An IoT Monitoring System for Dairy Products

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Abstract. The inclusion of IoT technologies in smart cities and the industrial domain has drastically influenced the life cycle of processes. The gradual reduction in sensor costs and the ubiquitous connectivity provided by open source, un/licensed networks have sky-rocketed the digital transformation of businesses. Specifically, the distribution of products with a short life cycle, such as dairy products, is a highly important domain that demands consistent monitoring of the product and the surrounding environment to preserve quality and safeguard the consumers' health. Continuous monitoring of vehicle fleets is necessary to safeguard temperature and humidity conditions during delivery from the factory and the distribution center to the retail stores. Due to unpredictable situations that may arise during this process, the conditions of the dairy products are constantly monitored with internal sensors, and GPS location devices mounted on delivery trucks. Additionally, sensors have been placed on dairy crates, thus producing detailed information for prohibiting the quality deterioration of dairy products. An IoT monitoring system has been developed that includes a sensor kit placed on dairy crates to monitor dairy product conditions. Furthermore, a versatile module mounted on each truck is also designed and used to retrieve and broadcast the product's conditions during delivery utilizing Bluetooth Low Energy as the medium for connectivity.

Keywords: IoT · Smart Cities · Bluetooth Low Energy · Last-mile Delivery · Ehealth · Dairy Products · Cold Supply Chain

1 Introduction

The preservation of the quality of dairy products during delivery is a demanding task for producers and transportation companies that is closely linked to multiple environmental and human-oriented factors that can affect the products' quality. It is often observed that

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products could lose their organoleptic properties and even become deteriorated due to inadequate storage and transportation conditions [1]. It is of high importance to provide stakeholders with real-time information systems for monitoring the conditions during the transportation of fast moving perishable goods. Preserving transparency across all aspects of the food supply chain (collecting goods, preprocessing, processing, packaging, delivering from one stage to another) is extremely important for both suppliers and consumers. Although real-time data aggregation has been steadily adopted by the industry it remains a challenge in the transportation domain. In order to address this problem, the incorporation of IoT sensors and vertical applications that track, and monitor the conditions of dairy products has been developed. A substantial number of dairy-oriented companies have included IoT technology in multiple sectors of their production line [2]. Indicatively, deploying sensors for real-time monitoring of the milk tank levels is one of the most common implementations in the dairy supply chain [3]. Sensor-based technologies enhance the workability of the entire dairy industry by providing real-time information and an improved way of providing traceability solutions [4–7]. In this context, the supply chain of the dairy industry is considered extremely complex as it involves numerous internal and external factors such as proper storage availability, temperature, humidity conditions, weather fluctuations, packaging, cold supply chain availability, last-mile logistics, retail store particularities and many others [8]. However, to safeguard secure and on-time delivery of dairy products once crates have departed from their origin (factory storage, distribution center), sensors are placed on crates to monitor the whole process and ensure the proper implementation of the hygiene standards. During the past years, monitoring the cold chain focused on temperature data loggers embedded in trucks and shipping containers to ensure quality temperature handling during delivery. All the collected data had to be processed offline by specialized personnel, to ensure the product's quality. In recent years, real-time data monitoring is the main method for ensuring the product's quality in cold supply chains.

The i-EAT (Intelligent Food Safety & Control) project developed a specialized sensor kit for using it on typical dairy crates named i-EAT Tag. The kit includes RFID tags and sensors for measuring (i) vibration, (ii) acceleration and rotational velocity, (iii) atmospheric pressure (altimeter) and (iv) temperature. Additionally, an IoT module indented to be used by delivery trucks has been designed and engineered to facilitate the connectivity of the crate's sensor kit and provide the medium for forwarding the accumulated data to the cloud named i-EAT Truck kit. The i-EAT Truck kit operates similar to a gateway that communicates with the sensor kits and provides connectivity services. Finally, a comprehensive cloud-based real-time monitoring system has been developed to aggregate all the transmitted information and present information about the vehicle, the crate and the dairy products which is not examined in the current work. Specifically, this paper focuses on the i-EAT Tag and i-EAT Truck kits and their respective operations.

