



Article

Streamlining Traceability Data Generation in Apple Production Using Integral Management with Machine-to-Machine Connections

Jing Xie ^{1,2,3}, Chunxu Wan ³, Alfredo Tolón Becerra ² and Ming Li ^{1,*}

¹ Information Technology Research Center, Beijing Academy of Agriculture and Forestry Sciences/National Engineering Research Center for Information Technology in Agriculture/National Engineering Laboratory for Agri-Product Quality Traceability, Beijing 100097, China; xj_panda@126.com

² Department of Engineering, University of Almeria, 04120 Almeria, Spain; atolon@ual.es

³ Department of Information Technology, Beijing Vocational College of Agriculture, Beijing 102442, China; 73047@bvca.edu.cn

* Correspondence: lim@necita.org.cn

Abstract: Legal requirements and consumer demands have motivated the development and application of traceability technology. Farming practices are the starting point of the agri-food supply chain and the destination of the agri-food traceability system (AFTS). The amount of resource information and the complexity of the production process of agri-food become the main obstacles to the wide application of AFTS. This study introduces an integrated machine-to-machine system that allows collecting field operation information automatically. This system includes an IoT-based integrated hardware system, a smart farm cloud (SFC) platform, and a mobile application, which accomplished the collection, upload, and storage of operation information. This system had been used in “BSD” organic apple orchard in Qixia, Shandong Province, China for about one year. The effectiveness of the system was evaluated by managing 270 apple trees in one plot of the orchard. Finally, a label with a QR code was successfully generated to provide consumers to query traceability information from a single tree to a fruit tray. This work was a background of a blockchain traceability system. Moreover, the future extendibility of the system was also discussed and prospected.

Keywords: single tree traceability; RFID; GPS



Citation: Xie, J.; Wan, C.; Tolón Becerra, A.; Li, M. Streamlining Traceability Data Generation in Apple Production Using Integral Management with Machine-to-Machine Connections. *Agronomy* **2022**, *12*, 921. <https://doi.org/10.3390/agronomy12040921>

Academic Editor: Andrea Sciarretta

Received: 3 February 2022

Accepted: 9 April 2022

Published: 12 April 2022

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1. Introduction

Food safety and quality play a fundamental role in our daily life, especially in the background of frequent food safety incidents. Food safety scandals have seriously challenged consumers’ confidence in the agriculture industry and made consumers become more careful about food choices [1–4]. Some research shows that consumers are focusing on food information and are willing to pay a premium for selected food safety attributes [4–7]. Traceability, which is referred to as the ability to trace and track, is gaining popularity in the agricultural products supply chain [8–10]. It involves control and data acquisition during each phase of the food supply chain and enables transparency through tracing and tracking [11–13].

Currently, traceability applications in agricultural products have been extensively studied [14–17]. As the most information-intensive application, the realization of traceability represents the collection, concatenation, and display of information [18,19]. Although the number of academic publications on food traceability is increasing, most of the existing agri-food traceability systems have not been assessed whether they are effectively implemented. The high level of traceability efficiency always comes with a high workload and labor costs. The traceability system with practical application value should realize traceability efficiency at the item or batch level with affordable costs.

Accordingly, the extent to which the agri-food traceability system is actually applied by Chinese farm managers remains limited [7,20]. The main obstacles to the wide application

of agri-food traceability systems continue to be the amount of resource information and the complexity of the production process of agri-food [5,20]. There are many different types of agri-food production, such as greenhouse cultivation, field planting, and livestock farming [21]. In addition, the information generated in the whole agri-food production process is fragmented and dispersed [22]. To obtain complete traceability data, farmers have to deal with many interrelated objects, e.g., farmland, farm input, and logistic objects [23]. Indeed, these issues in agriculture production sectors suggested that the important future challenges for agri-food traceability systems relate not so much to methodological issues, but rather to furthering its practical application in an efficient and trustworthy manner [24].

Apples are the most frequently produced fruit in orchards worldwide, with 86 million tons harvested in 2020 [25]. On 6 August 2020, the World Apple and Pear Association (WAPA) forecasts the 2020 EU fresh apple crop at 10.7 million tons [26]. China is one of the major world producers and exporters of apple products. China's apple production reached 44.066 million tons in 2020 [27]. Although traditional agriculture has transited to modern agriculture, small-scale apple production still accounts for a large proportion. Under this condition, the traceability of apples normally begins with the arrival of the fruit to industry [28].

For apple traceability, farming is the original step in the product's life cycle. The information generated in the farming process is an essential part of agricultural management and plays an important role in achieving apples' traceability [19,29]. For example, the geographical origin is a main characteristic that consumers care about. There are some varieties of apple with geographical indications, such as the Aksu apple in Xinjiang, Yantai apple in Shandong, and Jingning apple in Gansu. Because of the specific geographical origin and qualities, these apples are favored by consumers. As a result of that, counterfeit apples with geographical indications occur on a regular basis. Traceability technology is a common method to distinguish counterfeit products.

To our best knowledge, apple traceability in academic publications was managed at the single-tree level but ignored the rationality of information collection methods [19,28,30]. In the data acquiring sector, most of the traceability systems have a high manual component and could not acquire all the farm operations and inputs in the field [31], which would cause the information to be incomplete in the whole supply chain.

This work proposes a methodology for the automated acquisition of data related to apple products throughout the whole field cycle. To achieve this, an integrated hardware system, a cloud base web application, and a mobile app were designed. The first aim of this paper was to analyze the practical applicability of the traceability information obtaining system based on cloud, GPS, and RFID technology. On the premise of ensuring traceability accuracy, the second aim was to streamline agricultural operation data collection with machine-to-machine connections. In the end, we applied this approach in a practical case and verified its effectiveness.

2. Materials and Methods

2.1. Location and Orchard Situation

The "BSD" organic apple orchard was considered as the study site. It is located in Qixia City, Shandong Province. "Qixia apple" is a very famous fruit brand in China with the National Geographic Origin Certification Mark. The organic apple orchard covers an area of more than 200 acres and has a sales method of adopting fruit trees which makes a demand that traceability information should be provided to the apple tree adopters. The orchard is divided into 37 plots. The apple trees in most plots were planted in 2009 except for plots 4 and 5, the apple trees of which were planted in 2012. There are two kinds of apple trees in the orchard, golden dwarf and red Fuji.

2.2. Apple Planting Process and Information Flow

This orchard adopts the sales model of adopting apple trees. This model is a new direct way of apple sale, launched by high-quality fruit farmer professional cooperatives.

Consumers went to the orchard to find an apple tree to be adopted, and after signing an agreement, the adopted fruit tree can be listed. During the adoption period, consumers can visit the orchard, take care of the apple tree (under the guidance of professionals), and pick apples. If customers do not have time to manage the apple trees themselves, orchard staff could take care of the apple trees instead and provide the planting information and traceability information at the single-tree level to the adopter. As shown in Figure 1, the middle column reports the flow chart of the apple planting process while the left describes the related information flow of the apple traceability system, and the proposed traceability system is depicted on the right.

