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Use of Internet of Things for Monitoring, Automation, and Performance in Industrial Production of Cheese

Uso de Internet das Coisas para Monitoramento, Automação e Desempenho na Produção Industrial de Queijo

Aplicación del Internet de las Cosas en el Monitoreo, la Automatización y la Optimización del Desempeño en la Producción Industrial de Queso

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Abstract
This article describes a solution for monitoring, automation, and control in industrial production. The presented approach combines Internet of Things (IoT), cloud storage, and sensing technologies applied to a cheese manufacturing tank. The sensors attached to the cheese manufacturing tank enable readings of temperature, pH, and level, contributing to process control, streamlining decision-making, and consequently improving product quality. The system can be accessed via the internet, allowing remote access and control, where users select the type of cheese to be produced, and based on the algorithm, the tank autonomously performs the process. The results demonstrate that through the digitization process, it is possible to monitor and act upon the tank, either manually or through autonomous programming, using a multi-technology interface of open-source circuits and code, providing a low investment compared to proprietary solutions in the industrial market. In this present work, in addition to controlling and digitizing equipment data that directly affects profitability, the benefits of the implemented system extend to increased productivity, remote access, cloud storage, and the possibility of adapting industrial equipment (retrofitting) from different scenario segments, which were configured within a framework.
Keywords: Cheese; Cloud Computing; Digitalization; Internet of Things; Raspberry Pi.

Resumo
Este artigo descreve uma solução para monitoramento, automação e controle na produção industrial. A abordagem apresentada combina tecnologias de Internet das Coisas (IoT), armazenamento em nuvem e sensoriamento aplicadas a

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um tanque de fabricação de queijo. Os sensores acoplados ao tanque permitem a leitura de temperatura, pH e nível, contribuindo para o controle do processo, agilizando a tomada de decisões e, consequentemente, melhorando a qualidade do produto. O sistema pode ser acessado via internet, permitindo o acesso e controle remoto, no qual os usuários selecionam o tipo de queijo a ser produzido e, com base no algoritmo, o tanque executa o processo de forma autônoma. Os resultados demonstram que, por meio da digitalização, é possível monitorar e atuar sobre o tanque, tanto manualmente quanto por programação autônoma, utilizando uma interface multitecnológica composta por circuitos e código de fonte aberta, proporcionando um baixo investimento em comparação com soluções proprietárias disponíveis no mercado industrial. Neste trabalho, além do controle e da digitalização dos dados dos equipamentos que afetam diretamente a lucratividade, os benefícios do sistema implementado se estendem ao aumento da produtividade, acesso remoto, armazenamento em nuvem e possibilidade de adaptação de equipamentos industriais (retrofit) de diferentes segmentos, configurados dentro de um framework.
Palavras-chave: Queijo; Computação em Nuvem; Digitalização; Internet das Coisas; Raspberry Pi.

Resumen
Este artículo describe una solución para el monitoreo, la automatización y el control en la producción industrial. El enfoque presentado combina tecnologías de Internet de las Cosas (IoT), almacenamiento en la nube y sensorización aplicadas a un tanque de fabricación de queso. Los sensores acoplados al tanque permiten la lectura de temperatura, pH y nivel, contribuyendo al control del proceso, agilizando la toma de decisiones y, en consecuencia, mejorando la calidad del producto. El sistema puede ser accedido a través de internet, lo que permite el acceso y control remoto, donde los usuarios seleccionan el tipo de queso a producir y, con base en el algoritmo, el tanque ejecuta el proceso de forma autónoma. Los resultados demuestran que, mediante la digitalización, es posible monitorear y actuar sobre el tanque, ya sea de forma manual o mediante programación autónoma, utilizando una interfaz multitecnológica compuesta por circuitos y código de fuente abierta, lo que representa una inversión baja en comparación con soluciones propietarias disponibles en el mercado industrial. En este trabajo, además del control y digitalización de los datos de los equipos que afectan directamente la rentabilidad, los beneficios del sistema implementado se extienden al aumento de la productividad, el acceso remoto, el almacenamiento en la nube y la posibilidad de adaptar equipos industriales (retrofitting) de diferentes segmentos, configurados dentro de un marco de trabajo.
Palabras clave: Queso; Computación en la Nube; Digitalización; Internet de las Cosas; Raspberry Pi.

1. Introduction

The Internet of Things (IoT) can be applied to generate ideas aimed at solving problems and increasing process efficiency. It focuses on maintaining effective communication and interfaces through actuators, robotics, and analyzers (Ashton, 2021). On the other hand, Industrial Internet of Things (IIoT), employed in the industry, is considered a prerequisite for Industry 4.0. IIoT is the interconnection of sensors, instruments, and other network-connected devices that enable remote access and system monitoring. It allows for the activation, analysis, and control of different machines in the industrial sector (Firjan, 2016). Another relevant aspect is that IIoT enables the exchange and analysis of different data sources, which are examined through intelligent functions that send alarms or triggers to other systems. Thus, the use of Industry 4.0 technologies enables tracking, security, and quality management in industrial processing and manufacturing.

