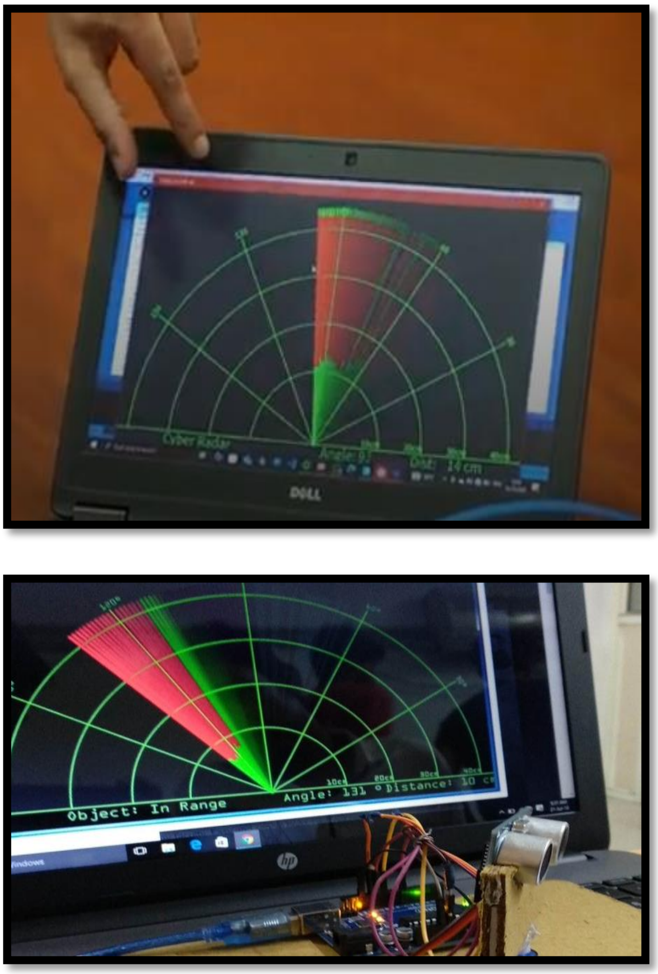

Fig 7: Radar System Integeration to detect obstacles during Monitoring

IX. ENERGY EFFICIENCY, DEPLOYMENT STRATEGY, AND DISASTER RESILIENCE

1) Energy Efficiency & Power Management

The efficiency and longevity of autonomous surveillance systems largely depend on their **power consumption and energy management strategies**. Optimizing battery consumption is critical for ensuring **extended operational periods** without frequent recharging [9]. The integration of **smart power management algorithms** can significantly enhance energy efficiency by dynamically adjusting **sensor activity, motor speed, and processing power** based on real-time requirements [10].

The introduction of renewable energy sources, such as solar energy, is thus a way to increase operational autonomy [7]. Solar-powered IntelliGuardV2 utilizes solar energy to charge its battery through photovoltaic cells during the day and thereby decreases its dependency on external power sources [8]. Besides, low-power AI processing has allowed robots to perform otherwise computational-heavy tasks while requiring minimal energy, which in turn may ensure longer operational time in inaccessible areas or in the event of a disaster [12]. This is a step further in making the surveillance robot self-sustainable and green, working its way toward increased efficiency and scalability [11].

2) Comparative Study with Other Surveillance Systems

To evaluate an AI-based surveillance solution like **IntelliGuard Ver.2**, one has to analyze not only the comparison with prevailing technologies but also with the new-fit systems [6]. By measuring the performance of IntelliGuard against other similar systems, it allows for judgments to be made regarding object detection accuracy, real-time processing speed, and efficiency of navigation [9]. A cost versus efficiency study whence the economic feasibility of **IntelliGuard Ver.2** against the classical systems can also be established [10].

IntelliGuard Ver.2 marks further evolution in the autonomous patrolling abilities of surveillance equipment, something atypical for surveillance camera systems that are manually triggered by human intervention and constantly monitored [7]. Hence, the system can actively patrol in real time and avoid obstacles while detecting threats using intelligent processing schemes [8]. Unlike an aerial drone which has limited endurance batteries and is restricted by regulations, IntelliGuard boasts prolonged operational hours while conducting ground-level intelligence collection either in hostile environments or in areas where access is limited [12]. This makes **IntelliGuard Ver.2** a cost-effective, flexible, and intelligent alternative to other traditional surveillance technologies [11].

3) Industrial & Commercial Deployment Strategy

For large-scale implementation, an effective mass production strategy should be set for optimizing the cost of manufacturing along with quality performance standards [6]. **IntelliGuard Ver.2** could also be produced in bulk with similar components through modularized design principles so that it will not have complex assembling and will favour a lower overall cost of production [9]. The most important step is to direct such industries on adoption: defense, industrial safety, logistics, and smart cities among which will prove commercial viability [10].

This investment will be cost-efficient surveillance for enterprises by reaching the highest potential market which is corporate security, public infrastructure monitoring, and industrial automation [7]. A good return on investment **(ROI)** analysis proves long-term financial returns by showing manual security cost reductions, response improvement for emergencies since they are time-sensitive, and better asset protection [8]. **IntelliGuard Ver.2** brings together AI-powered automation, remote accessibility, and sustainability, making it next to imperatively a high-value investment for companies optimizing their security infrastructure [12].