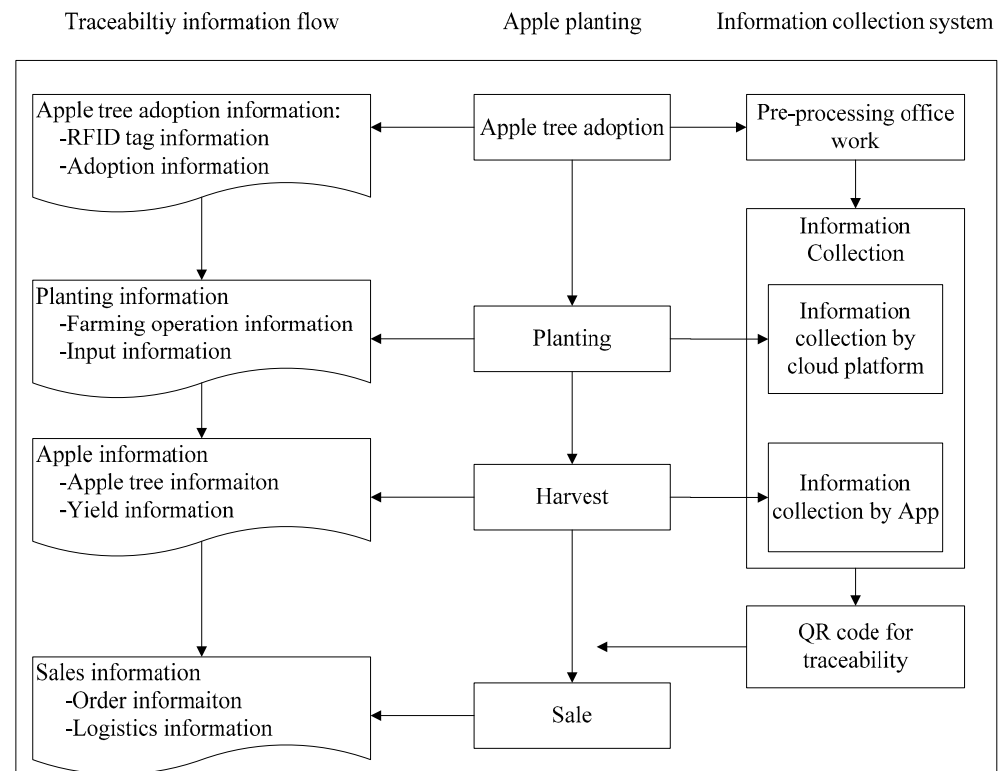


Figure 1. The apple production flow chart in the “BSD” organic orchard (**in the middle**), the traceability information flow (**on the left**), and the information collection system (**on the right**).

2.3. Hardware Integration

To streamline traceability data generation, an integrated hardware system was developed. This hardware system was flexible and allowed the identification of every apple tree in the orchard, the acquisition and uploading of data to a cloud platform, and the labeling of the apple products. Orchard staff could choose different modules to record different operation information. The components of the device are shown in Figure 2 described below.

A—Android smartphone (Huawei, Shenzhen, China), used to install and run the app. Connected with an RFID reader, printer, and electronic scale with several interfaces such as Bluetooth and USB. Storage capacity of 64 GB for datalogger, and communication with the web application with 4G.

B—RFID UHF reader/writer (BY-A100, Boyan Technology, Beijing, China). This device had configurable output power and provided USB and Bluetooth communication interfaces.

C—UHF RFID cable tie tags (BY-UZ-1, Boyan Technology, Beijing, China). Passive ABS tags with 512-bit memory, and waterproof to increase robustness against the orchard environment.

D—Printer (Zebra, Shanghai, China).

E—GPS receiver (WENHENG, Shanghai, China): WH-GN100-EVK was selected for position determination (accuracy of 3.5 m under open-air conditions).

F—Electronic weighing scale (Langke, Ningbo, Zhejiang, China), with 60 kg maximum range and 20 g division value.

G—Serial Bluetooth adapter (IRXON, Beijing, China), It is used to realize the communication between GPS, electronic scale, and computer/mobile phone.

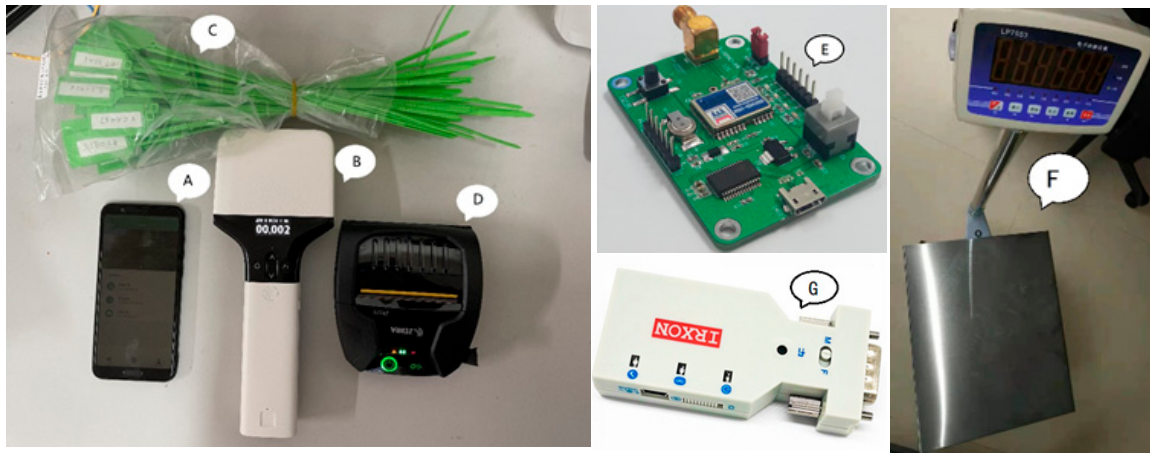


Figure 2. Hardware components.

All the devices can be powered by internal lithium batteries or dry cells. The components of the integrated hardware system have their pros and cons and using all of them can streamline data generation, increase the system's reliability, and give it the flexibility to adapt to different needs [31–34].

2.4. Software System Framework

To provide accurate traceability information to apple tree adopters, data from the field level should be recorded, processed, and utilized by different role users (farmer/consumer) (Figure 3). Therefore, the two system layers were designed. The smart farm cloud platform (SFC) combined information on orchard management. The orchard manage app was a lightweight system that could be run on mobile devices. It provided the convenience of obtaining information in real time and on site. The two layers can communicate through 4G/5G. The system flow is described below:

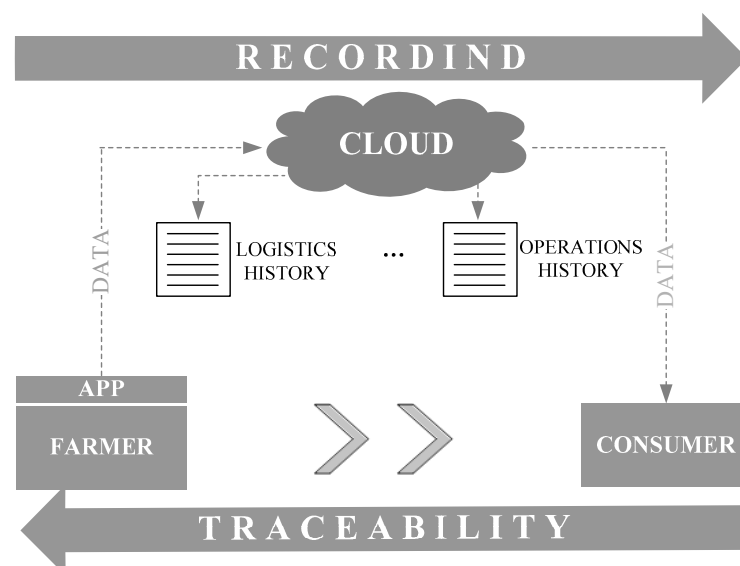


Figure 3. Information flow set for controlling apple traceability.

