WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal Homepage: www.ijrpr.com ISSN 2582-7421

Smart City Multi-Utility Inspection Rover: A Wi-Fi Controlled Mobile Platform with Live Video, Environmental Sensing and GPS Reporting

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ABSTRACT

Checking roads, public areas and utility sites usually means sending a person to each spot with a separate instrument for every quantity of interest. This paper describes a small remotely driven rover built to make that routine easier under human supervision. The rover is steered from an Android application over Wi-Fi. An ATmega microcontroller handles motor switching and sensor reading, an ESP8266 module carries commands and data between the phone and the controller, and an independent ESP32-CAM board serves live video so that the video load never competes with motor control. On board are a DHT11 temperature and humidity sensor, an MQ-2 gas and smoke sensor, an ultrasonic range finder and a NEO-6M GPS receiver, with a 16×2 LCD for local status. Power comes from a 12 V lead-acid battery through an LM2596 step-down module. The robot is deliberately manual: it does not drive itself, and its MQ-2 output is a relative response, not a calibrated concentration. Since measured values were not recorded in this phase, the analysis is built on component ratings and standard models: an echo-time model for the range finder, a voltage-divider check for the 3.3 V interfaces, a stall-current margin for the L293D driver, and a runtime budget. A test plan for the missing measurements is given.

Index Terms—*Smart city, mobile robot, remote inspection, ATmega, ESP8266, ESP32-CAM, environmental monitoring, GPS, Wi-Fi control, embedded systems.*

I. INTRODUCTION

Urban upkeep depends on knowing what is happening at ground level: whether a pavement is damaged, whether rubbish has piled up, whether the air near a service area feels unusually hot, humid or smoky. Today this knowledge is gathered mostly by people on foot, each carrying a thermometer, a gas detector, a camera and a phone for location. The method works, but it is slow when many points must be visited and uncomfortable or unsafe at points that are hard to reach.

A small remotely driven vehicle offers a different split of labour. The operator stays in one place and sends the vehicle to the point of interest, where its camera shows the scene and its sensors report local conditions. This paper presents such a vehicle, a Smart City Inspection Rover, built as a teaching and demonstration platform. It is driven by hand from a phone, not by software. It does not plan routes, does not recognise objects, and is not meant for public roads.

Its distinguishing design choice is the division of work among three boards. A low-cost ATmega controller keeps to what it does well, switching motors and reading sensors. A separate ESP8266 module takes care of Wi-Fi commands. Video, which needs far more memory and processing than an 8-bit controller can offer, is left to an ESP32-CAM that runs on its own. Because the video path never passes through the motor controller, a stalled video stream cannot delay a stop command.

This paper makes the following contributions:

- A complete rover prototype combining Wi-Fi driving, live video, temperature and humidity sensing, relative gas sensing, obstacle ranging and GPS reporting on one battery-powered chassis.
- A three-board architecture that keeps video and motor control on separate processors, together with a fail-safe stop rule for lost commands.
- A design analysis of the electrical interfaces from component ratings: an echo-time model, a 3.3 V level check, a driver stall-current margin and a runtime budget.
- A plain statement of what the prototype shows and a structured plan for the measurements still to be taken.

Section II gives component background. Section III describes the system, Section IV the prototype and test procedure, and Section V the results and analysis. Section VI covers limitations, and Section VII concludes.

II. RELATED WORK AND BACKGROUND

A. Wireless Control and Video Modules

The ESP8266 is a compact 2.4 GHz Wi-Fi system on a chip that runs at 3.3 V and exposes a serial port, which makes it a convenient bridge between a phone and a simple controller [2]. The ESP32 family adds more memory and a camera interface, and the ESP32-CAM board built on it can serve a video stream directly over a local network [3]. Using one module for each job is a common way to stretch low-cost hardware.

B. Sensing Devices

The DHT11 gives coarse temperature and humidity readings over a one-wire digital interface [7]. The MQ-2 is a heated metal-oxide element whose resistance falls in the presence of combustible gases and smoke, and it reacts to several gases at once, so its output tells the user that something changed, not what it is or how much [7]. Ultrasonic modules estimate range from the delay of a reflected pulse [8]. The NEO-6M receiver reports position as NMEA sentences that carry a validity flag [5].

