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Proceeding Paper

Development of an Embedded IoT Platform for Acoustic Emission Monitoring in Industry 4.0 †

Lucas Zanasi Matheus [1], Paulo Vitor Pereira Oliveira [1], Fabio Romano Lofrano Dotto [1,*], Pedro de Oliveira Conceição Junior [1], Alessandro Roger Rodrigues [2] and Marcio Marques da Silva [3]

1 Department of Electrical and Computer Engineering, São Carlos School of Engineering (EESC), University of São Paulo (USP), São Carlos 13566-590, São Paulo, Brazil; lucaszanasi@usp.br (L.Z.M.); paulo_vitor@usp.br (P.V.P.O.); pedro.oliveiracjr@usp.br (P.d.O.C.J.).
2 Department of Mechanical Engineering, São Carlos School of Engineering (EESC), University of São Paulo (USP), São Carlos 13566-590, São Paulo, Brazil; roger@sc.usp.br
3 Antonio Adolpho Lobbe College of Industrial Mechatronics Technology (SENAI), São Carlos 13574-320, São Paulo, Brazil; marcio.msilva@sp.senai.br
* Correspondence: fabio.dotto@usp.br

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Abstract: This work presents a system combining hardware and embedded software to simplify the acquisition of acoustic emission signals using a wireless IoT sensor. Integrated into a larger ecosystem, the system supports fault diagnosis, feature extraction, pattern classification, and cloud interface. It consolidates complex apparatus into a single tool, enabling remote sensor configuration during tests. The system also incorporates computational models for feature extraction and failure analysis, organizing tests through forms without needing external computers. This innovation advances the use of acoustic emission sensors in line with Industry 4.0, enhancing IoT sensor applications and improving manufacturing process efficiency.

Keywords: acoustic emission; IoT sensor; embedded IoT platform; Industry 4.0

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1. Introduction

Industry 4.0 is characterized by the integration of digital technologies into industrial processes, with a focus on efficiency, connectivity, and automation. It is driven by the Internet of Things (IoT), which connects machines, devices, and sensors to collect real-time data and monitor production processes. This technological transformation improves resource utilization and enhances precision in critical processes such as drilling and grinding [1], in addition to optimizing tool wear monitoring in milling [2].

Acoustic Emission (AE) sensors play a crucial role in real-time fault detection, identifying issues such as tool wear and microcracks in metallic and composite materials [3]. When integrated with IoT technologies, these sensors enable remote monitoring and generate data for predictive analysis, helping to prevent failures and optimize equipment maintenance [1]. AE sensors, made with low-cost piezoelectric materials, have proven to be efficient, particularly in automated manufacturing environments [4].

This industrial model, which combines advanced sensors with real-time data processing technologies, is fundamental to the success of Industry 4.0, where continuous monitoring and predictive maintenance become competitive advantages [5]. However, the application of IoT-based AE sensors is still in the early stages of development and requires technological improvements for full industrial implementation. Current models require a complex infrastructure, including cables, power supplies, and data acquisition systems [6].

This work proposes the development of a system consisting of embedded hardware and software, designed to facilitate the collection of acoustic emission signals through a developing wireless IoT sensor. The system will be part of a robust ecosystem, designed to support the implementation of fault diagnosis models, feature extraction, pattern classification, and integration with cloud storage systems.

2. Methodology

The main objective of this work was to develop an embedded software system that centralizes all functions for collecting, processing, and monitoring IoT acoustic emission sensors, eliminating the need for multiple tools. Additionally, the goal was to create integrated hardware housed in a portable case, equipped with a single-board computer (SBC) and a touchscreen LCD for use in field and laboratory testing.

For the IoT integration software, Python was used to develop a graphical user interface (GUI) via the Tkinter library. This interface allows the adjustment of various parameters that vary according to the experiment being conducted, such as gain, sampling rate, digital filter parameters, and the number of samples in the generated data file.

To handle data processing, an algorithm was developed to convert raw binary data from the AE sensor into real number samples for signal analysis. Additionally, basic signal processing and waveform visualization algorithms were implemented to analyze the acoustic emission signals effectively.

