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Labview-Controlled ESP32-Based Smart Vehicle Health and Vibration Monitoring System

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ABSTRACT.

This paper presents the design and preliminary experimental evaluation of a compact smart vehicle health monitoring system based on an ESP32 microcontroller and LabVIEW. The prototype combines wireless vehicle control with real-time acquisition of electrical, rotational, distance, and inertial parameters. An ACS712 current sensor monitors motor current, an optical slot sensor estimates wheel rotational speed, an HC-SR04 ultrasonic sensor provides obstacle-distance information, and an MPU6050 inertial measurement unit provides three-axis acceleration data. The ESP32 communicates with a LabVIEW supervisory application through Wi-Fi using TCP/IP. LabVIEW provides vehicle control, live sensor visualization, waveform monitoring, data logging, and a condition-dependent health assessment framework. Preliminary measurements were collected under stationary, forward, reverse, left-turn, and right-turn conditions. The measured operating-condition differences provide initial reference values for subsequent anomaly and health-index development.

1. Introduction

Vehicle condition monitoring uses measured electrical, mechanical, and inertial parameters to identify changes from normal operation. A mobile laboratory platform is useful because motor loading, wheel speed, vibration values, and turning conditions can be observed together rather than as isolated measurements.

This work develops a four-wheel-drive model vehicle using an ESP32 as the embedded controller and LabVIEW as the supervisory measurement and control environment. The system wirelessly transmits sensor measurements to LabVIEW and receives motion commands from the same interface. The principal objective is to establish experimentally measured reference data for different operating conditions and use those references as the foundation for vehicle health assessment.

Because current and rotational speed depend strongly on the commanded operating condition, separate references are used for stationary, forward, reverse, left-turn, and right-turn states rather than applying one global threshold.

The main contribution of this work is the integration of wireless ESP32-based multi-parameter sensing with LabVIEW-based supervisory control and condition-dependent vehicle health assessment. Unlike a single global threshold approach, the proposed framework establishes separate healthy reference conditions for different vehicle commands and operating states. The system provides a common platform for monitoring motor current, wheel rotational speed, and inertial acceleration while simultaneously enabling wireless vehicle control and data visualization. The present work focuses on establishing the experimental platform and preliminary reference dataset, while statistical validation and fault-specific diagnosis are identified as subsequent development stages.

2. System Objectives

• Develop a wireless ESP32 sensor-acquisition and vehicle-control platform.

• Control the four-wheel-drive vehicle from a LabVIEW graphical interface.

• Acquire motor current, wheel rotational speed, obstacle distance, and three-axis acceleration.

• Display live measurements and waveforms in LabVIEW.

• Collect experimental reference data for different operating conditions.

• Provide a foundation for condition-dependent vehicle health and vibration assessment.

3. System Architecture

The prototype consists of a four-wheel-drive acrylic chassis, ESP32 controller, L298N motor driver, sensing modules, wireless TCP/IP communication, and LabVIEW supervisory software. The ESP32 performs sensor acquisition and motor control. Sensor values are formatted as comma-separated data and transmitted to LabVIEW.

Table 1. System components and their functions.

Component	Function
ESP32 	Sensor acquisition, motor control and TCP/IP communication
L298N 	Drives the four DC motors
ACS712 Current Sensor - 5 Amps 	Measures motor supply current
Optical slot speed sensor 	Generates wheel-rotation pulses
MPU6050 / GY-521 	Measures three-axis acceleration
HC-SR04 	Measures obstacle distance and prevent the vehicle from collision or damages
LabVIEW	Control, visualization, logging and health assessment

3.1 Hardware Implementation

3.1.1. Motor Drive

The prototype uses a four-wheel-drive acrylic chassis with geared DC motors. An L298N dual H-bridge interfaces the motors to the ESP32. The two motors on each side are connected in parallel so that both motors receive the same polarity. A two-cell 18650 battery arrangement provides a nominal motor supply of approximately 7.4 V. During the present prototype testing, the ESP32 is powered independently through USB.

3.1.2. Current Measurement

An ACS712 5 A current sensor is placed in series with the motor supply. Its analog output is connected to ESP32 GPIO32 through a resistor divider. Current is estimated using the nominal sensitivity of approximately 185 mV/A. Because the sensor has a zero-current offset, stationary measurements are used to characterize the measurement offset before condition assessment.

