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Real-Time Monitoring of Induction Motor Parameters Using ESP32 and MQTT Protocol

Israel Gondres Torné, Rubem Silas Dias Silva, Lennon Brandão Freitas Nascimento, Alejandro González Ramírez
Electrical Engineering Department- School of Technology. State University of Amazonas. Brazil.

INTRODUCTION & AIM

Three-phase induction motors are widely used in industrial systems and represent a substantial share of electrical consumption in Brazil. According to data from the Brazilian Energy Research Company (EPE), around 35% of the country's energy production is directed to the industrial sector, and electric motors account for approximately 50% of this demand. Despite their high reliability, induction motors are susceptible to failures caused by factors such as aging, installation conditions, improper applications, and mechanical or electrical stresses, which often result in unplanned downtime and productivity losses. In an increasingly competitive industrial environment, continuous monitoring of motor operating conditions is essential to support predictive maintenance strategies and enhance equipment reliability while reducing operational costs.This work presents the development and implementation of a real-time monitoring system for electrical and mechanical parameters of three-phase induction motors using embedded Internet of Things (IoT) technologies. The proposed solution integrates an ESP32 microcontroller with multiple sensors for measuring temperature, vibration, current, and voltage. Data are wirelessly transmitted using the MQTT protocol to a Python-based monitoring interface that provides real-time visualization through a graphical dashboard. The firmware was developed using FreeRTOS to manage concurrent tasks for sensor acquisition and communication, ensuring synchronization and efficient processing. The hardware architecture includes two custom printed circuit boards: one dedicated to sensor acquisition and system control, and another for power quality analysis using the ADE7758 chip. Validation tests performed in a laboratory environment demonstrated the system's ability to record relevant operational changes, capturing temperature and vibration variations during startup and steady-state operation, as well as current and voltage fluctuations influenced by noise and assembly factors. The proposed solution reinforces the viability of IoT-based monitoring for improving reliability, reducing downtime, and supporting data-driven maintenance decisions in industrial environments.

METHOD

This section presents the tools and methods employed in the development of this work. The proposed hardware system consists of four primary elements, as illustrated in Fig. 1. The central element is the control unit, which is responsible for managing the measurements acquired from the sensing peripherals and for transmitting the recorded data using the Message Queue Telemetry Transport (MQTT) communication protocol. The remaining elements comprise dedicated hardware modules for the measurement of physical and electrical quantities, including vibration, temperature, and electric power quality.

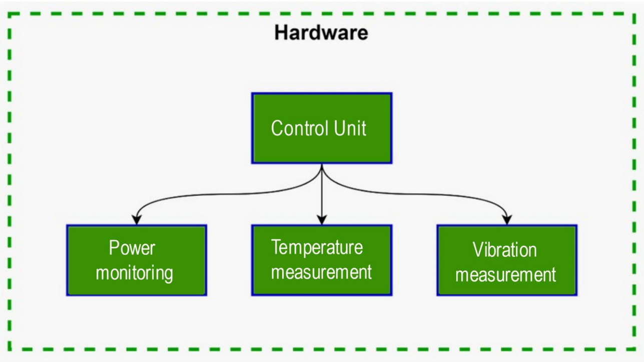
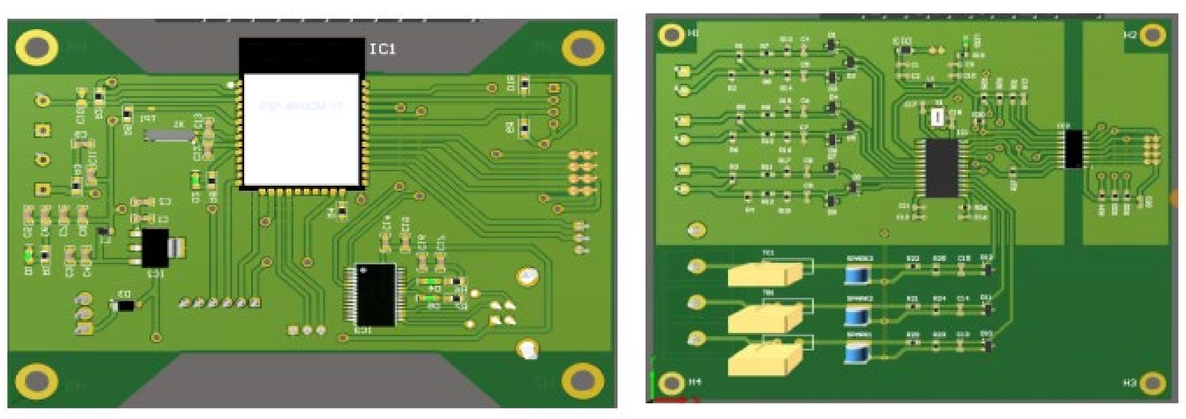


