Automation and monitoring of lab- and industrial-scale food processing facilities for quality project management

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Abstract. This paper presents the challenges and strategies for automation and monitoring in food processing at the pilot scale, within a teaching and research environment, the Technological Hall of the SayFood Laboratory. The objective is to ensure data accessibility, enhance quality management, and improve knowledge of unit transformation processes. Given the high heterogeneity of the equipments, various sensor technologies and data acquisition strategies are explored, along with software and hardware implementations tailored to support both research and industry needs. The integration of open-source solutions, Python-based tools, and web technologies is discussed, with a strong emphasis on the Industrial Internet of Things (IIoT) and interoperability.

1 Context

Processes in food and bioproduct engineering can cover serval domains from raw materials to the customers, and involves various contributors such as students, researchers, and industries. Their needs converge on accessing data and improving quality through monitoring physical parameters like temperature, pressure, humidity, mass, and energy consumption on multiple involved transformation processes like grinding, mixing, filtering and heating. In our facilities, laboratory- and industrial-scale equipments enable to support broad projects and research. In order to implement quality in our processes and project management, a plan has been set to investigate, define and develop solutions to monitor all equipments.

Processes equipments arrangements are with or without embedded control & monitoring software, electronics, and/or old instrumentations. Applications can be manually operated by users, controlled through commercial Human-Machine-Interface (IHM) or are in need for revamping to support new projects requirements. Some systems require data to be stored on the server for post processing; others mainly need to have the physical and process parameters to monitored in order to act manually on the changes.

Several softwares are commercially available (for example WinCC, PCVue, LabVIEW, EcoStruxure…) to develop Human Machine Interface for Supervisory Control and Data Acquisition (SCADA). Current laboratories and industries can limit their choice on some communication protocols (Serial, Modbus, Local Area Network), as software licences costs are dependent on the number variables and communication protocols to ease of data management.

Non of the solutions on market, or developed by other researchers suit our broad spectrum of food processing equipments.

A solution is then deployed to track and monitor equipments collecting, saving and arranging data for quality and metrology management.

2 Technological Platform & SayFood

SayFood is composed of 5 multidisciplinary teams dealing with raw-materials-to-consumers subjects. It has dedicated laboratories for chemistry, microbiology and sensory analysis, an experimental restaurant and a technological platform. In total, 200 equipments are then available for research, teaching & training and knowledge transfer.

The current paper concentrates on the Technological platform which is spread over 2720 m^2. It has 70 pilots with heterogeneous applications. It covers all aspects of food processing and transformation.

Over the manual, automatic or semi-automatic equipments being available in our facilities, case studies focus on three pilot-scale systems: the "*fluidised bed*", it required the installation of various sensors (air flow, humidity, temperatures, mass) and a signal acquisition strategy to help the user during the manual process; the "*tangential flow filtration*", a revamping and upgrading of its electronic is necessary; the "*plate heat exchanger*", pressure and temperature sensors were added to evaluate heat exchange parameters.

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What's more, two solutions (IoT, commercial) are investigated for temperature monitoring in our cold chambers due to quality requirements.

A general objective is then to set-up and deploy a supervisory solution for all the equipments available at SayFood.

Ongoing efforts within the Technological Hall aim to improve automation and data accessibility. To support these initiatives, several key systems have been instrumented for monitoring and control, ensuring efficient data acquisition and process management.

3 Data-Acquisition and supervision strategy

The challenges in data acquisition for our pilot-scale equipments of the Technological Platform include equipment heterogeneity, data accessibility, and cost. A significant aspect is the heterogeneity of equipment landscape, as pilots often consist of devices employed in various food transformation processes and from different manufacturers, each utilising different communication protocol standards.

Processes equipments arrangements are with or without electronics and sensors. They may include or not embedded control and monitoring software, electronics, and/or legacy instrumentations.

