Amarelli's Industry 4.0 Transformation with IoT and Digital Advertisement: Optimizing Operations and Engaging Customers

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Abstract

This paper presents a vertical IoT solution for Amarelli, a licorice producing company, aiming to optimize their operations and enhance their customer engagement through the integration of IoT technology, Enterprise Resource Planning (EPR) system, e-commerce and social media advertising. The proposed solution includes several key components, such as IoT-enabled production monitoring, warehouse monitoring, RFID tracking, and real-time data analysis. The solution also integrates an ERP system, to provide business intelligence and e-commerce combination to enhance online presence and customer engagement through social media advertising. This vertical solution will enable Amarelli to improve efficiency, productivity, and profitability, while also providing valuable insights into customer preferences and purchasing behavior. The implementation of this solution will position Amarelli at the forefront of Industry 4.0, and help the company to stay competitive in today's rapidly evolving marketplace.

1. Introduction

Amarelli is a company placed in Calabria, Italy and produces high-quality licorice. The company is known for its traditional production methods and commitment to using natural ingredients. Founded in 1731, it is one of the oldest licorice producers in the world. Amarelli's licorice is made using finest ingredients, including local licorice root extract and natural flavors. The company prides itself on its focus on sustainability and ethical production methods. Amarelli's licorice is enjoyed by people around the world, and it is a beloved traditional treat in Italy. Today, Amarelli continues to innovate and expand its offering while preserving the traditional taste and quality. Moreover Amarelli boasts is a museum dedicated to the history of licorice. It features exhibits on the cultivation, processing, and use of licorice, as well as its cultural significance throughout history. The museum is located in an old licorice factory and offers visitors the opportunity to learn about the production process and taste different licorice products.

In this work we present a comprehensive analysis, design and implementation of an Industry 4.0 solution for the Amarelli company. The main objectives is the optimization of the Amarelli production process, the integration and automation of business operations, and the improvement of marketing strategies. The proposed solution includes following key components: IoT for production monitoring and Enterprise Resource Planning (ERP) integration, e-commerce integration, and social-media advertisement. By combining of IoT and social-media advertisement the company can optimize both production and commercial activities improving customer experience and increase sales.

2. State of the Art

The Industrial Internet of Things (IIoT) is a rapidly growing field that has the potential to revolutionize the way industries operate. IIoT refers to the use of connected devices and sensor technology in industrial environments to gather and analyze data, with the goal of improving efficiency, productivity and profitability. One of the key areas where IIoT is usefully applied is manufacturing and production. IoT-enabled sensors and devices can be used to monitor the performance of machines and equipment in real-time, allowing for predictive maintenance and reducing downtime. Additionally, IIoT can be used to track and optimize the production process, by providing real-time data on efficiency, quality control, and inventory levels. Another key area where IIoT is being applied is in supply chain and logistics. IoT-enabled devices can be

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used to track the movement of goods and optimize transportation routes, resulting in cost savings and improved efficiency. Additionally, IIoT can be used to monitor the condition of goods in transit, in order to ensure that they are delivered in optimal condition. Industrial IoT represent one of the most effective evolution of Industrial Automation and Control Systems (IACS) proposing system with higher level of integration between heterogeneous technologies and connectivity. From and architectural perspective, in [1] authors proposed an extensive framework for IIoT to analyse and characterize devices, system architecture and security. [2] discuss about the benefit of IIoT in manufacturing and how it can be a key-factor in the Big Data and data analytics for the smart transition of industrial process providing improvements at each level of the such as production and logistic phases. The huge increasing of interaction between devices and cloud platforms in Industry 4.0 expose the needs of significant extension of computation capabilities. In [3] is described how edge computing can optimize network communication, information fusion, and cooperation with cloud computing showing benefits in terms of network usage and data processing comparing cloud-based approach with edge computing integrated solutions. Regarding warehouse tracking in [4] is proposed to exploit UHF RFID technology items by analysing RSSI and phase with a supervised clustering approach. Many challenges are open regarding evolution of emerging wireless IoT technologies and in particular LoRa is a very promising in industrial applications. In particular in [5] is described a medium access strategy suitable for LoRa supporting real-time transmissions. Several challenges in LoRa technologies are related to transmission collisions in massive IoT scenarios. Although LoRa supports orthogonality, in [6] is proved that non-orthogonality effects may occur. A possibile solution have been proposed in [7] to improve the performance of LoRa gateways.

