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Proposal for Development and Implementation of an Asset Monitoring System in Stamping and Thermoplastic Injection Tools

Lidomar Becker. Brenno Domingues. Diego de Souza. Joel Ribeiro. Thamiris Costa. Ismael Secco. Moises Teixeira. Luis Trabasso.

SENAI Innovation Institute for Manufacturing Systems, R. Arno Waldemar Döhler, 308 - Santo Antônio, Joinville, SC 89218-153, Brazil (e-mail: lidomar.becker@sc.senai.br).

Abstract: The proposition of this system is an initiative that aims to develop an advanced monitoring system for tools and molds utilized within thermoplastic stamping and injection processes, using Internet of Things (IoT) technologies. We propose a network of intelligent sensors that collect real-time data on the operating conditions of equipment. Such an approach enables the implementation of predictive maintenance, thereby optimizing asset utilization, and reducing operation costs through early detection of failures and wear. Moreover, the project undertakes to operational sustainability by improving energy efficiency and reducing material waste. By extending the operational lifespan of the equipment and enhancing the quality of end products, this endeavor reinforce its multifaceted benefits. The integration of data streams within cloud infrastructure furnishes a comprehensive perspective on asset performance, thereby facilitating both strategic and operational decision-making processes.

Keywords: Asset Monitoring; IoT; Industry 4.0; Predictive Maintenance; Industrial Automation.

1. INTRODUCTION

The Internet of Things (IoT) represents a revolution in the way we interact with digital world. This network consists of interconnected devices and it is capable of comprising a wide range of technologies, from simple sensors to complex computing devices. The core of IoT lies in the ability of these computing, sensing and communication devices to share data and information through a wide variety of network protocols (Mansour et al., 2023).

One of the main advantages of IoT is its ability to enable the interconnection of a variety of devices, both wired and wireless, and their hybrid combinations. This means that everything from traditional office devices to modern smart home devices can communicate and collaborate efficiently, bringing a new layer of automation and convenience to our lives (Mansour et al., 2023).

In the manufacturing industry, specifically within the thermoplastic stamping and injection sectors, operational efficiency and asset management are critical to business sustainability and competitiveness. As the demand for high-quality and low-cost products increases, so does the need for monitoring systems that can improve equipment reliability and lifespan. In this context, the advent of the IoT has provided novel opportunities for the digital transformation of these industrial processes (Soori et al., 2023).

The use of IoT-based technologies has been attracting the attention of researchers in the area. Battistoni et al. (2021) proposed a distributed Smart Personal Protective Equipment solution for monitoring employee safety, changing common personal protective equipment (PPE) into smart PPE, through the use of IoT technologies.

Chataut et al. (2023) already carries out a comprehensive literature review on the application of devices based on IoT technologies in health, agriculture and smart cities sectors. concludes that IoT is a rapidly growing area, which has been used in different sectors, bringing several benefits, in terms of automation, efficiency and improvements in decision making.

In this work, we propose a solution of a monitoring system using IoT technologies to collect and analyze tool and mold operation data. By implementing smart sensors directly into equipment, we can acquire detailed information about the status and performance of critical assets. This data, when processed and analyzed, allows predictive maintenance to be carried out, which is essential to prevent unexpected failures and reduce unscheduled downtime. Furthermore, the system aims to improve energy efficiency and minimize material waste, thus contributing to reducing operating costs and protecting the environment. With the ability to provide answers about the operating conditions of machines, managers can make more informed and accurate decisions, improving not only productivity, but also the quality of the final product. The solution proposed is a work-in-progress, which provides an architecture containing the arrangement of the elements necessary to monitor assets within the industry.

This approach meets the growing demands of a globalized market, but also aligns industrial operations with sustainability practices. By integrating IoT technologies into a traditional manufacturing environment, the project establishes asset management in the stamping and injection molding industry, marking a step forward in the journey towards Industry 4.0.

The contribution of this work is the proposal of a system basing in IoT technology aimed at real-time monitoring of the operational conditions of equipment used in stamping and thermoplastic injection processes. It is noteworthy that the monitored variables can be customized according to user requirements, allowing the connection of multiple sensors to the system as needed.

The remainder of this paper is organized as follows. In Section 2, we present the development of the monitoring system structure. In Section 3, we present the works' conclusions and future works.

2. DEVELOPMENT

The initial phase of the project determined a study to identify the main operational requirements and technical challenges that could be addressed with the introduction of sensors.

