Design and Development of an Efficient Traceability System for Greek Kiwifruit

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Abstract

It is vital to establish and use a traceability system in the fresh supply-production chain. It is a consumer requirement, a useful tool for farmers to add value to their products and a single way to ensure the quality of food products. Nowadays, traceability systems incorporate Information and Communication Technologies (ICT), such as IoT, cloud computing and Big Data, aiming to provide cost-effective production and traceability functionalities. IoT and cloud computing cover a range of different technologies that can be used to satisfy traceability requirements and facilitate rational decision making. In this work, we exploit the capabilities of these technologies and propose a smart traceability framework for kiwifruit. We design, develop, and apply the proposed scheme to a Greek kiwifruit farming. The results show that traceability requirements for transparency, safety and quality are satisfied. Moreover, this implementation provides meaningful insights related to intelligent fresh fruit traceability.

Keywords

Kiwifruit traceability system, internet of things (IoT), cloud computing, smart traceability

1. Introduction

During the last decade, traceability, namely the capability of consumers to access the history of the products they buy and consume, has achieved significant importance because of market globalization and the need for safe and quality products [1]. Consumers are forming a new lifestyle based on the awareness of the need for environmental protection, are avoiding the waste of resources, adopting healthier eating patterns, seeking fresh, tasty, nutritious, and safe foods, and are turning to the consumption of fruits and vegetables, which they believe will offer them concrete health benefits. One such fruit is the kiwi, which is rich in vitamins and antioxidants and provides many health benefits to humans. For this reason, it is now included in the daily diet. At the same time, modern farmers, who have introduced kiwifruit in their agricultural production, do not only use it for their consumption but mainly for trade. This new situation poses significant challenges for the food production/marketing sector in terms of ensuring food safety, environmental protection, and profitability from farming.

The key issue is the application of traceability in this sector, which is a long and complex process and concerns cultivation, packaging, storage, and distribution at the point of sale. Traceability is a valuable tool, appropriate for ensuring the safety of kiwifruit, supporting its quality, and promoting it in the global market. Traceability is *"the ability to trace and follow a food, feed, food-producing animal,*

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and other substances to be consumed, through all stages of production, processing, and distribution" [2]. A traceability system is an efficient process that may track a product and trace related information of the product as it moves along the supply chain (forwards and backwards) and enhances the management of safety and product recall. It satisfies the regulatory obligations, enhances consumer confidence, and improves business performance.

A crucial part of developing a traceability system is a comprehensive understanding of all the steps involved in producing a product, including description and engineering (technologies, techniques, tools) [3]. Gautam et al. [4] propose a traceability system for kiwifruit, using Radio Frequency Identification (RFID) tags. Cao et al.[5], also include RFIDs technology and uses the 2D coding to establish a traceability system of the kiwifruit breeding. The objective of this work is to design and develop an accurate tracking and tracing system, starting from the cultivation to the distribution of kiwifruit. It should be applied in a Greek company operating in terms of farming and trading of kiwifruit. The implementation will be based on the Internet of Things (IoT) and cloud computing technologies. IoT enables the anytime and anywhere connectivity of anything, while cloud computing allows the performing of complex computation [6]. These technologies are the most appropriate, economic, integrated, decision-making and security solutions for implementing traceability systems [7].

Our contribution is threefold:

- We propose and develop an advanced kiwifruit traceability system
- The insights gained from this work may be helpful to others involved in cultivating and producing kiwifruit.
- Our implementation will be applied to other similar sectors with a few modifications.

The remaining work is organized as follows: Section 2 presents the kiwifruit supply chain, Section 3 describes the system's design and implementation, Section 5 presents the conclusions of this work.

2. Traceability for Kiwifruit

2.1. The Kiwifruit Supply Chain

Greece is the fourth largest exporter and fifth largest producer of kiwifruit globally [8]. The supply chain network of kiwifruit comprises various stages, including planting, cropping, harvesting, grading, storing, processing, and selling.

