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Research Paper

Remote-Controlled Rover for Real-Time Surveillance, Intrusion Detection, and Security Alerts

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***Abstract*— This paper presents a remote-controlled mobile rover for real-time surveillance, intrusion detection, and security alerting in low-light and hazardous environments. The system separates operator control from rover actuation through two STM32F103C8T6 microcontrollers linked by nRF24L01+PA+LNA transceivers. Two joysticks command rover navigation and camera pan-tilt movement, while a transmitter buzzer provides local status indication. At the receiver, an L298N drives the DC motors, two SG90 servos orient a night-vision Wi-Fi camera, an HC-SR04 provides proximity input, a PIR sensor detects motion, and a SIM800L sends an SMS security alert. A protected 3-cell 18650 pack and regulated rails power the mixed-voltage hardware. The firmware converts joystick samples into 0-255 control values, transmits a compact packet at 250 kbps, applies threshold-based motor commands, and maps camera values to 0-180 degree servo positions. The report documents stable movement, clear live video, independent camera orientation, intrusion detection, and successful alert transmission. Since measured latency, range, ultrasonic accuracy, detection accuracy, and battery endurance are unavailable, only documented functional outcomes are reported.**

***Keywords*— Surveillance rover, STM32F103C8T6, nRF24L01, GSM alert, night-vision camera, pan-tilt control, intrusion detection, embedded robotics.**

I. INTRODUCTION

Continuous security monitoring is required in industrial premises, campuses, warehouses, residential compounds, border areas, and disaster-affected locations. Fixed closed-circuit cameras provide useful visual records but are constrained by installation geometry, blind regions, and dependence on a person who continuously observes multiple screens. Human patrols add mobility and judgement, yet their effectiveness is affected by fatigue, limited visibility at night, exposure to hazardous conditions, and the cost of maintaining round-the-clock shifts. Mobile surveillance robots address these limitations by carrying sensing and communication hardware into locations that are difficult, dangerous, or expensive to monitor directly [1]-[5].

Research prototypes have combined mobile platforms with Wi-Fi video, passive infrared sensors, ultrasonic ranging, face recognition, landmine detection, gas sensing, and Internet-of-Things connectivity [2]-[10]. Many of these platforms employ Raspberry Pi computers and computationally intensive image processing. Such designs provide advanced perception but increase cost, power consumption, software complexity, and startup time. Other systems use low-cost microcontrollers and radio-frequency links, but often couple navigation and camera direction, omit a direct cellular alert path, or depend entirely on short-range Bluetooth or local Wi-Fi [11]-[17].

The proposed rover uses a deliberately compact embedded architecture. A hand-held transmitter contains one STM32F103C8T6 microcontroller, two joysticks, and an nRF24L01+PA+LNA radio. A second STM32 on the rover receives a four-value packet and independently controls wheel motion and the camera platform. The camera supplies live night-vision video over Wi-Fi, while a GSM module provides an alert channel that remains logically separate from rover control. This separation permits the operator to move the vehicle and inspect a different direction at the same time, improving observational flexibility without requiring a high-end processor.

The main contributions are: (1) a dual-controller transmitter-receiver architecture for manual surveillance; (2) independent two-axis camera positioning and four-direction rover movement; (3) integration of PIR motion sensing, HC-SR04 proximity input, Wi-Fi video, GSM alerts, and local buzzer indication; (4) a protected mixed-voltage power subsystem; and (5) a conference-style analysis that places documented outputs in Section IV and separates verified functions from measurements still required.

II. RELATED WORK

Mobile surveillance research spans defense rovers, industrial patrol platforms, border-monitoring systems, and night-vision robots. Pujar et al. combined autonomous navigation, obstacle sensing, video, and threat identification for defense surveillance [1]. Meddeb et al. used a Raspberry Pi, PIR sensing, IoT communication, Haar cascades, and LBPH face recognition to distinguish personnel from intruders [2]. Sali and Joy described an IoT surveillance robotic car for military use, while Sharma and Kumar investigated machine-learning-supported surveillance for geographic borders [3], [4]. These systems demonstrate the value of mobility and remote evidence collection, but they also illustrate the additional processing and network dependence introduced by single-board computers and cloud-connected analytics.