The advent of highly accurate and cost-effective sensors paved the way for the development of a high-quality system that could be easily adopted by many companies as the proposed system (sensor kit and IoT equipment and the cloud software tool) can be easily integrated with the company's proprietary software tools. IoT technologies have transformed logistics activities as they provide effective and added-value solutions to critical business processes [9, 10].

Inside the truck, numerous other sensors are also used for providing complete information about the real-world conditions. For example, there are data streams from the vehicle's proprietary equipment (e.g., the truck's velocity, the condition of the fridge equipment, the vehicle's engine status, sensors located in the truck's doors for monitoring the time they remain open/close and many more. This enables stakeholders to identify the heat exposure periods of the dairy products in the loading and unloading processes and many other incidents that may jeopardize the dairy products.

A sensitivity analysis is also critical as the crates could be placed in many different storing locations inside the truck that could be directly or indirectly connected with the health status of the dairy products. The crate sensor kit could provide enlightening insights by monitoring conditions in specific locations inside the truck during delivery.

To further explain the architecture of the proposed IoT system the remainder of the paper is structured as follows: Sect. 2 presents the related field research focused on a narrow field of supply chain logistics known as cold chain logistics. Section 3 elaborates on the system architecture of each module. Section 4 emphasizes the use case of the proposed system with all the possible cases. Finally, Sect. 5 concludes by presenting the systems' functionality, and the added benefits. Furthermore, future directions of the proposed system are introduced.

2 Related Work

IoT technology has drastically improved many fields of our everyday living by providing real-time information about our surrounding environment and optimizing processes according to environmental conditions. This further strengthens the gradual integration of IoT sensors in the logistics sector and accelerates related research by enabling new ideas to be tested for sustainable operations. In this section, we showcase IoT applications in the supply chain context with a special focus on cold supply chains.

IoT coupled with GPS location services enhances the ability to track real-time vehicles while sensors that monitor state, and conditions can provide insights into daily business processes. Cold Chain Logistics (CCL) is considered a new frontier in the supply chain domain due to the fact that it involves the preservation of products and the delivery of perishable goods using dedicated freezing equipment. Considering the fact that perishable products have a short lifetime and they could lose their organoleptic properties or even become deteriorated due to temperature fluctuations during transportation, it is imperative to follow specific regulations [11]. Standards for controlled temperature in refrigerated delivery services have been widely proposed such as ISO 23412:2020 [12]. Similarly, the ISO/TC 315 ensures the optimal conditions for CCL, for instance, the hygiene conditions during the carriage/storage phases that prevent product contamination, the safety and reliability of the cargo and many more. Additionally, CCL providers integrate sensors in their truck's cabins either for freezing or for refrigeration purposes and expose the information to clients via dashboards. APIs in the application layer or universal connectors are also used for integrating the new solutions with proprietary software tools. This ensures integration to third-party applications and the processing of the accumulated data for monitoring the status during delivery. However, during the transportation of the cargo, several factors are affected as a vehicle is involved in many trips for delivering products. Optimal planning is critical for the lifetime of the products and minimal exposure to external conditions (indicatively temperature) is needed to ensure the cargo's health and safety conditions. Therefore, algorithms are being utilized extensively to identify optimal solutions for the Travelling Salesman Problem [13]. This optimization problem orchestrates deliveries in the logistics domain by highlighting the minimal route for a specific starting and ending point and several loading/unloading places. Several constraints may be imposed making it hard to find an optimal solution. For instance, the fuel consumption, the number of vehicles, the capacity of each vehicle, and the time window for delivery are a handful of constraints to this problem that needs to be analysed.

