

Sustainably enhancing olive oil production: intelligent system architecture

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Abstract—Olive oil production is a noteworthy economic activity in multiple places worldwide. Due to environmental degradation and lack of resources with population growth, there is a global tendency for more sustainable and efficient practices, driving the implementation of more responsible agricultural and industrial systems. This paper aims to develop an intelligent system architecture focused on optimizing the production of olive oil, improving product quality, reducing operational waste, and maximizing the efficient use of natural resources. Through the use of Industrial Internet of Things (IIoT) technologies, the proposed solution aims to monitor and control the parameters of olive oil production automatically. In addition, the study addresses sensors already used in the market and existing systems to compare and seek improvements. The proposed architecture contains three layers: device, edge, and cloud computing layer, which are integrated and enable the implementation of a scalable and complete solution that allows real-time visualization and control of the production process.

Keywords—IoT, IIoT, Digital Twin, Industrial Automation, Digitalization, Efficient Production, Sustainability.

I. INTRODUCTION

Olive oil is a food that has been part of cuisine for millennia. Vossen [1] points out that the edible olive seems to have coexisted with humans for about 5000 to 6000 years, and it is believed that its origin can be traced to areas along the eastern Mediterranean Coast. Furthermore, according to [2], olive oil production has tripled only in the last 60 years, reaching 3 266 500 tons in the 2019/20 crop year. Countries such as Spain (34%), Italy (11,20%), Greece (8,42%), and Portugal (4,28%) stand out as some of the world's largest olive oil producers.

In the northern region of Portugal, olive oil holds significant cultural and economic importance, especially in Trás-os-Montes and Alto Douro region, recognized for their high quality and characteristics of olive oil. The olive oil from Trás-os-Montes even holds the Protected Designation of Origin (PDO) certification [3], which guarantees its origin and quality. The production of olive oil can also align with Sustainable Development Goal (SDG) 8 - Decent Work and Economic Growth, by supporting local economies through sustainable agricultural practices and fair labor conditions.

This paper aims to design an intelligent system for olive oil mill production that enhances sustainability by combining IIoT with a Digital Twin (DT) to optimize the usage of natural resources while maintaining a high standard of olive oil quality. This approach aligns with SDG 12 - Responsible Consumption and Production, which emphasizes reducing waste and efficient resource usage in production systems. With the integration of state-of-the-art monitoring and control technologies, the proposed architecture also seeks SDG 9 -

Industry, Innovation and Infrastructure, demonstrating how innovation in industrial processes can promote sustainable and resilient infrastructure in the food production sector. The scientific contribution of this work lies in the integration of emerging technologies with an approach oriented towards sustainability and efficiency in olive oil production, with potential application in other food industries.

Olive oil production is a process that goes through several stages, from reception to storage, until obtaining olive oil without using chemical products. Several factors influence the quality, such as the cooling temperature by water addition. The stages and relevant aspects of production are described below.

- **Reception:** the olives are received from the harvest. In the work [4] it is explained that, among other factors, the maturity level of the olives is crucial to the quality of the olive oil obtained. Furthermore, the time between the harvest and the oil production must be as short as possible to prevent olives' degradation.
- **Cleaning:** the olives are separated from the debris from the harvest, using different techniques and procedures to remove leaves, stones, and other waste. Giovacchino, Sestili & Di Vincenzo [4] say that foreign matter must be removed to avoid negative influences on oil quality.
- **Milling:** the olives pass through a hammer mill or a stone mill and are crushed and transformed into a paste. This paste is composed of oil, water, and olive solids. The process must be carried out with the lowest possible increase in temperature so as not to harm the quality of the oil. The study [4] explains that the grinding method used directly influences the amount of phenolic oils and the temperature, which can vary from 4 °C to 15 °C. In [5], it is discussed how the addition of water in the milling helps in the separation of the oil, it can also cause losses of phenolic compounds.
- **Malaxing:** the process by which the olive paste is slowly mixed to facilitate its extraction. The process is carried out at a controlled temperature. The study [6] demonstrates the reduction of phenolic compounds with the increase in temperature in the malaxation of olive oils, so the temperature must not be higher than 20-25 °C.
- **Decanter:** is a process that separates solid residues from the water. It is necessary to control the temperature to be lower than 25 °C to ensure quality extraction.