3. Architecture Description

3.1. BUSINESS REQUIREMENTS ANALYSIS

The analysis process started from the study of the company's production process, and based on them the technical and functional requirements of the platform were defined. This phase was guided by following essential principles:

- ability to operate on Big Data;
- possibility of performing multiple types of analysis within a single integrated environment;
- ease of interaction between the system and its users.

3.2. ANALYSIS OF THE BUSINESS PROCESSES

For the design of the business intelligence platform, it was necessary to analyze the business processes, starting from production through packaging and warehousing to sales. The operational activities can be schematized as follows:

Act 1: **Licorice root reception and analysis.** Amarelli selects and acquires the raw material of Calabrian origin and performs quality analysis. If the results meet standards, it proceeds to the next stages of the production cycle;

Act 2: **Storage.** The raw material is deposited in a storage area awaiting processing;

Act 3: **Product develpment process.** Included in the stage are the activities of:

a) cutting and fraying licorice;
b) extraction and decanting;
c) concentration and cooking;
d) paste processing with possible addition of flavorings;

Act 4: **Product drying and polishing.**

Act 5: **Storage of the finished product.**

Act 6: **Packaging and storage.**

4. IoT system for Industry 4.0 applications

In this section we present the IoT system designed and deployed for the digital transformation of Amarelli. The system has been designed with three main objectives: 1) monitoring the production process by means of automated readings of heterogeneous metrics (such as weights of roots, temperature, humidity); 2) tracking the boxes of semi-finished products; 3) analyzing energy consumption data by integrating Energy dataloggers into the plant.

The importance of monitoring environmental parameters during the production process is mostly related to the analysis of the presence of fungi or toxins. Indeed, temperature and humidity is certainly one of the major contributor to the proliferation of fungi and toxins in licorice roots. A particular toxin, called ochratoxin (OTA), must be monitored through laboratory tests at different stages of the production process to ensure that its concentration is under certain limits ((EU) 2022/1370 of 5 August 2022). The ability to correlate the results of sample analysis of a specific production batch with environmental conditions could help to predict the risk of contamination, allowing early action during the production phase, reducing wasted time and energy and consequently increasing production. Another important parameter to be monitored is the weight of the products. Weighting is carried out at three stages of the production process: a) raw root before to start the extraction phase, b) licorice paste before the extrusion phase, c) semi-finished product to be stored. The different weightings provide useful information on the amount of raw material transformed into semi-finished product, information on the drop-weight of the pulp during processing, and have a quantitative track of the stock useful for the packaging stage. Automated tracking of the manufacturing process aims to minimize human intervention, with resulting benefit in terms of operation failure and allows real-time updating of production status of stock in the warehouse. Finally the integration of dataloggers provides real-time measurements of energy spent for each production batch during the manufacturing phases and helps to define optimization actions in a business intelligence perspective.

4.1. Environmental sensors

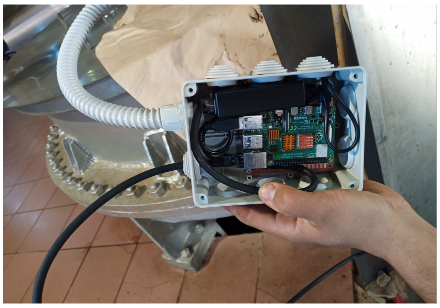
The Amarelli plant has two pots for cooking licorice broths. This process needs human interaction to verify the development status through handcrafted operations. We introduced sensors to support the cooking process. By default, the pot does not provide any sensor for temperature monitoring during the cooking phase, moreover it was not possible to easily integrate an immersion temperature sensor, due to the presence of automated paddles in the pot which are always active and mix the licorice. For this reason, we decided to design a custom IoT device consisting of an Infrared temperature sensor and a general purpose (e.g. Arduino or Raspberry) processing unit with radio and wired communication interface. For the sensor part we adopted PyroMiniUSB[8], a low-cost device composed by an infrared sensor, a optical len and a serial conversion circuit for communications via USB (see figure 1). It allows the measurement of non-contact surface temperature. We placed the sensor close to the pots, enclosing the processing unit inside a waterproof box (see figure 2b) and it extracts with a tunable sampling time (e.g. 1sec) several Infrared information, included the target temperature. Acquired data are converted to a JSON string and, depending on sensor implementation, data can be sent directly to the Cloud Platform server via MQTT protocol or to the Edge IoT Server.