3.1.3. RPM Measurement

An optical slot sensor generates wheel-rotation pulses. The ESP32 counts the pulses using an interrupt input and converts the count to revolutions per minute. The present configuration uses one pulse per revolution.

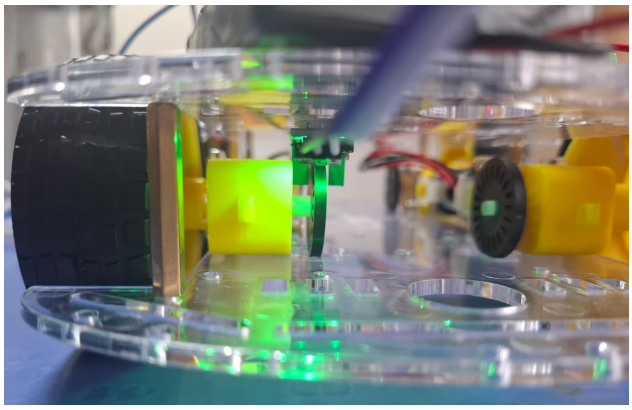


Fig. 1. Speed sensor mounted on the disc connected to wheel.

3.1.4. Inertial Measurement

The MPU6050 communicates with the ESP32 through I2C using GPIO21 (SDA) and GPIO22 (SCL). The accelerometer is read in the ±2 g range. Raw acceleration contains both dynamic acceleration and gravity; therefore, the raw values are not directly treated as calibrated vibration severity.

3.1.5. Ultrasonic Measurement

The HC-SR04 provides obstacle-distance information. TRIG is connected to GPIO5 and ECHO is connected to GPIO34 through a resistor divider. The ultrasonic measurement is treated as an obstacle/safety parameter rather than vehicle travel distance.

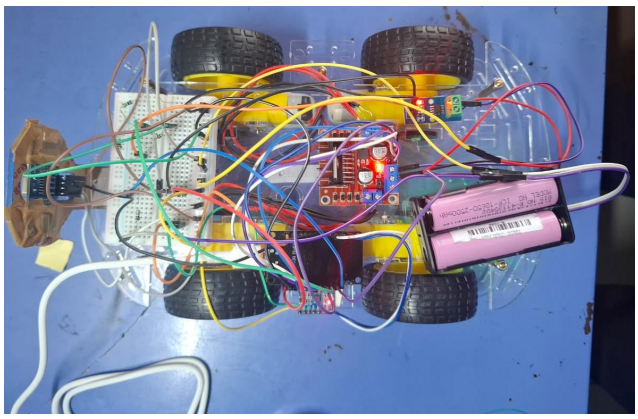


Fig. 2. Full hardware model image.

3.2. Software and TCP/IP Communication

The ESP32 firmware initializes the sensors, establishes Wi-Fi, starts a TCP server on port 8080, processes motion commands, and periodically transmits sensor data. LabVIEW opens the TCP connection, reads the comma-separated packet, converts it into a numeric array, displays the values, and sends vehicle commands.

The transmitted packet format is: Current, Distance, RPM, AccelX, AccelY, AccelZ. Array indices 0–5 correspond to these six parameters respectively.

3.3. Vehicle Control

The LabVIEW interface provides Forward, Reverse, Left, Right, and Stop commands. Commands are encoded and transmitted through TCP/IP. The ESP32 interprets the command and applies the corresponding L298N input states. Differential steering is used for turning.

Table 2. Vehicle control commands.

Command	**Action**
F	Forward
B	Reverse
L	Left turn
R	Right turn
S	Stop

3.4. Condition-Dependent Health Assessment

The proposed vehicle health assessment is based on reference measurements obtained during healthy operation under known operating conditions. Since motor current, rotational speed, and vibration characteristics vary with the commanded vehicle state and mechanical loading, separate reference values are considered for stationary, forward, reverse, left-turn, and right-turn conditions. For a measured parameter x and its corresponding healthy reference x_ref, the absolute deviation is calculated as: $e = |x - x_{ref}|$.