As illustrated in Figure 1, following the harvesting procedure, kiwifruit is taken to the packing plant, sorted according to their qualitative and quantitative characteristics. Then, they are stored under suitable conditions until they are made available for sale through the distribution system. At all these stages, a tremendous amount of data is generated and collected but never communicated. Furthermore, Praat et al. [13] claim that the summarization of information has significant value for the growers and guides them in decision-making. Our implementation bridges the gap. The integrated traceability system will be able to file and communicate information regarding the quality and origin of the products and guarantee consumer safety. Integrating a traceability system into the supply chain shall record and transmit information concerning the products' quality, the root, and food safety.

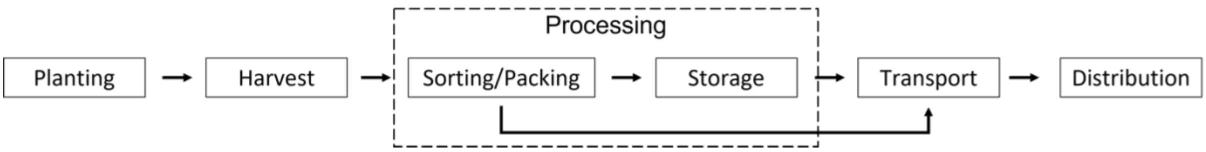

Figure 1: The entire supply chain of kiwifruit.

2.2. System Requirements

According to Bougdira et al. [3], the requirements of a traceability system can be classified into four categories: business (the goals of the system), functional (from the user's perspective), and operational (interactions between entities), and technological (tools and technologies).

- *Business requirements*: the implementation of an integrated intelligent traceability system, which can track the flow of kiwifruit, trace the relevant information, control the conditions of all the processing/storing procedure, check the quality of the products, and comply with the national and European regulations. The system records data and events and can handle heterogeneity and operate everywhere in an autonomous and secure manner.
- *Functional requirements*: it refers to data capturing, storing, processing, sharing with users/consumers, to recording of events and time, to the communication with the environment (e.g., via sensors and environment control system at the storage room of kiwifruit).
- *Operational requirements*: they include a) the identification and localization process b) systematic recording, transmitting, accessing, and linking data, processes and information c) custom security, access options and data integrity d) decision-making tasks and monitoring activities, e) the information retrieval process.
- *Technical requirements*: the use of technologies, techniques, and tools for a) the identification and/or verification process b) the automated data capturing and transmission c) the traceability data management and d) the processing of data in real-time.

2.3. The Information Pathway

The development and implementation of the traceability system is necessary to monitor and record information at every stage and link of the product life cycle. According to Olsen and Borit [10], traceability is defined as *"the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications"*. The information is associated and linked with the identity of each product (or each batch of products). The system keeps track of each Traceability Resource Unit (TRU), - the batch in our case - and the information attributes associated with it. The process of collecting, recording, and transmitting information should be automated, capable of operating in real time [18] and allow for rapid recall of information in future time. Therefore, the traceability system shall include information on all the processes of production, processing, and marketing of kiwifruit, as well as on the date and time they take place. In terms of our implementation, we distinguish the following areas, where data is captured:

- Farm data logging subsystem (farm specifications, fertilization, etc.),
- Subsystem for data collection,
- Chemical control subsystem (hardness, solids, sugars),
- Harvesting subsystem (harvesting crew, date, quality control, total tonnage),
- Storage subsystem (cold store number, temperature, date, storage date),
- Processing subsystem (processing and packaging, class, number, etc.),
- Database management subsystem.

Links among the subsystems allow data exchange and the effective operation of the entire system.

2.4. The Main Components of the Traceability System

Our implementation is an integrated traceability system that adopts the multilayer approach [7], [12], [13], 14]. The kiwifruit traceability system includes the following components:

A. *Identification*: for our implementation the Traceable Resource Unit (TRU), *"which is under consideration"* [18], is defined as the batch. Each TRU is assigned a unique code, so that it can be tracked and traced along its route throughout the supply-production chain. The EAN-13 Barcode is used as the unique code. It is generated from the system.
B. *Data acquisition*: it is achieved either using a portable device (scanner, smartphone camera) or via an easy-to-use mobile application by using auxiliary forms, when automatic data entry is not possible. As for the first case, initially, the traceability codes are printed and placed on TRUs. The automation of the data collection process eliminates data errors due to manual data capturing [15]. For each subsystem (stage of production) the characteristics and attributes of the products

to be collected are defined. The captured data, collected at each of the seven different stages as defined above, is stored in the system and is available for future searches. The recording ensures the association of the entity identifier and its properties [3].

