Collaborative Work for a Virtual Instrumentation Network

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Abstract: Collaborative work in virtual instrumentation networks strengthens teamwork among mechatronics engineering students through a CAN network for monitoring and controlling industrial processes. Strategic tasks were distributed, evaluating indicators of communication, cooperation, and goal achievement. Implementation with ESP-Wroom32 microcontrollers, MCP2515 modules, and digital sensors ensured accuracy in data acquisition. In the production of alcoholic beverages, redundancy was incorporated into sensors for greater safety and reliability. The HMI interface in LabVIEW facilitated real-time visualization, optimizing decision-making. In addition, a standardized protocol was designed to minimize errors in data transmission and an alert system to detect anomalies. The efficient integration of hardware and software enabled reliable automation, while its application in academic settings fostered critical thinking and problem solving with a real-world industrial focus.

Keywords: *Instrumentation, Mechatronics, Teamwork, Networks, Cooperation.*

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I. INTRODUCTION

Technological and economic advancements in recent decades have profoundly reshaped global labor dynamics. Automation, digitization, globalization, and the growing interconnection among industries have created a competitive and specialized environment. These developments have transformed not only professional expectations but also the way educational institutions prepare students for modern careers. Universities are now challenged to remain current and relevant, adapting academic programs, teaching strategies, and evaluation methods to meet the evolving demands of an interdisciplinary and innovation-driven economy.

Vocational training can no longer focus exclusively on technical knowledge. It must also foster cross-disciplinary skills such as critical thinking, adaptability, communication, and—most importantly—collaborative work. These transformations in the labor market are reinforced by economic agreements such as the United States–Mexico–Canada Agreement (USMCA), which has intensified regional competitiveness. The expansion of trade borders and value chains across member nations has increased the demand for skilled professionals capable of addressing both technological and organizational challenges in an integrated economic environment. Consequently, continuous learning, teamwork, and multidisciplinary collaboration are now essential attributes for success in the professional world.

Higher education institutions must therefore not only identify these key competencies but also establish effective strategies to cultivate them through laboratory work, classroom projects, and real-world simulations. Numerous studies emphasize that teamwork is among the most valued skills by employers, as it enhances creativity, fosters efficient collaboration, and facilitates collective achievement of complex goals.

In response to these needs, this project introduces the integration of a virtual instrumentation network using the CAN communication protocol, collaboratively developed by students in a mechatronics engineering program. The initiative not only strengthens students' technical understanding of embedded systems and industrial communication but also nurtures their teamwork, coordination, and decision-making skills—core components of their professional formation. Through shared responsibilities, mutual support, and collaborative problem-solving, students experience a realistic simulation of professional engineering challenges that prepare them to thrive in modern industry.

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➢ *Objectives*

To create a virtual instrumentation network using CAN communication, with the aim of monitoring and controlling industrial processes. The CAN (Controller Area Network) is a high-level communication protocol that was developed by BOSCH in the 1980s for use in the automotive industry, but has been adopted in numerous applications outside this industry, including virtual instrumentation and real-time control systems. The use of CAN in virtual instrumentation allows for the efficient and reliable transmission of information between sensors and actuators [1] , resulting in greater accuracy and speed in data acquisition. It is a high-speed serial network that has proven to be cost-effective, efficient, and very economical. Sensors and actuators can be connected very simply using a twisted pair cable, reaching speeds of 1 MBit/sec with 40 devices simultaneously [2].

Organize course participants to work independently and collaboratively to carry out an activity that has a real impact on the development of the Teamwork graduation attribute.

II. METHODOLOGY

A. *Collaborative Work*

The global demand for qualified professionals continues to grow; however, several studies [3][4] reveal that graduates often demonstrate only moderate levels of essential soft skills compared with industry expectations. Among these competencies, teamwork remains a decisive factor in employability, as confirmed by research across disciplines and regions [5][6]. To address this gap, this study promotes structured collaborative activities designed to foster critical professional abilities and strengthen students' readiness for the job market.

The project was divided into specific stages, with clear task distribution among student teams. Evaluation criteria focused on key indicators of collective performance:

- Effective communication: clarity, consistency, and quality of information exchange among members [7].
- Collaboration and cooperation: extent to which members support one another, share resources, and coordinate efforts [8].
- Goal achievement: ability of the team to meet milestones and deadlines [9].
- Conflict resolution: capacity to manage and resolve disagreements constructively [10].
- Equitable participation: fairness in the allocation of roles and responsibilities [11].