In Figure 3 the data acquisition during three working days of two pots is depicted. Cooking starts at about 7:00 a.m. and ends at 12:30 p.m., corresponding with the end of the work shift. The maximum temperature level is close to 90°C.

Regarding other environmental devices other temperature and humidity sensor are installed in drying rooms and semi-finished warehouse. In particular, we adopted Airgloss ProSense, a versatile device which can detect a wide range of contaminants such as: Volatile Organic Compounds, Carbon Monoxide, Nitrogen Dioxide, Carbon Dioxide, Temperature and Relative Humidity. It is directly interfaced to a MQTT Broker by using an application-side API [9].

Figure 1: PyroMiniUSB

(a) Infrared temperature sensor



(b) Processing unit: RPi4 + PoE

Figure 2: Infrared temperature device installed on an Amarelli cooking pot.

4.2. RFID tracker

RFID technology was used for tracking the raw material and semi-finished products during the production process. Specifically, it was necessary to track the passage

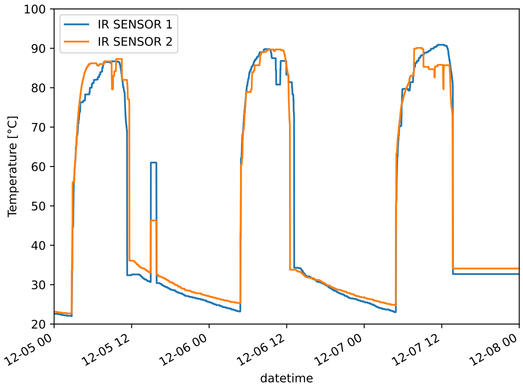


Figure 3: IR temperature measurements

of carts loaded with boxes containing the products. Each box was equipped with an RFID TAG and gates were installed between factory departments.

To facilitate simultaneous reading of multiple passive tags, it was decided to use Ultra high frequency (UHF) RFID systems operating on frequencies from 300MHz to 3GHz. UHF frequencies are regulated by a global standard called EPC Global Gen2 (ISO 1800-63) UHF standard. The benefits are evident in processes where it is necessary to capture information from many tags at the same instant of time in order to provide synchronized tracking of goods. The tracking system updates the status of the tags each time they pass through the gate, in order to update the location of each box during the production process. For detecting the direction of the box movements at each gate crossing, the gate is equipped with photocells placed in both sides of the gate and it is activated by exploiting the effect of Motion Radar.

In order to validate the robustness of the RFID-based tracking system, we conducted several feasibility tests. In our experiments, a cart containing 28 boxes passed through the RFID gates 10 times. The boxes have a shape similar to the ones shown in the figure 4. The gates are equipped with two circularly polarized antennas with 9.0dBi gain and configured with a transmission power of 1W. Tests showed that 100% of the time the tags are read correctly. In industrial manufacturing environment, radio interference is a significant challenge: to avoid problems of false tag readings (due for example to proximity boxes not included in the cart), we also placed an electromagnetic shielding mesh, composed by several metallic elements placed close to the antennas as shown in Figure 5.

Figure 4: A cart loaded with a batch of boxes containing the semi-finished licorice products.

Figure 5: RFID Electromagnetic Mesh Shield installation

4.3. Energy Datalogger

Energy metering is provided by a third-party operator which measures water, gas and electric energy consumption. The measurements are detailed for each building area in order to analyze the consumption of different production sectors. The energy datalogger system is composed by a set of energy meters connected to a PLC, which save data on a FTP server (add here Details of device brand and model). The IoT Edge Server extracts periodically data from the FTP server and forwards them to the Big Data Platform.

4.4. Traffic Volume Analysis

We validate the traffic amount analysis of the proposed IoT system by measuring the transmitted during the production process over one year. The amount of traffic depends on several factors such as the number of sensors, sampling time of each sensor, the amount of data fields for each reading in correlation with the intensity of production shifts. For sake of clarity detailed we analyzed the following sensors:

- *Datalogger*: data provided by 2 different dataloggers (one for electric consumption monitoring and one for water/gas consumption monitoring) transmitted with an inter-time period of 1 minute.
- *RFID Tag Trackers*: data generated by 20 tags (in average) read by 4 RFID gates each day.
- *Environmental Sensors*: measure acquired by 2 infrared temperature reader and 2 environmental temperature/humidity sensors with a transmission inter-time period of 1 minute.
- *Weight Scale*: measured from 2 IoT devices which transmit 4 times a day.