Applications can be manually operated by users, controlled through commercial Interface-Home-Machine (IHM) or are in need for revamping to support new projects requirements. Some systems require data to stored on the server for post processing ; others mainly need to have the physical and process parameters to monitored in order to act manually on the changes. This diversity necessitates a versatile solution capable of interfacing with multiple protocols to ensure data acquisition and integration across all systems. Additionally, some manufactured systems are equipped with embedded sensors designed for only regulation purposes and their data are not readily accessible. This limitation drives us to develop custom solutions to access and record the necessary data.

Several commercial software solutions providing data acquisition and monitoring capabilities, such as WinCC, PCVue, LabVIEW, and EcoStruxure, are available as Human-Machine Interfaces (HMI) in Supervisory Control and Data Acquisition (SCADA) systems. Additionally, those commercialare often expensive for a research laboratory due to licensing fees, which are typically based on the number of variables monitored and the specific communication protocols used. This cost barrier makes it challenging to implement such solutions on a large scale and forces to limit laboratories and industries can limit their choice on some communication protocols (Serial, Modbus, Local Area Network), as software licences costs are depend to the number variables and communication protocols, for ease of data management.

4 Pilots and current data

This section presents the actual data-acquisition methods and some data of the process pilots, in particular for the plate heat exchanger, the cold chambers, the fluidised bed and the tangential flow filtration. These reflect the diversity of equipments and uses that can be encountered at the Technological Platform.

4.1 Tangential Flow Filtration

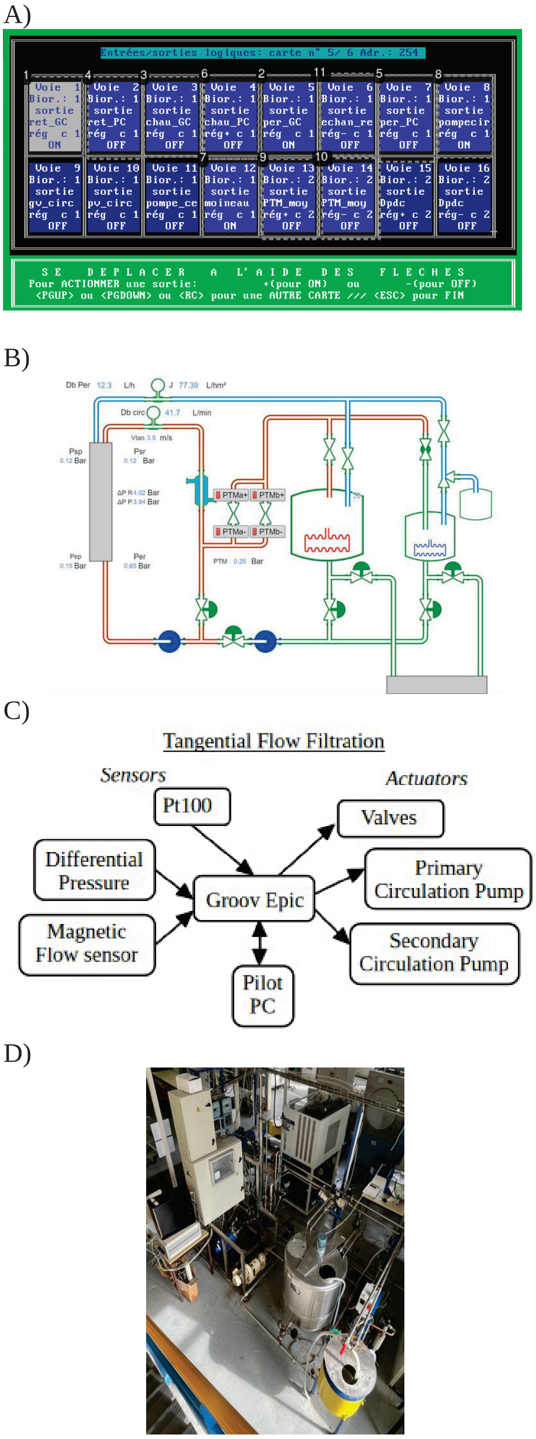

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Fig. 1.Tangential Flow filtration – A) Previous and B) actual versions of the HMI, C: Data-acquisition medhod