- Vertical centrifuge: a phase that replaces or complements decantation. Due to the difference in density and vertical centrifugation movement, olive oil is obtained and sent to storage, and the reject is discarded. Water is added to facilitate extraction in dried olive masses.
- Storage: to guarantee the quality and durability of the olive oil, it is important to store it at a controlled temperature. In addition, measurements are periodically taken in laboratories to check whether the stored olive oil maintains its quality over time.

Aiming to implement a system that helps the manufacturer in quality and sustainability, it is essential to monitor and control the various factors that affect the quality of the olive oil, namely, the degree of maturation of the olives, temperature during the different stages of production, humidity, the fat content of olive oil and compounds that determine the quality of the olive oil that are traditionally only verified in the laboratory. The system will act in all stages of olive oil production to ensure effective monitoring and control.

The article is organized into the following sections: state of the art regarding architectures and technologies used for sensorization, monitoring in olive oil mills; the proposed architecture highlighting the sensors and technologies proposed; experimental implementation and future work; and the conclusion.

II. SENSORS AND AUTOMATION FOR OLIVE OIL PRODUCTION

In recent years, Industry 4.0 has been transforming production processes by applying new technologies, among which IIoT stands out. The work [7] explains IIoT as connecting all industrial assets, including machines and control systems, with information systems and business processes. Furthermore, IIoT paves the way for a better understanding of the manufacturing process, enabling efficient and sustainable production. Therefore, sensors are essential to acquire data from important assets to optimize processes and achieve the expected results. However, the sensors must be chosen appropriately due to the food industry environment.

Precautions must be taken during implementation, such as considering the maximum pressure that the sensor can withstand, the diameter of the tube, the sensor's Ingress Protection against solids and liquids, and the type of communication used to integrate it into the systems. If the sensor is in direct contact with food, it must be coated with non-toxic materials, such as stainless steel, to not compromise the process.

Temperature and humidity are relevant parameters for olive oil production, and many solutions are available for these measurements. It is necessary to determine which aspects of these sensors are appropriate to the solution and what are the project priorities, such as the measurement range, accuracy, response time and price. Each supplier offers a range of solutions, often customized for each application.

For olive oil production, a sensor with a fast response time, high precision, and an adequate temperature range is important. Several solutions are available with these specifications, some examples of temperature sensors can be seen in Table I.

TABLE I. TEMPERATURE SENSORS SUITABLE FOR OLIVE OIL PRODUCTION.

Model	Supplier	Features
iTHERM ModuLine TM411	Endress + Hauser [8]	Measurement Range: -50 °C to 200 °C. Response time: 1,5s. Accuracy: class A. Encapsulation: up to IP69K. Communication: 4-20 mA; HART; Profibus PA; Foundation Fieldbus.
Rosemount X-well Technology	Emerson [9]	Measurement Range: -50 °C to 300 °C. Accuracy: class A. Communication: 4-20 mA; HART and Wireless HART protocol.
FLIR AX8	Teledyne FLIR [10]	Measurement Range: -10 °C to 150 °C Accuracy: ± 2 °C Encapsulation: IP67. Communication: Ethernet/IP; Modbus TCP; UDP; SNTP; RTSP; RTP; sftp; HTTP; ICMP; IGMP; SMTP; SMB; DHCP; MDNS.
Rosemount 565	Emerson [11]	Measurement Range: -50 °C to 250 °C Accuracy: 1/6 DIN Class B. Up to 16 spot elements. Communication: Foundation Fieldbus.

The iTHERM ModuLine TM411 sensor is an example of a PT100 type Resistance Temperature Detector rod sensor, widely used because its precision, stability and adequate measurement ranges to olive oil production, as can be seen in Table I, owning all the characteristics suitable for use. Furthermore, it is a sensor that needs to be in direct contact with the material to be measured, allowing it to be used in all stages of production. Still, adaptations are required for installation whether in the machines or the pipelines.