In Table 1 the traffic analysis in terms of number of packet transmitted from IoT Edge Server, and the respective overall payload in megabytes, are shown.

	Datalogger	RFID Tracker	Enviromental Sensors	Weight Scale
# of TX	1.05M	0.146M	2.1M	2K
Payload	146MB	29.3MB	626MB	0.7MB

Table 1
IoT System Traffic analysis over one year

5. Big Data Platform description

Big Data management need a scalable software platform able to collect, store and process data, and with a presentation layer useful to present insight to the end user preserving information privacy and security. Figure 6 shows the platform structure, based on three layers useful for data storage (data layer), data processing (business layer) and data presentation (presentation layer). The software frameworks combines databases, analytics tools, and integration software between Big Data and other applications. The architecture is implemented as a kubernetes cluster, in order to optimize and manage the scaling of Big Data processing. This infrastructure can be delivered "on-premises" or on the "cloud". On-premises solutions require the infrastructure to be installed at the user's enterprise servers; cloud solutions, on the other hand, are pay-as-you-go services offered by a third-party vendor (provider) that, on the pay-as-you-go model, are accessed via the Internet through a virtual platform typically hosted and managed (in part or in full) by the provider itself.

5.1. Platform Logical Architecture

At the architectural level, the following are mainly provided:

- Big Data storage and management capabilities;
- access capabilities to such data, to enable the execution of different types of analysis, both inductive and descriptive. To this respect, the platform is based on a three-layer architecture, including:
  - **The data layer**, which provides a distributed file system as well as all the functionalities needed to process structured (tables), and unstructured (text, time series) data.
  - **The application layer**, which provides functionalities for data pre-processing and cleaning, and will also provide (i) a set of data mining algorithms, capable of working on different types of data, and (ii) an inference engine, enabling automatic reasoning support.
  - **The presentation layer**, providing web dashboards, reports, and OLAP interfaces, that will allow users interactive exploration of the stored information.

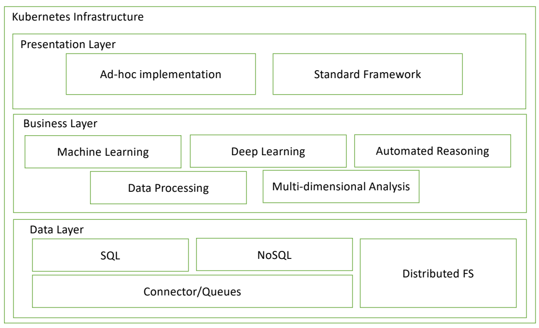


Figure 6: Big Data Platform Layers

The platform is based on a microservice architecture, where the services are provided by a Kubernetes cluster hosted in the cloud. There are two main microservices:

- **Gateway + Front End application:** this is a Java + Spring Boot microservice, that forwards requests to other backend microservices and exposing the Front-End pages written in Angular. This microservice also takes care of security and authorization management.

- **Master Data + Ingestion:** this is a Java + Spring Boot microservice that manages the master data, supporting the whole system and the data ingestion. Data ingestion can take place from different information sources. In particular, the system acquires data from the IoT infrastructure using an MQTT broker.

Figure 7 is an illustration of the physical architecture of the system.

IoT data collection and monitoring system and includes three main entities:

1. *Sensor devices.* Consists of environmental sensors, automated weight scales and energy meter deployed in the plant to trace in real-time useful information during the production.

2. *IoT Edge Server.* Devices can implement different communication technologies such as WiFi or LoRa and for that reason we considered to introduce a local service for data collection, processing and protocol conversion. In order to converge communication to the Cloud platform in a flexible way, the IoT Edge Server translates the different protocols into a subset of shared application protocol to the processing platform. Moreover it support local data processing to optimize the data processing, providing outlier detection, data aggregation and offloads to Big Data Platform processing.

3. *Big Data Platform Interface.* Define the communication interface between IoT Edge Server and Big Data Platform. The definition of the communication interfaces depends on the available protocols on Big Data Platform. In general is preferred to use standard application protocols (such as MQTT [10], AMQP [11] or CoAP [12]) and support security and privacy data preserving mechanisms. In our specific use case we considered the communication between IoT system and the platform via MQTT.