The Labstak Tangential Flow Filtration (TFF) pilot, shown in (Fig. 1-D)), had an initial control and monitoring solution developed in our facilities with an human-machine-interface based-on MS-DOS (Fig. 1-A)). The control strategy has been revamped as Opto22 Groov Epic is incoporated with analog inputs and outputs and Pt100 modules. It has a web-based development tool and the HMI has the main parts being represented Fig. 1-B). This pilote is used for example in pre-filtration or to solution concentration applications. Without going to much in details in the experimental protocols, a first pump feeds to primary line, returning to the main tank. When the flow rate is stable, the second feed pump is turned ON to push the solution to the secondary line equiped with the filtration membrane. By applying a differential pressure across the filtration membrane, permeate and rententate are separated.

Doule jacket tanks are used with heating control either from the steam line at our infrastructure or using an independent heat regulation system.

The Groov Epic monitors the differential pressure, temperatures, magnetic flow (Optiflux 4300 (Krohne) + 800 series (Foxboro)) and controls a series valves (Gemü) and the pumps rotation speeds (Fig. 1-C)). It is also equipped with a P4Q-CV16 quick exhaust valve in case that critical pressure is reached. An example of results is presented on Fig. 2.

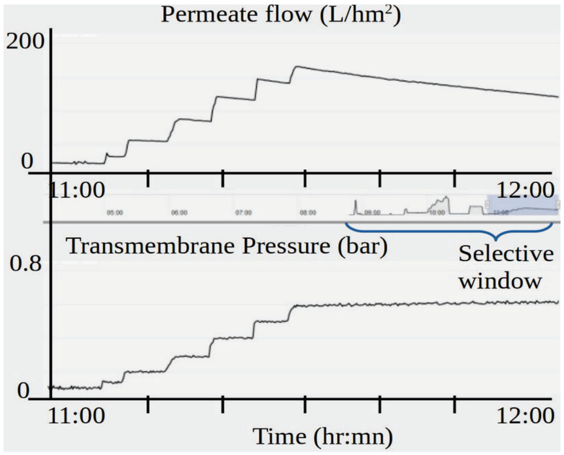

Fig. 2. Permeate flow and transmembrane Pressure

On the HMI, there is a section to visualise raw and calculated parameters as a function of time. As the pressure is increased across the filtration membrane, the formation of the "cake" is observed. With a selective window, it is possible to trace back the acquired data during the processes for verification or post data treatment.

4.2 Fluidised bed

The Glatt Fluidised bed is manually operated with electro- and pneumatic-control (Fig. 3-B)). It can be used for drying, agglomeration and particle coating.

A series of sensors are placed around the fluidised bed to monitor the process and to bring physical parameters information to the user. The environmental conditions (air flow, temperature) have to be reached to progress through the protocol. They can be adjusted according the materials characteristics (particle size, mass) being employed.