These metrics provide a framework for assessing collaboration and ensure that the work progresses according to the established schedule without direct instructor intervention. The first objective is to guarantee balanced participation, followed by cooperative engagement toward achieving the project's technical goals. Collectively, these indicators guide the activity's execution and support the development of professional competencies aligned with the mechatronics engineering graduate profile [12–14]

➢ *Implementation*

The connection of the virtual instrumentation network is proposed as shown in Figure 1. In this way, we can connect more sensors on demand, in which each node must have a different ID.

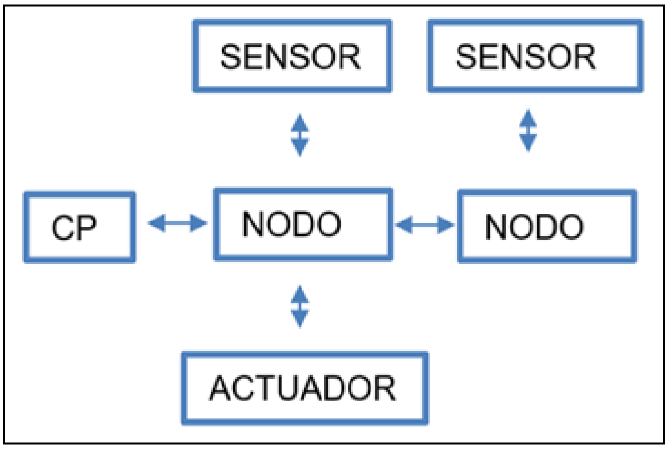

Fig 1 Communication Diagram.

Participants should organize themselves into teams to build each node, assign ID numbers, distribute tasks for building the HMI screen in LabVIEW, and perform system testing.

The connection of the mcp2515 to the ESP Wroom32 controller is made following the diagram shown in Figure 2.

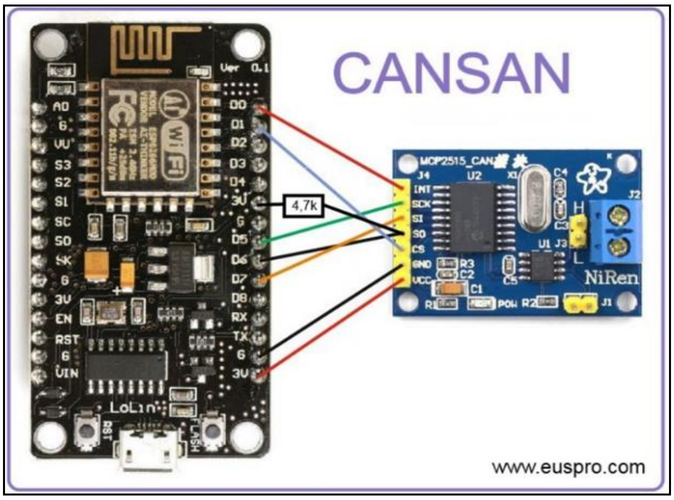

Fig 2 Cansan [22]

➢ *MCP-2515 Connection*

The library published by Cory J. Fowler for using the integrated MCP2515 with the Wroom32 card[15] is used as the basis for programming the cards. This establishes the sending of data packets from the sensors distributed throughout the instrumentation network.

Each sensor implemented is a digital sensor that requires SPI communication or elaborate interaction, as in the case of ultrasonic sensors where an input pulse is measured. For this reason, a microcontroller is needed to process the acquired signals or to interact with the specific sensor. It

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should be noted that it is not possible to communicate such elaborate sensors with a stand-alone CAN node such as the MCP25050[16] , which, although they are CAN nodes with input/output pins, analog-to-digital converters are not capable of processing signals. The sensors implemented in this project are:

- HC-SR04 Short-range ultrasonic sensor[17] .
- HX711 Sensor specialized in reading and processing load cells[18] .
- HW-038 Water level sensor.
- HCSR501 Infrared motion sensor [19].

Most of these libraries are directly available in the Arduino IDE application or online, allowing for rapid implementation of all circuit elements.

B. Application to the industrial process

For the implementation phase, the procedure illustrated in Figure 3 was followed. This diagram outlines the structural design used to build and test the prototype. The system integrates several sensors to monitor key process variables in real time, ensuring accuracy and reliability throughout operation.

Each sensor node is based on an ESP-Wroom32 microcontroller, chosen for its processing capability, connectivity, and compatibility with the Arduino development environment. The nodes communicate through the CAN (Controller Area Network) protocol using MCP2515 modules as interface components. This configuration allows efficient and organized data transmission among distributed nodes, maintaining synchronization and minimizing data loss.