C. *Data processing and management*: the collected traceability data are transformed into suitable formats [16] for communication, processing, storage, monitoring, and future retrieval. The information retrieval process of a TRU involves its identification (e.g., using a code), tracking or tracing while its monitoring allows users to make decisions.

D. *Applications*: an act that allows users to interact with the traceability system.

Data transmission is supported by an underlying network while its exchange in the application layer is based on Application Programming Interfaces (APIs).

3. The Architecture of the Kiwifruit Traceability System

This section introduces the whole design scheme of the traceability system and describes in detail the implementation of each part. Figure 2 depicts the points of interest of the kiwifruit supply chain, which are the most critical control points of a traceability system. The kiwifruit traceability system is based on IoT and cloud technologies. In terms of functions, it can be divided into the following parts: Application, IoT Platform, data sensing/data input.

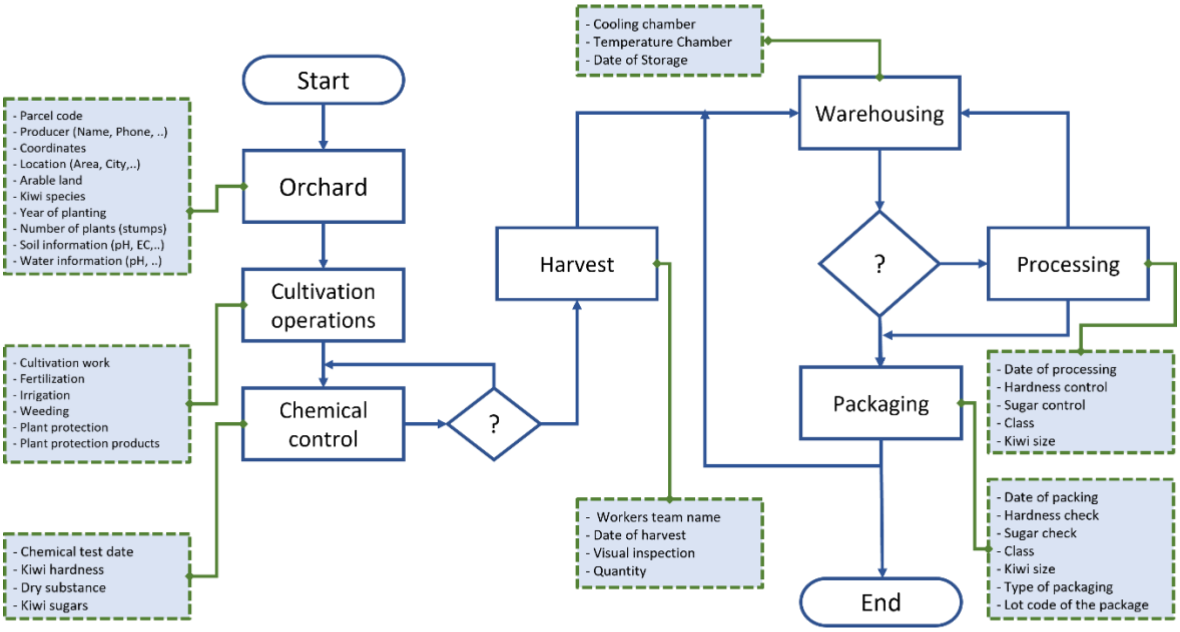

Figure 2: The key points of the supply chain of kiwifruit and the collected information

3.1. Application

The application, with a user-friendly interface, automates data collection by reading barcodes and entering them into the traceability platform. At the same time, the application allows user input of data via forms, if the automated process is not possible. The application is the front-end development or otherwise known as the client-side development, that is the part where users interact with a traceability system. The application development is based on agile methods and the use of web technologies (html, CSS, JavaScript).

3.2. IoT Platform

The IoT platform is an enabling architecture at cloud level, which allows the monitoring, management, and control of a wide range of end devices. It provides businesses with a flexible way to securely build their cloud-based applications and services. Using IoT platform facilities, services and functionalities simplifies the data communication and integration between the physical layer (hardware) and the server system (software). The IoT platform, using the client-server communication model, provides storage facilities, data processing and analyzing and, tracking and tracing services. The IoT platform is the back end of the system. Its development is based on multi-layer technologies: MongoDB was selected as the database, APIs were developed using REST architecture, while data is exchanged between traceability subsystems using JSON standards. The implementation details are described in Figure 3.