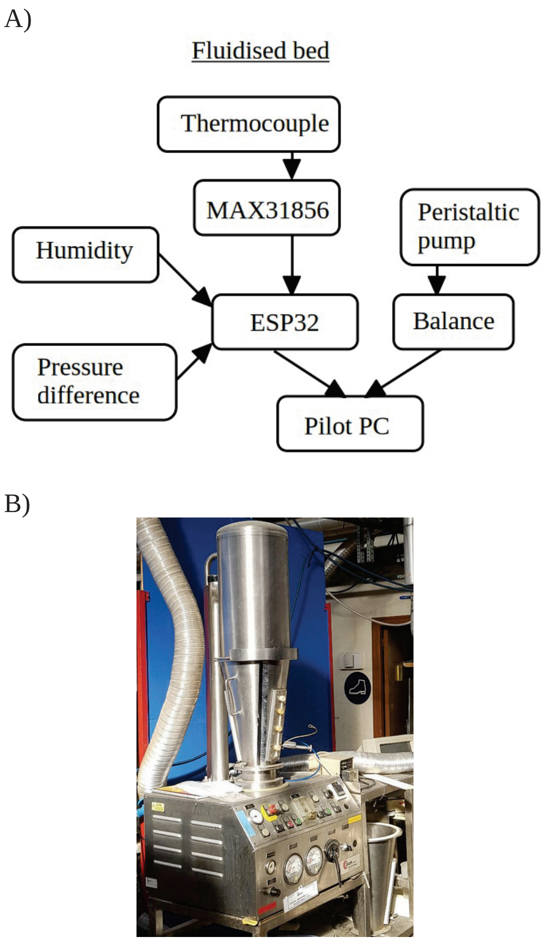

Fig. 3. Fluidised bed – A) Data-acquisition method, B) Fluidised bed pilot

A series of sensors are placed around the fluidised bed to monitor the process and to bring physical parameters information to the user. The steady environmental conditions (air flow, temperature) have to be reached to progress through the protocol. They can be adjusted according the materials characteristics (particle size, mass) being employed. The pilot is instrumented with two humidity transmitter (HF5A Rotronic) located at the air entrance and exit, three thermocouples and a differential pressure transmitter (FCX-AIV) for air flow measurement. A balance (Precisa LS6200D) is combined with a peristaltic pump (Petro Gas Berlin) to control the amount of liquid solution being sprayed through the nozzle at the top of the chamber. A desiccant dehumidifier (Munters M120) can be connected at the air entrance if a better control on the air humidity is required. An ESP32 board is prepared to acquire all data from the sensors (Fig. 3-A)). An HMI code is developed in Python to collect and display all data.

4.3 Spray Dryer

The Spray Dryer comes from GEA with built-in control based-on WinCC ((Fig. 4-B)). The user modifies the physical settings parameters (temperature, flow rate) of the process through the HMI of the Siemens Simatic TouchScreen. This communicates with an analog input and output PLC (S7-300) to control and monitor the equipments surrounding the pilot, such as Pt100 temperature measurement, peristaltic pump (Watson Marlow 530u), air flow measurement via differential pressure gauge and Rotronic Hygroflex (Fig. 4-A)).

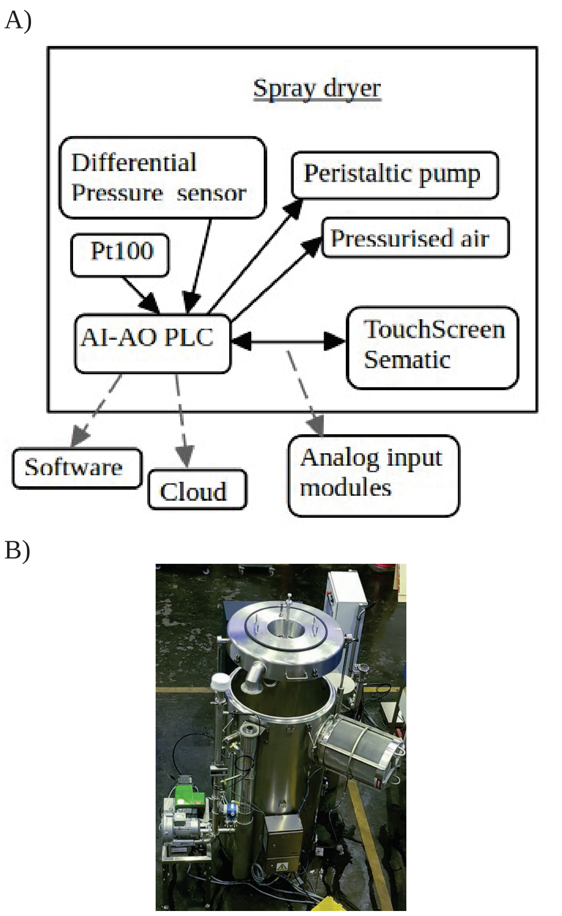

Fig. 4. Spray dryer – A) Control of the equipment, B) Spray dryer pilot

Simatic Cloud Connect Interface (CC712) and OPC Simatic NET Software are evaluated to get a remote access to all acquired data and to enhance the data transfer to the supervisory PC.