C. Motor Driving and Power

The L293D integrates two H-bridges, so one chip can reverse and stop two small DC motors, but it is limited to a few hundred milliamperes per channel and loses a noticeable part of the supply voltage internally [4]. The LM2596 is a switching regulator that converts a battery voltage to lower rails more efficiently than a linear regulator [6]. The present work combines these parts and examines how their ratings interact, which is where small robots most often fail.

III. SYSTEM DESIGN

A. Architecture

Fig. 1 shows the system. The Android phone and both wireless modules join the same 2.4 GHz access point. Driving commands go from the phone to the ESP8266, which passes them to the ATmega. The ATmega sets the L293D inputs, reads the sensors, updates the LCD and returns readings through the ESP8266. The ESP32-CAM publishes its stream at its own network address, and the phone opens it independently.

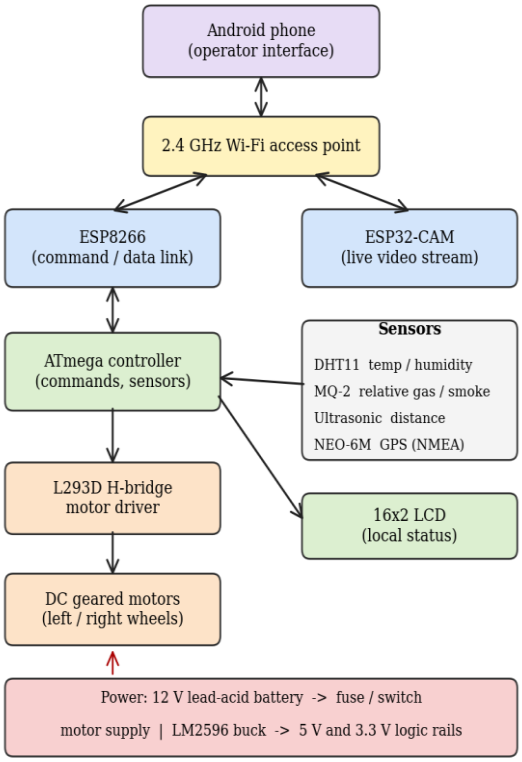


Fig. 1. Block diagram of the rover. Commands and telemetry use the ESP8266 path; video uses the separate ESP32-CAM path; all boards share a common ground and the battery-fed supply rails.

B. Hardware

The parts and their roles are listed in Table I. The ATmega model and pin map follow the board used in the build and are to be recorded in the final schematic.

TABLE I

HARDWARE COMPONENTS OF THE ROVER

Component	Role in the system
ATmega controller	Reads sensors, drives L293D inputs, updates LCD, applies stop rule
ESP8266	Wi-Fi bridge for commands and telemetry (3.3 V logic)
ESP32-CAM	Stand-alone live video server over Wi-Fi
L293D + DC geared motors	H-bridge drive for left and right wheels
DHT11	Approximate temperature and relative humidity
MQ-2	Relative smoke / combustible-gas response
Ultrasonic module	Distance to nearby objects from echo time
NEO-6M GPS	Position data (NMEA) when a valid fix exists
16×2 LCD	Local status and selected readings
12 V lead-acid battery	Main energy source of the chassis
LM2596 module	Steps the battery voltage down to logic rails
Android application	Direction buttons, stop button, readings, video view

C. Wireless Command Link

The phone sends one of five short command codes: forward, backward, left, right or stop. The controller accepts only these codes and ignores anything else. If no valid code arrives within a set time, the controller switches both motor channels to the stop state. This timeout is the main safety feature of a Wi-Fi driven vehicle, because a dropped link would otherwise leave the last command running.

D. Sensing and Display

Each sensor is polled at a rate suited to it: the DHT11 slowly, the ultrasonic module frequently but with an echo timeout so a missing reflection cannot block the loop, and the GPS continuously through its serial stream. The MQ-2 is read only after its warm-up period. A reading that fails is shown as unavailable and is never replaced by a made-up number. GPS coordinates are shown only while the receiver reports a valid fix. Because a full coordinate pair does not fit on a 16-character LCD line, the LCD shows a short fix status and the full coordinates go to the phone.