The deviation can subsequently be converted into a normalized condition score using an experimentally determined tolerance T, as $S = 100(1 - e/T)$, with the score limited to the range 0–100. A measurement equal to the reference therefore produces a score of 100, while a deviation equal to or greater than the selected tolerance produces a score of 0. For the STOP condition, zero RPM is considered the expected healthy value and therefore receives a high RPM score rather than being interpreted as a fault. Current measurements are first corrected for the ACS712 zero-current offset. For vibration assessment, raw accelerometer values are not directly used as vibration severity because the measured Z-axis contains the gravitational component. Vibration severity is proposed to be derived from the dynamic acceleration component after gravity removal. Dynamic acceleration features such as RMS and peak acceleration are therefore proposed after removal of the static component. The individual current, RPM, and vibration scores can subsequently be combined using equal weighting to obtain an overall health index. The tolerance values are considered experimental parameters and require validation using a larger healthy dataset. Both current and RPM can change because of load, not necessarily because the vehicle is unhealthy.

Table 3. Condition vs Parameter behavior examples.

Condition	**Current**	**RPM**
Flat surface, light load	Lower	Higher
Incline/heavier load	Higher	Lower
Obstacle/resistance	Higher	Lower
Turning	Can change	Can change
Motor/gearbox problem	May increase	May decrease

4. Preliminary Experimental Results Used for Fixing References

4.1. For STOP condition, setting references:

(i) Resting RPM: All readings showed RPM = 0.00. All stationary measurements produced 0 RPM, which is consistent with the expected stopped condition. So for the STOP condition: RPM_baseline = 0. A health score of 0 should not be given when the RPM is 0 for STOP, as zero RPM is healthy in this state. However, for a moving vehicle, 0 RPM is not healthy. Therefore, reference values have to be set for all conditions individually.

(ii) Accelerometer readings: The readings were approximately: Axis X: -0.018 to +0.015 g (~0 g); Axis Y: 0.027–0.040 g (~0.033 g); Axis Z: 1.139–1.181 g (~1.17 g). The important observation is Z ≈ 1.17 g, which is primarily the effect of gravity on the three-axis acceleration measurements of the sensor, not a vibration value. The MPU6050 is sitting still, so it detects Earth's gravitational acceleration. For a stationary sensor, ideally the acceleration magnitude is around sqrt(X^2 + Y^2 + Z^2) ≈ 1 g. Our value is somewhat above 1 g, which can be due to sensor offset/calibration.

(iii) Current: The current readings range approximately from -0.9 to +0.43 A while the car is stopped. That is too much variation to interpret directly as actual motor current when the motors aren't running. This suggests the ACS712 measurement has noticeable zero-offset/noise, so don't use Current = 0 A as your raw baseline yet. More importantly, your negative current values don't mean the battery is actually receiving current; they're an artifact of the ACS712 zero-current offset/calculation. We should calculate a better zero-current offset from these stationary readings.

4.2. Giving scores from the set references:

For a sensor where the healthy reference is R, Error = |Measured - Reference|. Then define an acceptable tolerance T, yielding a score of Score = 100(1 - Error/T), limited to 0–100. Exactly at reference -> 100, small deviation -> high score, at the tolerance limit -> 0, beyond tolerance -> 0.

Tolerance (T) is the maximum acceptable difference between the measured value and the healthy reference value. In this way, reference values for each condition like forward, reverse, left, and right were tested on a flat surface and given reference values. The final score is the simple average of all the individual scores: H = (S_I + S_R + S_V) / 3. This gives equal importance to current, RPM, and vibration.

Table 4. Preliminary healthy-operation reference measurements under different vehicle commands.

Condition	Current (A)	RPM	Accel X (g)	Accel Y (g)	Accel Z (g)
Rest	−0.195*	0	~0	0.034	1.17
Forward	0.634	2148	0.309	0.505	0.988
Reverse	1.528	1656	−0.301	0.321	1.183
Left	0.957	0	0.618	0.235	0.881
Right	0.941	1740	0.175	0.560	1.106

* The values represent preliminary reference values obtained from the available healthy-operation samples and are not statistically validated operating limits.

* The resting current is the measured ACS712 offset and should not be interpreted as actual negative power consumption.