Comparatively, IoT platforms targeted at the transport and logistics domain have been developed in research projects and tested in pilots [14] to present the accumulated data of the fleet in real-time and facilitate the development of next-generation logistics applications. Although the IoT domain is inherently scattered by different types of devices and data types, several approaches for addressing the heterogeneity factors have been proposed. The incorporation of sensors in the dairy supply chain from the manufacturing to the distribution level must be handled appropriately for the heterogenous data by adopting ontologies and using metadata vocabularies [15]. Interestingly, IoT and blockchain are expected to establish a new architectural approach in the development of IoT applications. The connectivity of a vast number of sensors and actuators generating real-time information about the ambient environment and the use of blockchain for ensuring the immutability of the data can revolutionize the IoT domain. Freight transportation that involves different parties can leverage IoT-enabled blockchain solutions to safely store the temperature, status of shipping containers, position, and arrival times. The immutability of the data provided by the blockchain's fundamental principles helps the parties to trust the data and take actions accordingly. The traceability of the assets specifically in the dairy supply chain was implemented with the use of blockchain technology which can be extended to numerous food supply chain products [16]. Similarly, an IoT with a blockchain-enabled food monitoring application has been developed that tracks the temperature of the cargo and geolocation information [17]. This in fact guarantees the trustfulness, integrity, immutability and traceability of the data from all the involved stakeholders. Moreover, several attempts have been presented in the literature to incorporate IoT and Artificial Intelligence in dairy farms in order to enhance the dairy farmers' ability to monitor and track the livestock and further increase all the by-products [18]. Similar to dairy products that need to be preserved in low temperatures, vaccines must also be kept in extremely low temperatures during transportation while even the slightest temperature fluctuation during transportation must be taken into consideration for the ineffectiveness of the vaccine [19]. Several IoT monitoring systems for the CCL have been proposed with different architectures to provide the backbone of this emerging domain [20].

3 IoT Architecture

The architecture of the proposed system is separated into two distinct sections. A kit (named i-EAT Tag) is integrated with an active RFID tag for the identification and monitoring of a single crate. Off the self, sensors were selected for measuring the conditions of the crate during delivery. An exhaustive market research was conducted prior to the implementation to identify candidate products that could meet the project needs. Due to the fact that harsh conditions would be met on a daily basis by these sensors, we opted for sensors that are able to withstand low temperatures, humidity, and vibrations while maintaining low downtime. An inertial sensor (acceleration, gyroscope, altimeter sensors) was used for identifying the relevant movement of the crate and a temperature sensor for monitoring temperature fluctuations. The purpose of this specialized kit is to be placed on a crate and monitor the product's placement and temperature in order to estimate how this affects the product's lifetime. The second kit (named i-EAT Truck kit) which is deployed on the vehicle level is also integrated with sensors for monitoring the temperature inside the refrigerator and acts as an active logger for storing data about the products and the vehicle's condition. Data could be further analyzed for presenting the results to stakeholders. An overview of the architecture is shown in Fig. 1 where the connectivity of each sub-component is highlighted.

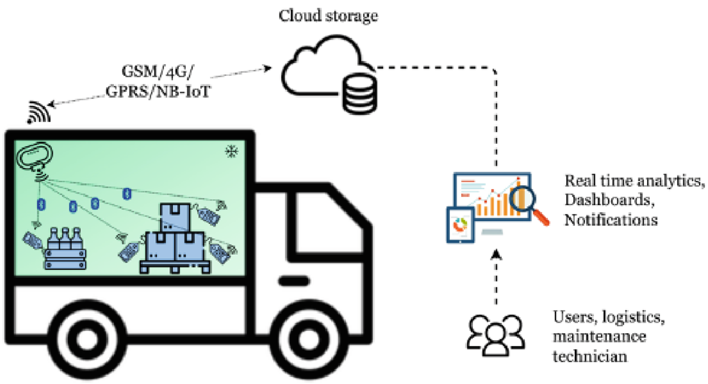

Fig. 1. System architecture

3.1 Crate Kit (i-EAT Tag)

The i-EAT unit is placed on product handling units (typically a plastic crate) that is included in a pallet. Each unit leverages Bluetooth Low Energy (BLE) to connect to the i-EAT truck kit in order to transmit the sensors' measurements. It must be noted that iEAT Tags are going to be reused multiple times as they are mounted and unmounted in numerous crates. Thus, demanding high energy autonomy with minimal power consumption for the onboard computation processes. Having considered the above, the MCU that was selected for the i-EAT Tags is STM32WB55C, which embeds BLE connectivity with low power needs. The RISC architecture is ideal for such projects since it is extensively utilized by mobile devices that need high computing power with minimal energy footprint.