2.4.1. Web Application “Smart Farm Cloud Platform (SFC)”

SFC worked over the Ali elastic cloud server, with the MySQL database system. It is programmed to manage and trace the production journey of orchards, fields, and greenhouse crops. In this study, taking apple planting as an example, the web application allowed to create an orchard management information software for orchard registration, authentication of administrators, registration of plots and sectors, planting operations, input, apple products, and other additional associated information. The main functions were to establish planting files for the orchard, receive field and single-tree level information from the mobile app, host them in the database and show them to the user when requested. Figure 4 shows the structure of the web application user interface with seven differentiated sections: my farm (A), farm management (B), planting operation (C), products traceability (D), value-added services (E), system settings (F), and big data analysis (G). The function of each section is described as follows:



Figure 4. The interface of the web application “smart farm cloud platform”.

A—My farm: farm planning and digital display (google map, video surveillance information, environmental monitoring information).

B—Farm management: seedling management, agricultural resources management, order management and equipment management, consumer management, and so on.

C—Planting operation management: such as planting, processing, packaging, quality inspection, logistics operation.

D—Products traceability: traceability label template design, traceability label printing, logistics tracking.

E—Value-added services: planting expert system (planned).

F—System settings: basic system settings, personnel management, equipment management, and permission settings.

G—Big data analysis: use big data technology for planting analysis, order analysis, yield analysis, etc.

2.4.2. App on the Mobile Phone: “Mobile Orchard (MO)”

The orchard manage app was a mobile application designed for this study. With this app, farmers can acquire and upload information on the web application. The beta version was demonstrated using android smartphones. Through the app, apple farmers can read the apple tree tag, collect agricultural operation information, and realize the conversion of RFID tag information and barcode. Figure 5 shows an example of the application interface. The main functions are as follows:

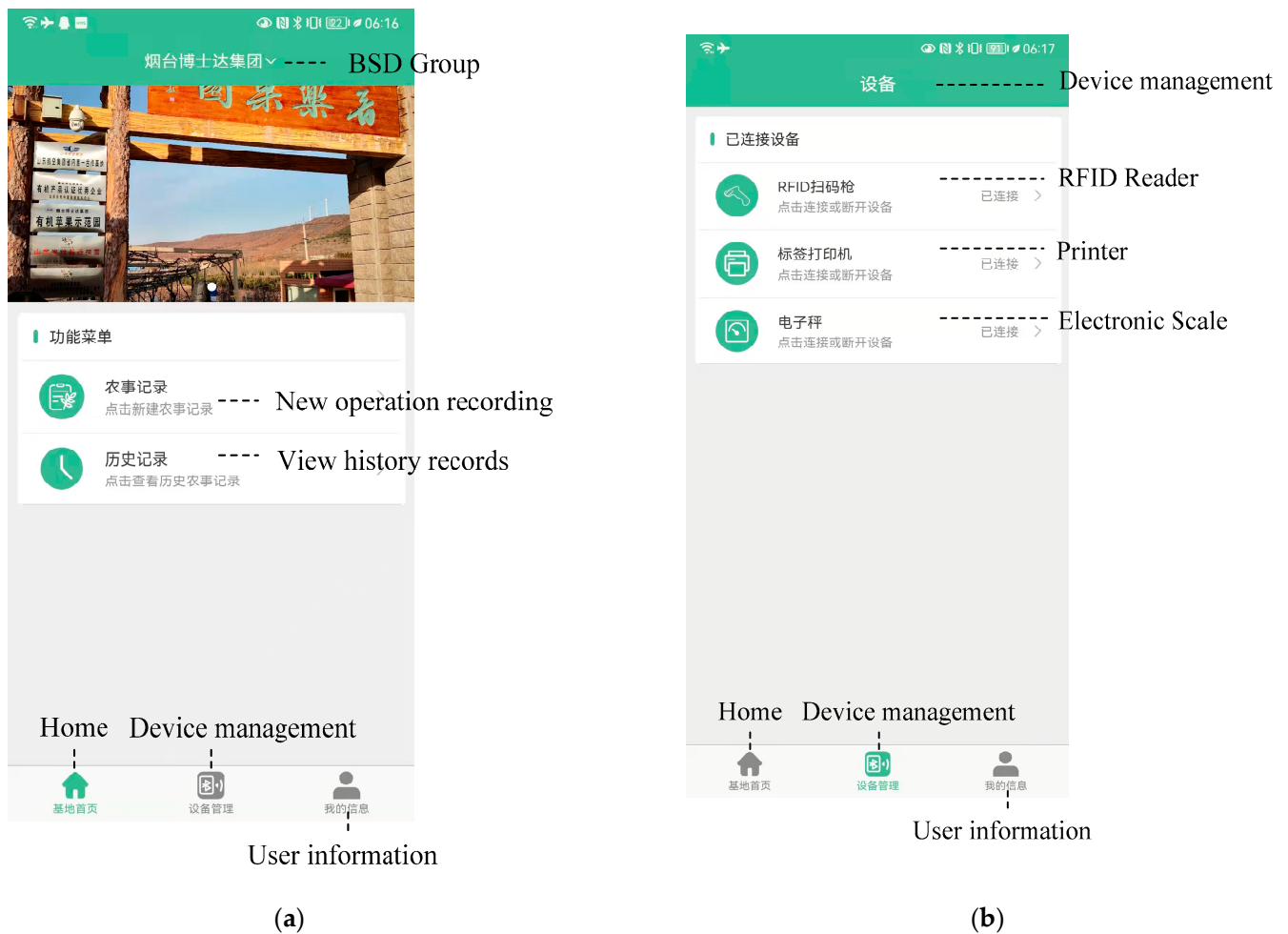


Figure 5. Typical interfaces of the “Mobile Orchard”: (a) home page, (b) device management page.

Agricultural operation management: the farmer can record the new operations, review the history records, and upload the records to the cloud platform. New operations could record during apple growing (weeding, pruning, fertilizer treatments, irrigation, apple bagging, harvesting ...).

Device management: connection and communication management of hardware devices (RFID readers, printers, and electronic scales).

2.5. Working Methodology

The new traceability data generation method includes the integration of IoT (Internet of things) technologies, such as RFID, QR code, and GPS. We implemented the data into the cloud platform and mobile app, and marking the trees with RFID tags (Figure 6).

2.5.1. Pre-Processing Office Work

When starting an operation in the orchard, the items involved in the operation were pre-programmed in the office.