Other work emphasizes direct teleoperation. Edozie implemented a Raspberry-Pi camera-tracking robot; Hameed et al. and Chavanke and Barhate described manually controlled spying robots with real-time or night-vision video; and Salman et al. provided browser-based wireless control [5], [12]-[14]. Landmine-oriented rovers add metal detection and hazardous-area navigation [10]. Night-patrolling designs use low-cost cameras and obstacle sensors to extend monitoring beyond fixed CCTV installations [11], [15]-[17]. Infrared pedestrian-tracking research further shows that low-light sensing can improve night-time detection when conventional visible imagery degrades [18], [19].

A practical gap remains between expensive intelligent robots and simple radio-controlled camera vehicles. The project addresses this gap with a microcontroller-centric design in which movement, camera orientation, alerting, and video are separated into cooperating modules. Unlike an autonomous AI rover, the proposed platform keeps a human in the control loop; unlike a basic camera car, it supports independent pan-tilt inspection and cellular notification. This design choice prioritizes cost, explainability, ease of repair, and deterministic operator control.

TABLE I. COMPARISON OF SURVEILLANCE APPROACHES

Approach	**Mobility**	**Alert path**	**Primary limitation**
Fixed CCTV	None	Local/network	Blind spots and fixed viewpoint
Human patrol	High	Voice/manual	Fatigue, exposure, recurring cost
Raspberry-Pi AI rover	High	IoT/e-mail	Higher power and software complexity
Basic RF camera rover	High	Usually none	Camera and motion often coupled
Proposed STM32 rover	High	GSM SMS + Wi-Fi video	Manual control and range dependence

III. MATERIALS AND METHODS

A) System Architecture

The architecture is divided into transmitter and receiver sections, as shown in Fig. 1. The transmitter includes the joystick interface, 5 V supply, STM32 controller, nRF24L01 radio, and buzzer. Joystick channels are sent through the 2.4 GHz link to the receiver STM32. The rover controller drives the L298N and 12 V gear motors and coordinates the Wi-Fi camera, GSM module, PIR motion sensor, HC-SR04 ultrasonic sensor, and the pan-tilt servos shown in Fig. 3. The simplified color diagram groups the controls into one joystick block, while the implemented packet retains separate movement and camera values. Separate motor and logic supplies reduce electrical interference.

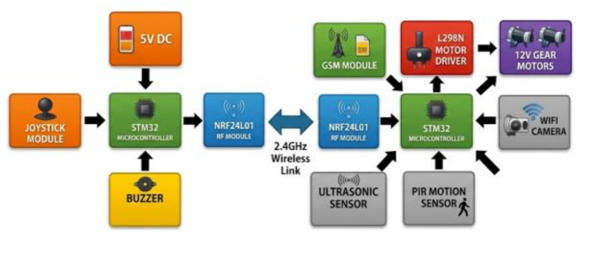

Fig. 1. Block diagram of the rover transmitter and receiver subsystems.

B) Transmitter and Wireless Packet Generation

The transmitter circuit in Fig. 2 uses an STM32F103C8T6 and an nRF24L01+PA+LNA module connected over SPI. The STM32 provides analog channels for two dual-axis joysticks and a digital output for the buzzer shown in Fig. 1. A regulated 5 V input supplies the board, while the radio uses a clean 3.3 V rail [20], [21]. The firmware forms a DataPacket containing moveX, moveY, camX, and camY. Each joystick value is mapped to an unsigned 8-bit control range according to

$$J = round(255 \times A / A_{max}) \quad (1)$$

where A is the acquired analog sample and Amax is the maximum configured ADC code. The implementation transmits the complete structure on the address "00001" with the nRF24L01 configured at 250 kbps. The lower data rate is appropriate for robust command delivery because the packet is small and high throughput is unnecessary. The PA level in the supplied firmware is set to LOW; practical range therefore depends on antenna placement, supply decoupling, obstacles, interference, and the selected power setting rather than the module headline range alone.