For the identification process of each crate, active RFID tags were selected since minimal effort is needed for integrating them into the system. For the inertial sensor, we selected ISM330DHCXTR since it is tailored for industry applications. Specifically, it employs, a 3D accelerometer with a configurable scale from (±2/±4/±8/±16 g), a 3D gyroscope that is able to read values from (±125 up to ±4000 degrees per second) that will enable us to measure a broad range of movements since the loading and unloading task is frequently performed manually (by hands). An SPI/I^2C serial interface is also embedded in the inertial sensor enhancing the capabilities, all the while a sensor hub capable of efficient data collection is integrated for connecting additional external sensors. The sensitivity of the inertia sensors enables tracking tilt detection and free-fall with wakeup functionality for low-energy consumption. It also provides a machine learning core that facilitates data cleaning and filtering on the sensor data (false readings, activations, etc.). This is performed by intelligently recognizing patterns in movements during the loading and unloading of each individual unit. Although the inertia sensor is equipped with an internal temperature sensor, we opted to integrate a standalone temperature sensor (NTC Thermistor) connected via the auxiliary serial interface in order to measure the ambient temperature and record the detailed environmental conditions of the handling unit. The selected external temperature sensor was able to identify minimal fluctuation with (±0.5 degrees of accuracy) compared to the embedded one, thus providing precise measurements for further processing.

Due to the fact that i-EAT Tags are going to be reused for multiple deliveries, energy consumption and battery-related issues were a major concern. After, considering battery life improvements and the autonomy levels of the kit, the research team decided to design the kit to autonomously operate for a month. This decision will enable efficient operation planning while the replacement of the battery will be effectively handled by the stakeholders.

Additionally, an intelligent system for optimal energy management based on the physical movement of the unit was integrated. The main purpose of the system was to intelligently consume energy based on the actions triggered by the loading and unloading activities and exploit the wake-up mode of the MCU whenever this is considered efficient.

Another consideration that had to be taken into account during the development phase was the mounting and unmounting procedure of the i-EAT Tag on dairy crates. On the one hand, a one-step installation phase was the key to enable non-experts to deploy i-EAT Tags. On the other hand, the research team had to consider the harsh

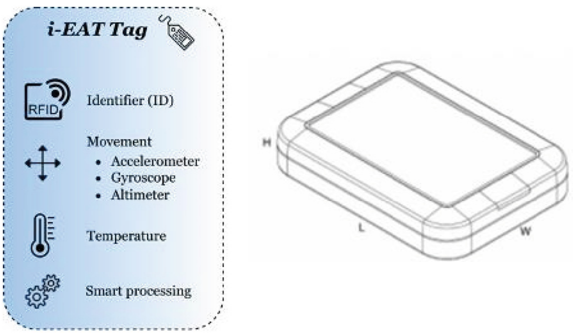

Fig. 2. i-EAT Tag contents and enclosure

conditions of the loading and unloading activities during transportation. Therefore, the i-EAT Tags are enclosed in a tightly sealed container with all the embedded electronics as shown in Fig. 2 and are tolerant to temperature and humidity fluctuations.

3.2 Vehicle Kit (i-EAT Truck)

The development of the i-EAT Truck unit was engineered by embedding several identical parts from the i-EAT Tag. Due to the fact that this kit was going to be deployed on a variety of vehicles with completely different equipment, it had to interoperate with numerous systems. Therefore, the research team focused on modularity and seamless integration with the existing hardware equipment.