Registration: when a new agricultural subject (planting base, orchard, and so on) logs into the SFC, it is prompted by the platform to enter authentication information. After the registration application is passed, the administrator of agricultural subjects can access SFC with the appropriate username and password (Figure 7).

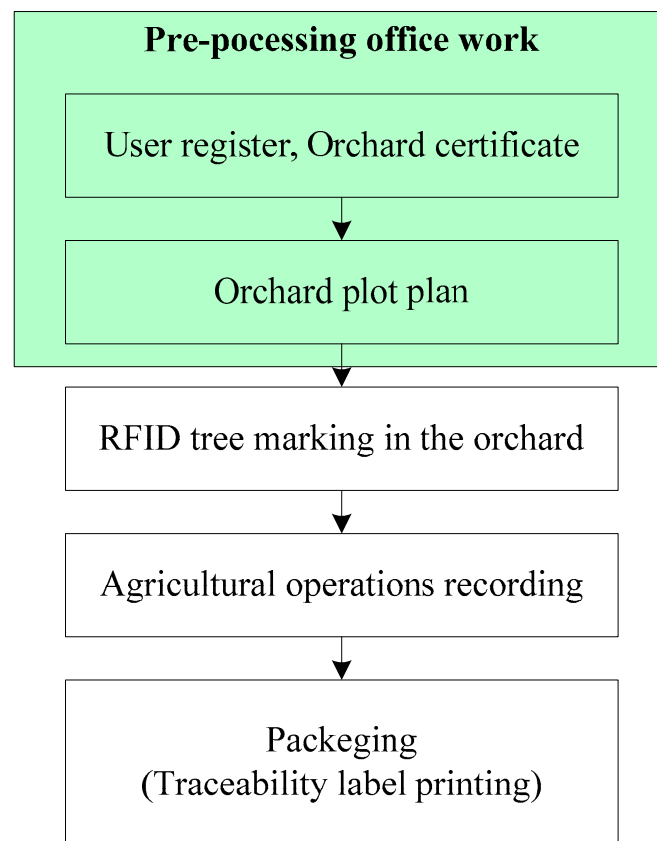
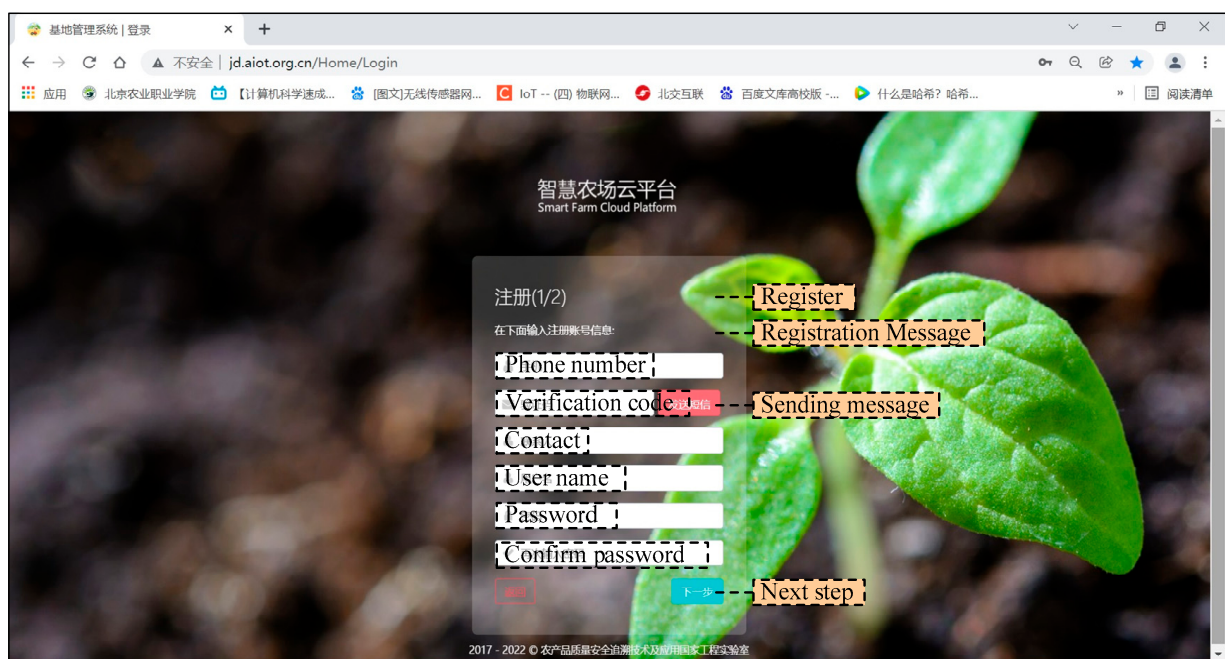
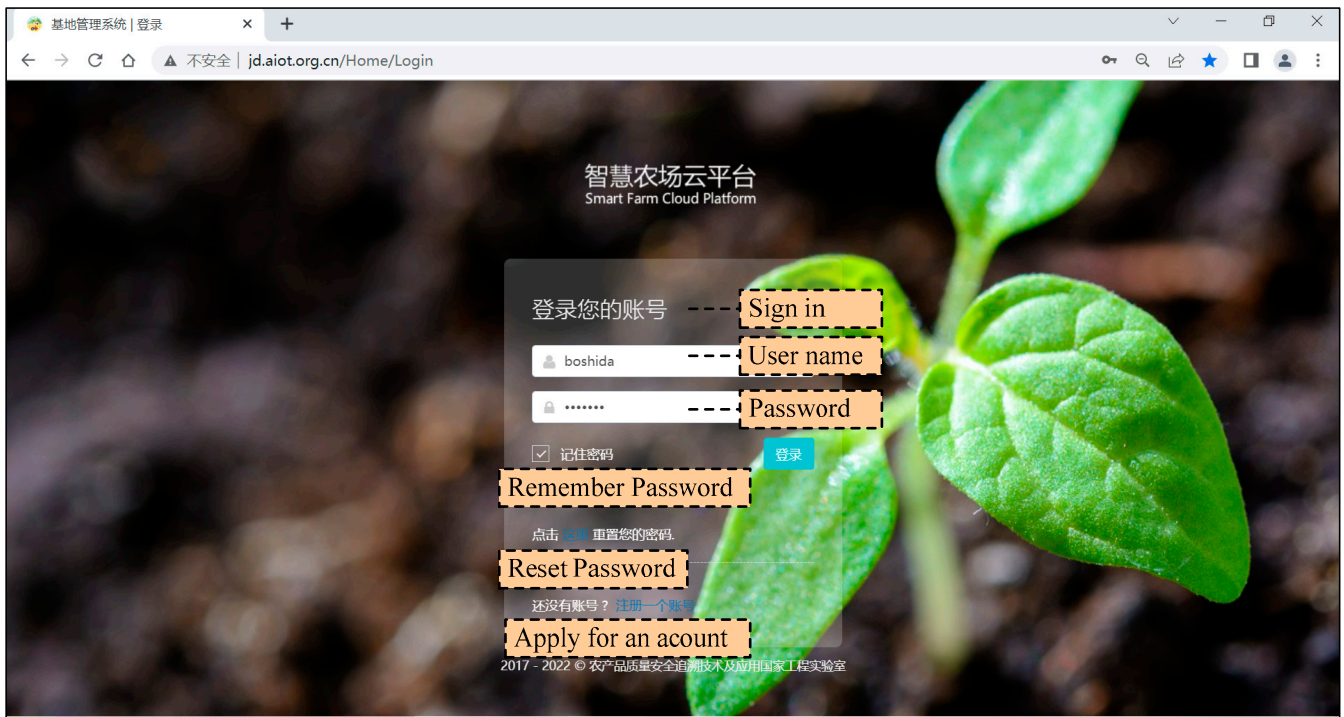


Figure 6. Flow chart of the work methodology.