For hardware integration, a single-board computer (SBC) with an AMLOGIC S905 CPU and a Linux-based operating system was selected to create an IoT application platform. This setup enabled integration with cloud services via the MQTT protocol, using a Mosquitto broker implementation. The hardware also includes a touchscreen LCD for user interaction and Wi-Fi (IEEE 802.11b/g/n) for wireless communication with the AE sensor and remote data transfer.

Finally, laboratory tests were conducted to integrate the IoT sensor, validating the system's hardware and software functionality. These preliminary trials were performed in a simulated environment using a Mosquitto client, and the results were compared to those from a conventional data acquisition system.

Figure 1 illustrates the architecture of the IoT system implemented for integration with IoT-enabled acoustic emission (AE) sensors, focusing on the collection, processing, and monitoring of acoustic emission data through a wireless data link. As shown in the figure, the system begins with a test configuration that allows the adjustment of various sensor data acquisition parameters, such as gain, trigger, IP address, MQTT port, username, password, connection type, MQTT subscription topic, sampling rate, acquisition window time, IIR digital filter coefficients for feature selection, IoT frame length, standard data analysis statistics, among others.

After configuring these parameters, two key actions take place: (i) the parameters are sent for remote sensor configuration, and (ii) the MQTT server (broker) is set up and activated for cloud integration. At this point, the system establishes an active data link with the AE sensor, enabling the acquisition of signal samples when process events occur. From these events, specific data analysis, feature extraction, and fault diagnosis algorithms can operate, informing the operator if any action is required or automatically adjusting machine parameters to control the process.

The entire interaction is handled via a touchscreen LCD display connected to the hardware, without the need for external systems. Additionally, tests can be registered, organized, and executed according to user-defined settings, creating a local and remote database for historical event logging.

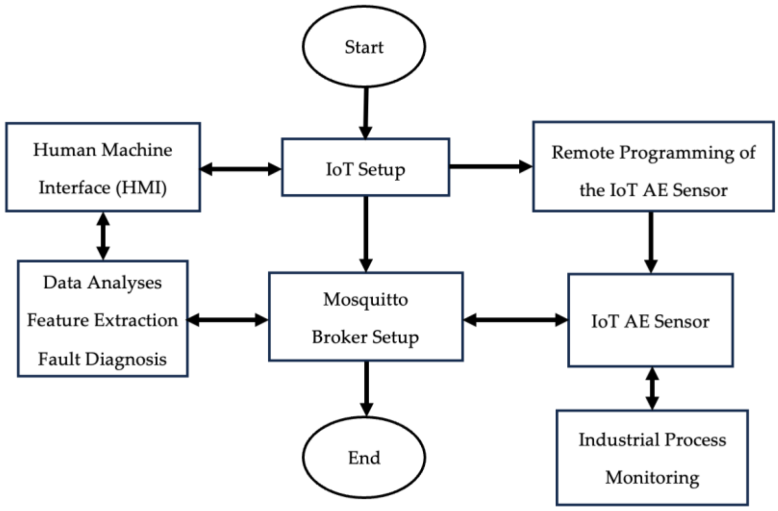


Figure 1. Architecture of the IoT system implemented.

3. Results and Discussion

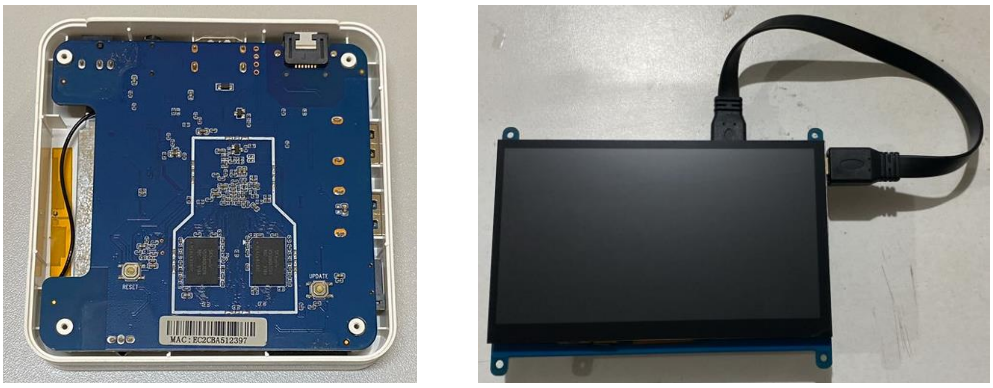
The results of this work include the successful development of a functional portable case equipped with a single-board computer (SBC) and an LCD touchscreen. The system incorporates simple and intuitive embedded software, allowing users to easily adjust the necessary configurations for experiments with the IoT acoustic emission (AE) sensor. Figure 2 shows the internal components of the implemented hardware, including the single-board computer (SBC) and LCD touchscreen, before being integrated into the enclosure.