It is also investigated the possibility to employ Opto22 analog input modules (SNAP-PAC) or Groov Epic to interact with the transferred signals between the Simatic TouchScreen and the PLC, as expertise is already available in our facilities.

4.4 Plate Heat Exchanger

The Vicarb plate heat exchanger (PHE) is employed to calculate exchange coefficients between a cold and hot fluid lines (Fig. 5-B). This requires the combination of temperature and pressure and flow rate measurements and also having the characteristics of the PHE pilot [1, 2].

Four water pressure sensors from DFRobot (range: 0-1.6MPa; Accuracy: 0.5-1% Full Scale) and 4 Pt100 (connected to Adafruit Pt100 Amplifier: MAX31865) enable to monitor the temperatures and the pressures at the inputs and the outputs of the cold and hot water lines. Their signals are acquired with an ESP32. The water flows are adjusted with float flowmeters (Tubux M30, Mecon). A Raspberry Pi communicates with the ESP32 and makes a compact solution. Secure Shell (ssh) protocol is employed to get access through the local network (LAN) to remote user pc to transfer data, which are also saved on a back-up PC (Fig. 5-A)).

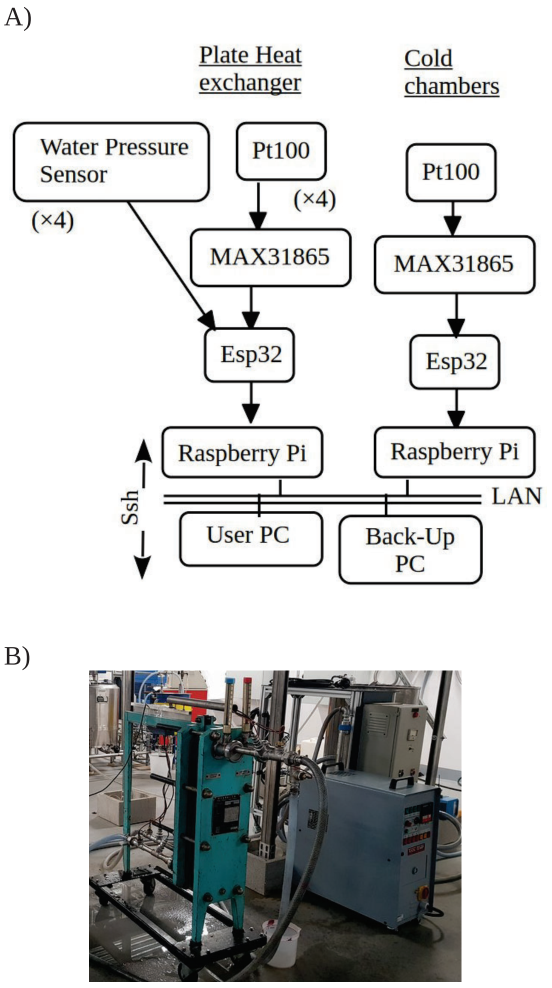

Fig. 5. Plate heat exchanger – A) Data-acquisition method, B) PHE pilot

4.5 Cold Chambers

Two methods have been set-up to collect the temperatures of the cold chambers (4 and -20° C) in separated locations (laboratories, Food grade area). Managing cold chambers temperatures is carried out automatically in our facilities and records not shared by the geostationary. For regulatory, management quality of our facilities and project collaborations, it is mandatory to have access to these data; this can help in identifying if preventive and curative maintenances are required.