According to Ahmed et al. (2017), most IoT applications not only focus on monitoring discrete events, but also on mining information collected by devices that are equipped with sensors and that require protocols such as Message Queue Telemetry Transport (MQTT) and Data Distribution Service (DDS). Considering that sensors are throughout employed across numerous industries, the resultant data volume is anticipated to be substantial. The data generated from these devices can be instrumental in identifying emerging research trends and examining the effects of specific events or decisions. This data undergoes processing through various analytical tools from many devices and transport that data to the IT infrastructure. It targets large networks of small devices that need to be monitored or controlled from the cloud. MQTT makes little attempt to enable device-to-device transfer, nor to "fan out" the data to many recipients. Since it has a clear, compelling single application, MQTT is simple, offering few control options. It also doesn't need to be particularly fast. In this context, "real time" is typically measured in seconds (Schneider, 2017).

The IoT system consists of a large number of devices interconnected through heterogeneous devices in wired and wireless networks. Heterogeneous networks include sensor networks, wireless Wi-Fi networks, mobile networks, 3G/4G/LTE/5G communication networks, and dedicated industrial networks (Qiu et al., 2020).

The objective is to structure an end-device, a gateway, a database and a monitoring program (dashboard) that could monitor critical variables through sensors, such as temperature, pressure, vibration and humidity, which are indicative of potential failures or wear in tools and molds. Figure 1 describes a basic diagram of the structure of the proposed system.

Figure 1 lists the main elements of the project: end devices, gateway, data server and Application Programming Interface (API) and external access devices (Mobiles WEB).

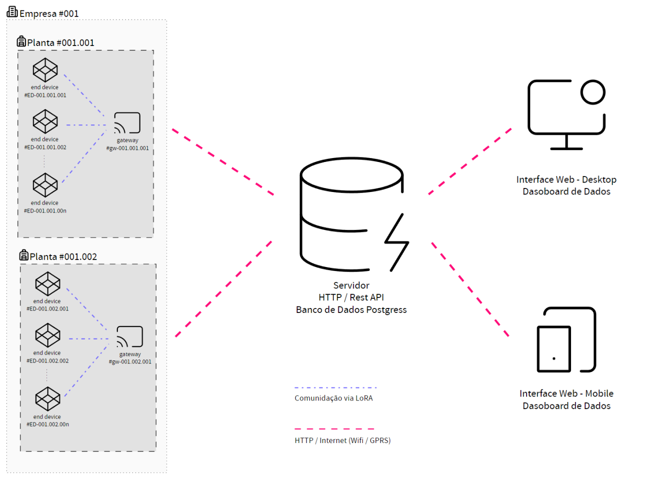

Figure 1. IoT monitoring system diagram.

Each device at the edge of the network monitors through sensors digital or analog inputs and outputs, accelerometer data, for instance, and these signals read on the tooling are sent through a LoRa (Long Range) radio link to a gateway, which recognizes the origin (ID - Identifier) of the data, stores and, through a WiFi connection (Wireless Fidelity), transmits the data to the API and, this, to the database (Django). In this database, data is identified, formatted and presented to mobiles interfaces.

An essential element of the project is the end device, which is attached to the tooling and, through attached sensors, can periodically read data. This data is read at a predefined sampling time. A tracker may be attached to the device end device. This tracker has direct communication with the database system to send real-time location information of the monitored tooling.

Figure 2 shows the scope for developing the device's internal firmware.

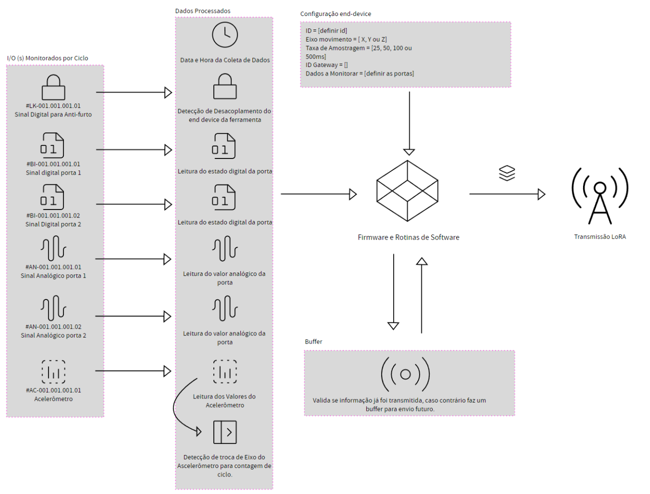

Figure 2. Firmware and end device diagram.