An alternative is to use non-invasive sensors such as Rosemount™ X-well™ Technology sensors, which are placed externally in the pipes and can read the temperature of the internal contents adequately, simplifying installation and maintenance. To monitor the temperature of the reception stage, thermal cameras, such as the FLIR AX8, may be implemented, which can check the temperature remotely without interfering directly with the production line. As for storage tanks it is possible to use sensors like the Rosemount™ 565 Multiple Spot Temperature Sensor, which uses multiple PT100 sensors to monitor the temperature throughout the tank.

Regarding humidity sensors, Table II shows some suitable choices for olive oil production.

The Hydro-Mix XT-FS sensor is a moisture sensor that uses microwave technology, so it is not affected by dust and other environmental conditions. According to its specifications it is a possible solution for measuring moisture in olive oil.

Two other sensors for measuring moisture in the milling phase are presented, the M-Sens NIR and the DA 7350, both using Near-infrared (NIR) spectral technology that has improved the olive oil industry, allowing the evaluation of several parameters more quickly and accurately. Considering the M-Sens NIR, it is capable of measuring moisture and, optionally, temperature, achieving high precision and sample rate, offering a range of communication protocols and adequate protection for use. However, if the system aims to evaluate other parameters, the DA 7350 stands out, allowing for more complete analyses.

For measuring injected water flow [15] addresses in detail the different volumetric flow meters for industrial use and the

TABLE II. HUMIDITY SENSORS SUITABLE FOR OLIVE OIL PRODUCTION.

Model	Supplier	Features
Hydro-Mix XT-FS	Hydronix [12]	Measurement Range: 0% to 100%. Accuracy: 0.2% for aggregates, 0.1% in the mixer and 0.5% for other materials. Sample rate: 25 measures per second. Communication: 4-20mA; RS485.
M-Sens NIR	Envea [13]	Measurement Range: 0% to 95%. Accuracy: $\pm 0,1\%$. Sample rate: 60 calculus per second. Material to measure: Dust, powder, granulates and other bulk solids. Encapsulation: IP69. Product distance: 20,3 cm to 40,6 cm. Communication: Ethernet/IP; Profinet; Profibus-DP; Modbus TCP/IP; Modbus RTU; Ethernet; DeviceNet.
DA 7350 In-line NIR & Camera Instrument	Perkin-Elmer [14]	Material to measure: granules, pellets, powders, pastes, liquids and more. Measured parameters: moisture, sugar, fat/oil, starch, protein, speck count, Color in CIE L*, a*, b* color space. Encapsulation: IP67 and IP69K. Sample rate: > 20 spectra and measures per second. Communication: UPC UA; Profinet; Modbus TCP; Profibus DP; Modbus ASCII; Analogue outputs; SQL Queries.

advances in recent years. According to [15], electromagnetic flow meters allow accurate measurements while at the same time offering low cost, less maintenance, no moving parts, ease of installation and high stability. The main limitation of flow meters, a widely used option for water management and the food industry, is that they can only measure conductive liquids, such as water. Regardless, electromagnetic flow meters are suitable for monitoring the water injected in olive oil production, such in the cleaning, milling, decanter, and centrifuge stages.

In addition to classic temperature and flow sensors, the integration of specific sensors to monitor the composition of fat water can deliver important insights to optimize the phase separation process. Technologies such as NIR spectroscopy can evaluate the concentration of water-soluble compounds. According to [16], combining data from an 18-channel multispectral sensor with a neural network could assess the fat content non-destructively, opening up possibilities for continuous monitoring of fat content in olive oil production lines at the exit of the vertical centrifuge, in which have the oil ready.

Multispectral sensors and computer vision systems can be implemented at the olive reception to identify the ripeness status in real-time. The work [17] uses NIR technology, using a JAI AD-080CL Multi-Spectral Camera to capture images in both visible color and NIR spectrum simultaneously and creates a computer vision system that determines in real-time the quality of olives based on several characteristics of the fruit, quality control in the production line.