Figure 1. Hardware system. Source: Authors.

The control unit was implemented using the ESP32-WROOM-32D microcontroller due to its available resources, including 520 kB of RAM, Wi-Fi connectivity, native support for real-time operating systems, and dual-core processing, meeting the requirements of the proposed application. The microcontroller was integrated into a PCB providing the necessary operational interfaces and communication with the sensing peripherals through I²C, SPI, and UART buses. The circuit layout is shown in Fig. 4(a).The monitoring unit was designed for measuring electrical parameters of the three-phase induction motor. The ADE7758 integrated circuit was selected because it is a dedicated device for power-quality measurement and is widely used in industrial applications. The first stage of the hardware includes three voltage measurement channels and three current measurement channels, as illustrated in Fig. 4(b).

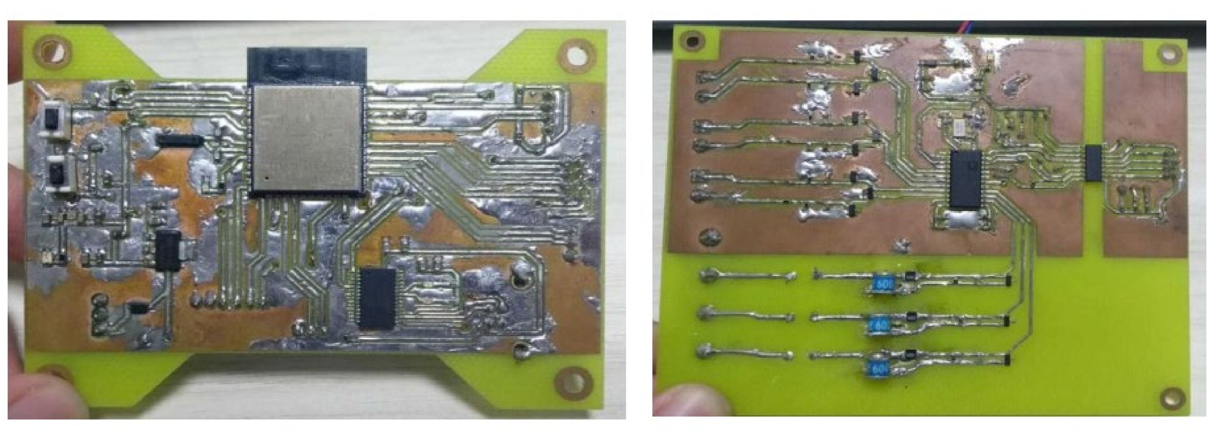


(a) (b)

Figure 2. 3D representation of printed circuit boards: (a) Management board, (b) Energy meter. Source: Authors.

