FruitGuard - System for the Management, Protection, and Enhancement of the Fruit Supply Chain

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***Abstract*—Fruit harvesting and traceability are vital in fruit crop production for maintaining quality and minimizing waste. The proposed system integrates wearable smart devices, electronic labels, QR codes, and cloud-based software to track the entire production process, from harvesting to distribution. Smart devices provide relevant information to harvesters, while electronic labels identify location and fruit type. Reading/writing modules record data like container weights, and RFID tags monitor crate locations. An additional study optimized RFID tag orientation in cold storage. QR codes offer detailed product information to consumers, and the management software ensures data collection, storage, and analysis while prioritizing privacy and security. In summary, the system aims to optimize fruit production management and enhance traceability across the supply chain.**

***Index Terms*—Supply chain, traceability, RFID, fruit harvesting**

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I. INTRODUCTION

As of January 1, 2005, the European Union (EU) introduced compulsory traceability regulations for fruits and vegetables by enacting European Regulation 178/2002, known as the Food Law [1]. Article 18 of this regulation imposes administrative traceability requirements on all food products, whether produced within the EU, imported, or exported. Traceability refers to the capacity to monitor a product or a commodity as it progresses through the entire supply chain, whether it be from the point of production, processing, or distribution until it reaches the hands of consumers. This involves employing different technologies [2] and systems to record and trace the product's journey, ultimately enhancing transparency and accountability within the supply chain. It plays a crucial role in guaranteeing the safety [3], quality, and legitimacy [4] of the product.

An effective traceability system has become an essential requirement, particularly in consumer-centric industries where customer loyalty, trust, and confidence hinge on guaranteeing product quality and safety [5]. With the growing prevalence of digital technologies and the rising expectations for transparency and traceability within the supply chain, this capability is increasingly crucial. It mitigates disruptions in production and distribution while enhancing the capacity to track and trace potentially problematic product batches efficiently. Therefore, in addition to the well-being of the orchards [6] [7], it is crucial to develop robust analytical tools to ensure food traceability,

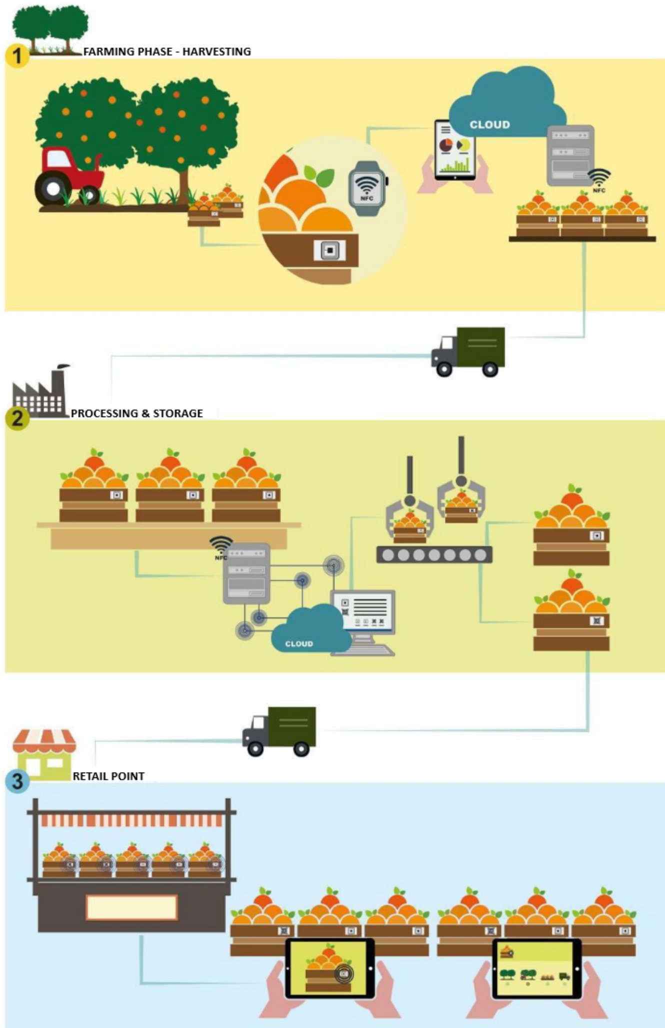

Fig. 1. Overview of FruitGuard project. The field phase collects data about harvesting, pruning, pesticide application, etc. Such information is integrated with processing and storage details gathered in phase 2. Finally, consumers can access all this information by scanning a QR code

safety, and quality, particularly for products originating from the fruit and vegetable sector. These techniques should be flexible, reliable, swift, and cost-effective. The system introduced in the upcoming chapters addresses these challenges. It has been developed and features the following characteristics: it leverages wearable or easily portable smart devices, RFID labels, reading and writing modules, QR codes, QR printers, and cloud-based management software.