(a)

Figure 7. Cont.



(b)

Figure 7. Registration/login Interface: (a) agricultural subject registration, (b) user sign in.

Orchard plot plan: at the “My farm section” (Figure 4, Section A), the farmer can create the plot or traceable unit that it to manage according to the actual situation and requirements of the orchard. In this study, three levels of areas were planned: orchard, plot, and traceable unit (single apple tree). There are 37 plots in the “BSD” organic apple orchard and 2 to 17 acres per plot. The plot is assigned an ID by the web application, and its boundary was positioned by the GPS receiver. The traceable unit was assigned a tree ID, read from the RFID tag which is going to be hung on the apple tree for marking (Figure 8). The combination of the PLOT ID and the apple tree ID could serve to classify the information uploaded from the orchard management app.

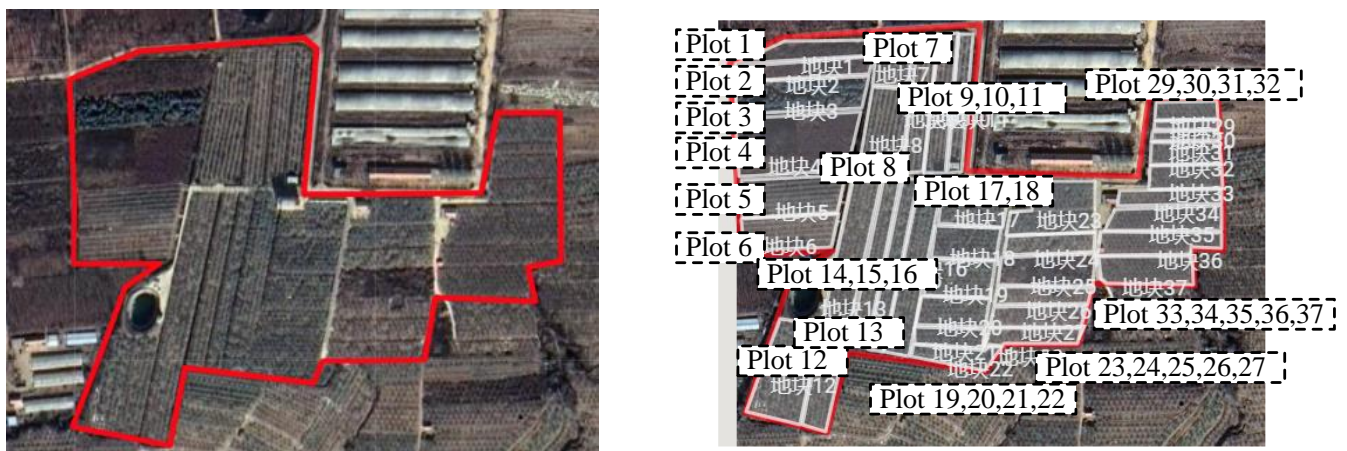


Figure 8. The interface of orchard plot planning.

Meanwhile, the tree characteristics (species, planting time, and adopter) were collected and associated with apple tree ID during the office process.

2.5.2. RFID Tree Marking

Before marking, the RFID number of the tag was added to the inventory dataset with an RFID reader and assigned to every single apple tree on the web application. Afterward, the apple tree was marked with the RFID tag at the bottom branch by cable ties (Figure 9).

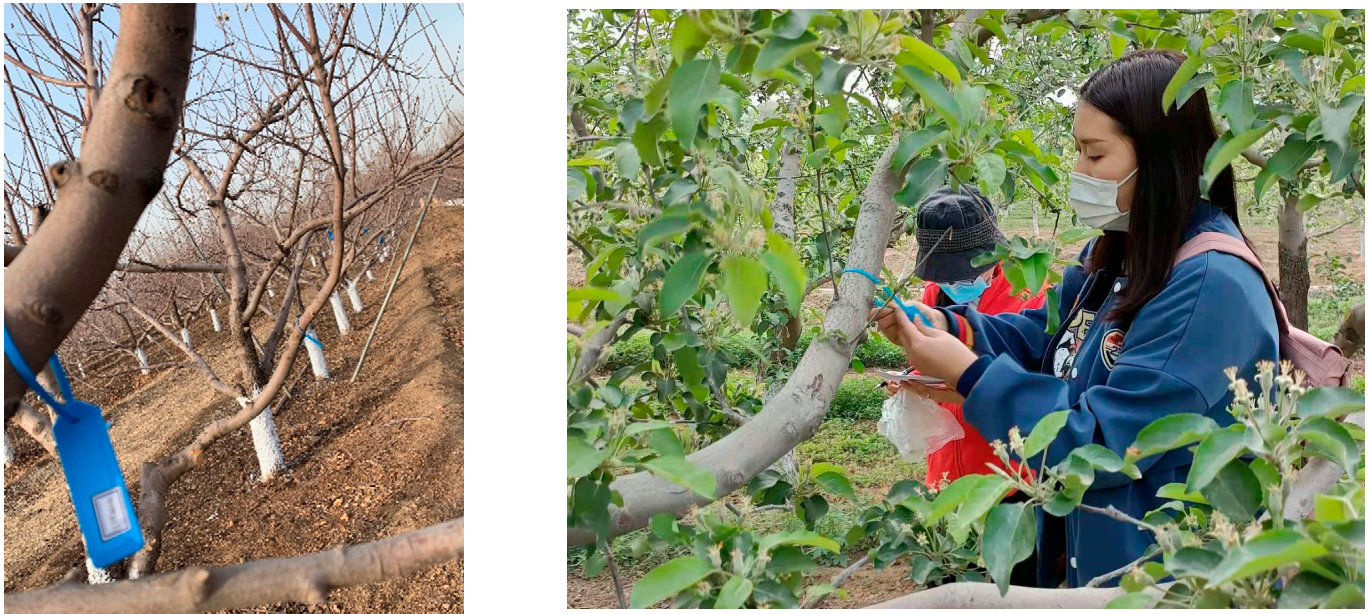


Figure 9. Fixing the RFID tag at the bottom branch.

2.5.3. Operations Recording

According to the apple growing process and the traceability requirements, the system designed two operation collection methods, by batch (GPS) and by a single tree (RFID).

By batch: Most operations in the field section were performed by plot, such as irrigation, pruning, and fertilizer treatments. In this way, we use the mobile location function. When farmers worked in the orchard, the current GPS coordinates were continuously acquired with the operation data. In the pre-processing office work, the boundary position (polygon) of every plot was located, saved, and associated with PLOT ID. With the current GPS coordinates and the boundary position, the current plot where the operations were taking place could be determined by the ray-casting algorithm for testing the inclusion of points in polygons. After acquiring the PLOT ID, the apple tree IDs in this plot could be determined. Then the current operation associated with the tree IDs is uploaded to the cloud platform SFC (Figure 10).