RESULTS & DISCUSSION

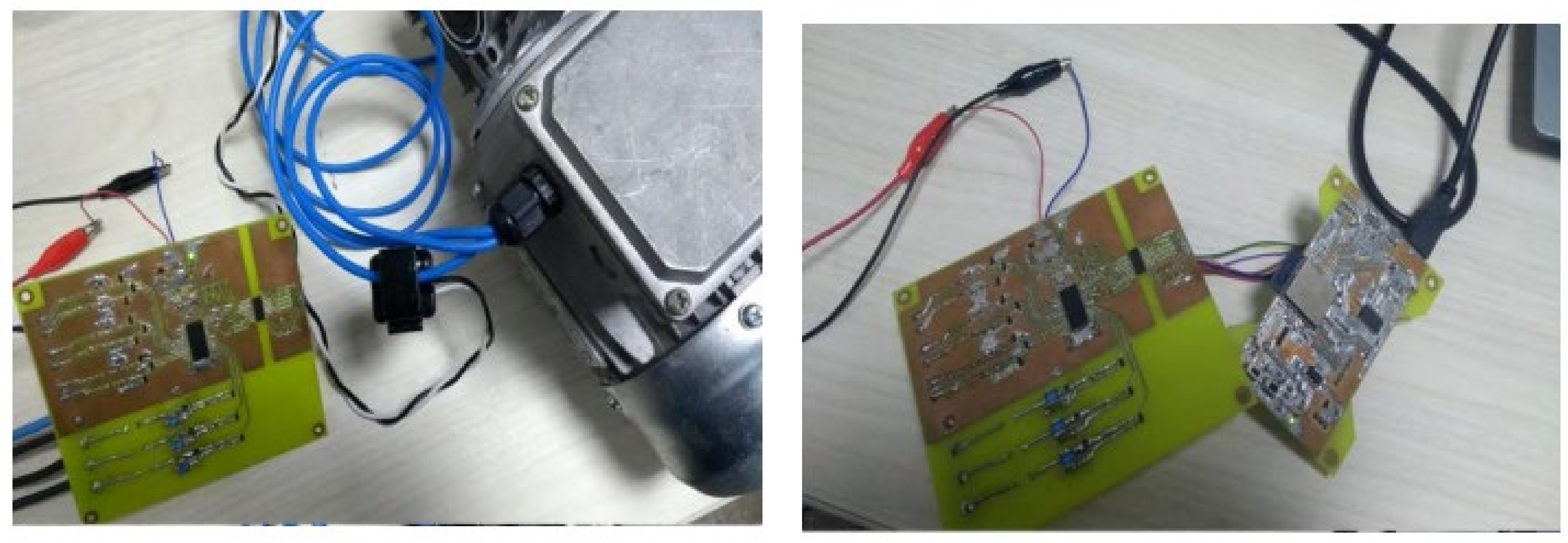
As a result of the embedded hardware development, printed circuit boards were produced for both the control unit and the power-quality measurement module. Figure 3 presents the final stage of the assembled boards.



(a) (b)

Figure 3. Assembled printed circuit boards: (a) Control unit, (b) Power-quality meter. Source: Authors.