End devices are data reading and broadcast devices. They are not directly connected to the internet and communicate with the system through a gateway. For this, LoRa transmission technology is used. Each device has a unique ID and is associated with a unique gateway. It is possible to enable and disable the variables that will be monitored by the device, releasing the firmware routines. Among the possible variables are acceleration in the three coordinate axes, digital/analog input/output signals and anti-theft (identifying the connection to the tooling). Inputs and outputs are monitored per cycle. This code block presented in Figure 2 is executed cyclically according to the sampling rate defined in the settings. Basically, this routine is responsible for reading the device ports and then determining the status of the monitored ports.

The firmware cycle establishes internal routines and these are executed cyclically. Through these routines, a data package is created with the monitored information, the date and time of the reading is inserted and then the data is forwarded to the gateway. At this point, the data is not processed or analyzed. All magnitude conversions and data meaning will be determined on the data server. This allows for a reduction in tasks and processing time on the edge device.

There is only one procedure for checking the inversion of the accelerometer axis, which makes it possible to detect a change of direction in the axis under monitoring, characterized by opening and closing cycles, in essence, through the transmission of low or high level signals. Another sequence of procedures is responsible for transmitting data and checking whether or not the operation is successful. In case of failure, this routine retries the transmission after a specific time interval. The underlying purpose is to avoid taking up crucial machine processing cycles.

With reference to the gateway, this device is located within the industrial park and has the objective of collecting data from one or more end devices, transmitted via LoRa, packaging this data and transmitting it to the database system via WiFi. It was limited to up to 16 end devices per hub. Figure 3 shows firmware scope for the hub.

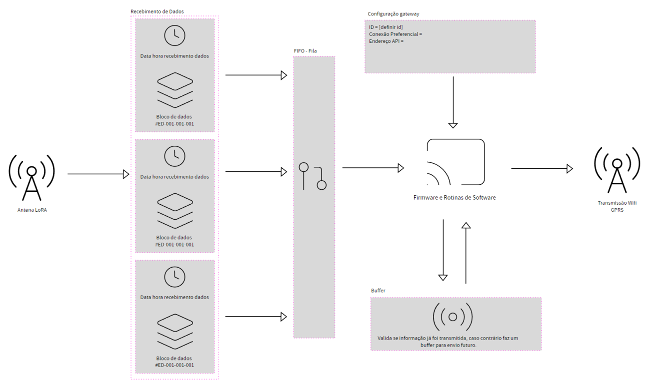

Figure 3. Firmware and gateway diagram.

The hub configuration allows you to identify (ID), connection type, access and password and API address (IP). Automatically after settings, clocks are updated and synchronized.

A routine is responsible for receiving data via the LoRA interface from end devices. For each received packet, date and time are added and then this information goes to the queue routine. There is no data transformation in this step. The routine that handles data queues is responsible for organizing the received data and assembling a data queue for transmission. Another routine, storage (buffer), handles sending data via wireless network, controlling failures.

Configuration, identification and association **entities** were included within the scope of the project. The **entities** can be: **company**, **plant** and **tool**.

Company and **plant** are system control **entities** and serve to identify the name of the company where the end device is located and the plant defines in which warehouse or sub-region it is located. The **ent tool** is the monitored device, for example, an injection mold, blow mold, a stamp or more complex tooling. The project targets tools that have more defined production flows, especially those that have repeated openings and/or closings.

The pillar of the system is the database (data server) which is the hub for all information. Responsible for receiving data sent from the gateway to the server. Composed of a stack of technologies, but which are summarized in a Rest API, a database and data transformation routines. REST APIs are used to write client and server applications in various programming languages without affecting the design of the API. Figure 4 shows the scope of the data server.

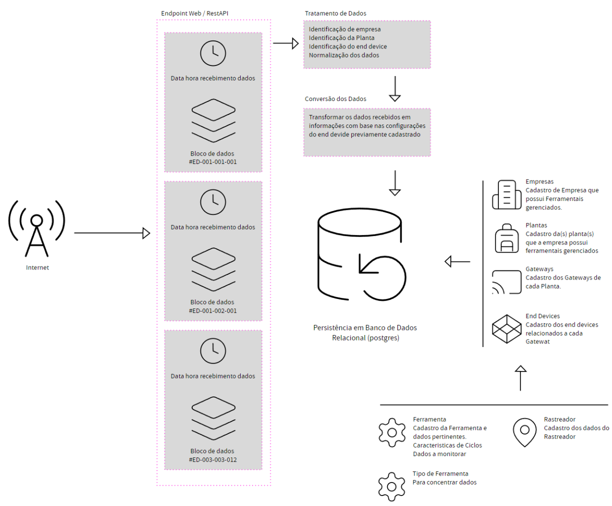

Figure 4. Scope of the data server structure.