With the implementation of the sensors and the collection of data, it's possible to advance and use DT technology, which emerges as a tool capable of assisting the industry. According to the Digital Twin Consortium [18], DT is a virtual representation of real-world entities and processes synchronized at a specified frequency and reliability. As discussed in the article [19], DT can potentially optimize processes and reduce waste through continuous monitoring and predictive analysis. In the case of olive oil production, this

means a more rational use of water, a reduction in energy consumption, and an increase in the quality of the end product by ensuring that all process variables are within optimal parameters.

The study [20] presents a practical application of DT in an olive oil mill in Andalusia, Spain. They implemented a cyber-physical system based on DT and a 3D SCADA interface, using the OPC-UA protocol for bidirectional communication between the physical systems and the digital environment. This approach enabled real-time monitoring of olive oil production processes and made it possible to carry out predictive simulations and preventive maintenance. This simulation capability is an important differentiator, as it allows critical production parameters to be adjusted without interrupting the process, making a significant contribution to operational continuity and the system's sustainability. The use of the OPC-UA protocol offers high interoperability and it is a practice that can be applied to the architecture proposed in this work.

The authors [21] aims to develop and implement a system to improve operational efficiency and product quality by automating the malaxation and centrifugation stages, through a modular architecture using widely available sensors (PT-100 sensors) to monitor temperature and flow in real-time, and standard industrial protocols (such as MODBUS RTU and APC 220) making the system accessible and scalable. The system consists of four main layers: the embedded sensor layer collects data from the production line. The data aggregation layer uses PLCs or microcontrollers to collect and process the data. The data layer manipulates these data on an industrial computer with the web server and application and the layer of visualization and monitoring of the data locally and remotely through a web interface.

The proposal of this work expands the monitored parameters, such as water flow and real-time quality, by adding more sensors, such as discussed before, in all manufacturing stages. Another innovation of the system is the precise control of the olive mill by automatically managing the electric valves and the industrial machinery, such as the speed of malaxing and the vertical centrifuge. Furthermore, it proposes utilizing the cloud to offer new functionalities involving AI and data analysis for more advanced and complete production analyses to identify patterns and trends, the implementation will be made in future work.

III. SYSTEM ARCHITECTURE PROPOSAL

The olive oil manufacturing process is highly demanding in its different stages, despite requiring minimal intervention and no added chemicals. Given the food industry environment and the previous restrictions, it is important to use highly reliable and safe technologies. Therefore, careful planning is necessary to integrate any new technology to avoid compromising the quality of the olive oil, prevent crop losses and ensure sustainability. Furthermore, as it is a dynamic environment, it is necessary to create intuitive software that only provides users with the needed permissions and functionalities.

The solution is designed to be simple, scalable, and compatible with different technologies to handle these challenges. The proposed architecture is available in Fig. 1. Based on the concepts defined in [22], the architecture comprises the Device, Edge, and Cloud application layers.

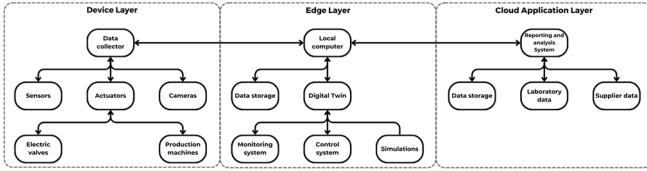


Fig. 1. System architecture.

A. Device Layer

This layer comprises cameras, sensors, actuators, and equipment to collect and transmit data to the Edge layer. The devices can operate with low latency using industrial communication protocols such as Modbus and OPC-UA, which are crucial for dealing with factory floor conditions.

The data collector is a device for collecting and transmitting data from the Device Layer to the Edge Layer. This device converts industrial protocols into conventional network communication protocols, such as Ethernet or Wi-Fi, and vice versa, enabling efficient communication.

Aiming to have easy integration with software and high speed, JavaScript Object Notation (JSON) is a reasonable option. In the work [23], it is possible to verify that the average transmission time of the maximum object reached was 0.11 ms, which is adequate for the requirements of the system.

In order to monitor and control the production of olive oil, a flowchart was developed containing the steps and the position of the devices necessary for a complete execution of the proposal, as shown in Fig. 2.