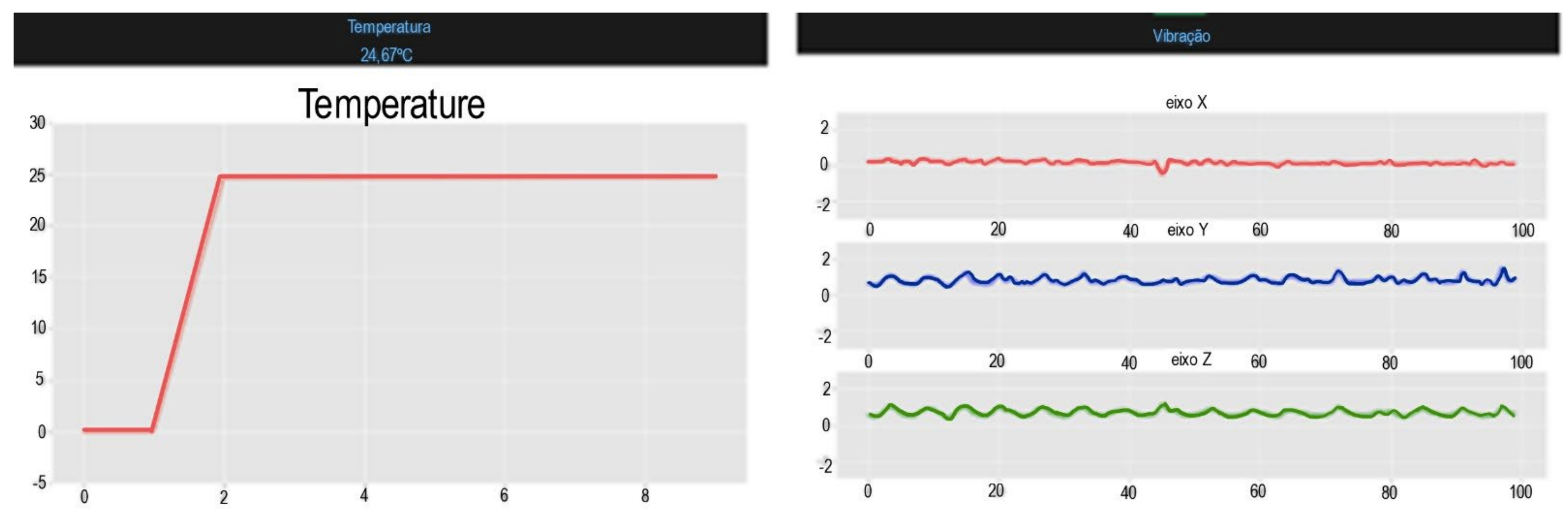
Figure 4 presents the integration test scenarios of the system hardware with a three-phase induction motor.



(a) (b)

Figure 4. Test and validation stages with the three-phase induction motor: (a) Integration of the power-quality meter with the induction motor, (b) Integration of the management board with the power-quality meter. Source: Authors.

To validate the firmware functionalities, integration tests were carried out between the PCBs, the firmware, and the data visualization application, producing the results shown in Figure 5.



(a) (b)

Figure 5. Real-time plotting: (a) Temperature levels, (b) Measured vibration levels. Source: Authors.

CONCLUSION

The development board demonstrated satisfactory results regarding the measurement of vibration and temperature sensors. The heat dissipated by the motor was minimal because, under the tested condition, it operated without mechanical load. Nonetheless, the temperature measurements obtained from the sensor were consistent with the temperature near the motor, although showing limited variation in response to changes in motor temperature.The vibration sensor adopted—an accelerometer—also performed successfully. It was possible to mount it onto the motor and capture vibration signals from the motor chassis. The results showed clear vibration responses during motor startup, where higher oscillation levels were observed, and during steady-state operation, where vibration remained comparatively stable.It is important to note that the region near the motor is susceptible to electromagnetic noise generated by the coils. This interference affected the I²C communication bus that links the temperature and vibration sensors to the control unit.The energy meter board test produced results close to the expected values for voltage and current measurements; however, the acquired values presented unusual fluctuations due to assembly limitations. Even so, the sensor readings and the energy meter outputs were satisfactory, and the combined performance of both boards was effective during testing.Based on research conducted throughout the project and the system development stage, opportunities were identified for extracting additional information through motor vibration analysis. Therefore, future work may explore vibration frequency-spectrum analysis and the use of artificial intelligence techniques for machine-state recognition based on the collected measurements.

FUTURE WORK / REFERENCES

Com base nos resultados obtidos, o trabalho futuro poderá concentrar-se no desenvolvimento de um sistema aprimorado de diagnóstico e predição de falhas em motores de indução trifásicos, utilizando a análise espectral dos sinais de vibração e técnicas de processamento avançado de sinais, como FFT e Wavelet. Além disso, recomenda-se a aplicação de modelos de aprendizado de máquina para a classificação automática do estado operacional do motor a partir da combinação dos dados de vibração, temperatura e grandezas elétricas. Espera-se, com isso, aprimorar a capacidade de detecção precoce de anomalias e oferecer suporte à manutenção preditiva. Outras melhorias poderão incluir o refinamento do projeto eletrônico para redução de interferência eletromagnética e aumento da precisão das medições.

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