II. System Description

The FruitGuard system is a comprehensive solution designed for the agricultural sector, primarily focusing on optimizing the collection and distribution processes (Fig. 1).

A. System components

This system incorporates cutting-edge technologies to enhance operational efficiency, traceability, and data management.

Fig. 2. adhesive NFC tag (on the left) to place in the field (Fig. 3) and portable gadget (on the right) assigned to each farmworker.

The first implementation point is in the fields. Farmworkers are equipped with wearable smart devices (Fig. 2 - right), and these devices are armed with low-power wireless capabilities, allowing seamless communication with other system components and Near Field Communication (NFC) technology. These smart devices, worn by farmworkers, act as data hubs, collecting and transmitting vital information throughout the production and distribution process. Every device can be associated to the company and with an anonymous ID. The ID can not be associated to a single worker, but the data collected can be adopted to monitor the overall productivity. The device is used to track the different phases of the production cycle (for example, harvesting, pruning, pesticide application, etc.) and how long the workers are performing the different tasks. This monitoring capability is possible thanks to the use of NFC tags.

Electronic labels assume a pivotal role. These adhesive tags (Fig. 2 - left) are strategically placed at key locations, such as the start of a field or orchard lot, and inside collection containers, storing essential data regarding location, product type, and processing stage (Fig. 3). The wearable smart device is used to read the tags and store the beginning and end of the farm worker's operations. For example, the worker will *scan* the tag labelled as "Begin operation" and the timestamp is registered in the device. After this step, the worker will *scan* the type of operation and the crop where the task will be performed. Similarly, the worker will *scan* the "End operation" to save the task duration in that specific field. During the collecting stage, an additional *scan* is performed. The collecting box is assigned to the worker: in this way, it is possible to add the origin information to the fruit box. Another device is located at the collection point in the fields. These wireless modules are intermediaries between the electronic labels and the system's control software. These modules read information from the wearable devices and write them in the cloud. Furthermore, these modules record the container's weight and link this value to the other information available

Fig. 3. Selection of a processing stage. Choosing a processing phase involves the farmworker positioning their smart device adjacent to the "start phase" tag, followed by placing it near the specific job description (harvesting, pruning, etc.). Upon completing the work, the farmworker positions the device near the "finish phase" label.

on the box (Collection time, origin field, etc). After that, new crates with RFID labels are shipped to the designated storage warehouse. Once arrived, each fruit crate is placed on a pallet in a random position. When the pallet is full, a forklift brings it to a refrigerating room, waiting to be shipped to retail points. To keep the traceability of the product, an RFID gateway was implemented to automatically detect the passage (Fig. 5) of all the crates and update this information on the product history.

B. Control Software

The control software is the system's heart, offering a user-friendly interface for configuring and managing smart devices, labels and printing QR codes. It also facilitates data analysis, presenting comprehensive, useful insights (Fig. 4). It retains only the necessary information for subsequent actors in the supply chain. The system relies on a dedicated remote storage

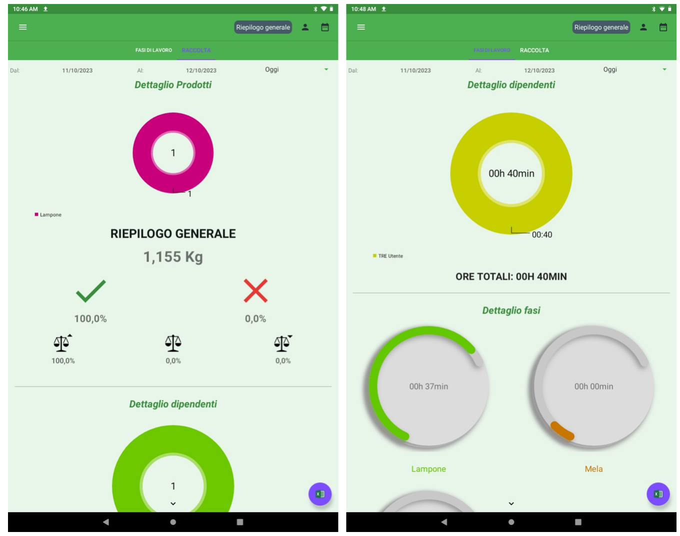

Fig. 4. example screenshots of farmer-side GUI with aggregate data about harvesting, crate weight and total worked hours.

space for each participating company. This secure cloud server stores data from a specific system configuration securely and privately. All data transmissions are encrypted, ensuring data confidentiality and security. This allows downstream actors in the supply chain to retrieve valuable information from electronic labels on containers and add their data regarding production, processing, storage, and shipping.