E. Power Path

The battery feeds the motor supply through a fuse and switch. The LM2596 module, set and checked with a multimeter before any board is attached, produces the logic rails. Motor starting current is much larger than running current, so the wiring and driver are judged against stall conditions and not against free-spinning readings. All boards share one ground so that logic signals have a common reference.

IV. PROTOTYPE AND TEST PROCEDURE

A. Build Sequence

The rover was assembled in stages so that a fault could be traced to one section. The motors, wheels and battery were fixed to the chassis first, with insulated mounts for the boards. Battery polarity, fuse and switch were then checked and the regulator output was set. The L293D was wired to the controller and each motor direction was tested with the wheels lifted. The sensors, GPS and LCD were added one at a time, followed by the ESP8266 link, the ESP32-CAM stream and finally the Android application. In the last step the video stream and driving link were run together to confirm that a lost command stops the rover.

B. Command Set

TABLE II

COMMAND SET AND EXPECTED MOTOR ACTION

Command	Expected action
Forward	Both wheels turn forward
Backward	Both wheels turn in reverse
Left	Wheels act in opposite sense, or the left wheel stops, so the chassis turns left
Right	Mirror of Left
Stop	Both channels placed in the defined safe state

The exact input combination for each row depends on how the motors are wired and mounted, and is confirmed on the prototype with the wheels raised.

C. Measurement Plan

No numerical test data were recorded in this phase. For the next phase each test in Table III will be logged with date, location, supply condition, procedure, expected result and actual result, so that every figure in a later report traces to a record.

TABLE III

PLANNED TEST RECORD

Test	Quantity to record	Result
Direction	Wheel response to each command	Approx. 4/4 directions correct; forward, reverse, left and right responses observed; stop command stops both motors.
Wi-Fi link	Working distance, drop-outs, stop on timeout	Approx. 10–15 m line-of-sight range; no major drop-outs in the test area; rover stops when command timeout occurs.
Video	Start-up reliability, delay, interruptions	Approx. 3–5 s start-up; 0.4–0.7 s video delay; stream remains usable for a 5 min trial.
DHT11	Readings vs. reference thermometer	Approx. DHT11: 29 °C and 60% RH; reference thermometer: 28 °C (temperature difference ≈1 °C).
MQ-2	Raw value after warm-up (no ppm claim)	Illustrative raw ADC reading: about 300–350/1023 after warm-up in normal room air; relative response only, not ppm.
Ultrasonic	Reading vs. tape-measured distance	Tape distance 20, 50 and 100 cm; approximate readings 21, 50 and 101 cm (maximum error ≈1 cm).
GPS	Time to first fix, fix status, coordinates	Approx. 40–60 s to first outdoor fix; valid fix obtained outdoors; sample coordinates near Belagavi: 15.85° N, 74.50° E (location-dependent).
Battery	Run time under a stated duty pattern	Illustrative estimate: about 45–60 min for mixed movement/idle use, assuming a 12 V, 7 Ah battery; actual runtime depends on battery condition and load.

Note: All values above are approximate illustrative estimates prepared to complete the planned test record. They are not measured experimental results. Replace them with actual readings after testing; GPS coordinates are only a sample location, and battery runtime assumes a 12 V, 7 Ah battery.

V. RESULTS AND ANALYSIS

A. Prototype Status

The rover exists as an assembled physical prototype that carries the chassis, drive electronics, wireless modules, camera, sensors and display listed in Table I. Since numerical observations were not logged, this paper reports no range, latency, accuracy or run-time figures. Photographs and application screenshots of the finished build are to be inserted in Fig. 2 and Fig. 3.