In the food industry, for example, studies address process control using automated image sensors and weight control to monitor the amount of food waste generated (Jagtap et al., 2021); management in the food supply chain (Baralla et al., 2020); the use of sensors for color reading in food (Jain et al., 2020); the employment of sensors for cheese ripening (Teixeira et al., 2020); and the use of sensors for low-cost industrial process control (Paladino et al., 2019). However, there are few studies addressing the implementation of low-cost IoT technologies for cheese manufacturing, making it difficult for small and medium-sized producers to access them. Through IoT, it is possible to connect heterogeneous devices, manage and exchange information, and utilize wireless communication technologies (Duong et al., 2020; Lawal & Rafsanjani, 2021). In conjunction with IoT, monitoring of the environment through sensors is possible, as well as data storage in servers located in different places, through Cloud Computing.

This article describes the implementation of a study that combines technologies in a monitoring and data storage system for the cheese manufacturing process. The objective of this work was to intelligently monitor, automate, and act in the industrial production process through IoT. Based on the available infrastructure in research laboratories, a cheese manufacturing tank was adapted by adding sensors for level, pH, and temperature measurement. Thus, actuators were implemented, such as agitation controls, solenoid valve activation through relays, and motor mechanisms. The data collected through sensors were sent over the internet to a cloud-based database and accessed through a web application, allowing users to monitor and act on the production process manually or automatically, according to predefined control procedures and standards.

2. Methodology

The materials used aim at reading, transmitting, and storing data, which were defined based on the requirements analysis stage and are presented in Table 1.

Table 1 - Materials used in the development of technological construct cited in the approach.

Product	Features	Quantity
Temperature Sensor	Type K Thermocouple - Model PT100 with MAX6675 board, measuring from 0°C (32ºF) to +600°C (1112ºF) with 0.25 °C(0.45ºF) resolution	1
pH Sensor Module	PH4502C 5-10mA module	1
High Temperature Bnc pH Probe Electrode	Measuring range from 0.00 to 14.00 pH and 0.2pH alkaline error	1
MCP3008	Analog/Digital Converter MCP3008	1
Diaphragm Digital Solenoid Valve	Steam Control - Digital Solenoid Valve Diaphragm 3/4 Viton High Temperature 180ºC (356ºF)	2
Ultrasonic Sensor	JSN-SR04T - Waterproof	2
Raspberry Pi 4 Model B Anatel	Broadcom BCM2711 processor, quad-core, Cortex-A72 (ARM v8) 64-bit SoC, Clock 1.5 GHz, RAM memory: 4GB DDR4, Built-in 2.4 GHz and 5.0 GHz IEEE 802.11b/g/n/ac wireless LAN adapter	1
Display Raspberry Pi Touchscreen 7″	Display Raspberry Pi Touchscreen 7″ 800×480 pixels	1
Cheese Tank	Cylindrical Cheese Tank, AISI stainless steel, Sotronic®, Capacity: 50 L	1

Source: Authors (2024).

The Cheese Manufacturing Tank has a cylindrical shape with a maximum production capacity of 50 liters. It is made of AISI 304 stainless steel, one of the recommended materials for food product manufacturing. It was positioned in the Food Manufacturing Laboratory of the SENAI/SC University Center - Chapecó Campus (Chapecó, Santa Catarina, Brazil), in a way that it can be used for practical and didactic classes with students from the Food Technology, Analysis and Systems Development, Industrial Automation, and Mechanical Engineering courses.

The Raspberry Pi is a small computer that features a single-board System on a Chip (SoC) capable of running desktop and server systems and can directly manage sensor devices and actuators through its GPIO ports. When connected to a monitor, mouse, and keyboard, the Raspberry Pi functions as a desktop computer.

The sensors are the components responsible for the readings, and the Raspberry Pi handles the communication with the sensors. It receives the information to be forwarded to a web system, where the data is stored on a server. These components must be strategically attached to the physical system to protect the hardware and its control boards from environmental agents that could damage them, such as dust, gases, mist, or moisture. Once the sensor is attached, it should be properly configured through software development, considering the characteristics specified in its datasheet. The implementation logic should be developed to enable the operation of its analog and/or digital electronic structure. The datasheet is a document provided by the manufacturer that contains the complete electronic schematic diagram, along with a set of physical and electro-electronic characteristics, to clarify its usage.