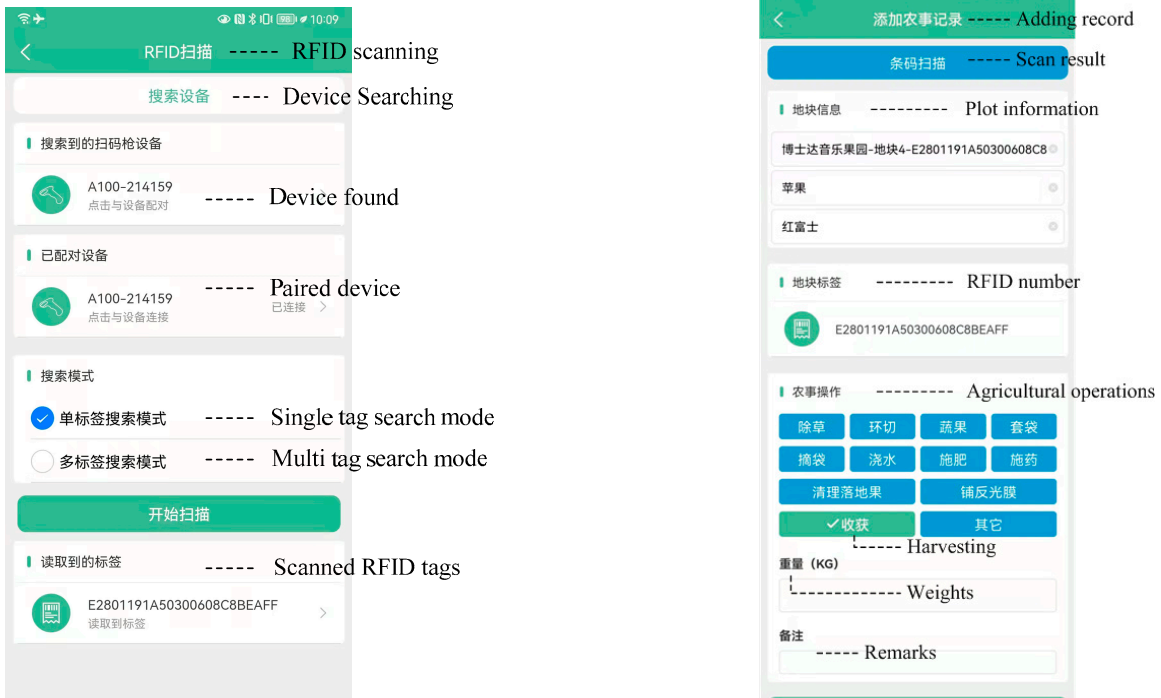
By single tree: There is a specific operation in the field section, harvesting. Because of the sales method of adopting apple trees and the traceability requirement, this operation has a specific request that it should link the apple production with the apple tree. When harvesting, apple batch numbers are generated by adding the information (weight of apples, harvesting time) of different trees and are associated with the tree ID by reading the RFID tag on every tree. Then the whole information could upload to the cloud platform SFC.

After apple harvest, the apples of every single tree will be sent to the adopters. Apples should be tagged to document which tree they come from. With the app on the mobile phone, the harvest information including tree ID and harvest time was printed on the label. The labels were attached to the apple basket realizing the information associated with the apple tree to the apple (Figure 11).



(a)

(b)



(c)

(d)

Figure 10. Mobile app interfaces of operation collection: (a) two collection methods, (b) collection method by batch, (c) RFID reader manage, (d) collection method by a single tree.

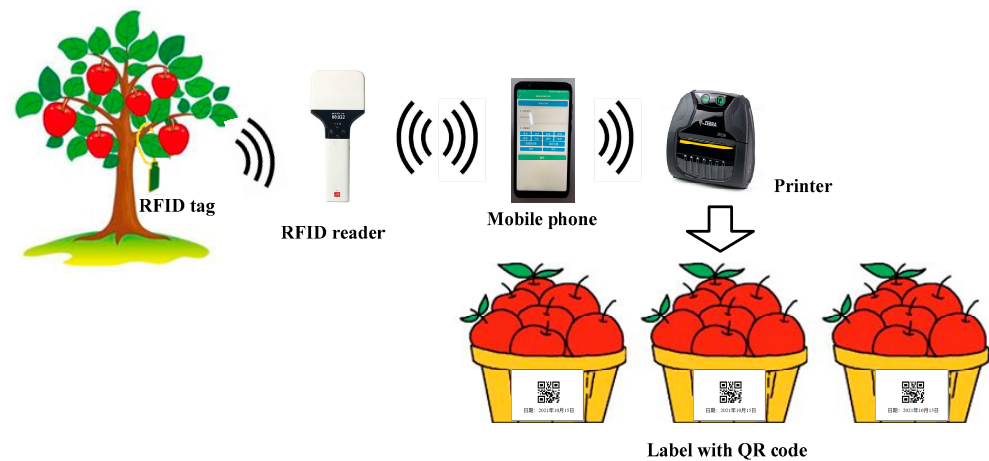


Figure 11. Information flow during the harvesting stage.

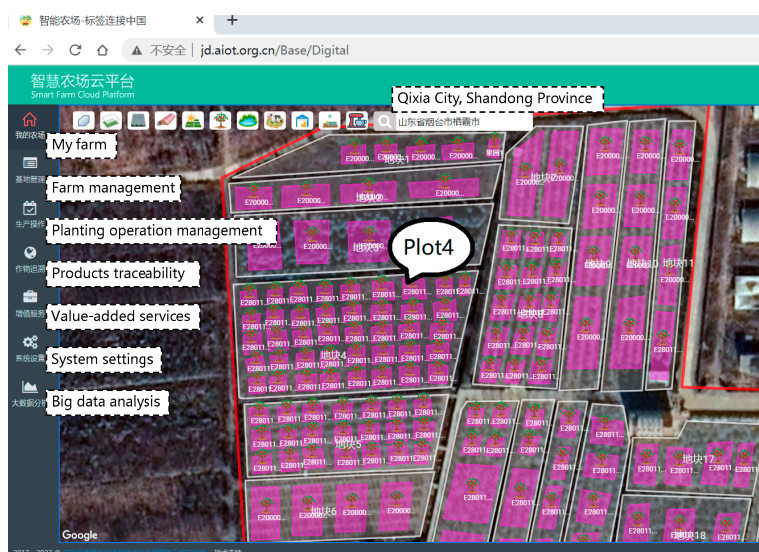
After harvesting, apples should be packed and delivered to the adopters. Meanwhile, traceability information is also required by adopters. The SFC provides consumers with an information query function based on traceability codes. When packaging, the traceability code was generated by scanning the label on the apple basket. Then the apples' traceability labels are printed, affixed to the final packaging, and provided to the consumers.

3. Results

3.1. Data Collection

The case study area is plot 4 (4.5 acres) in the “BSD” organic apple orchard. There are 270 red Fuji apple trees in plot 4, which were planted in 2012. This plot is the main area of apple tree adoption.