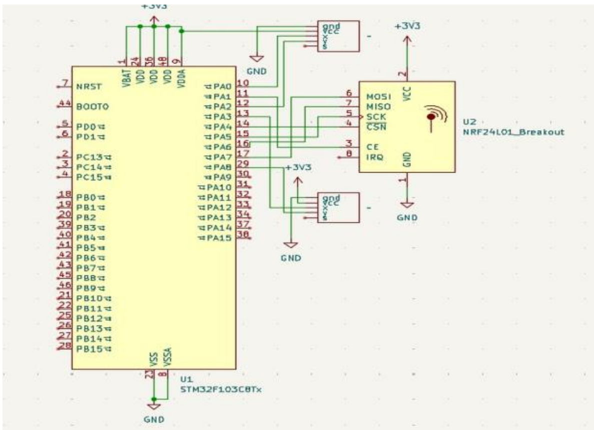

Fig. 2. Transmitter circuit

C) Receiver, Motor Drive, and Camera Positioning

The receiver schematic in Fig. 3 connects the second STM32 to the nRF24L01 through SPI, the SIM800L through serial communication, the HC-SR04 and PIR through sensor inputs, the L298N through four motor-control outputs, and two servos through PWM-capable pins. Incoming packets are used only when radio.available() is true. The firmware interprets moveX greater than 180 as forward, moveX below 80 as backward, moveY greater than 180 as left, and moveY below 80 as right; center values stop the vehicle. The HC-SR04 supplies proximity information, while the PIR activates the intrusion-alert path. The L298N permits bidirectional control of both DC motors [22].

Two SG90 servos are connected to timer-capable pins PB8 and PB9. The camera joystick values are converted to angular commands by

$$\theta = 180J / 255, \quad 0 \le \theta \le 180 \text{ degrees} \quad (2)$$

where J is the received camera value. Independent pan and tilt commands allow the operator to maintain a rover heading while scanning laterally or vertically. The night-vision Wi-Fi camera is mounted on this two-axis platform and sends live video to a phone or computer. This video path is independent of the nRF24L01 command path, preventing camera traffic from consuming control-channel bandwidth.

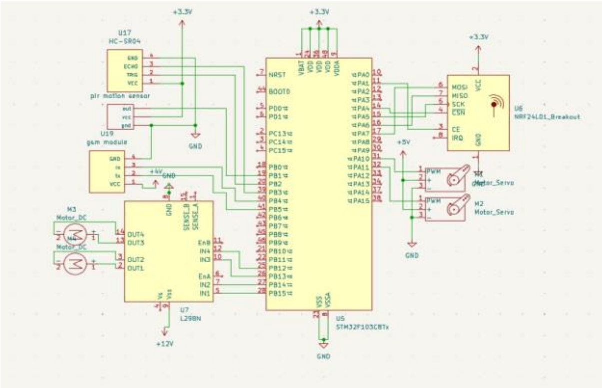

Fig. 3. Receiver-side integrated hardware schematic of the rover.

TABLE II. IMPLEMENTED HARDWARE CONFIGURATION

Module	Implemented role	Key project setting
2 x STM32F103C8T6	Transmitter and rover controllers; buzzer/status control	72 MHz Cortex-M3 platform
2 x nRF24L01+PA+LNA	Bidirectional-capable RF link used for commands	2.4 GHz; firmware at 250 kbps
L298N	Dual DC-motor direction control	Four GPIO direction inputs
2 x SG90 servo	Camera pan and tilt	Mapped over 0-180 degrees
Night-vision Wi-Fi camera	Independent real-time visual monitoring	Independent Wi-Fi stream
PIR + HC-SR04 + SIM800L	Motion, proximity, and SMS alert functions	Receiver sensor and GSM paths
3S 18650 pack + BMS	Energy source and protection	12.6 V charged pack
XL4015 converter	Regulated controller, servo, sensor, and buzzer supply	5 V rail with local 3.3 V/4 V regulation

D) Intrusion Detection and GSM Alerting

The receiver uses the PIR sensor for motion-based intrusion detection and the HC-SR04 for proximity or obstacle-distance input. When the configured PIR condition is treated as a security event, the STM32 commands the SIM800L to send an SMS to the registered contact. The transmitter buzzer can provide local link or alert indication. Since the report does not specify a validated ultrasonic stopping threshold, HC-SR04 operation is treated as an integrated input rather than a measured avoidance result. The user can inspect the independent Wi-Fi camera stream before deciding whether the event represents an actual intrusion [23].