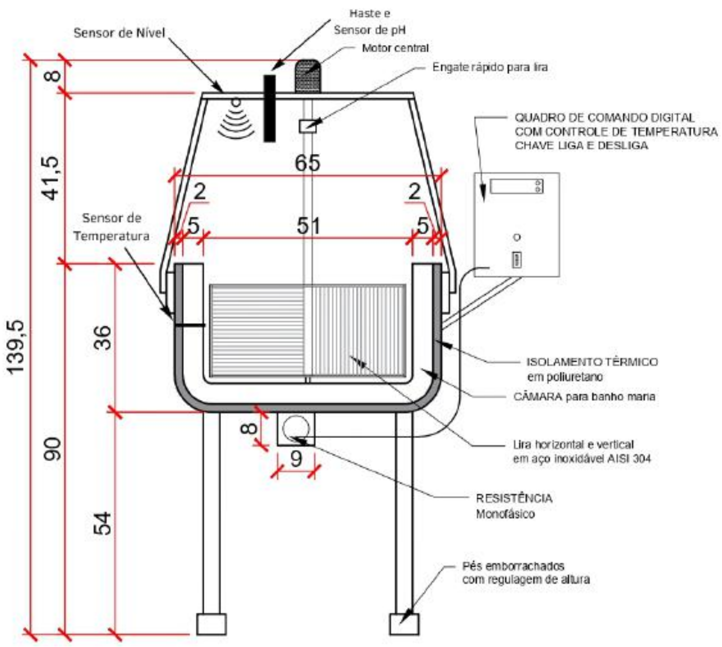
In this project, the JSN-SR04T ultrasonic sensor, positioned fixedly atop the tank's motor platform, utilizes ultrasonic waves to measure milk volume within the tank. This method involves emitting ultrasonic waves that reflect off the milk surface, capturing the sonic echo, and calculating the echo signal's duration time in milliseconds (ECHO). This time, combined with the known sound speed (Ss), facilitates the accurate measurement of the tank's real distance (Rd) to the milk surface. By applying an inversely proportional relationship, indicating that a shorter distance corresponds to a higher current tank volume (Ctv) - the system accurately calculates the milk quantity in liters. This calculation is based on inputs from the sensor, employing a simple equation detailed in Equation 1, to provide precise milk volume measurements, considering the distance between the sensor and the milk surface.

$$Ctv = \pi \times r^2 \times \left(Rd - \frac{(ECHO \times Ss)}{2}\right) \quad (1)$$

As observed, the total distance value is obtained by the current distance measured between the bottom of the tank and its upper edge, which is subtracted by the product of the duration time of the outgoing echo signal in milliseconds (ECHO), multiplied by the speed of sound and divided by two. This result should be a member of the product of π and also the square of the tank's cylinder radius.

Regarding the pH (hydrogen ion concentration) sensor, it allows indicating the neutrality, acidity, or alkalinity of a liquid solution. The set consists of a pH electrode and an electronic module that communicates with the Raspberry Pi. For the implementation of this, a probe was inserted, attached to the top and connected to the volume reading platform for measuring the number of liters of milk, as shown in Figure 1. Once the pH meter probe is submerged in the tank sample, analog electrical currents are sent through the Bayonet Neill Concelman connector (BNC RG-59) for conversion by the MCP3008, so that the 8 received channels can translate the reading into the digital Arrhenius scale. An opportunity for improvement in this process is the use of an automatic robotic arm for autonomous insertion of the pH sensor, but it was not added in this project due to budgetary constraints.

Figure 1 - Representation of the cheese manufacturing tank used in the experiment with the position indication of the components.



Source: Authors (2024).

According to Figure 1, the structural equipment sets attached to the tank, such as the heating resistor, are positioned in the lower cylinder and connected to the upper right panel. It contains a removable cutting lyre located centrally on the tank, allowing the motor to move it using Pulse Width Modulation (PWM).

The temperature sensor chosen was the PT100, which operates by varying the electrical resistance of a metal conductor based on the temperature. To install it, a protected opening was created on the side of the tank, without direct contact with the sample, and shielded by the stainless-steel armor of the tank itself in the form of a jacket.

For low-level implementation logic and hardware connection, the Python language was used, which is commonly applied on the Raspberry Pi platform and its system libraries. The code had to be designed in a way that it could not only process the data locally but also be prepared to be sent over a LAN 802.11n network to an external web system server, strategically developed to receive, process, and clean the data. The system libraries that supported the code are listed in Table 2.

Table 2 - List of libraries applied with the algorithm.

Nº	Library	Application	Source
1	RPi.GPIO	Control system input and output channels.	https://pypi.org/project/RPi.GPIO/
2	OS Path	Allow the use of file system paths and their parameters.	https://docs.python.org/3.9/library/os.path.html
3	time	Manage the different time-related conversions.	https://docs.python.org/3.9/library/time.html
4	datetime	Manage add-ins for handling dates and calendars.	https://docs.python.org/3.9/library/datetime.html
5	Adafruit MCP3008	Controlling the analog-to-digital converter microcontroller.	https://github.com/adafruit/Adafruit_CircuitPython_MCP3xxx/blob/main/examples/mcp3xxx_mcp3008_single_ended_simpletest.py
5	MySQL Connector for Python	Module responsible for promoting the communication of operations in SQL of the local application for connection with the external server.	https://dev.mysql.com/doc/connector-python/en/

Source: Authors (2024).