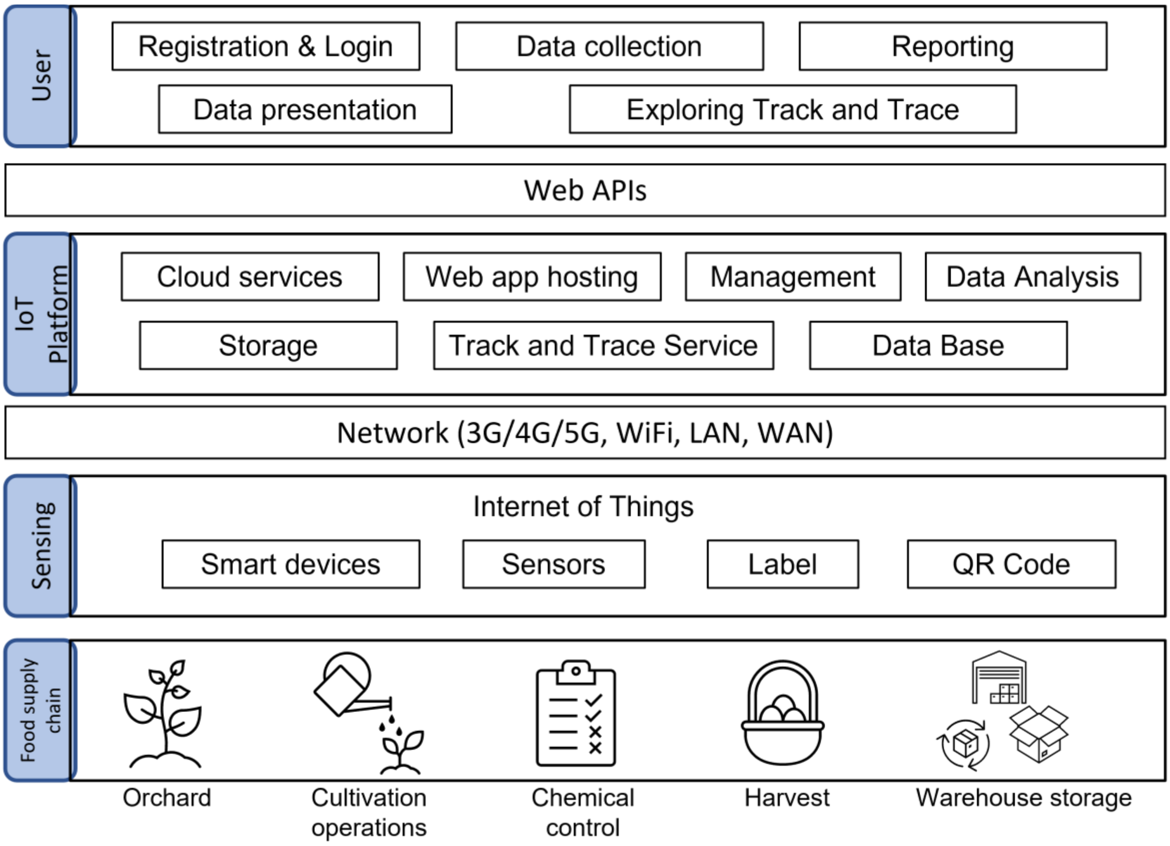

Figure 3: The architecture of the kiwifruit traceability system.

3.3. Data Sensing

For data collection, apart from sensors, we mainly use smart phones and related devices (e.g., tablets, laptops), which feature *"portability, mobility, accessibility to Internet"* [17]. This type of data capturing results in a faster, efficient, and error-free acquisition of data. The sensors are placed in the field to collect meteorological data (temperature, humidity, pressure, etc.). Collected data is delivered to the IoT platform via the network (Figure 2). The attachment of QR codes on product batches automates the data acquisition process along the supply chain, reduces the implementation cost and provides an integrated solution [7].