The field application was carried out using the methodology described: the plot was created and bounded at SFC ((120.747420, 37.208665); (120.748570, 37.208723); (120.747409, 37.208200); (120.748448, 37.208260)). The plot ID was 4. There are 270 apple tree IDs defined by RFID tags. The apple tree IDs were associated with plot ID 4. RFID tags were hung on apple trees to mark tree IDs (Figure 12).



(a)



(b)

Figure 12. Pre-processing work before data collection: (a) plot planning on web application SFC; (b) apple trees with hanging RFID tags.

The farmers installed the “Mobile Orchard” app on their phones and collected the usual operation data carried out in the orchard with the app. Regular field operations were collected by batch using GPS technology, while harvesting operations were done by the RFID method. The combination of the two collection methods effectively improved the efficiency of information collection. The operations performed in plot 4 were successfully uploaded from “Mobile Orchard” to SFC. In 2021, about 45 operations were successfully obtained. The detailed description of the main operations is shown in Table 1.

Table 1. Main operations and data performed in plot test with the system.

Operations	Date	Product	Parameter	Technology
Pruning	22 February 2021–28 February 2021	-	-	GPS
Pesticide application	18 March 2021	0.5% Emodin + 1.5% pyrethrin	Dose	GPS
	9 April 2021	0.5% Emodin + 1.0% matrine		
	10 May 2021	1.0% Osthole + 1.0% matrine		
	20 May 2021	1.0% Carvacrol + 1.0% osthole		
	4 June 2021	0.5% Emodin + 1.5% pyrethrin		
	8 June 2021	Bordeaux mixture		
	12 July 2021	0.5% Emodin + 1.0% osthole		
Carving buds	23 August 2021	0.5% Emodin + 1.5% pyrethrin		GPS
	21 March 2021–26 March 2021			
Weeding	2 April 2021–4 April 2021			GPS
	27 April 2021–28 April 2021			
	16 May 2021–17 May 2021			
Irrigation	15 July 2021–17 July 2021	water	Dose	GPS
	12 April 2021			
Artificial pollination	1 June 2021			GPS
Flower thinning	17 April 2021–23 April 2021			GPS
Apple thinning	24 April 2021–26 April 2021			GPS
Apple bagging	3 May 2021–7 May 2021			GPS
Re-pruning	22 May 2021–31 May 2021			GPS
Training	6 June 2021–8 June 2021			GPS
Removing bag	13 June 2021–18 June 2021			GPS
Harvesting, cleaning up fallen fruit	9 July 2021–11 July 2021			GPS
	27 August 2021–1 September 2021			GPS
	16 September 2021–21 September 2021		Weight	RFID

3.2. Application Effects

Before using the system, the operations data were obtained manually. A dedicated manager was responsible for entering information into computers. This system was put into use in 2021. During this time there were 21 registered users. Feedback was provided by 2 orchard managers and 19 farmers (8 full-time employees and 11 temporary workers). Managers noted the advantages of promoting optimal management of agricultural operations and facilitating information accessibility, which arises from the fact that the system can provide real-time and on-site information to support orchard management. Compared with obtaining and entering information manually, the system is effective and precise. Enhancement of management is an obvious advantage for before using the system, agricultural operations data was difficult to query and analyze. The SFC accumulates data on apples, environments, and agricultural operations, and stores it in an easily accessible format. Based on the data, management and decisions about apple-producing can be implemented. Meanwhile, some managers noted advantages, the system also enhanced costs and brought additional training work.

Most farmers agreed that the system could increase the automation of data collection by machine-to-machine connections, although some farmers believed this system enhanced the complexity of the work and brought extra workload.

3.3. Guaranteeing Traceability

With the agricultural operations obtained by the system, the “BSD” organic orchard could provide complete and accurate traceability information to the adopters with trace-

ability labels and codes (Figure 13). In 2020, the apple products of “BSD” organic orchard only had a simple origin label. In 2021, all the apple products in plot 4 had been sent to consumers with a traceability label.



Figure 13. Traceability label.

With the traceability code, all the apple products could be traced to every single tree. In addition to the regular traceability information of the apple (origin base name, varieties), it can also show consumers the apple planting process and agricultural operation information (Figure 14), which the consumers (apple tree adopters) are most concerned about.

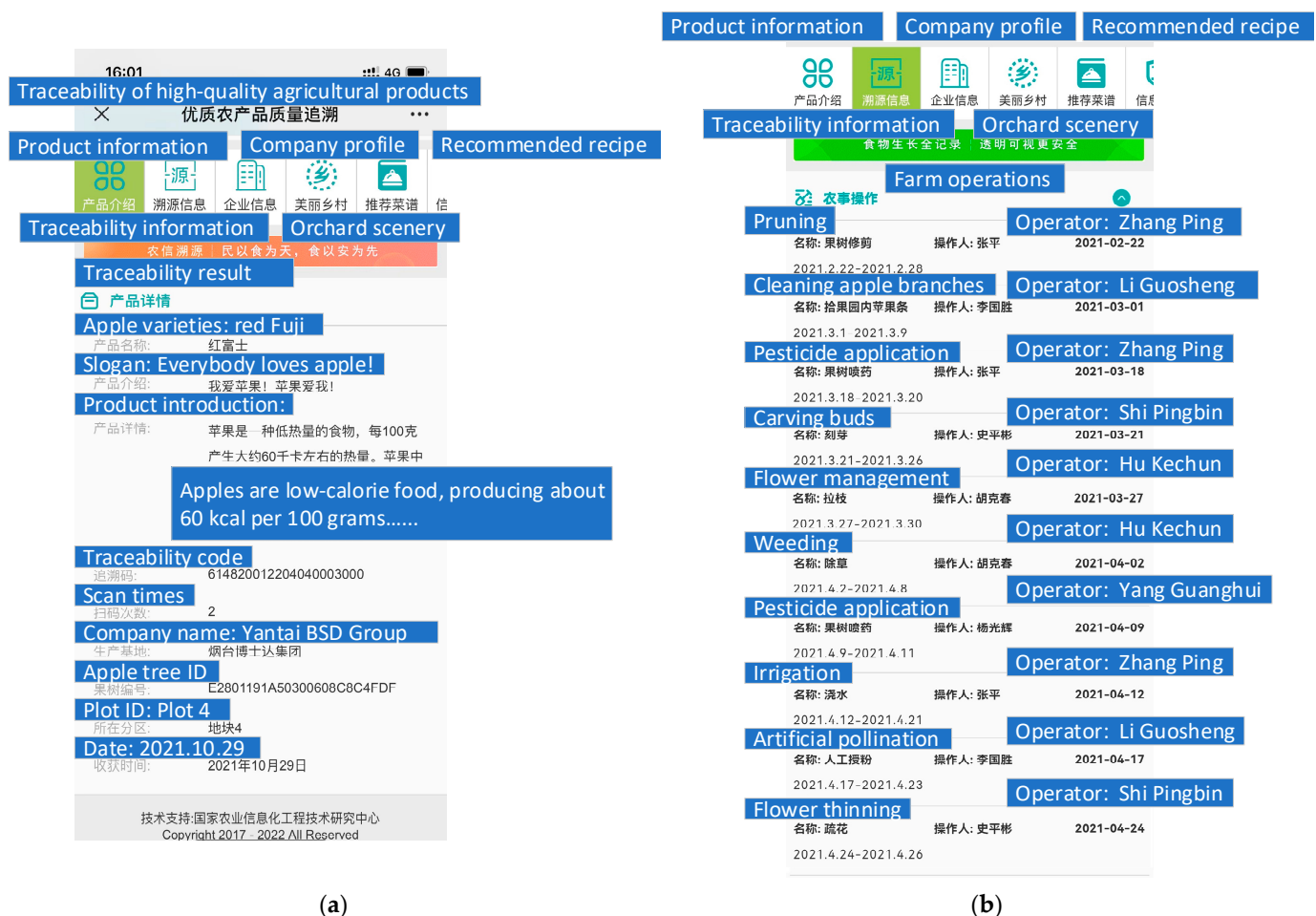


Figure 14. Apple traceability information queried by barcode scanning: (a) apple basic information, (b) farm operation details.