User access to tank data occurs through a web system, which allows monitoring of the current stage as well as the complete cheese production process. Among the features, users can create an account (Figure 2), maintain sensors via CRUD (Create, Read, Update, and Delete), as well as visualize the collected data over time through dashboards (Figure 3).

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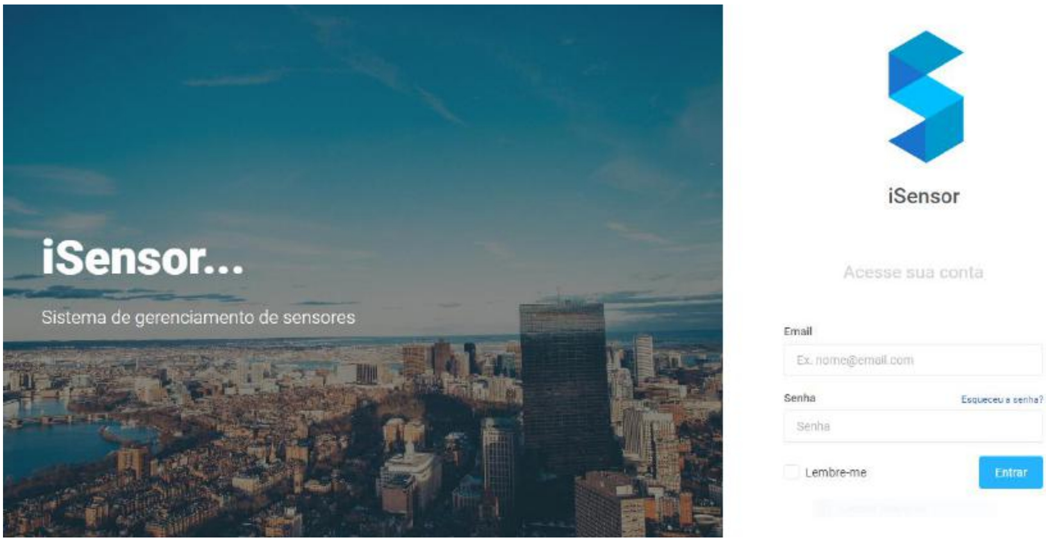
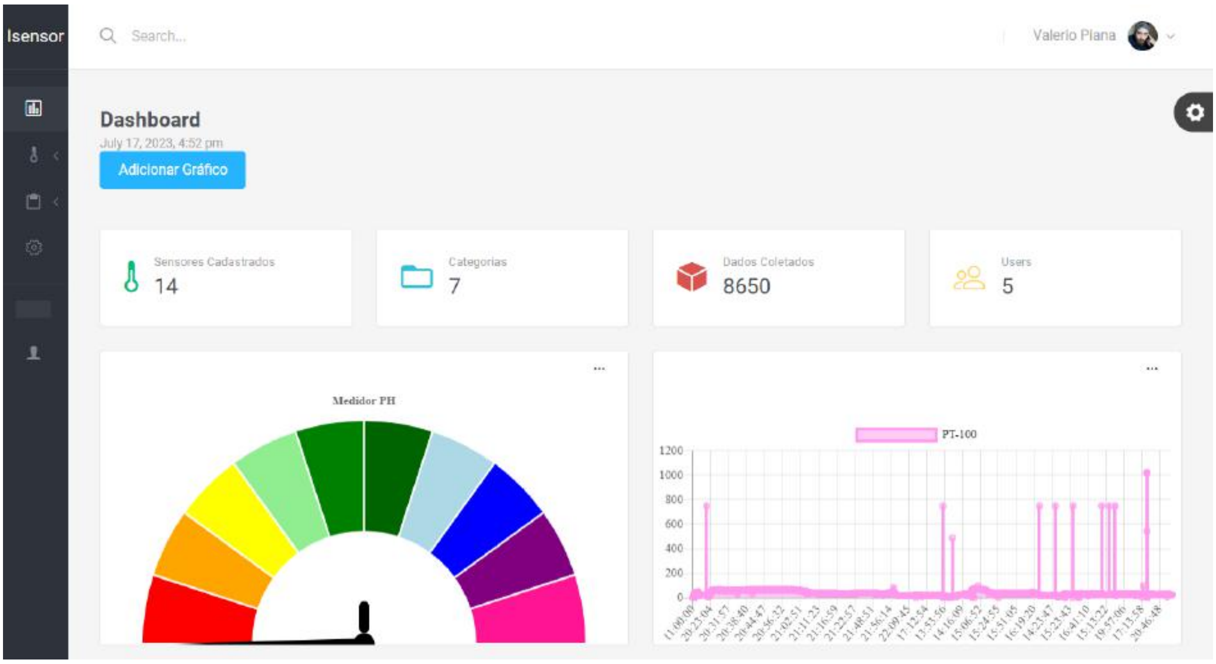
Figure 2 - System access screen.