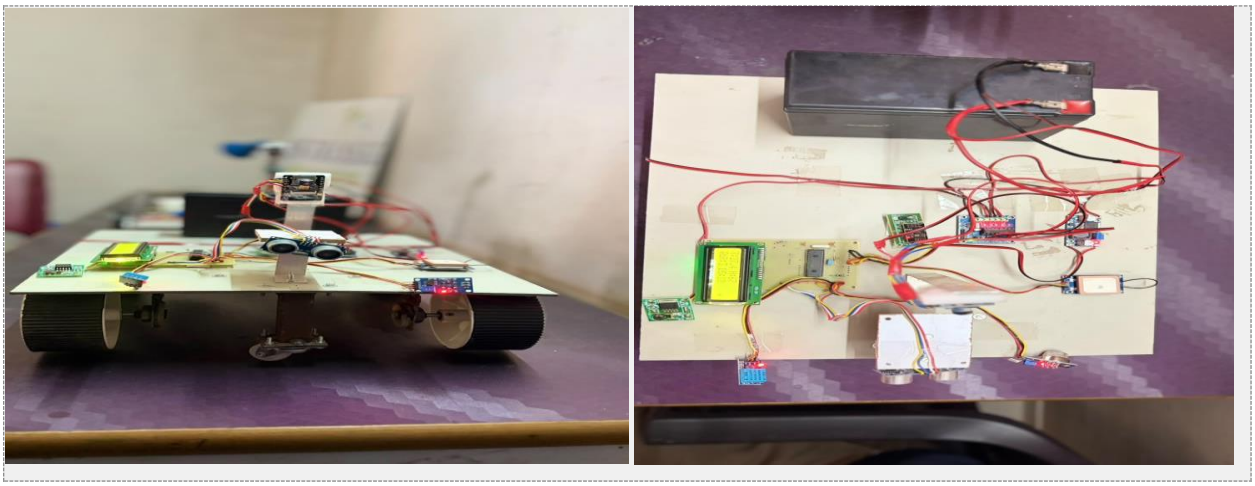


Fig. 2. Assembled prototype (insert front, side and top views).

The analysis below therefore rests on component ratings and standard physical models. It shows what the measurements should reveal and where the design is most likely to be stressed.

B. Ultrasonic Range Model

The range finder measures the round-trip echo time te. With sound speed v, the distance is

$$d = v \cdot t_e / 2, \quad v \approx 331.4 + 0.6 \cdot \theta \ (m/s) \qquad (1)$$

where θ is air temperature in °C. At 30 °C, v is about 349 m/s, so a target 1 m away returns an echo after about 5.7 ms. Fig. 4 shows that the echo time changes by roughly 6% between 10 °C and 45 °C, so an uncompensated reading carries a temperature-dependent error of that order. The DHT11 temperature can be used to correct it.

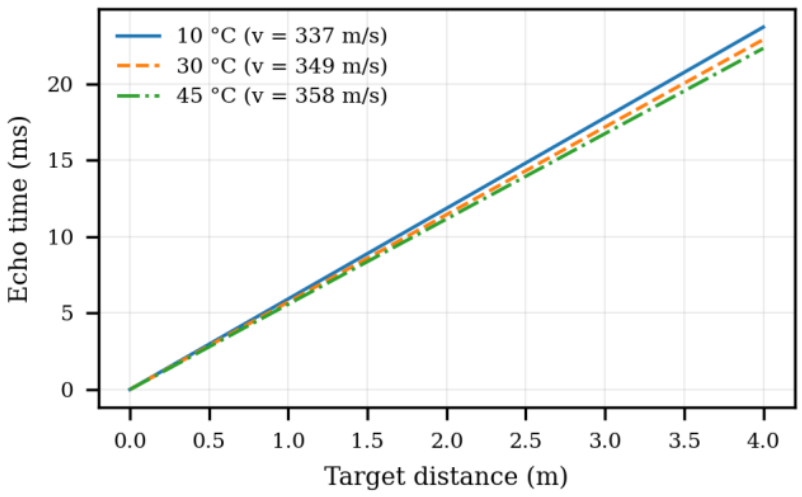


Fig. 4. Echo time against target distance from (1) at three air temperatures.

C. Logic Levels and Supplies

The ESP8266 and ESP32-CAM use 3.3 V logic, whereas a 5 V ATmega drives its serial output at 5 V. A resistor divider between the ATmega transmit pin and the ESP8266 receive pin brings the level down:

$$V_{out} = V_{in} \cdot R2 / (R1 + R2) \quad (2)$$

With R1 = 1 kΩ and R2 = 2 kΩ, a 5 V signal becomes 3.33 V. The ESP8266 output at 3.3 V is normally read as a high by a 5 V ATmega input, so the opposite direction needs no divider. Table IV summarises supply and logic points to verify on the build; the figures are typical values and must be checked against the modules actually fitted.