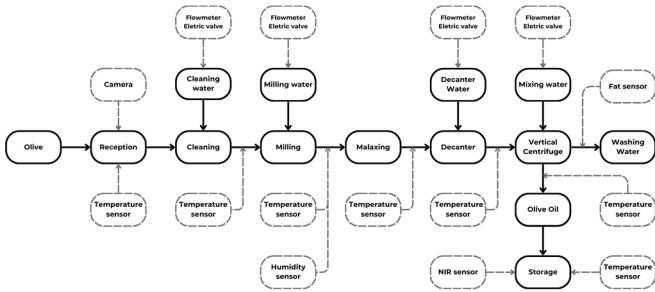


Fig. 2. Flowchart of olive oil production and sensors positioning.

At the reception stage, the ripeness of the olives is crucial to ensure the quality of the final oil. Multispectral cameras are proposed at the entrance of the production line to perform the quality analysis. In the milling stage, temperature control is essential to preserve the phenolic compounds. Temperature sensors are proposed in the mills to monitor the heat generated during the process. A flow meter and an electric valve can also control the water flow during this stage.

During malaxation, the olive paste is mixed to facilitate oil separation. Temperature sensors can be used the consistency of the mixture. In the decanter stage, flow meters, electric valves and temperature sensors can be installed at the decanter outlets to check the efficiency of the separation.

In vertical centrifugation, flow meters and temperature sensors can ensure that the oil is correctly separated. Spectroscopy-based sensors monitor the composition of the fat water, identifying losses of valuable compounds. In the

final stage, storage, multipoint sensors monitor the temperature in different parts of the tanks to ensure homogeneous conditions.

In addition, the system proposes automatic control of the start, stop, and speed of the machines involved in the process, such as crushers, mixers, and centrifuges. For example, the system can detect when the olive paste has reached the ideal consistency for malaxation and then adjust the machine speed or automatically stop the process, avoiding over-processing.

So, this control aims to ensure that the relevant parameters are regulated efficiently without constant manual intervention.

B. Edge Layer

This layer contains devices and systems for real-time production control, process optimization, and data analysis. The main goal of this layer is to create a DT, allowing the operator to control and monitor the system in real-time. To implement a DT in olive oil production, it is necessary to follow a set of steps that involve modeling the physical and virtual parts, integrating data, and providing services.

According to Tao and Zhang [24], a DT should include the Physical Shop-Floor (PS), which corresponds to physical equipment such as presses and malaxers; the Virtual Shop-Floor (VS), which consists of virtual models developed with software such as AutoCAD for geometric modeling and MATLAB/Simulink for simulating dynamic behavior; the Shop-Floor Service System (SSS), responsible for encapsulating tools and information systems using platforms such as ThingWorx to manage maintenance and optimization services; and finally, the Shop-Floor Digital Twin Data (SDTD), which comprises the collection and fusion of physical and virtual data, carried out using databases such as InfluxDB to store historical sensor data.

The connection between the physical and virtual parts is fundamental. It must be established by protocols such as OPC-UA, guaranteeing the continuous exchange of information to enable the DT to offer predictive maintenance and control services in real-time. This iterative modeling, simulation, and validation process makes the DT an essential tool for optimizing operations and maintaining consistency between physical and virtual production conditions.

The system can acquire the data needed for real-time production line by monitoring the sensors and cameras implemented in the Device layer. In addition, provide precise and complete control over olive oil production through actuators.

This acquired data must be stored in a local database since it is critical data for the system. In this way, it must quickly respond to requests and be available even during an Internet connection failure. For incoming data from sensors, which are continuous data with timestamps, it is proposed to use a database specialized in time series, such as InfluxDB. As for images obtained from cameras, a plausible solution would be to use NoSQL databases, such as MongoDB.

To guarantee the integrity and authenticity of data obtained from devices, it is necessary to use digital certificates and hardware-based encryption, thus increasing system security.

With the implementation of a DT, several functionalities are proposed, such as allowing the operator to simulate different production scenarios based on existing data,

permitting the change of parameters such as the flow of water and temperature, and observing how would impact the production.