The final node in the network includes an Arduino microcontroller that acts as a bridge between the instrumentation system and a computer. This link is established via serial communication through a virtual COM port, allowing data to be transferred to a LabVIEW-based HMI for monitoring and analysis.

The simulated process represents the final stages of alcoholic beverage production, covering three key phases:

- Final Distillation
- Hydration and Resting
- Bottling and Labeling

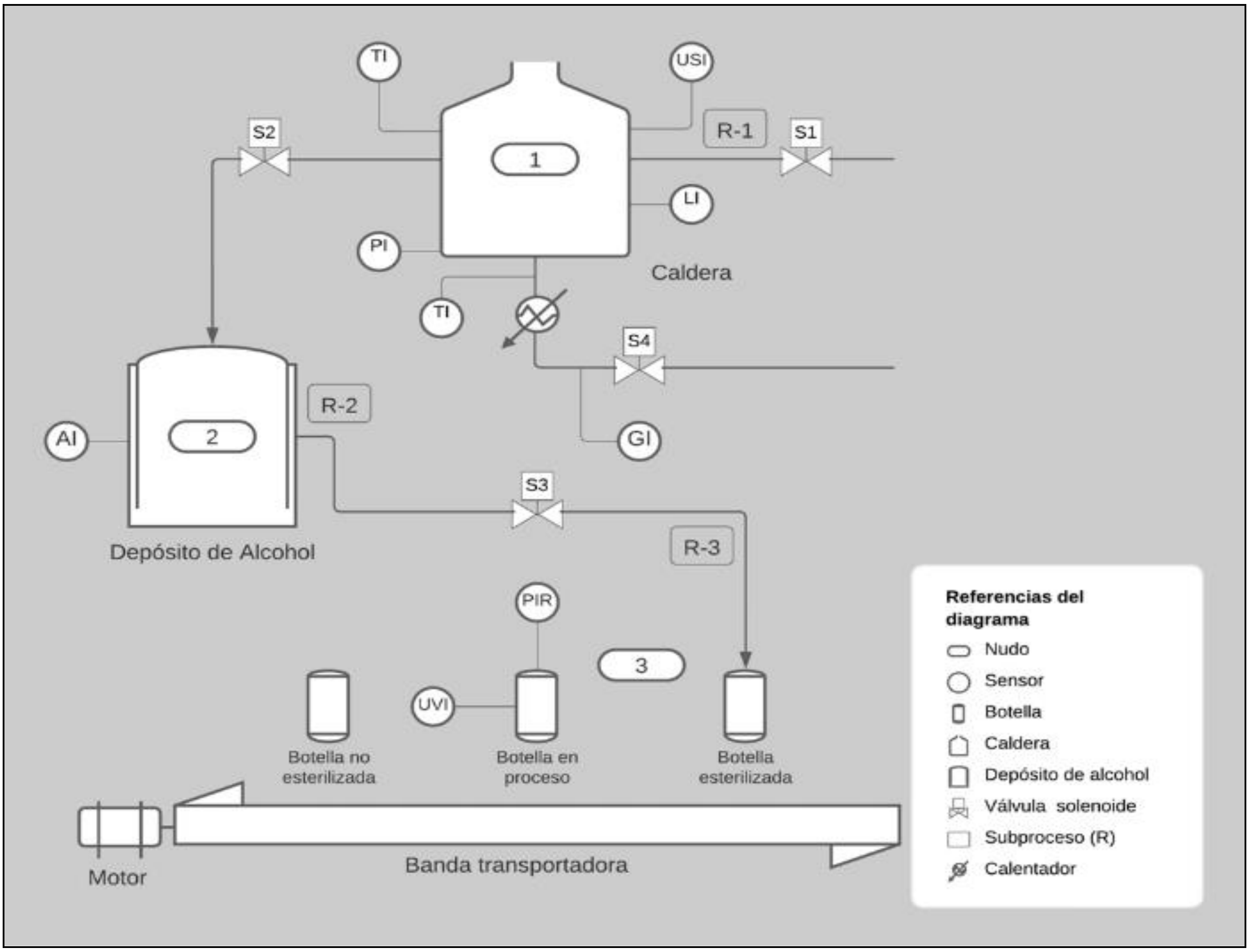

Fig 3 Proposed Process Diagram

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C. Final Distillation

At this stage, it is necessary to ensure that the boiler is lit correctly. As this is a critical stage that involves risks, it was decided to have redundancy in the sensors, i.e., when the command to light the boiler is sent, the correct liquid level must be checked, the gas valve must be opened, the electrode must be lit, and it must be checked that it has lit.