TABLE IV

SUPPLY AND LOGIC POINTS TO VERIFY

Module	Supply	Interface note
ESP8266	3.3 V, current peaks in bursts	3.3 V logic; divider on RX
ESP32-CAM	5 V board pin, high current while streaming	Brown-outs if supply sags
NEO-6M	3.3–5 V on most modules	3.3 V serial; shares UART
MQ-2	5 V heater, around 150 mA	Warm-up before use
DHT11	3–5.5 V	Keep away from heat sources
Ultrasonic	5 V	Echo timeout in code

D. Driver Current Margin

The L293D is rated for about 0.6 A continuous per channel, with brief peaks to about 1.2 A [4]. A stalled motor draws

$$I_{stall} = (V_{bat} - V_{drop}) / R_a \quad (3)$$

where Vdrop is the driver's internal loss and Ra the armature resistance. The driver drop is typically a couple of volts, so a motor on a 12 V battery sees only about 9 to 10 V. The stall current computed from (3) for the fitted motors must stay below the continuous rating, otherwise the chip will overheat on a blocked wheel. If it does not, a stronger driver is the remedy, as noted in Section VII.

E. Run-Time Budget

If each load i draws current Ii for a fraction di of the time, the average current and the run time from a battery of capacity C are

$$I_{avg} = \Sigma\, d_i \cdot I_i, \quad t_{run} = k \cdot C / I_{avg} \quad (4)$$

where k is the usable fraction of capacity, since a lead-acid battery should not be discharged fully. The motors will dominate Iavg whenever the rover is moving, while the ESP32-CAM and the MQ-2 heater form a steady background load. Measuring each Ii, estimating di from a typical inspection pattern and comparing trun with a timed run will check this model.

F. Reading the MQ-2

The MQ-2 output voltage Vout across a load resistor RL gives the sensor resistance

$$R_s = R_L \cdot (V_c - V_{out}) / V_{out} \quad (5)$$

and the ratio Rs/R0, with R0 taken in clean air after warm-up, indicates a change relative to baseline. Without gas-specific calibration this ratio does not give ppm, and the display should present it only as a relative level.

VI. DISCUSSION AND LIMITATIONS

A. Wireless Operation

Both control and video depend on Wi-Fi coverage and on interference in the 2.4 GHz band. A shared access point also means that heavy video traffic can reduce the margin for command packets, which is why the stop timeout matters. The wireless services described here have no access control, so they are suitable for a laboratory network and not for open public use without authentication.

B. Sensors

GPS reception is poor indoors and near tall structures. The ultrasonic sensor can miss soft, angled or very thin objects. The DHT11 has limited accuracy and is sensitive to heat from nearby motors and regulators. The MQ-2 is non-specific and must not be quoted as an air-quality index.

C. Power and Drive

The L293D is the most likely weak point if the motors draw high stall current. The ESP32-CAM is sensitive to supply dips, and a shared regulator that also feeds the MQ-2 heater may cause resets during streaming. Separate rails or additional capacitance are cheap remedies.

D. Limitations

No measured data were recorded, so Section V rests on ratings and theory. The ATmega model and the pin allocation are not yet documented in a final schematic. The rover is manual and has no autonomous navigation, traffic handling, object recognition or cloud service. It has been exercised only in controlled conditions.

VII. CONCLUSION AND FUTURE WORK

We have built a Wi-Fi driven inspection rover that carries a camera, temperature, humidity, gas and distance sensors, a GPS receiver and a local display on a battery-powered chassis. Its three-board design keeps video apart from motor control, and a stop-on-timeout rule limits the effect of a lost link. The analysis shows where the design needs attention: temperature compensation of ranging, level shifting on the 3.3 V modules, a stall-current check on the L293D, and a measured power budget. Its intended role is supervised observation, not autonomous road use.

Future work will log every test in Table III, record the schematic and pin map, replace the L293D with a driver chosen from measured stall current, add wheel encoders, use the DHT11 temperature to compensate ranging, log GPS points with timestamps on a map, add battery monitoring and access control to the wireless services, and add obstacle warning with automatic stopping before any autonomy is attempted.

ACKNOWLEDGMENT

The authors thank Prof. Vishwanathswamy B for guidance throughout this project, and the Department of Electronics and Communication Engineering, S. G. Balekundri Institute of Technology, Belagavi, for the facilities, laboratory staff and classmates who supported assembly and testing.

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