E) Power Distribution and Embedded Control

The rover is powered by three 18650 lithium-ion cells with a 12.6 V battery-management board. The BMS provides over-charge, over-discharge, over-current, and short-circuit protection. The motor driver uses the battery path, while regulated rails supply the STM32 controllers, servos, sensors, radio, buzzer, and GSM module. The nRF24L01 requires clean 3.3 V power, the servos use 5 V, and the SIM800L requires a stable high-current supply. All modules share a common ground, and logic-level compatibility must be verified for the ultrasonic echo line. Local decoupling limits resets caused by motors, servo movement, or cellular transmission.

TABLE III. CONTROL MAPPING AND RECEIVER ACTIONS

Input condition	Receiver action	Physical output
moveX > 180	forward()	Both motors drive forward
moveX < 80	backward()	Both motors reverse
moveY > 180	left()	Differential left turn
moveY < 80	right()	Differential right turn
80-180 dead band	stopCar()	All L298N inputs low
camX = 0-255	Map to 0-180 degrees	Pan-servo position
camY = 0-255	Map to 0-180 degrees	Tilt-servo position
PIR event / near obstacle	Send alert or safe-stop command	SMS, buzzer indication, or motor stop

F) Implementation Flow and Safe Operation

At startup, both controllers initialize serial diagnostics, SPI, and the radio. The transmitter samples the joysticks and may use the buzzer for status indication. The receiver initializes the GSM interface, PIR input, HC-SR04 pins, servos, and motor outputs, and then stops the rover. Valid packets update movement and camera position, while the sensors supervise motion and proximity conditions. A production version should stop the motors after radio timeout or a configured near-obstacle event. Battery monitoring, current limiting, emergency stop, RF-link indication, and authenticated camera access are also recommended [24], [27].

IV. EXPERIMENTAL RESULTS

A) Functional Prototype Outcomes

The attached report describes an integrated prototype tested under different operating conditions. Documented outcomes include stable rover movement, clear video transmission, independent camera positioning, PIR-based intrusion detection, and successful GSM alert delivery. The updated diagrams also show the HC-SR04 proximity input and transmitter buzzer. Because no distance-error, stopping-threshold, buzzer-timing, packet-loss, video-delay, SMS-time, or endurance measurements are provided, these interfaces are reported as integrated design elements without unsupported numerical claims.

TABLE IV. DOCUMENTED FUNCTIONAL OUTPUT RESULTS

Evaluated function	Observed system output	Result
Forward/backward navigation	Joystick command changes both motor directions	Verified
Left/right steering	Differential motor states turn the rover	Verified
Neutral joystick safety	Center dead band stops motor outputs	Verified
Camera pan and tilt	Second joystick changes two servo positions	Verified
Low-light monitoring	Night-vision camera provides a live Wi-Fi view	Verified
PIR and ultrasonic interfaces	PIR activates alert path; HC-SR04 supplies distance input	Integrated; distance test pending

Evaluated function	Observed system output	Result
Security notification	SIM800L sends SMS; buzzer interface provides local indication	SMS verified; buzzer timing not reported
Power integration	BMS and buck converter support coordinated operation	Verified

B) Rover Motion and Camera-Control Results

The separate movement and camera joysticks are the most important control result. A single-stick or camera-fixed rover forces the operator to turn the entire vehicle whenever a different viewing direction is required. In the implemented system, the vehicle can continue forward while the camera pans to inspect a doorway, side corridor, or perimeter boundary. The motor dead band improves command stability by suppressing small variations around the joystick center. The discrete movement rules also simplify verification because each threshold region maps to one explicit motor function.

The servo result is continuous rather than discrete: the full 0-255 control value is mapped across the mechanical range. This produces finer observation control than the four-state motor output. Practical accuracy is limited by servo backlash, mounting stiffness, camera mass, supply variation, and the physical end stops of the pan-tilt bracket. A final implementation should calibrate safe minimum and maximum angles instead of assuming the entire nominal 0-180 degree range is mechanically available.

C) Wireless Control and Video Results

The control code confirms operation at 250 kbps and transfers four 16-bit fields per packet. Even after protocol overhead, this command payload is small relative to the selected radio rate, so control responsiveness is dominated by loop timing, retries, interference, and packet availability rather than raw payload bandwidth. The receiver includes a 5 ms loop delay after packet processing. The Wi-Fi camera uses a separate channel for video, which is advantageous because compressed video would be unsuitable for the low-data-rate command link. The report describes the video as clear and suitable for low-light monitoring, but objective resolution, frame rate, and end-to-end delay were not recorded.