To check the correct liquid level, the information provided by the ultrasonic level sensor (USI), the load cell (PI) at the base of the tank, and the level sensor (LI) is taken into account. This reduces the likelihood of a high-risk event such as ignition without the correct volume of liquid.

To check ignition, an increase in temperature (TI) in the boiler chamber must be noted, and the gas sensor (GI) must not detect the presence of unburned gas. This redundant check consists of the following sensors:

- *Hydration and resting:* Once distilled, it is left to rest before hydration and, once hydrated with water from Galicia and brought to 43°Vol, it is left to rest again before bottling so that everything blends well. The alcohol sensor (AI) is installed in this section to verify that there are no leaks in the gas tank.
- *Bottling and labeling:* In the final stage of the process, the bottles are disinfected with UV light. To verify disinfection, an ultraviolet radiation sensor (UVI) is used to detect a constant level of UV light. During product packaging, a proximity sensor (PIR) is used to check the position of the bottles in the packaging and prevent collisions.

III. RESULTS

To develop the HMI interface (Figure 5) where the information obtained from the sensors will be displayed, it was necessary to send the information through the serial port. This information was found to be easier to structure, read, and process using the JSON structure[20] in LabView. This implementation can be seen in Figure 4.

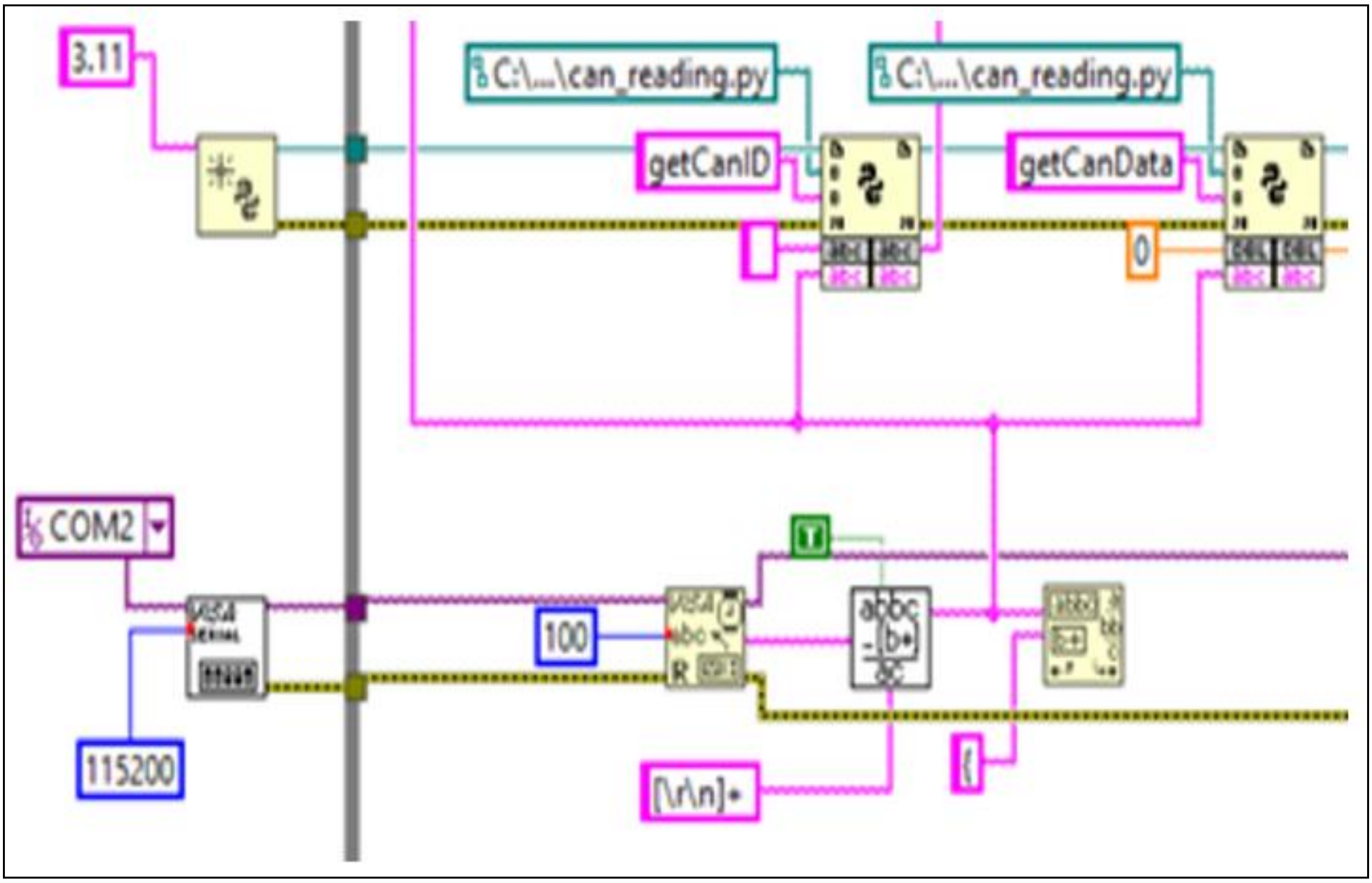

Fig 4 Proposed Implementation with the JSON Structure.

To receive messages through the serial port, it was determined that for this particular project, it worked best this way:

- Open VISA serial communication
- Use a read node
- Extract the necessary information
- Sensor selection
- Display message on indicators

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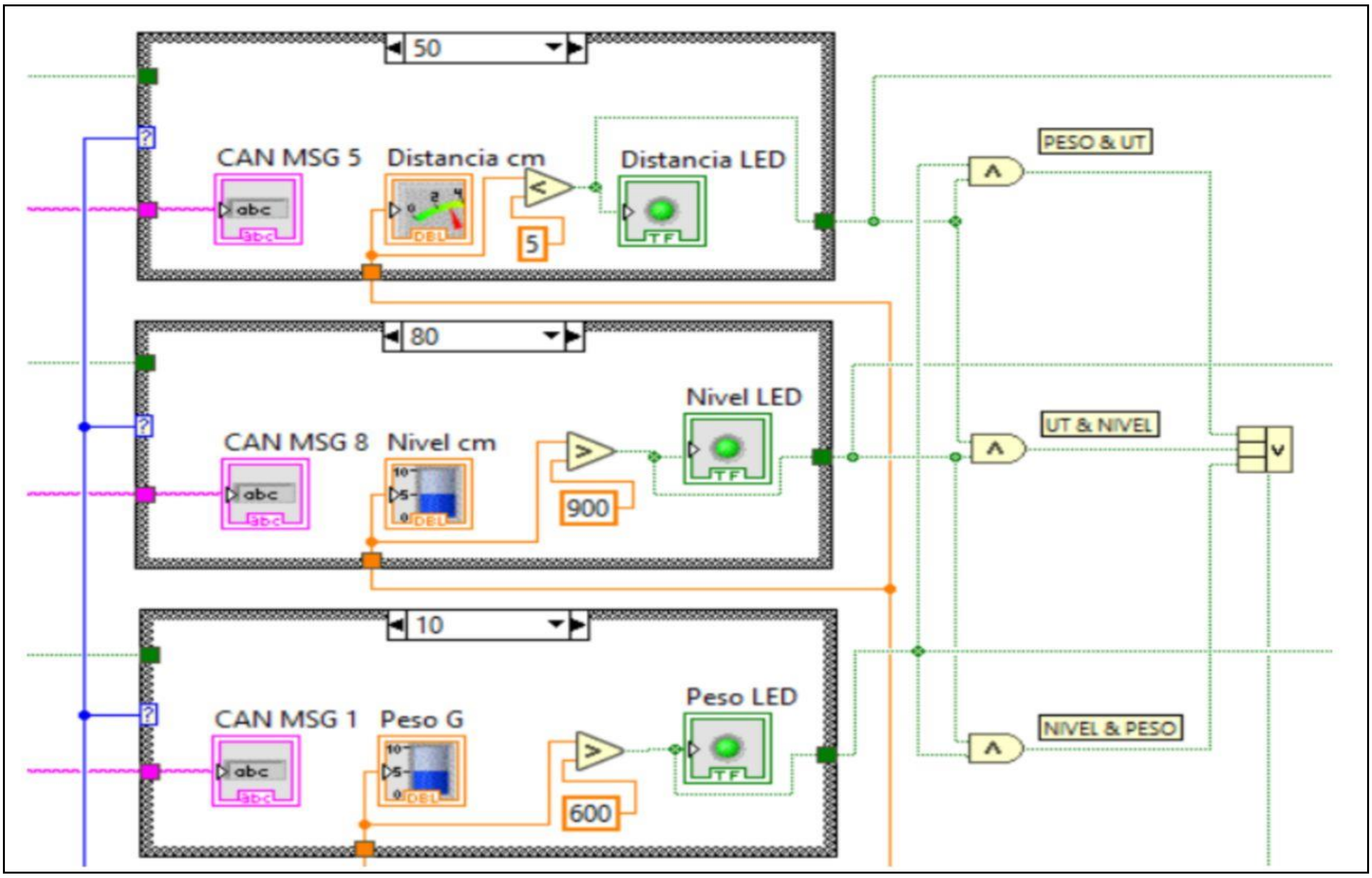