The i-EAT Truck kit operates similar to a gateway with additional functionalities for edge processing during transportation. In detail, the unit leverages BLE connectivity in order to detect all i-EAT Tags inside the cargo. After an i-EAT Tag is identified a connection is established and data streams are initiated. Operational processes of every loading and unloading crate equipped with the i-EAT Tag are monitored. The aggregated data streams, either from the i-EAT Tags or the i-EAT Truck unit are sent to the relevant stakeholders, and real-time information about the status of the vehicle and the crate, the duration of the loading and unloading processes are recorded and forwarded to a centralized cloud application for further processing.

To ensure the complete trustfulness transportation of perishable products and the operations that take place during delivery, sensors have been also integrated into the truck's doors in order to extract data for the duration of the loading/unloading processes. These sensors are directly connected to the i-EAT Truck unit and forwarded directly to the cloud application. For instance, in case of an extended period of exposure to high temperature, the health and safety conditions of the dairy products can be significantly affected. This action triggers a process that informs the stakeholders about inconveniences.

The i-EAT Truck unit is equipped with a STM32WB35CE MCU for adequate processing capabilities and future upgradability. Although many transportation vehicles are already equipped with a GPRS system we opted to integrate a dedicated GPRS (SARA-G450) in the i-EAT Truck unit for ensuring reasons: (i) zero downtime in case the vehicle goes out of order, and (ii) plug-and-play solutions to a variety of transportation vehicles that lack GPRS system mainly due to legacy equipment. The same inertial sensor (ISM330DHCXTR) that is embedded in each i-EAT Tag unit was selected for the i-EAT Truck unit also. The embedded inertial sensors on i-EAT Tag units and the inertial sensor of the i-EAT Truck unit can be combined in such a way to increase measurement accuracy and be used as a cross-reference mechanism. A similar approach was taken when selecting a temperature sensor for the i-EAT Truck unit; a standalone temperature sensor (NTC Thermistor) connected via the auxiliary serial interface from the inertial module was integrated in order to measure the ambient temperature and record the detailed environmental conditions of the freezer. Equally important was the ability to provide auxiliary connections for integrating built-in sensors from the truck into the i-EAT Truck unit that monitor operations of the freezer and/or the vehicle. This approach can broaden the market reach of the proposed system since legacy vehicles can utilize the system with minimal modifications.

Since all the accumulated data from the truck's built-in sensors, auxiliary sensors and the transported crates attached to the i-EAT Tag unit are timeseries data, each record includes a timestamp and GPS location information. Finally, the project's team considered the autonomy of the i-EAT Truck unit to be immensely important and included two powering options. A power supply option from the vehicle was considered the main power source, and a backup option with a rechargeable lithium battery is also proposed for redundancy. To provide a robust solution, that can be mounted on any vehicle and have easy access to the embedded electronics, the research team engineered an enclosure with a lid (Fig. 3). Expandability was critical for integrating new sensors, modules and antennas for connectivity.

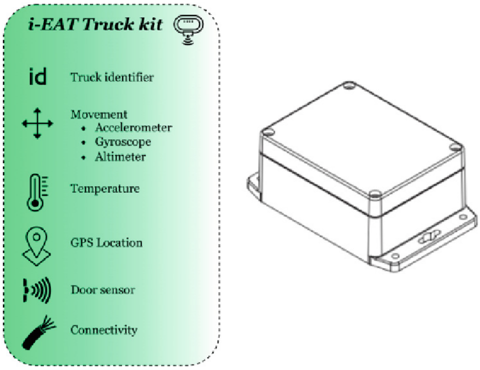

Fig. 3. i-EAT Truck kit contents and enclosure

4 Pilot Use Case Scenarios

Prior to the commercial use of the kits in real-world scenarios, the proposed system was tested in several use cases. The typical workflow in a cold supply chain is considered during the pilot use cases of the project (Fig. 4). In detail, the workflow consists of the pallet accumulation and the loading process from the factory storage to the truck. Followed by the transportation to the branch store, which includes unloading, unpacking, and pallet preparation for preparing the transportation to the retailers. During transportation, several intermediate stops are possible. It must be noted that across the whole process of loading, and delivery, several delays could occur, thus exposing the product to high temperatures. Therefore, temperature sensors are included to monitor the conditions from the factory to the retailer's fridge.