Source: Authors (2024).

Figure 3 - System dashboard visualization screen.



Source: Authors (2024).

The web system was developed using HTML, CSS, and JavaScript programming languages, supported by the Bootstrap 4.4.1 framework. It also utilizes a MySQL database for communication with the hardware over the network, enabling administration and data collection from the GPIOs. Figure 4 presents the Relational Database Model of the application.

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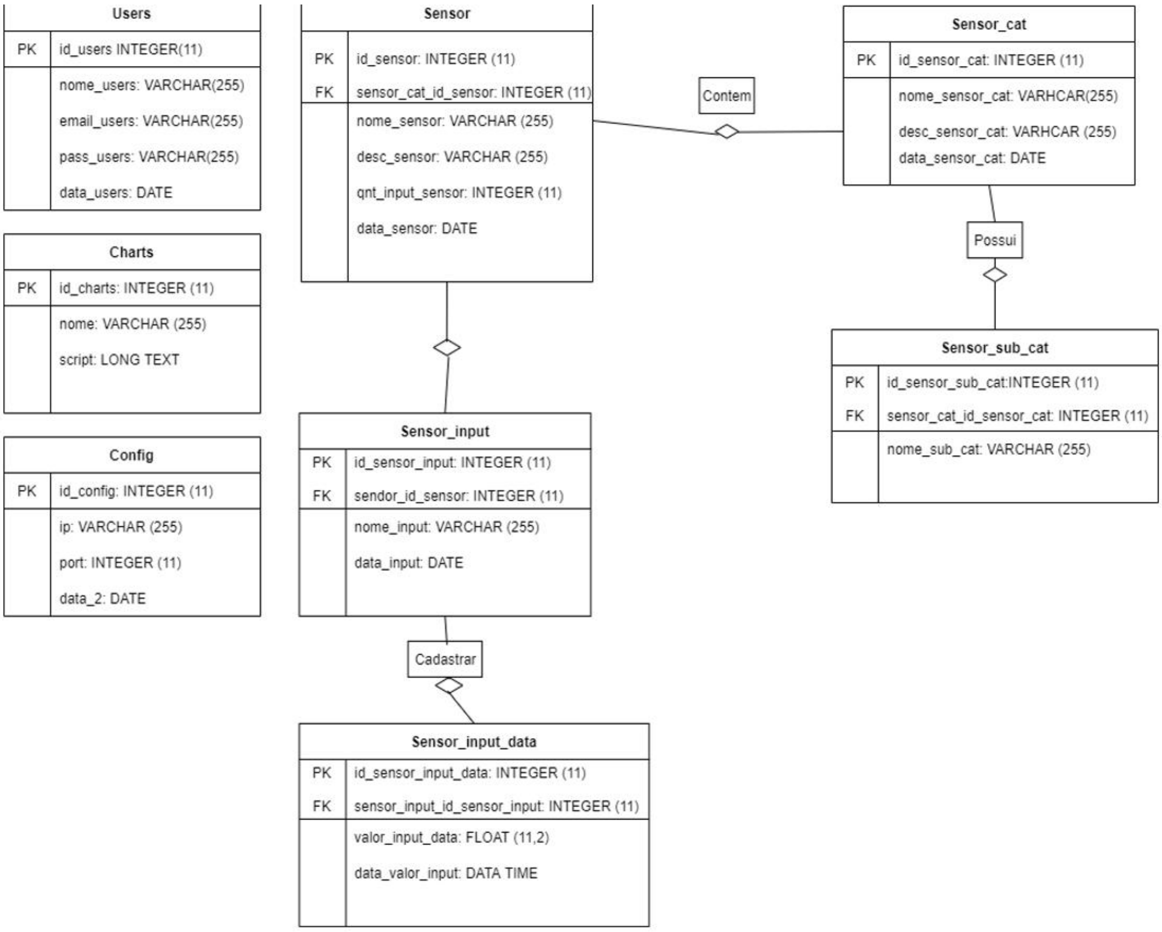
Figure 4 - UML relational model of the system illustrating the relationships between data.