Traditionally, specific software such as Matlab is required for processing the data collected during experiments, which introduces additional time between experimental tests and increases the risk of data loss. The new approach proposed in this work overcomes these limitations, providing a much faster and more productive way to conduct experiments, significantly improving the workflow compared to conventional methodologies.

This standalone setup simplifies the user's interaction with the sensor by eliminating the need for auxiliary equipment, thus facilitating the execution of experimental tasks and system management. Integrating all functionalities into a single application streamlines the process, removing complex steps that previously required prior experience to connect the sensor to a computer, utilizing non-intuitive software, and facing difficulties in data download.

Figures 3 and 4 illustrate, respectively, the configuration screens of the IoT AE sensor used to prepare the test and the waveform of an AE signal collected via a wireless data link. Validation tests were conducted using a PC with a Mosquitto MQTT client, enabling remote command transmission and reception, simulating an IoT AE sensor. The system proved viable for remote sensor configuration, real-time data acquisition, and cloud integration. The ability to adjust parameters such as sampling rate, digital filters, and data windows directly through the touchscreen interface provides a user-friendly experience and simplifies the execution of experiments.

Additionally, by incorporating algorithms for data analysis, feature extraction, and fault diagnosis within the system, the processing of acoustic emission signals becomes autonomous. This capability enhances the system's potential for predictive maintenance in industrial environments, where early detection of tool wear or process anomalies is critical. By centralizing the configuration and management of these processes, the system improves usability while reducing the time and resources required to conduct experiments with IoT-enabled AE sensors.



(**a**) (**b**)

Figure 2. Internal components of the implemented hardware: single-board computer (**a**) and view of the LCD before being integrated into the case (**b**).

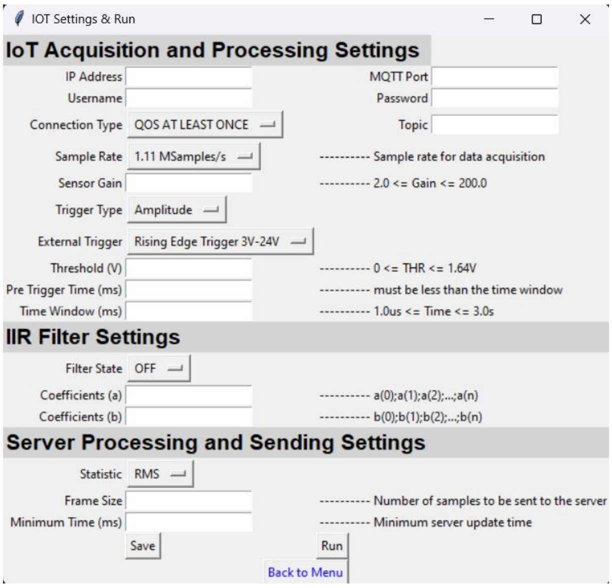


Figure 3. IoT acquisition and processing settings window.