Experimental validation is fundamental in ensuring that the digital model effectively represents the physical system. This validation will be done by comparing actual production data with the data predicted by the DT in different simulated scenarios. In addition, tests will be carried out to assess how the simulation can predict faults and suggest corrections before problems occur physically.

The main interface would allow the user to check sensor data, configure desired setpoints, and check which parameters are being applied, such as the number of valves activated and the machines' speed.

The user chooses whether to set the parameters automatically or manually. If the system is in automatic mode, it will prioritize maximizing the quality of the olive oil while minimizing the use of resources. Since this data requires more computing power for AI analysis, the cloud processes this request. If the service is unavailable, the last production's parameters are used.

In addition, the system would show information on the natural resources used, visual and audible alerts are also required so that the operator can quickly identify anomalous data in equipment or processes and take appropriate action.

Finally, the proposed system would have other pages to access different views, such as dashboards and settings, such as switching to cleaning mode and security-related information, requiring authentication for several features. Therefore, a complete system is proposed to meet the Edge needs of an olive oil mill.

C. Cloud Layer

This layer handles, processes, and integrates various data while performing more complex analyses and enabling online visualization. The data processing of this layer will not be crucial to the industrial process, so more significant latency will not be a huge problem, with the expectation of around a few seconds. Some analyses that require more computational power, such as parameter optimization and camera image analysis to identify the olives' characteristics, are carried out in the Cloud.

In addition to data from the production process, the application would receive data from suppliers, such as when the harvest was carried out and the variety of olives, as well as laboratory data, such as the physical and chemical characteristics of the oil obtained. By integrating all this data and conducting some analyses, it would be possible to get a complete report on the entire production chain.

Besides facilitating several complex processes in the company, it would also enable future analyses and more precise simulations of aspects such as the amount of olive oil that will be produced under certain conditions in the harvest and production stages and the projection of the quality of the olive oil using machine learning models with the data obtained. Consequently, the intelligent system implementation will allow better harvest planning and company goals and less waste of natural resources.

IV. SENSORS AND AUTOMATION FOR OLIVE OIL PRODUCTION

As DTs are developed for each case, there is no general model or software that fits all cases, so in order to validate the framework developed, it is necessary to implement the system in an olive oil mill and develop applications to obtain the desired result, which is a time-consuming process consisting of several stages.

Initially, sensors had to be installed in the oil mill to collect data during production. Thinking strategically, was installed sensors widely used in the area, such as temperature and flow sensors. The OPC-UA communication protocol was used because of its high scalability and data transmission.

However, data collection is still taking place, so synthetic data was generated to develop the data monitoring program, Fig. 3. To implement this system, the Node-RED program was used for data visualization and InfluxDB as a database for sensor data, as it is a database specialized in time series data.



Fig. 3. Monitoring system using synthetic data.

At the end of the olive oil production period, the data obtained will be analyzed using Python and machine learning models will be trained to detect patterns and abnormalities using different algorithms to verify which performs best.

In addition, to centralize the functionalities, a web application will be developed using React.js, which will be hosted in the cloud using Amazon's AWS. However, the dynamic control and alert functionalities will also be implemented on a local server to reduce latency and allow changes and warnings to be made in real-time.

V. CONCLUSIONS

This work proposed an intelligent system for monitoring and controlling olive oil production using IIoT technologies. The system seeks to guarantee the quality of the olive oil while reducing the environmental impact by using natural resources better.

By employing a wide range of sensors expanding the monitored parameters, real time data acquisition, and automated control mechanisms through AI algorithms and data analysis, the system proposal demonstrates a significant potential to improve the efficiency and sustainability of olive oil production. Showing an innovative solution for handling the industry's challenges contributes to improving yield and aligns with efforts to enhance sustainability within the agricultural sector.

Future work intends to implement this system to test its effectiveness under different circumstances and evaluate its environmental influence. In addition, it is possible to implement new functionalities to analyze the data obtained and integrate it with supplier and consumption data and data

from the production system to track the entire production process.

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