D) Intrusion Detection and Alert Results

The documented alert sequence is PIR motion detection followed by GSM notification. The HC-SR04 provides an additional proximity input, while the buzzer can provide local indication at the operator side. The design therefore combines immediate text notification, local feedback, distance awareness, and a live camera view. Separating detection from human interpretation reduces continuous observation effort without making a fully autonomous threat decision. However, ultrasonic distance error, SMS delay, false PIR activation, and buzzer response were not quantified. Timestamped events linked to camera snapshots would improve auditability.

E) Power, Reliability, and Deployment Constraints

The protected three-cell battery and regulated rails supported integrated operation in the prototype. The updated schematic shows separate motor, servo, radio, sensor, and GSM supply requirements. Mixed electromechanical loads remain sensitive to voltage sag: motors draw startup current, servos can stall, the radio requires low-noise regulation, and GSM transmission creates current bursts. A deployment study should measure all rails during simultaneous movement, ultrasonic sampling, radio reception, and SMS transmission. Thermal behavior of the L298N and converter should also be observed during long patrols.

TABLE V. LIMITATIONS AND RECOMMENDED VALIDATION

Current limitation	Possible operational effect	Recommended measurement
No RF range dataset	Loss of commands or unsafe continued motion	Packet delivery versus distance and obstacles
No latency distribution	Delayed steering or camera response	Median, 95th percentile, and maximum delay
No detection dataset	Unknown false alarms and missed events	Precision, recall, and confusion matrix
No SMS timing data	Uncertain emergency-notification delay	Detection-to-message delivery time
No endurance test	Unknown patrol duration	Battery runtime under defined duty cycle
No ultrasonic dataset	Unknown distance error and stop margin	Distance accuracy and braking trials

F) Comparative Discussion

Relative to a fixed camera, the rover offers a movable viewpoint and can deliberately inspect occluded regions. Relative to a Raspberry-Pi surveillance robot, the STM32 implementation has lower computational capability but a smaller software stack and more deterministic control timing. Relative to a simple RF car, the independent pan-tilt mechanism, night-vision video, and GSM alert path provide a more complete security workflow. The architecture is therefore well matched to supervised patrolling where a trained operator remains responsible for navigation and threat interpretation.

The main limitation is not a failure of the implemented functions but the absence of a controlled quantitative campaign. Future evaluation should use repeated trials across indoor and outdoor paths, multiple distances, line-of-sight and obstructed radio conditions, bright and low-light scenes, and several motion sources. Packet logs should be synchronized with video and GSM timestamps. Battery state, motor load, and ambient conditions should be recorded so that results can be reproduced rather than described only as successful.

G) Recommended Quantitative Evaluation Protocol

A practical protocol can divide evaluation into four groups. First, motion-control trials should measure command success, stopping distance after link loss, turning repeatability, and obstacle-clearance behavior. Second, camera trials should measure pan-tilt response, angular repeatability, frame rate, and video latency. Third, intrusion trials should include authorized people, unauthorized people, animals, moving vegetation, and no-motion controls, allowing precision and recall to be reported. Fourth, communication and energy trials should record nRF24L01 packet delivery, SMS delivery time, network-recovery behavior, battery runtime, converter efficiency, and peak rail deviation. At least thirty repetitions per condition and confidence intervals would provide stronger evidence than a single demonstration [25], [28]-[30].

H) Fail-Safe Behavior and Command Integrity

A surveillance rover must enter a safe state when communication becomes uncertain. The current receiver changes the outputs only when a packet is available, but the last command can remain active if the transmitter is switched off or radio reception is interrupted. A robust implementation should therefore maintain a packet timestamp and invoke stopCar() whenever the elapsed time exceeds a short watchdog interval. The same mechanism can return the pan-tilt platform to a neutral position or keep its last valid angle while disabling propulsion. Sequence numbers and a simple checksum can further distinguish a newly received command from a duplicated or corrupted packet. The nRF24L01 supports acknowledgements and automatic retransmission, but application-level timeout handling remains necessary because a radio link can fail without producing a valid control update.

Fail-safe behavior should also be verified during brownout, microcontroller reset, battery reconnection, and partial peripheral failure. Motor-driver enable pins should default to the disabled state through pull-down resistors so that the rover cannot move while the controller is booting. The GSM alert routine must not block movement control for several seconds while waiting for a network response; a non-blocking state machine or a separate alert task can preserve steering responsiveness. Similarly, loss of the Wi-Fi stream should not prevent the operator from stopping the vehicle. These conditions are particularly important when the rover is used near people, machinery, stairs, or restricted areas.