On a similar approach to the PHE pilot, a Raspberry Pi collects data cold from chambers next to laboratories with Pt100 and is connected to the back-up PC (Fig. 5-A)). Fig. 6 shows the continuous monitoring of the cold chambers temperatures. Plots are updated every 2 mn. The peaks are due to a defrost process to avoid having ice-forming in the chambers.

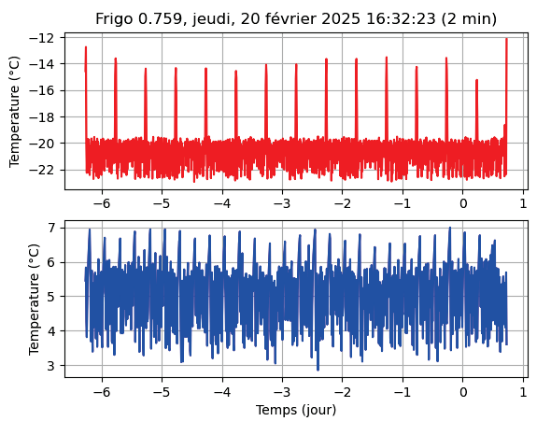

Fig. 6. Cold chambers temperatures monitoring displayed on the Back-up PC

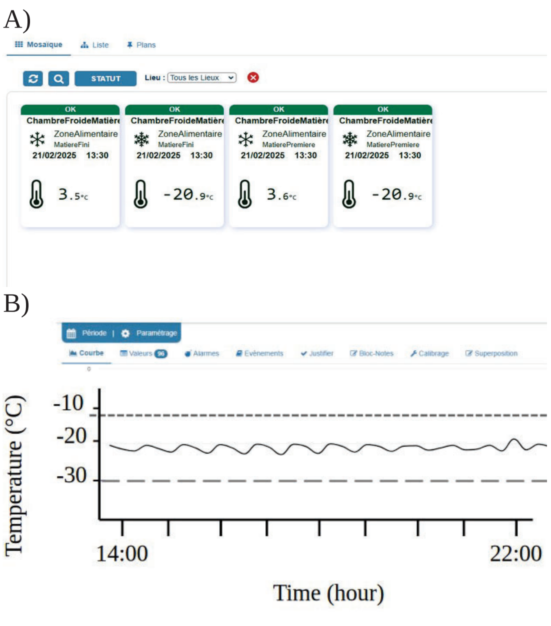

Fig. 7. Temperatures Monitoring of Cold Chambers for alimentary area ; __ __ : low-threhold and _ _ _ _ : high-threshold for alarms

On the other hand, cold chambers are also located in the food grade area. Wireless FoxNet Temp recorder is employed to automatically send temperature measurements on cloud via RJ45 Ethernet connexion. The Thermotrack Webserve software, a remote temperature monitoring solution, a web enables to visualise the data (Fig. 7). It has automatic calibration documentation management to ease configurations. Fig. 7-A) is a real-time display of the actual temperatures. Alarms can be set if low and high thresholds are reached due to dysfunction and to take quick and necessary actions. Records are available for future investigations; an example is shown in Fig. 7-B), with the thresholds being set at at -30 and -12°C.

These two approches of temperature monitoring are incorporated in the supervisory solution.

5 Architecture deployment

The previous section shows the diversity of the pilots, the signals being acquired and the communication protocols considered (serial RS-232, Modbus, node-RED) of the available technical solutions.

Several data transfer protocols are possible for data transfer and deploying our solutions over the network. For IIoT solutions, just to site some, there are, for example, File Transfer Protocol (FTP), Hypertext Transfer Protocol (HTTP) and Secure Shell (SSH). Identifying which ones are suitable depends on parameters such as bandwidth requirements, latency requirements, range, energy efficiency, number of devices to be connected, compatibility with existing system to facilitate integration and operation.

The pilots PC's, based-on Windows or Linux operating system, are connected to the Virtual Local Area Network (VLAN) (Fig. 8).