III. Storage Gateway Analysis

As already mentioned, at the storage warehouse, each fruit crate placed on a pallet comes with its own RFID tag randomly positioned on one of the five sides of the crate. When multiple crates are stacked on top of each other on the pallet, it's possible to have a considerable number in a single stack. This stacking arrangement can lead to some RFID tags being hidden within the stack of fruit crates. As a result, the signals transmitted by the RFID antennas may have difficulty reaching and communicating with these hidden tags. This can potentially lead to issues with reading or tracking the crates that are not directly exposed to the RFID antennas due to their concealed position within the stack [8] [9]. To address this issue, we conducted experiments where we loaded a pallet with multiple crates, each containing RFID tags randomly placed on them. During our testing, we utilized a forklift to transport the pallet through a designated portal equipped with three antennas. One of these antennas was oriented in a downward direction, placed on top of the gateway, while the other two were situated on the sides of the pathway, facing towards the centre (Fig. 5).

During these trials, we made several passes with varying crate numbers, forklift speeds, and at different heights. After each passage, we recorded the number of RFID tags successfully read by the system. This allowed us to assess the system's performance and the impact of crate quantity, forklift speed, and height on RFID tag readability. Finally, two types of

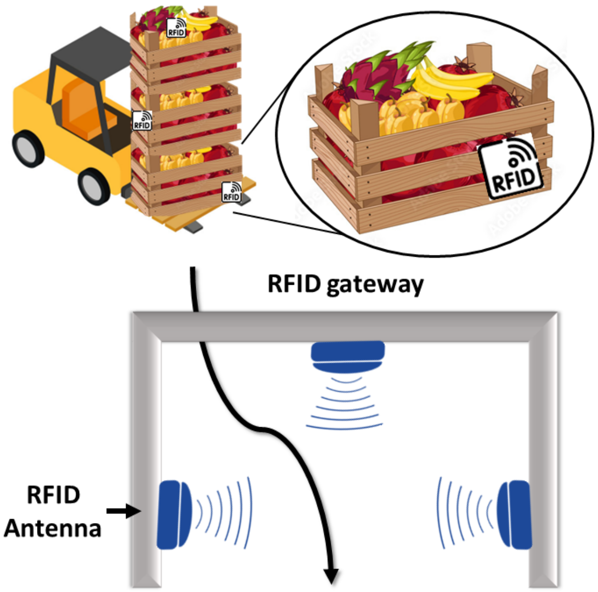

Fig. 5. RFID gateway to automatically detect fruit crates passage. Two antennas are placed horizontally and one perpendicular to the forklift passage.

experiments were carried out. In the first one, crates filled with approximately 7 kg of overripe or even rotten fruits were used. In the second experiment, the crates contained neatly arranged fruit baskets harvested just before reaching full ripeness.

IV. Results and discussion

The first experiment aimed to create a substantial mass of water within the fruits to understand how much it would obstruct the passage of electromagnetic waves. The results of these passes are summarized in the Table I.

TABLE I
GATEWAY CROSSING TAG DETECTION - TEST 1

Passage No.	*Tag detected*	*Forklift Speed*
1	64%	Normal
2	60%	Normal
3	48%	Faster
4	48%	Faster
5	52%	Normal
6	52%	Normal
7	64%	Slower

The first column represents the sequential pass through the portal, "RFID Tags Detected" indicates the percentage of RFID tags successfully read out of 25 placed on the crates, and "Forklift Speed" denotes whether the forklift operated at a normal, faster, or slower speed during the pass. Results show variations in RFID tag detection percentages across different passages, with correlations to forklift speeds. Passages with normal or faster forklift speed generally correlate with a higher successful tag detection. Faster speed (passages 3 and 4) induces more missing reading. In the second experiment, we focused on the readability of RFID tags on standard crates with fruit baskets ready for the GDO. The results, summarized in Table II, show the number of RFID tags detected out of 80 placed on crates during various passes through the portal.