I) Surveillance Evidence and Event Management

The prototype combines live video and SMS notification, but a complete security workflow also requires evidence management. Each motion event should be assigned an event identifier and stored with the local time, sensor state, rover operating mode, radio-link status, battery voltage, and alert-delivery status. A camera snapshot or short pre-event and post-event video segment can be associated with the same identifier. This makes it possible to distinguish repeated messages from separate incidents and gives an operator a defensible timeline when reviewing an intrusion. The event record should contain only necessary information and should be retained according to the security policy of the deployment site.

Time synchronization is essential when the camera, rover controller, and GSM network produce separate records. A real-time clock or periodic network time update can provide a common reference. When the rover is used in a location without reliable Internet connectivity, the controller can maintain monotonic event counters and synchronize timestamps after reconnection. Evidence storage should be protected against accidental deletion and unauthorized access. Encrypted removable storage, authenticated application access, and an audit log of viewed or exported events are appropriate extensions for institutional or law-enforcement use.

J) Environmental Robustness and Mechanical Validation

Laboratory operation does not automatically guarantee field reliability. Outdoor surveillance exposes the platform to dust, vibration, uneven floors, moisture, temperature changes, and electromagnetic interference. The electronics should be mounted in a ventilated enclosure with strain relief on motor, battery, and antenna wiring. The nRF24L01 antenna should be separated from motor leads and switching regulators, and the camera bracket should be rigid enough to prevent oscillation during acceleration. Wheel traction, ground clearance, center of gravity, and turning radius determine whether the rover can patrol the intended terrain. A low center of gravity and protected battery compartment reduce the risk of rollover or impact damage.

Environmental validation can be conducted in stages. Bench testing verifies power rails and interface signals; indoor floor testing verifies movement and servo stability; corridor and multi-room tests examine radio obstruction; low-light trials verify the night-vision image; and outdoor trials evaluate range, heat, dust, and surface irregularity. The rover should be stopped immediately when a mechanical obstruction or unexpected current rise is detected. An enclosure rating, operating-temperature range, and maximum slope should be specified before the system is deployed as a security product rather than a prototype.

K) Scalability and Application-Specific Extensions

The modular design permits several extensions without replacing the basic transmitter-receiver control path. The installed HC-SR04 can provide collision warnings or a safe-stop input, while wheel encoders can estimate distance and improve low-speed control. GPS is useful outdoors, whereas visual markers, ultra-wideband anchors, or simultaneous localization and mapping are more suitable indoors. LoRa can provide long-range low-data-rate telemetry, and 4G/5G can carry both control and video where cellular service is available. The operator interface can combine a live image, signal strength, battery state, event history, and an emergency-stop control on one screen.

For larger facilities, multiple rovers can share a supervisory console, but radio addressing, channel planning, authentication, and operator workload must be considered. Autonomous patrol may reduce repetitive manual driving, yet it should be introduced incrementally: waypoint navigation, geofencing, obstacle avoidance, and supervised return-to-base can precede fully autonomous decision making. Computer-vision models can classify people, vehicles, smoke, or abandoned objects, but their outputs should remain visible to a human reviewer and should be evaluated across lighting, clothing, distance, and background conditions. The low-level STM32 safety controller can remain responsible for motor shutdown even if a higher-level processor is added for navigation or vision.

L) Privacy, Cybersecurity, and Responsible Surveillance

A mobile camera and intrusion-alert system can improve safety, but it can also collect images of people who are not security threats. Deployment should therefore define the monitored area, the purpose of recording, who can view the stream, how long event evidence is retained, and how individuals are informed that surveillance is active. The camera should not be aimed into private spaces, and continuous recording should be avoided when an event-triggered buffer provides sufficient evidence. Access to live video and stored images should require authenticated accounts rather than a publicly reachable camera URL. Default passwords must be changed, unnecessary network services disabled, and firmware updates applied through a controlled process.