The Server consists of an application developed in Django/Python that offers and makes available online a Rest API that receives information from the system's hubs (gateways). The server functions include: company registration, plant registration, gateway registration, end device registration, tool registration, tool type registration, tracker registration (GPRS/GPS).

The Edge-Computing paradigm has spread as the number of the Internet Protocol (IP) connected devices has increased dramatically. This paradigm aims to move part of the computation from Cloud resources to the Edge of the network, closer to the data sources, because shortening the network path decreases the latency usually generated by the Internet connection to the Cloud, and at the same time, reduces the occupancy of the Internet bandwidth (Shi et al., 2016). Data is stored in the PostgreSQL database. Its basic operation takes place mainly in 3 major divisions: RESTFUL API, which is the layer for receiving and sending data via HTTP; PostgreSQL relational database and data processing and transformation. The server is made up of an orchestration of Docker containers. It is possible to run this Docker Compose on any Windows or Linux host that has the service installed. This composition of containers is made up of:

- App: application container that will run the Django API through *Gunicorn*;
- Nginx: reverse proxy container to expose the App service to the internet;
- DB: container that will run the database and persist the information;
- Certbot: container that generates digital certificates for generating SSL for the use of HTTPs.

The following data is recorded on the server: company, plant, hubs (gateway), end devices, tool, type of tool, associated tracker, users (access profiles), etc.

The API offers specific endpoints to feed the Web and Mobile interfaces with information. It is through this API that information used by external interfaces for data sampling, viewing reports and generating graphs will be consolidated.

To support the entire data structure, there must be a set of entities and relationships that represent this organization in a relational database and in MVC code, which is an architectural pattern that divides an application into three distinct components: Model, View and Controller. For the documentation and determination of these entities, procedures were documented to define the names, information and relationships between each of these entities.

The WEB and Mobile interfaces are the interfaces through which managers, administrators and users will interact with the system. It is through this interface that administrators will: register a company; plant registration; tool registration; registration of tool categories; registration of end devices; registration of gateways.

It is also possible to: monitor cycles and data collected from end devices; generate quantitative reports; track the location of tools; view theft or signal loss alarms; see alarms for cycles or usage outside of expectations.

All devices and entities in the system are addressed with a specific coding to facilitate their identification. This identification is done as follows:

- **Company**, receives an address block from 000 to 999. Example: #001, #002, #812;
- **Plant**, receives an address linked to the company and subsequently its own identification from 000 to 999. Example:
  #001.003 - Plant 003 of company 001;
  #010.001 - Plant 001 of company 010;
- **End device**, receives an address from 000 to 999 with a hierarchy relationship with company and plant. Example: #ED-003.123.023: End device 023, from plant 123 of company 003;
- **Gateway**, receives a relational address. Example: #GW-132.451.002: Gateway 002 of plant 451 of company 132.

An application interface facilitates the exchange of data between devices in a fluid and secure way, expanding the system's integration capacity. The platform provides essential data for the Web interface, improving the user experience and facilitating access to necessary information and configurations. The creation of a communication protocol and data typing are essential to guarantee consistency, security and effectiveness in the exchange of information between different components of the system.

The management interface provides a comprehensive control panel for monitoring and administering devices, companies, plants, and collected data. It offers features such as GPS tracking, alert configuration, and alarm management, allowing for effective administration and the extraction of operational intelligence.

Finally, the cloud or database solution includes the implementation of a robust API and Docker containers, supporting variable parameterization, data security, and integration between devices and platforms. This modular and multi-platform infrastructure aims for scalability and efficiency in data management.

Another analysis tool is the monitoring panel dashboard. It is an essential tool for successful project delivery. Through it, it is possible to monitor and detect failures or deviations and allow quick action on the production process. It also allows decision-making based on market needs. Within this, the importance of reporting accuracy is evident, allowing continuous improvements in the face of industry challenges.

Figure 5 presents a block flowchart of the first functionality proposition for the system monitoring panel.