3.4. Effort Analysis for the System

3.4.1. Pre-Processing Office Work

Preparation time for the system application in the office was necessary. One orchard manager worked 2 h to read the 270 RFID tags, assigned adopters to RFID tags, and labeled every RFID tag with its adopter's name. One orchard manager worked 1.5 h to create orchard, plot, and traceable unit (RFID code) on the SFC platform, entered orchard information and adopter's information (associated with the with the RFID code). The needed equipment was RFID UHF reader/writer (BY-A100), UHF RFID cable tie tags, Zebra Printer, and a computer.

3.4.2. RFID Tree Marking

It took 1.5 h to mark 270 trees with the RFID tags by two farmers, with the adopters' names on the RFID tags and each tag hung on the corresponding apple tree.

3.4.3. Operations Recording

During the early stages of the system design, agricultural operation information was collected from every single tree [30]. With this approach, recording one farm operation needed to scan RFID tags and enter operation data 270 times, which was extremely inefficient. When using GPS to collect farm operation information in batches, it cost about 1 min to enter the whole operation data of plot 4.

While during apple harvest, the information (weight of apples, harvesting time) was associated with tree ID by reading the RFID tag on every tree. So, farmers had to scan each tag on the apple tree first, then synchronize the weight and time data. In the end, harvest information was printed on a label with a Zebra printer, pasted with apple products. The time taken for the entire process varied from 2 min to 5 min, which depended on the level of familiarity with the "Mobile Orchard" app.

Compared with the duration of the main farming operations in 2020, the duration of corresponding farming operations did not increase significantly in 2021 (the number of farmers was basically unchanged). It is reflected from the side that the collection of agricultural information with this system did not increase the workload (Table 2), although it was difficult to quantify the time consumption of the original manual recording method.

Table 2. Comparison of time spent in an agricultural operation.

Main Agricultural Operation	Duration (Day)	
	2020	2021
Pesticide application	9	8
Carving buds	5	6
Weeding	11	10
Irrigation	3	2
Apple bagging	11	13
Harvesting	4	6
Total	43	45

4. Discussion

The performance of the system has enabled an automatic record of the inputs and operations involved in the traceability of the apple. It changes the information collection and management status of using handwritten or manual input with office software in the past and facilitates the transfer of reliable information between the orchard and consumers, which enables improved product quality through control of important variables and increased consumers' trust. Moreover, the information associated with apple planting might be expanded by adding other parameters to record in the whole supply chain, such as the climatic variables and warehouse environment variables [28]. The information, with the precise agricultural techniques, will make the system become a powerful tool for the

farmer to establish the orchard logbook and manage the data from all aspects of production, processing, warehousing, logistics, and others [35].

This system adopts two collection methods, by batch and by individual trees, with GPS and RFID technology. The combination of these two methods realized data entry automatically, which greatly improves the efficiency of agricultural operation data collection by ensuring the traceability accuracy of a single apple tree. However, the same technical issues may exist. In 2021, the GPS method was only used in one plot, which means the program only need to determine in or out, which is much simpler than identifying multiple contiguous plots. In the future, the positioning accuracy under different cases requires more testing, and we may need a more accurate type of GPS, although the cost would be higher. When the single tree marking with RFID tags and the scanning of the tags worked well but with some reading range changes. When trees bear apples, the appropriate range to make a reading with 100% becomes smaller than lab tests. Meanwhile, the two methods both involve previously establishing some proper work route to identify the plot at the pre-processing office work (such as initial positioning of the GPS and RFID tag assignment) before starting the field operations collection. These changes in the working operation could be a problem in the early stages of training. For some farmers, it is difficult to manage a mobile app that is too complicated. Developing a user-friendly, simple, and clear interface both for the cloud platform SFC and mobile application Mobile Orchard would make this challenge easier.

The implementation of the system would not entail much outlay when compared to the advantages that could be obtained by increasing the added value of apple products. With the sales method of adopting fruit trees, most of the consumers (adopters) are willing to pay more for the apples accompanied by a reliable traceability system.

The traceability system developed here uses QR codes to present traceability information to consumers. The information includes apple varieties, apple tree ID, plot ID, and agricultural operations data. Abundant and trusted data can increase consumer confidence, thus increasing the value of the apple products.

The system developed here is a starting point for the implementation of blockchain technology in the apple supply chain [36]. Blockchain is a promising technology that has great potential for ensuring the veracity and incorruptibility of information from the field to the consumer and improving traceability performance by providing security and full transparency [33,37–40]. This aspect will be addressed in the next article, where a blockchain-based framework for apple supply chain traceability is described.

5. Conclusions

This work proposes an integrated, machine-to-machine traceability data generation system. With this system, apple products could trace to every single tree. Abundant and trusted traceability information was offered to the consumers via traceability labels. Under the premise of ensuring traceability accuracy, web application SFC, mobile application MO, and the integrated hardware system were developed, which allows the automatic recording, storing, and managing of all the operations carried out along apple production in the orchard, without extra workload and labor costs.

This system was used for about a year in the “BSD” organic apple orchard in Qixia, Shandong. The RFID technology worked properly in the identification of every single tree. Additionally, GPS identified the plot. With the GPS and RFID technologies, it realized the combination of information batch and individual collection, improved collection efficiency, and reduced operational complexity. These are the advantages of the system. Disadvantages included increased cost and some pre-processing work. Nevertheless, the system is an open platform, which provides wide room for future development and improvement of traceability, such as blockchain. Further studies are necessary to reach these goals.

Author Contributions: Conceptualization, J.X. and M.L.; methodology, J.X.; software, C.W. and J.X.; writing—original draft preparation, J.X.; writing—review and editing, J.X. and M.L.; supervision, A.T.B. and M.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Program of China (Grant No. 2017YFE0122500), National Natural Science Foundation of China (Grant No. 31871525), Beijing Municipal Natural Science Foundation (Grant No. 4182023), and the FP7 Framework Program (PIRSES-GA-2013-612659), Science and Technology Innovation Program of Beijing Vocational College of Agriculture (XY-YE-21-07).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: No data, models, or code were generated or used during the study.

Conflicts of Interest: The authors declare no conflict of interest.

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