3.4. Using and Testing the Application

Extensive real-life tests were carried out to verify the correct functioning of the system. Each test is a sequence of steps corresponding to the execution of a specific stage of the system. Our goal is to test its functionality and efficiency. In a typical example, the administrator creates the users and assigns roles to them (user-worker, operator, etc.). The process starts with a user logging to the system and inputting his credentials using the simple-to-use mobile application. If the user is a worker, he or she interacts with the system and runs various activities and tasks. Such an example of steps is illustrated in Figure 4, which is related to farm activities (creating, processing, viewing, and deleting). The input or collected data are transferred to the cloud via a communication network. In particular, the automatic and manual collection of data in the system, the recall and display of data, in accordance with the requirements of the specifications, were tested. In this study, user activities and sub-activities are performed while the system's performance is left for future work.

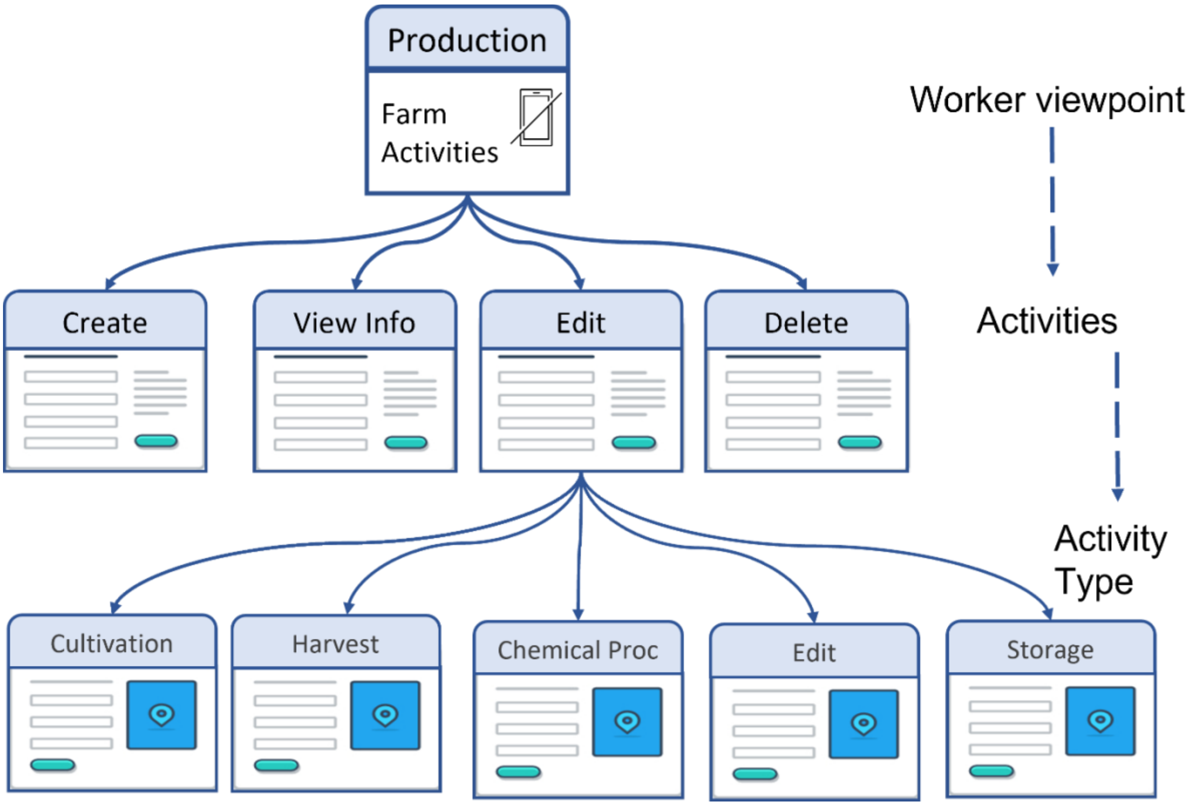

Figure 4: A view of front-end of the kiwifruit traceability system.

4. Conclusion and Future Work

In this work, we present an integrated kiwifruit traceability system, based on IoT and cloud technologies. It comprises the IoT platform, capable of tracking and tracing the batches of products using QR codes, and an application running on smart devices and supports seamless communication among the system's components. Our solution may be applied to other related sectors following some adaptations.

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