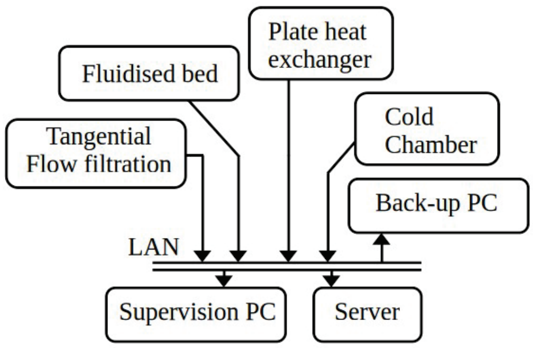

Fig. 8. Connexions of the pilots through the network to the Supervisory and back-up PC's

For our development, Message Queuing Telemetry Transport is chosen, being "Publish-Subscribe" protocol. It is reliable, easy to implement, suitable for IoT devices with limited bandwidth and power. The maximum size for each MQTT packet message that can be sent is 256MB. Also, due to its lightweight design, it can be incorporated in Raspberry Pi-based solutions.

An initial test was carried out generating and arranging random-data, with a time-stamp, and connecting several PC's with a Python code.

Following the development, MQTT data message from the pilots are continuously sent to the network. The HMI of the supervisory PC is designed to display the real-time data for the process occurring in the selected pilot. Attention is brought on getting and analysing the HMI requirements from researchers and trainers in pedagogic projects. The user has also the possibility to check the history. A copy of the data is directly sent to the server and the back-up PC. This facilitates managing and tracking pilot uses.

On the top of this, a generic web interface is developed for real-time data visualisation and metadata handling.

It used a webserver providing a Representational State Transfer in an Application Programming Interface (REST API) based-on FastAPI; it is a modern and high-performance web framework for creating APIs with Python and which has modules automating documentation. The user interface is developed in ReactJS, an open-source JavaScript library that builds user interfaces for web and mobile applications. The main advantage of ReactJS is that it is scalable, simple and fast.

The software development quality strategy uses version control (git), both automated and manual testing, continuous integration, environment consistency and isolation, an agile development methodology incorporating feedback from users and a comprehensive documentation. All components will have automated tests, both unit tests and integration tests, which are run automatically on code changes and/or on a scheduled basis using continuous integration tools.

The automation of data and metadata handling using the Dataverse APIs is also tested. The solution currently envisaged is a component on the user interface, with a specific metadata form and then use the Dataverse APIs to transfer the data to a long-term storage area.

6 Conclusion

The poster demonstrates that a Python-based open-source and web-based supervisory system can be deployed across a range of food and bioproduct processing equipment. The custom-built solution integrates multiple devices, IIoT and different protocols to provide a scalable and cost-effective alternative to commercial SCADA or HMI systems. Our developments fit for both educational and industrial applications.

The implementation is still in progress and future development will expend the number of supported pilots within our system. For convenience, current developments focus more on pilots that communicate via existing APIs, such as those coupled with an Opto22 Groov EPIC system.

The Groov Epic also offers the potential to be interfaced with Node-RED and MQTT for data transfer to and from database [3, 4]. C.-Y. Chen et al. demonstrated the combination of Raspberry Pi, Node-RED and MQTT in the development of a web-based plateform to control and monitor lighting and air conditioning in laboraory [5]. This shows that our considerations are promising.

Our approach is to gradually integrate additional protocols step-by-step, such as a Python client for Modbus TCP/IP or the MQTT protocol.

Regarding metadata entry, the required fields must be defined on a case-by-case basis, depending on the experiment. These specific metadata fields should align with ontologies developed by researchers, with also some aspects potentially being automated. Data formatting for compatibility with other databases, such as the PO2 database [6], will be proceed on the server side.

Similar processes are used in other domains (biotechnologies, chemistry, pharma, petrochemistry, cosmetics).

At SayFood, the instrumentation team has the potential to design, evaluate, test and implement strategies around food processing technologies and data management bringing expertises in electronics, automation, metrology, AI and quality.

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