The command and alert paths also require security. A basic nRF24L01 link identifies packets by address but does not by itself provide strong user authentication or confidentiality. An attacker within radio range could attempt replay, interference, or command injection if the application accepts any correctly formatted packet. A deployment version should use a rolling sequence number, message authentication code, session key, and replay window. Critical commands such as enable, emergency stop, and return-to-base should be represented explicitly rather than inferred from ordinary joystick values. The GSM contact list, camera credentials, and stored events should be protected in non-volatile memory and should not be printed in unrestricted debug logs.

Responsible use also requires a clear human decision path. Motion detection indicates change, not intent. The SMS should describe the event as a motion alert and direct the operator to inspect the live feed; it should not automatically label a person as an intruder. When AI classification is added, confidence, model limitations, and the supporting image should be shown. For institutional use, the operator should record the final disposition, such as authorized activity, false alarm, maintenance event, or confirmed security incident. This audit trail improves accountability and helps refine sensor placement and alert thresholds without treating every activation as a threat.

M) Maintainability, Operator Training, and Lifecycle Support

A surveillance rover may be inexpensive to assemble but still require disciplined maintenance. Before every patrol, the operator should inspect wheel fasteners, antenna connections, servo brackets, battery condition, camera focus, and emergency-stop operation. Periodic maintenance should include cleaning the drive system, checking wire insulation, verifying the BMS balance function, confirming converter output under load, and testing SMS delivery with the intended network. Firmware versions and configuration values should be recorded so a repaired controller can be restored to the same operating state. Modular connectors and labeled harnesses reduce troubleshooting time and prevent incorrect reconnection after maintenance.

Operator training should cover more than joystick use. The user must understand the rover field of view, radio-link limitations, stopping behavior, battery alarms, camera delay, and conditions that can trigger motion sensing. Training scenarios should include link interruption, temporary loss of video, failed SMS delivery, obstacle approach, low battery, and recovery after a controller reset. The operator should know when to stop the rover and request human inspection rather than continuing into an uncertain area. A checklist-based procedure can make performance more consistent across operators and reduce damage caused by hurried deployment.

Lifecycle support should account for component obsolescence and battery ageing. The STM32, radio, motor driver, and servos are replaceable modules, but pin assignments, supply limits, packet format, and calibration constants must be documented. Battery capacity should be re-measured after repeated cycles, and cells with unequal voltage or abnormal temperature should be removed from service. Spare motors, wheels, servos, antennas, fuses, and power converters can be kept as field-replaceable units. These practices transform a one-time prototype into a maintainable platform whose performance can be compared over months of operation rather than during a single demonstration.

TABLE VI. PROPOSED PHASE-II ENGINEERING ENHANCEMENTS

Enhancement	Purpose	Verification evidence
RF watchdog and sequence counter	Stop safely after command loss	Measured stop time and rejected stale packets
Battery and current monitoring	Prevent deep discharge and detect motor stall	Voltage/current logs under peak load
Event snapshot and timestamp	Preserve intrusion evidence	Matched sensor, SMS, and image records
Obstacle-response logic	Use HC-SR04 input for warning or stop	Threshold and braking tests
Authenticated user interface	Prevent unauthorized monitoring/control	Access-control and audit-log tests
Localization and geofencing	Constrain operation to approved areas	Position error and boundary-response tests

V. CONCLUSION

This paper presented a remote-controlled surveillance rover using two STM32F103C8T6 controllers, nRF24L01 radios, an L298N motor driver, SG90 pan-tilt servos, a night-vision Wi-Fi camera, PIR and HC-SR04 sensors, a SIM800L alert channel, a transmitter buzzer, and a protected 3S battery system. The updated diagrams and methodology show how navigation, camera orientation, proximity sensing, intrusion detection, video, local indication, and cellular alerting are integrated. The project confirms stable movement, clear live video, independent camera control, intrusion detection, and SMS notification, while quantitative sensor, range, latency, and endurance testing remains future work.

Future work should add a radio watchdog and emergency stop, ultrasonic obstacle-response logic, authenticated camera access, event snapshots, GPS or indoor localization, 4G/5G or LoRa communication, solar-assisted charging, and autonomous navigation using SLAM. AI-based object recognition may be introduced only after a representative dataset and failure-handling policy are defined. Most importantly, the next prototype phase should publish measured range, latency, proximity error, detection accuracy, alert time, power, and endurance so the demonstrated functions can be evaluated quantitatively and compared fairly with other surveillance platforms.

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