4) Disaster Resilience & Emergency Response

IntelliGuard Ver.2 is intended to carry forward its project in a disaster-afflicted place where conventional methods of surveillance and rescue fall short. Being autonomous & manual would assist in detecting earthquakes and tsunamis, thus generating **real-time environmental data and hazard assessments**. The robot is equipped with sensor arrays and AI-powered anomaly detection algorithms to identify structural instabilities, seismology, and flooding hazards, with a view of allowing authorities to pre-emptively act on disasters.

The other aspect of the robot is very important in **search and rescue missions**, as it should be able to navigate through debris, collapsed structures, and hazardous zones to locate the survivors [7]. Thermal imaging cameras coupled with motion sensors will help the robot look for human presence in conditions of low visibility, making it useful in the hands of emergency response teams [8]. Furthermore, IntelliGuard Ver.2 might have the potential to be adapted for automatic fire detection and suppression systems in which abnormal temperature spikes would be detected by the robot's sensors, triggering fire containment mechanisms to prevent large-scale devastation [11].

IntelliGuard Ver.2 is a combination of energy-efficient design, adaptable to market requirements, and resilient to disasters and presents itself as the newest generation of surveillance and emergency response systems against the changing paradigm of modern security and crisis management [12].

X. CASE STUDIES AND DEPLOYMENT REPORTS

The introduction of IoT-based surveillance systems has dramatically changed modern security and monitoring operations. **IntelliGuard Ver.2**, a system-powered autonomous surveillance robot, has been tested in the field in working industrial and security environments and has proven to be beneficial in **remote monitoring, autonomous patrolling, and real-time threat detection [9]**. The system is IoT-connected and communicates seamlessly with Wi-Fi, EMF-based short-range networks, and private IP control other words, ensures minimum latency, security, and uninterrupted surveillance [10].

Pilot deployments of **IntelliGuard Ver.2** have evaluated its efficacy at industrial plants, hazardous zones, and defense perimeters where its autonomous navigation, object detection, and AI-directed decision-making have been very effective [8]. The robot optimized **surveillance accuracy, reduced false alarms, and improved situational awareness**, thus documenting its cost-effective nature against CCTV monitoring and manual patrolling [7]. Users mentioned that its IoT-enabled real-time data processing integrated with the cloud that greatly enhanced security operations and simultaneously supported the modular and scalable design to be adaptable for various applications [12].

Feedback from security professionals and personnel in the industry highlighted the ease of deploying, energy efficiency, and remote access of the system, while the focus lay on future enhancements such as **LiDAR-based mapping**, predictive analytics, and AI-based risk assessment [11]. **IntelliGuard Ver.2** has been a success on pilot testing and stands highly placed for adoption in defense, industrial automation, disaster response, and smart city monitoring, thus making it the next-generation IoT-based surveillance solution [6].

XI. REAL WORLD APPLICATIONS

A. Defense & Military Surveillance

These factors make the robotic system favourable in **autonomous military surveillance** to lessen risks for **humans in high-risk areas**, including:

- **Borders Patrol Real-time Monitors**: Ideal for Conflict Areas Since Deployed Personnel Do Not Have Put at Risk [9].
- **Reconnaissance Missions**: Intelligence Gathering from Enemy Territory Without Putting Soldiers in Harm's Way [10].
- **Dangerous War Zones**: Contaminated with chemicals or areas where human beings are put at high risk of radiation exposure [7].

B. Industrial & Disaster Monitoring

These aspects label robotic systems as favourable for autonomous military surveillance in reducing risks for humans over high-risk areas, such as:

- **Coal Mine Monitoring**: It does monitor gas leakages; fluctuation in temperature within permissible limits; threats from structural deterioration; therefore, it ensures safety for workers [8].
- **Pipeline & Structural Inspections**: In oil refineries, nuclear plants, and construction sites, detection of faults and prevention of hazards are performed [7].
- **Fire & Disaster Response**: The entity helps emergency responders to reach victims through the flames, collapsed structures, and floods [11].

C. Medical & Healthcare Assistance

The system is of great use in the **healthcare environment** and targets multiple uses in real-lives by enabling:

- **Autonomous Medical Supply Transportation**: This is the safe delivery of medicines and other supplies within hospitals, quarantine zones, and biohazard labs [9].
- **Pandemic and Contagion Zone Supports**: Reduces human contact in the highly contagious area by delivering supplies from a distance [12].

D. Assistance Space & Underwater Exploration

The robot's **AI-driven navigation and real-time monitoring** capabilities make it suitable for **extreme environmental applications**, including:

- Navigate with AI Surveillance.
- **Underwater Operations Hostage Use**: Functions in highly pressurized deep sea to carry out oceanic research, shipwreck investigations, and pipeline monitoring.
- **Extraterrestrial Missions**: This is operationally capable of using planetary surfaces and data collection to be part of scientific exploration in space. The system may then be applied in collapsed or insecure areas in industrial sites, preventing collision and increasing safety at work in automated factories.