A detailed illustration with several cases is shown in Fig. 5 from the i-EAT Tag placement on the crate to the retailer's store. The purpose of this diagram is to highlight the possible cases that can affect the health and safety conditions of dairy products.

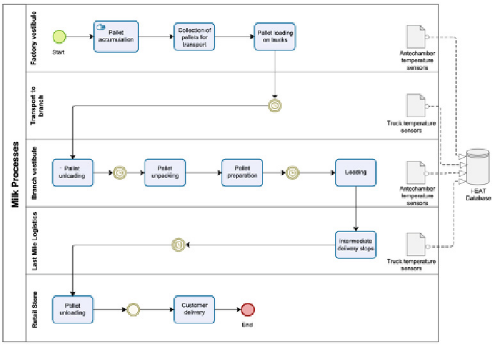

Fig. 4. BPMN diagram (Workflow)

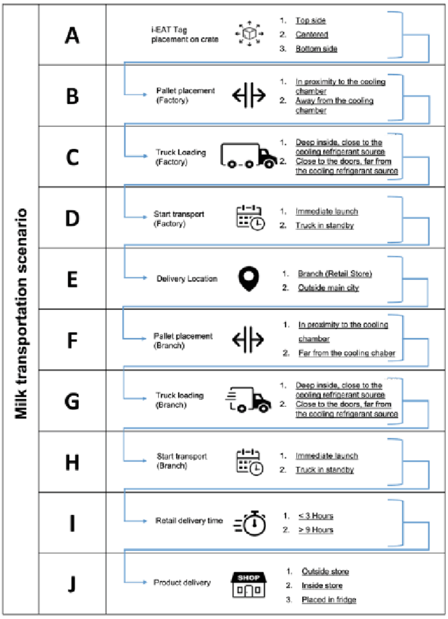

Fig. 5. Use case scenarios for the i-EAT project

5 Discussion and Conclusions

Although the potential of integrating IoT solutions into logistics activities is yet to be explored, the proposed system digitalizes the CCL and provides value-added services to stakeholders. Real-time monitoring of the perishable products' supply chain to determine their health status is a challenging task that could safeguard health and safety in the food industry. The main stakeholders that are being affected by the proposed IoT system are businesses, society and consumers.

The adoption of the proposed system can improve the company's image, and the monitoring of the quality of perishable products while reducing production and distribution costs. The advantages include:

- Increasing traceability conditions in the food supply chain,
- Monitoring and evaluating critical parameters that can affect the quality and lifespan of the products in real time,
- Limiting the reaction time when health and safety issues arise,
- Reducing food quality losses and food waste.

The evolution of Information and Communication Technologies, along with sensors and IoT devices, provides tools for developing innovative products from a farm-to-fork perspective. The i-EAT (Intelligent Food Safety and Control) project created an innovative tool focusing on dairy products. Our scope is to extend the recommended consumption duration of fresh products by improving the cold supply chain's conditions and, furthermore, reducing the rate of returns in the reverse supply chain. This can maximize added value in economic, environmental and social terms, while at the same time enhancing the competitiveness of the dairy industry at European and International levels.

A contemporary IoT monitoring system is developed for monitoring dairy products in the CCL. The proposed system ensures the effective transportation of dairy products by monitoring the parameters of the surrounding environment (storage conditions, external environmental conditions) and even the conditions on individual crates. This enables real-time evaluation of the dairy products in order to inform stakeholders of any inconveniences in the transportation process. Although the system is fully functional, several features and improvements are still to be committed to improving the overall performance.

In our future work, we will provide all the technicalities of the cloud application and the underlying architecture. Specifically, the cloud application will be responsible for gathering the data from all the i-EAT Truck units that accumulate and forward connected i-EAT Tags on individual crates.

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