It is worth pointing out that all components communicate within a private, secure VPN. End users access the platform by connecting to the microservice that exposes the front-end.

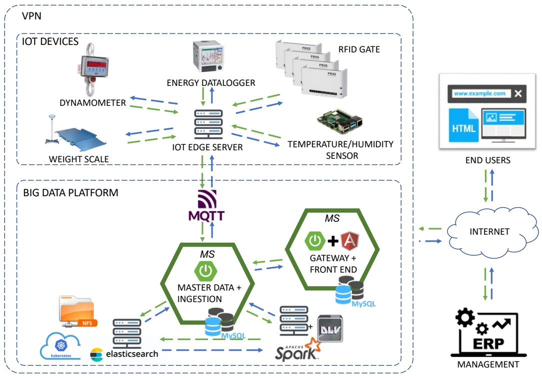


Figure 7: Big Data Platform Architecture

6. Digital Advertising application

The Amarelly factory has a marketing strategy based on brand awareness, therefore they do not distribute pervasive advertising campaigns, nor use traditional advertising media. They have focused their customers recruitment on the notion of *community*, built upon the visitors of the Amarelli museum and/or store. Moreover, they also manage online sells by a traditional e-commerce.

The main purpose of the proposed application is to provide Amarelli with a decision support system, integrated into the big data platform, in order to select suitable combinations of products which need to be sponsored, and customers who potentially may like them. This is in accordance with the principles of the considered industry, that is, avoiding the spreading of advertisements to users who could be not so much interested.

In particular, a data warehouse has been implemented, fed from the already available e-commerce database. This will allow the industry manager to perform classical OLAP queries. Moreover, further services have been designed in order to perform RFM (Recency, Frequency, and Monetary value) analysis (see, e.g., [13, 14]) on data retrieved from the data warehouse and that, in future work, will be integrated with those coming from Amarelli's community social network. According to Amarelli's strategy, aiming at favoring the direct contact with customers, an email marketing service has been developed to send targetted messages to specific user classes (see Figure 8). It has been implemented using the Java programming language, and a set of commonly used libraries to simplify development and configuration, that is, Spring Boot and Spring Data JPA. Data are stored on a PostgreSQL database which, thanks to the use of Spring JPA, can be replaced transparently for the application.

The Spring Boot layer constitutes the business logic that responds to the application invocations, received via REST web services. By reading data from the database

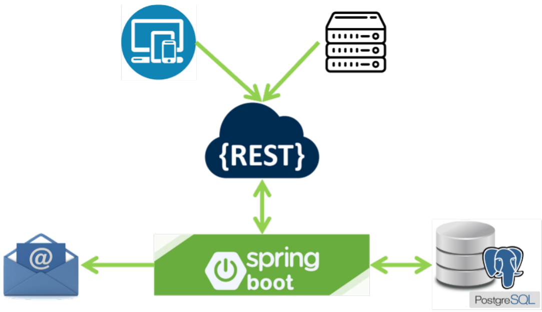


Figure 8: Targetted Email Marketing Service Architecture

and processing them suitably, it composes and sends the requested promotional messages (e.g., emails). The REST APIs can be invoked transparently for the application, for example from a web page set up for the manual launch of marketing actions. Another available option is to automate the sending of promotional messages, for example according to a change of RFM category.

7. Conclusion

The research presented here has faced the challenge of designing an Industry 4.0 solution for the "old-style" licorice factory Amarelli. This allows the optimization of the Amarelli production process, the integration and automation of its business operations, and the enhancement of its customer engagement, through digital platforms based on IoT and big data analytics. The proposed solution includes several key components, such as IoT-enabled production monitoring, data warehouse, RFID tracking, and real-time data analysis. The solution also integrates an ERP system, to provide business intelligence and e-commerce combination to enhance online presence and customer engagement through social media advertising.

As future work, we plan to continue with the experimentation with the company, by extending IoT systems to more complex control phases, reducing repetitive human activities, reducing production faults and thus improve the overall quality of production. We want to improve localization extending Radio RFID finger-printing with other radio techonologies such as e.g. Bluetooth-low-energy, which could be useful to have a fine-grained indoor localization to detect objects in the departments of the production plant. Moreover, data stored in the data warehouse will be integrated with further information extracted from the Amarelli's social network associated to its community. This will be useful in order to detect new possible consumers to be invited for visiting the museum/store in Calabria, enlarging the community.

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