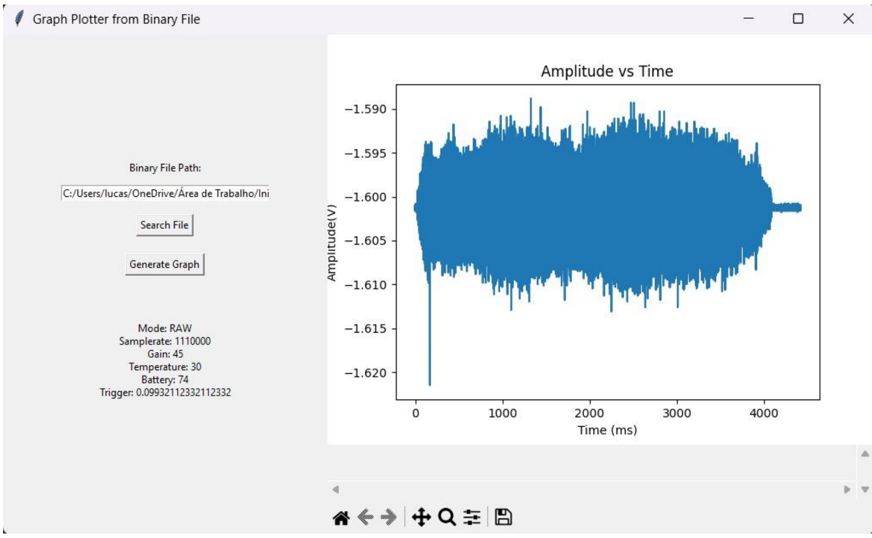


Figure 4. Waveform of an AE signal collected through a wireless data link.

Finally, Table 1 highlights the key differences between the traditional and the new methodologies for using AE sensors, emphasizing the improvements brought by the developed ecosystem. The new solution streamlines data handling and analysis, minimizing delays and reducing the risk of data loss, making it a more efficient and reliable approach to acoustic emission monitoring.

Table 1. Highlights the key differences between the traditional and the new methodologies.

Features	Traditional AE System	IoT Ecosystem Developed
Sensor Integration	Proprietary software, requires licenses, limited use	Unified and open platform, supports data analysis algorithms
Data Acquisition	Manual process, requires multiple software and hardware	Automated data collection with cloud integration and real-time analysis
Hardware Integration	Requires PC, oscilloscope, data acquisition card	Integrated hardware with full support for IoT-based AE ecosystem
Cloud Integration	Additional converters needed for cloud integration	Direct integration with Google Cloud, AWS, and other platforms
Data Storage and History	Specific software needed to save and organize data	Integrated database for data storage and historical logging

4. Conclusions

The development of the IoT ecosystem for integration with acoustic emission (AE) sensors has brought significant advancements compared to traditional methodologies. Given that AE sensors require technological advancements and present operational complexity, demanding specialized equipment and significant expertise from the operator, this study focused on integrating all necessary components into a single device. The goal was to facilitate the pre-configuration and efficient use of these sensors.

The proposed solution, which combines integrated hardware with embedded software in a single, intuitive platform, eliminates the need for multiple auxiliary devices, such as PCs and oscilloscopes, and reduces the reliance on complex proprietary software, like Matlab. The system simplifies the setup and operation of IoT-enabled AE sensors, which are currently being developed by the research group, reducing the complexity of data processing and making the entire process more efficient.

The implementation of algorithms for data analysis, feature extraction, and fault diagnosis enables autonomous real-time processing of AE signals, enhancing the system's potential for predictive maintenance in industrial environments. Additionally, direct integration with cloud platforms via MQTT and support for services like Google Cloud and AWS provides a robust solution for continuous monitoring and remote analysis.

Preliminary tests were conducted through simulation to validate the system's configuration and ensure its future functionality. Field tests will be carried out once the development of the IoT AE sensor by the research group is complete. The touchscreen interface and the ability to adjust parameters such as sampling rates and digital filters further simplify the system's use, making it more accessible and productive for experiments.

Considering the relevance of acoustic emission sensors in various fields of study, the usability and efficiency improvements delivered by this project can contribute to advancements in future research, minimizes the risk of errors and data loss, and facilitates long-term data management, representing a valuable contribution to Industry 4.0 and industrial process monitoring.

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writing—original draft preparation, L.Z.M.; writing—review and editing, L.Z.M., P.V.P.O. and F.R.L.D.; visualization, M.M.D.S., P.d.O.C.J. and A.R.R.; supervision, F.R.L.D.; project administration, F.R.L.D.; funding acquisition, F.R.L.D. All authors have read and agreed to the published version of the manuscript.

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