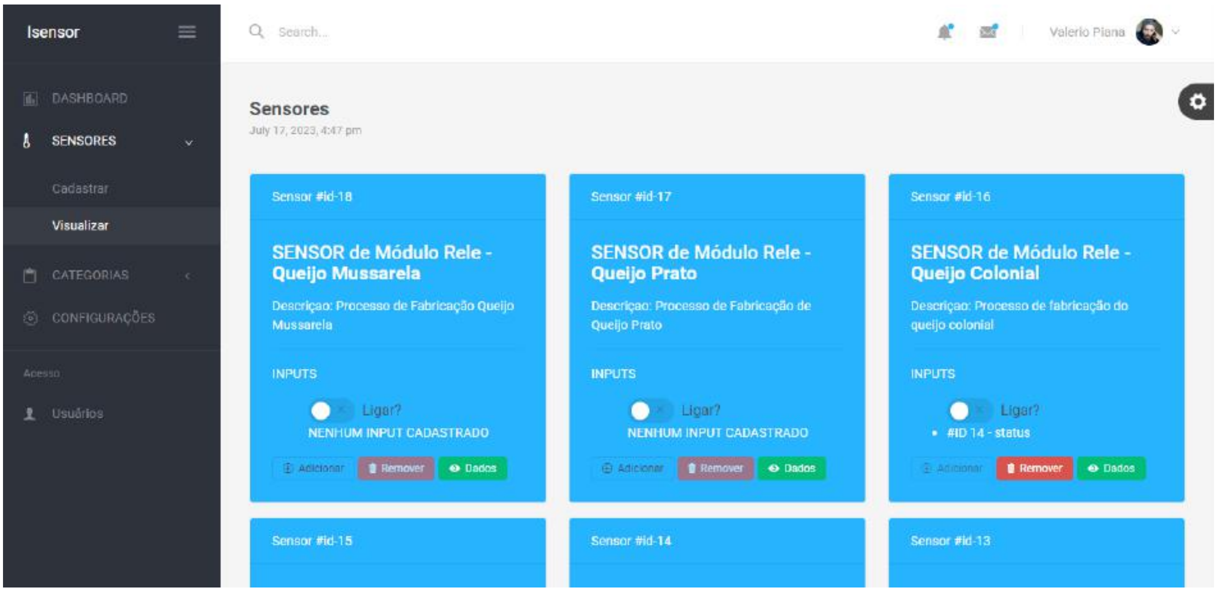
Source: Authors (2024).

In order to provide information encapsulation for each stage, the process was developed to initially promote data interaction by the SoC through a Python script. Locally encapsulated, each reading operation is sent to the Relational Database Management System (RDBMS) using the MySQL Connector Python. The data is processed within the server to eliminate outliers through data normalization. After normalization, the data is displayed in smart dashboards for user monitoring, allowing users to connect from anywhere in the world with internet access.

For cheese manufacturing, flowcharts of formulations were created to be strictly followed. For each recipe, a different routine was registered within the code to make the procedures feasible according to the desired quality parameters.

The web tool developed for the system aims to manage not only the information displayed in smart dashboards but also remote interaction with the system. It allows for the activation or deactivation of recipes that are currently in the production process, as can be seen in Figure 5. The logic was developed in such a way that once the recipe's sliding button is selected to activate the recipe, the system initiates its production process according to the registered rules.

Figure 5 - Screen for viewing registered recipes within the "Sensors" tab.



Source: Authors (2024).

3. Results and Discussion

Various direct and indirect benefits can be observed through the development and implementation of the system for digitizing and interacting with the cheese manufacturing tank data. The first direct benefit was seen in the evaluation of financial feasibility in terms of cost-effectiveness. Comparing traditional market solutions such as proprietary Programmable Logic Controllers to the implementation of an open architecture SoC, the investment was more affordable and accessible (Piana et al. 2022). This opens up possibilities for its application beyond educational and research laboratories, extending to cases where there are budget limitations, such as locations with limited credit availability or small producers and businesses. The Raspberry Pi SoC was considered because it is widely used in other works, such as Herrero et al. (2020), which advocates for the device as it receives signals from the machine, processes them, and sends data to the database through a wireless connection.

Moreover, there were gains in the ability to interact between systems heterogeneously. By using an open platform, it is possible to implement any information abstraction layer according to the needs of the business rules (Piana et al. 2022), without being limited to proprietary protocols or having to pay for the use of a technology or artifact from a specific company, which is typically applied in a wide range of devices in the traditional industrial automation field. Gupta and Rakesh (2018) use the Raspberry Pi because it acts as the brain of the system, handling all operations from sending commands to the sensors to displaying the output in heterogeneous systems.

Another important observation from the work is that when analyzing Food Safety protocols (HACCP - Hazard Analysis and Critical Control Points), the application of alternative sensors, such as the JSN-SR04T, was chosen as an innovative way compared to the usual methods in the food industry for measuring milk quantity. This approach avoids direct contact with production ingredients and mitigates exposure to agents harmful to human health while maintaining efficiency when compared to traditional calibrated equipment, with an error rate of only ±0.1 on the pH scale. Throughout the entire manufacturing process, digital measurements were compared with externally calibrated equipment to validate the information.

Figure 6 - Cheese manufacturing tank in use during the manufacturing process.