The preliminary data show clear operating-condition dependence. The selected Forward samples produced approximately 0.634 A and 2148 RPM. Right-turn measurements produced approximately 0.941 A and 1740 RPM, while the Left-turn configuration produced approximately 0.957 A and 0 RPM for the monitored wheel. Reverse measurements produced approximately 1.528 A and 1656 RPM after excluding the initial low-speed transient samples.

Acceleration values also changed with operating condition. Values near 1 g on the Z axis indicate the influence of gravity. Therefore, the present acceleration data should be regarded as raw motion measurements rather than final vibration severity values. Future processing will remove the static component and calculate vibration features such as RMS, peak, crest factor, and frequency-domain characteristics when an adequate sampling rate is available.

4.3. LabVIEW Supervisory Interface

The LabVIEW front panel integrates TCP connection parameters, vehicle controls, raw sensor indicators, RPM and current waveform displays, vibration-related indicators, and an overall health display. Connection status, current command, sample count, data-logging controls, nominal battery voltage, and estimated power can also be displayed. Recommended logged fields are Time, Command, Current, Distance, RPM, AccelX, AccelY, and AccelZ.

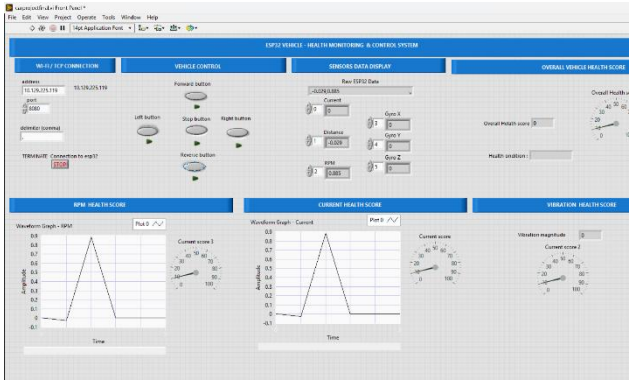


Fig. 3. Image of LabVIEW car control and health monitoring dashboard.

4.4. Energy Estimation

For the present prototype, electrical power is estimated using the nominal battery voltage (7.4 V) rather than a directly measured battery voltage. Therefore, the resulting energy value represents an estimation and not a real-time measurement of battery energy consumption.

The electrical measurements can support an energy-monitoring layer. Estimated instantaneous power is P = V I, and energy can be estimated by integrating power over time. Since the HC-SR04 measures obstacle distance rather than vehicle travel distance, it is not used directly to calculate vehicle energy-per-distance efficiency.

5. Future Work / Scope

• Collect larger healthy datasets for every operating condition under controlled surface and battery conditions.

• Calibrate the ACS712 zero-current offset and improve current stability.

• Increase local accelerometer sampling and implement gravity removal and vibration-feature extraction.

• Develop command-dependent health scoring using experimentally determined limits or multivariate anomaly detection.

• Add battery-voltage sensing for real-time power and energy estimation.

• Implement automated LabVIEW data logging and statistical analysis.

• Evaluate the system using controlled mechanical or electrical fault conditions.

6. Limitations

The present study has several limitations. The experimental dataset is relatively small and was collected from a prototype vehicle under limited operating conditions. The ACS712 measurements exhibit noticeable zero-current offset, while the accelerometer measurements include gravitational and sensor-offset components. Therefore, the current results are considered preliminary reference measurements rather than validated fault thresholds. The present RPM measurement also depends on the selected pulse-per-revolution configuration. Furthermore, detailed vibration analysis requires a higher local accelerometer sampling rate than the present wireless transmission interval. The proposed health score therefore represents a framework for condition assessment rather than a validated diagnostic system.

7. Conclusion

A compact ESP32- and LabVIEW-based smart vehicle health monitoring prototype has been developed and experimentally tested. The system integrates wireless vehicle control with current, RPM, obstacle-distance, and three-axis acceleration measurements. Preliminary results demonstrate that these measurements vary with operating condition, supporting the use of condition-specific reference values.

The prototype provides a practical platform for embedded instrumentation, wireless data acquisition, and vehicle condition monitoring. Further calibration, larger datasets, and dedicated vibration processing are required before the health index can be considered validated. The proposed architecture provides a foundation for these improvements.

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