TABLE II
GATEWAY CROSSING TAG DETECTION - TEST 2

Passage No.	*Tag detected*	*Forklift Speed*
1	66.25%	Slow
2	66.25%	Slow
3	56.25%	Normal
4	51.25%	Normal
5	38.75%	Faster
6	38.75%	Faster

Such data substantially confirm the results of the first experiment because they reveal a pattern where higher RFID tag detection percentages are associated with slower forklift speeds. In fact, passages 1 and 2 have the highest detection rate at 66.25% and are set to "Slow" forklift speeds. Passages 3 and 4 have slightly lower detection percentages (56.25% and 51.25%) and are associated with "Normal" forklift speeds. Overall, it can be inferred that forklift speed has a significant impact on the readability of RFID tags. Slower forklift speeds increase the likelihood of successful tag detection, while faster speeds lead to decreased tag readability.

V. Conclusions

The system described offers an innovative solution for enhancing traceability and data collection in the agricultural industry. It utilizes wearable smart devices, electronic labels, label reader/writer modules, and QR codes to track and manage various aspects of the production and distribution process. These components work together seamlessly to provide valuable information, such as company data, anonymous IDs, hourly costs, workday timestamps, fruit types, and, if applicable, land lot numbers. The cloud-based storage system ensures the security and confidentiality of data, allowing authorized users along the supply chain to access and contribute to product information. Consumers can use a dedicated app (yet to realize) or in-store displays to retrieve valuable product details, fostering transparency and trust. An additional study on RFID tag readability highlights the importance of RFID technology in the fruit industry, particularly in the context of accurate tracking, monitoring, and traceability. The insights suggest optimizing RFID use. To enhance tag readability and ensure effective traceability, it is necessary to study and tune further parameters, such as forklift speed, antenna distance and orientations, fruit water content, etc.

Overall, the developed system not only provides data collection and traceability benefits but also supports informed decision-making, quality control, and consumer engagement within the agricultural sector. It represents a significant step toward modernizing and optimizing farming practices while meeting the demands of a data-driven marketplace.

REFERENCES

[1] Schwägele, F., 2005. Traceability from a European perspective. Meat science, 71(1), pp.164-173.

[2] Hassoun, A., Alhaj Abdullah, N., Aït-Kaddour, A., Ghellam, M., Beşir, A., Zannou, O., Önal, B., Aadil, R.M., Lorenzo, J.M., Mousavi Khaneghah, A. and Regenstein, J.M., 2022. Food traceability 4.0 as part of the fourth industrial revolution: key enabling technologies. Critical Reviews in Food Science and Nutrition, pp.1-17.

[3] Yu, Z., Jung, D., Park, S., Hu, Y., Huang, K., Rasco, B.A., Wang, S., Ronholm, J., Lu, X. and Chen, J., 2022. Smart traceability for food safety. Critical Reviews in Food Science and Nutrition, 62(4), pp.905-916.

[4] Grundy, H.H., Brown, L.C., Romero, M.R. and Donarski, J.A., 2023. Methods to determine offal adulteration in meat products to support enforcement and food security. Food Chemistry, 399, p.133818.

[5] Khanna, T., Nand, P. and Bali, V., 2022, May. Measuring the Impact of Blockchain-Based Supply Chain Traceability Systems on Consumer Trust. In International Conference on Advancements in Interdisciplinary Research (pp. 102-112). Cham: Springer Nature Switzerland.

[6] Zhang, J., Huang, Y., Pu, R., Gonzalez-Moreno, P., Yuan, L., Wu, K. and Huang, W., 2019. Monitoring plant diseases and pests through remote sensing technology: A review. Computers and Electronics in Agriculture, 165, p.104943.

[7] Garlando, U., Calvo, S., Barezzi, M., Sanginario, A., Ros, P.M. and Demarchi, D., 2022. Ask the plants directly: Understanding plant needs using electrical impedance measurements. Computers and Electronics in Agriculture, 193, p.106707.

[8] Hsu, C.H., Chao, H.C. and Hyuk Park, J., 2011. Threshold jumping and wrap-around scan techniques toward efficient tag identification in high density RFID systems. Information Systems Frontiers, 13, pp.471-480.

[9] Barge, P., Biglia, A., Comba, L., Gay, P., Aimonino, D.R. and Tortia, C., 2019. The influence of food composition and tag orientation on UHF RF IDentification. Journal of Food Engineering, 246, pp.242-252.