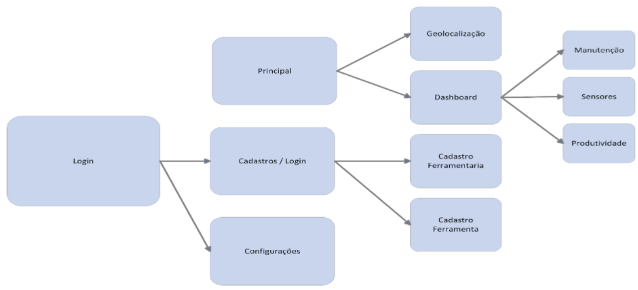

Figure 5. Flowchart of proposed features.

The proposed dashboard design must address how information is captured, modeled, and displayed on the screen. A dashboard is a project monitoring tool that allows the project management team to know the status of the industrial process and make quick decisions. It must be user-friendly, easy to understand, and monitor progress effectively with consistent measurements. Therefore, the use of a panel in the industry is vital (Gara et al., 2021).

Figure 6 presents a primary scope of the main screen of the developed dashboard. This report screen presents various types of information in graphical formats. It contains the main functionalities of the system.

Figure 7 allows us to identify the signals without analysis received from the various sensors present in the system. It is possible to associate information on time, level,

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Figure 6. Primary dashboard reporting screen.

frequency, for instance, of the signals selected and collected from the devices.

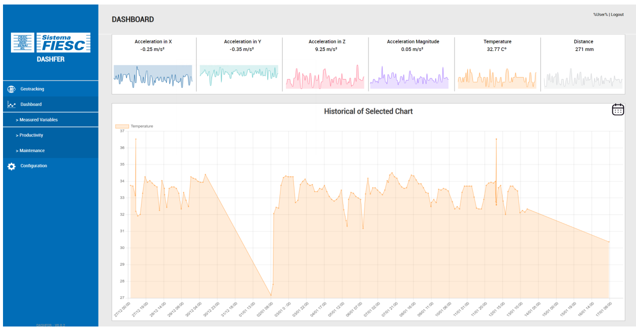

Figure 7. Primary screen for sensor signals on devices.

Another sensor evaluated was the Neo-6MVX GPS module. This GPS module is capable of accurately determining the exact location of the object to which it is attached, providing data on latitude, longitude, date, time, and movement speed. In addition, it was also tested the GSM GPRS SIM800L module.

In Figure 8, it is presented the location status of the tooling, with geopositioning information through M2M (Machine to Machine) chips.

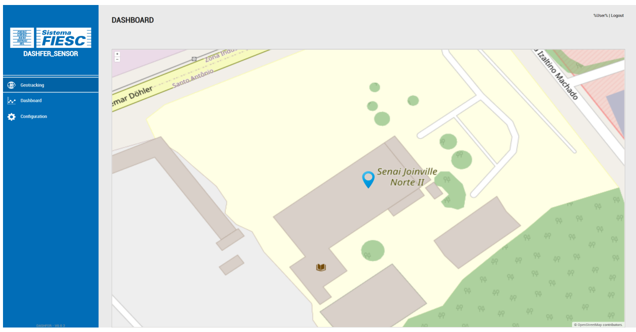

Figure 8. Tooling geo positioning screen.

3. CONCLUSION

In this work, we present a solution of an ongoing work on the development of an architecture containing the integration of elements necessary to monitor assets in the industry. The proposed monitoring system allows receiving data from injection molding processes and stamping tools, and is capable of transferring relevant information to the customer or tool owner, respectively. The main process characteristics information for the collected data are the production signature, which allows geolocation and chronological recording of the tool and quantity of parts produced, and variable machine processing conditions for stamping and plastic injection processes.

For production signature, a GPS device or similar system provided tool position information to ensure tool operation in suitable facilities. Acceleration sensors collect data on tool dynamics, which are applied to monitor usage time and quantity of machined parts. Possibility of adding different sensors using analog and digital signal patterns. These variables include vibrations, times, forces, position, contact, among others.

In this context, the work addressed some of the main challenges for tool companies in the automotive sectors, industries that are related to a growing demand for costs and efficiency in the series production of injection molded parts and stamped parts.

The data generated can also be used for predictive, preventive and maintenance purposes. The proposed system is reinforced by LoRa/WiFi communication technologies to ensure that the data collected by the sensors are sent to a cloud platform, which generates information that assists in production and management processes. The database infrastructure supports the volume of data generated.

For future work, we propose enhancing the power system to increase its autonomy and incorporating a precise indoor location system. In addition, we propose the application of artificial intelligence for data analysis, and the application of the proposed system within other fields.

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