Fig 5 Sensor Redundancy

Using the concept of redundancy [21] for sensors, at least two of the three sensors responsible for monitoring the tank status are required. This function can be seen in Figure 5. If this condition is met, the switch shown in the HMI interface (Figure 6) is enabled.

Fig 6 HMI Interface

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The points established in the collective work indicators were satisfactorily met, which allowed for efficient and organized execution of the project. Throughout the development, key aspects were evaluated, such as timeliness in the delivery of progress, the quality and functionality of the implemented code, as well as the correct interpretation of the proposed system. This rigorous monitoring ensured the constant evolution of the project, allowing for the identification and correction of possible deviations in a timely manner.

One of the most notable aspects was the team's ability to use appropriate technical language, adapted to the context and type of audience. During the follow-up meetings, detailed presentations were given that included clear explanations of the functions and configurations of the main components, such as the ESP-Wroom32 microcontroller and the MCP2515 module. These presentations allowed the team to understand the relevance of these elements in the system architecture, promoting informed decision-making consistent with the project objectives.

The team demonstrated a high level of self-management, organizing and distributing tasks without the need for constant supervision. Activities were planned based on the individual skills of each member, ensuring an equitable distribution of the workload and efficient execution. Each member proactively assumed specific responsibilities. Of particular note was the configuration of the hardware for the CAN network nodes, where the ESP-Wroom32 was integrated with the MCP2515 module, as well as the connection of various sensors that provide critical data for the system.

In addition, the collective work was distinguished by its maturity in conflict management. When differences of opinion or conflicting proposals arose on how to approach a phase of the project, respectful and constructive dialogue was promoted, in which all opinions were listened to with openness. Subsequently, consensus agreements were sought, always prioritizing the benefit of the project and the fulfillment of common objectives. This attitude allowed for a collaborative, focused, and efficient work environment.

Together, these factors contributed to the success of the project, strengthening not only the technical skills of the members, but also key skills such as effective communication, shared leadership, and critical thinking geared toward problem solving. The experience represents a valuable contribution to the students' graduate profile, preparing them to competently face the challenges of the professional environment.

IV. CONCLUSIONS

The integration of hardware and software was successfully achieved, resulting in an efficient, reliable, and scalable technological solution for the monitoring and control of industrial processes. This integration included the implementation of a CAN communication network, the use of ESP-Wroom32 microcontrollers, MCP2515 modules, and various measurement sensors, linked to an interface developed in LabVIEW. This architecture allowed for continuous data flow between the nodes and the central system, facilitating the acquisition, visualization, and real-time analysis of critical process variables.

One of the key points was sensor redundancy, intentionally designed to ensure safety and operational continuity. This strategy mitigated the risk of individual failures, ensuring cross-validation of readings and preventing potentially dangerous events, such as boilers being turned on without sufficient liquid. This redundancy was implemented by combining ultrasonic sensors, load cells, and traditional level sensors.

From a software perspective, the use of advanced digital tools such as LabVIEW allowed data to be processed and displayed clearly and dynamically, facilitating real-time decision-making. The interface was designed with a special emphasis on usability, allowing the user to monitor multiple variables intuitively.

During testing, which lasted an average of four continuous hours, no loss of information or delays in communication between nodes were reported. As a preventive measure, the microprocessors were programmed to turn on an alert LED in the event of data packet loss, but this condition was not activated during testing. This result demonstrates the robustness and reliability of the communication system implemented.

In terms of the human and academic development of the project, a high level of commitment and motivation was observed among the participants. Team members demonstrated initiative, asked relevant questions, conducted additional research, and met the objectives set out in the schedule. Teamwork was characterized by constant, fluid, and conflict-free collaboration, which fostered a positive and enriching learning environment.

Overall, the project not only met the established technical objectives but also strengthened key skills in the students, such as problem solving, collaborative work, self-management, and critical thinking, which are fundamental elements for their future entry into the professional world.

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