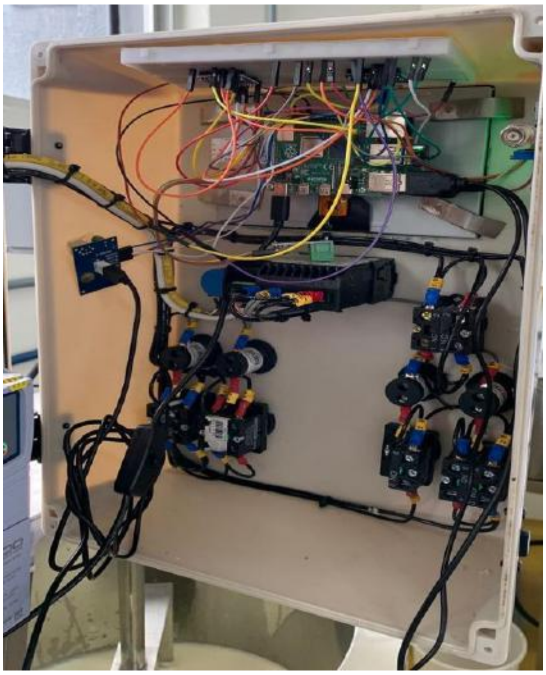
Source: Authors (2024).

An important point to consider in the development and implementation process is the need to dimension all recipes and production processes for each style of cheese, considering their specificities and the abstraction of the preparation flowchart for integration into low-level code. This point highlights the necessity for professionals in the specific food industry to work together with professionals in the analysis and systems development field, in order to translate functional and non-functional manufacturing requirements into commands that will be executed automatically by the machine. It was observed that this is one of the most delicate and crucial stages of the process, as the manufacturing process needs to be accurately recorded, and calibration adjustments are required.

The temperature and pH sensors needed to be calibrated. For the temperature sensor, due to its location within the stainless-steel tank jacket without direct contact with the sample, a positive exothermic loss of 2°C was observed, requiring adjustments in the algorithm's temperature readings through programming. As for the pH meter, its calibration required prior use of a multimeter to evaluate the electrical current accepted by the BmC probe in pH buffer solutions of pH 4.00, pH 7.00, and pH 9.00. However, it was not possible to measure the tank level after the start of the manufacturing process, as the agitation of the milk cutting lyre caused physical wave-like effects and diffuse reflection, resulting in inaccurate ultrasound level measurements (resulting in false readings).

Another aspect that facilitated the system implementation was the use of a protoboard with 830 points (MB-102) to support the sensor and actuator system. This allowed for quicker testing and easy circuit modifications during the development and testing stages.

Figure 7 - Raspberry Pi Model B and system sensor and actuator circuits inside the electrical distribution box.

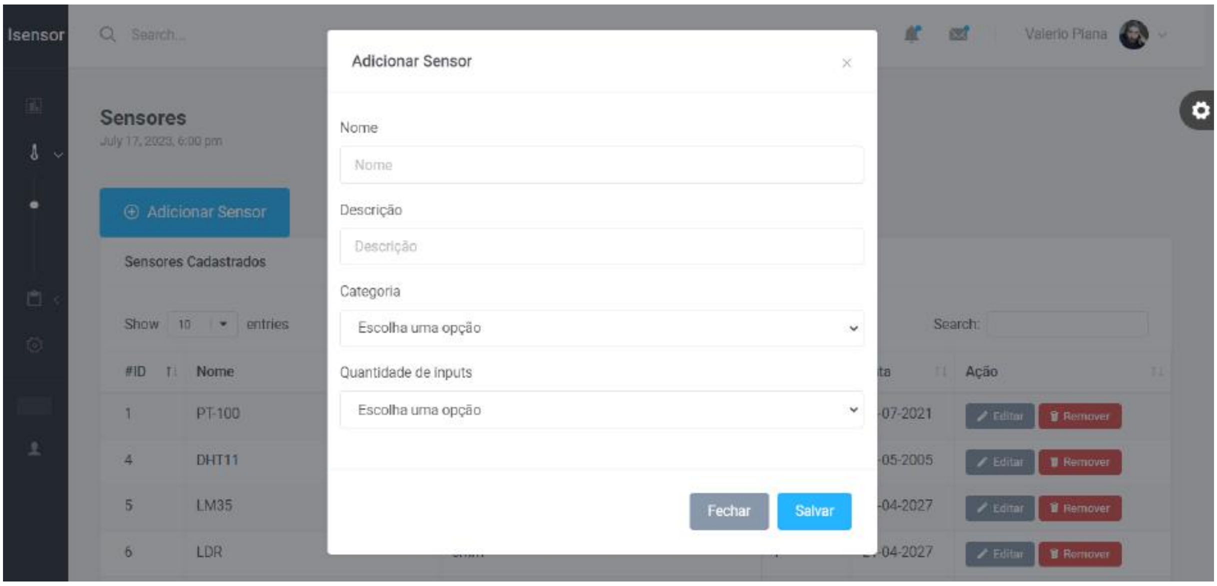


Source: Authors (2024).

Furthermore, since the developed system was fully dynamic for insertions and configurations, ensuring that no system resource was left behind in the implementation, the registration process provided a wide range of possibilities for different industrial scenarios of machines and devices. It allowed for the registration of various types of sensors and actuators.