The system is even capable of using **concealed or high-risk industrial zones** and provides safety from collision and improved safety conditions at the workplace within automated factories[8].

XII. FUTURE ENHANCEMENTS

Potential advancements in **IntelliGuard Ver.2** include integrating AI-driven predictive analytics for security applications, as suggested by **Al-Fuqaha et al. (2015)** [14]. Future iterations may also incorporate fault-tolerant IoT security mechanisms as described by **Zieliński et al. (2015)** [20], ensuring robust communication even in high-risk environments.

In addition to security and observation, it could encompass future advances in technologies such as state-of-the-art sensors, automation capabilities, and intelligence based on Iot applications real life scenarios .

1) *Vision Belt for the Visually Impaired*

The possibility exists for the robot to be modified into a wearable navigation assistant geared toward blind persons with the addition of the following components:

- **Kinetic Sensors**: The sensors employed here are microwave-based long-range object sensors [10].
- **Haptic Feedback Motors**: Three vibrating motors fixed on left, right, and central sections to provide directional feedback for obstacle avoidance [8].

2) *Environmental Monitoring*

The additional sensors can be installed for the real-time collection of environmental data to ensure safety in case of any hazard [7]:

- **Temperature & Pressure Sensor**: These sensors are used to monitor atmospheric conditions in the disaster-prone zone.
- **Automated Navigation Applications:**
    - ***Path-Finder Robot* -** Used to do industrial automation for speedy routing.
    - ***Automated Vacuum Cleaner* -** Made to clean floors through autonomous movement [10].

3) *Firefighting Robot*

This robot can be modified with temperature sensors and an automated water dispersal system into a firefighting unit capable of [11]:

- **Fire Detection & Suppression**: Identify high-temperature zones and autonomously deploy a water-based extinguishing system.
- **Automation of Emergency Response**: Assist in the fire rescue operations through the real-time hazard evaluation.

4) *Service and Indoor Automation*

The robot is adapted for further **indoor assistance and home automation** through integrating:

- **Wireless Communication Technologies**: Infrared (IR), Radio Frequency (RF), and ZigBee for remote control [7].
- **Smart Home Integration**: To perform chores, avoid obstacles, and navigate autonomously within structured environments [10].

5) *Autonomous Pick-and-Place Functionality*

Set up the robot for the picking of objects to be **automatically transported**, thus increases industrial applications by:

- **Robotic Arm Integration**: Using servo-controlled mechanisms to manipulate objects for the collection of samples for testing [12].
- **Sensor Optimization**: Exchange of ultrasonic with vision-based artificial intelligence for precision in object handling [6].

6) *Integration of LiDAR & SLAM for 3D Mapping*

Equipping the robot to augment navigation and environmental awareness by :

- **LiDAR Sensors**: High accuracy in depth perception for accurate obstacle detection and terrain mapping [8].
- **Simultaneous Localization and Mapping (SLAM)**: Facilitating real-time 3D mapping, thereby enhancing the autonomous navigation and path-planning capability of the robot in convoluted environments [9].

Such improvements would convert the surveillance robot into a multifunctional AI-driven autonomous system suitable for security, industrial, medical, and emergency response applications [10].

XIII. RESULTS & MAIN CONCLUSION

Affecting current developments in robotics, automation, and **the Internet of Things (Iot)** have been brought into very good use in various fields such as **security, military, and industrial applications [6]**. With such increasing importance being placed on robotic systems, we can tell that autonomous surveillance technologies have made a significant impact in changing critical operations with better efficiency, safety, and precision [9].

This research demonstrated an **ESP-32-based** surveillance robot capable of real-time monitoring and reconnaissance in various applications, proving its value [10]. The system combines a live-streaming camera, motor driver shield, and ESP32 microcontroller for seamless communication and navigation [7]. Movement is provided by DC motors, enabling the robot to move quickly and efficiently over various terrains [12]. This implementation demonstrates the potential for low-cost AI-powered robotic applications in military and security operations where real-time data acquisition and remote access are crucial [8].

The performance and accuracy of the surveillance robots depend on a variety of environmental factors [11]. The position and distance between obstacles in the test path affect the navigation efficiency, while the size and shape of the objects define how well the obstacles can be detected with algorithms [9]. Besides, external disturbance, for example, signal interruption, and changes in the atmospheric conditions can interfere with the readings of sensors and eventually influence the robot's decisions. Describing this, the robot is reliable with respect to the quality and accuracy of sensors since these sensors are vital for navigation, **object detection, and autonomous path planning [12]**.

Additions in the future are to be centered on installing sensors of superior precision to improve accuracy and adaptability [6]. **Advanced machine learning-based sensor fusions, LiDAR-based technologies**, and **SLAM algorithms** could provide substantial autonomy for the robot in dynamic and unpredictable environments [9]. It's a developing foundation for future surveillance robots - emphasizing AI and automation toward real security challenges and lessening risks for human beings in extreme conditions [10].

This study also demonstrates emerging applicability for robotic surveillance systems in developing future engagements in **defense, industrial safety, and emergency response programs [12]**.

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