As observed in Figure 8, the data collected by the sensors already appears on the dashboards, enabling real-time process monitoring. According to Sarikaya et al. (2018), dashboards are critically important in a data-driven world. They are diverse, appearing in many different contexts, and they are changing, democratizing, and diversifying as their usage proliferates. Their contexts of use are expanding beyond simple monitoring and single-screen reporting.

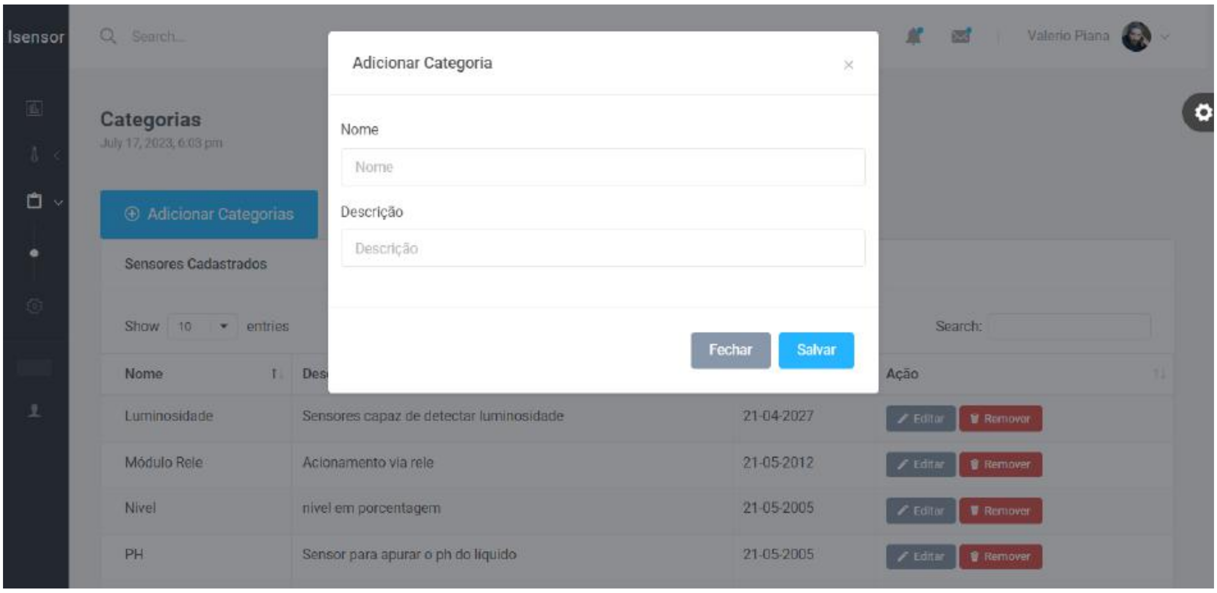
Figure 8 - Process of adding new sensors to the system.



Source: Authors (2024).

Regarding the operation of actuators in the cheese manufacturing process, as shown in Figure 8 and Figure 9, the user can register and manage Sensor and Actuator Classes (a new category). They can also edit and review sensors, actuators, and recipes. Each of these elements has a Unique Identifier (UID) that the web system automatically inserts into the database. This UID can later be used for query requests and data insertions through the connection driver for the RDBMS (MySQL Connector for Python).

Figure 9 - Window that enables the process of adding a new sensor and actuator category.



Source: Authors (2024).

Given the explored context, a system was developed that allows for the replication and adaptation of other equipment, whether it is new or legacy (retrofitting), in industrial, educational, and research settings. This system ensures application in diverse scenarios by digitizing equipment, enhancing product safety, mitigating production errors, and increasing industrial productivity and competitiveness.

4. Conclusion

This study successfully implemented a monitoring, automation, and intervention system for industrial production using Industry 4.0 technologies, particularly IoT and Cloud Computing. While the cheese manufacturing tank was selected as a testbed due to equipment availability, the developed framework extends beyond this specific application. It serves as a scalable and replicable model that can be adapted to other industrial production equipment, facilitating broader adoption of smart manufacturing solutions.

The proposed ecosystem enables real-time monitoring through sensors that collect data and transmit it to a cloud-based web system, which organizes and displays intuitive insights via intelligent dashboards. Automation is achieved through autonomous execution of key processes, replacing traditional manual operations that require on-site data collection and separate devices. Additionally, the system allows remote intervention, where operators can control the tank via a web application, ensuring improved efficiency, product quality, and process optimization.

The developed framework systematically details all production stages, including the hardware, software, and interface integration, providing a roadmap for digital transformation in industrial settings. Its modular design ensures scalability and adaptability, enabling other industrial equipment to benefit from similar digitization strategies.

Furthermore, the proposed solution stands out for its cost-effectiveness, offering an affordable alternative to commercial automation systems. This aspect is particularly relevant for small and medium-sized producers, who often face financial and technological barriers when adopting Industry 4.0 technologies. By lowering these entry barriers, the study contributes to the necessary transformation of the industrial sector, fostering greater efficiency, competitiveness, and innovation.

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