Computers and Electronics in Agriculture 98 (2013) 146–157

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

An innovative and low-cost gapless traceability system of fresh vegetable products using RF technologies and EPCglobal standard

Luca Mainetti, Luigi Patrono, Maria Laura Stefanizzi, Roberto Vergallo *

Department of Innovation Engineering, Salento University, Via Monteroni, 73100 Lecce, Italy

ARTICLE INFO

Article history:
Received 22 March 2013
Received in revised form 13 June 2013
Accepted 28 July 2013

Keywords:
RFID (Radio Frequency IDentification)
Item-level tracing system
EPC (Electronic Product Code)
Food supply chain
NFC (Near Field Communication)
Enterprise Service Bus

ABSTRACT

Traceability requirements in supply chain management are getting more and more strict in order to ensure product quality and public safety. Such requirements are particularly difficult to reach in the agro-food sector, especially for fresh ready-to-eat (RTE) vegetables, where specific needs exist; for example, mixed RTE salads are made of different produces, and there is the need to track and trace the treatments all the ingredients separately receive, avoiding gaps in the electronic histories. Traceability global standards, along with the adoption of Radio Frequency (RF) technologies have been widely experimented in this field; nevertheless, there are still many difficulties. Wireless Sensor Networks (WSN) cause a big impact on the existing information system, and meet the opposition of professionals in the field such as agronomists who feel out of the process. Additionally, Ultra-High Frequency (UHF) Radio Frequency IDentification (RFID)-based item-level traceability is still too expensive.

In this paper, we propose an integrated and innovative solution for the "gapless" traceability of fresh RTE vegetables produced by an Italian agro-food company. Most approaches to sensor-based implementations completely replace agronomists. By contrast, our solution keeps the agronomists in the greenhouses but empowers them with smart technology. The Agronomist Android mobile App uses Near Field Communication (NFC) technology to allow the linking of plants and traceability information, following the EPCglobal standard. We achieve low costs by using DataMatrix technology for item-level tagging, while restricting the use of UHF RFID to coarse-grained grouping levels (case and pallet). We adopt the Enterprise Service Bus (ESB) architectural style for granting flexibility and scalability while preserving compatibility with legacy applications. We obtained the experimental results we report by using a Living Laboratory approach; the experiments we carried on have demonstrated the good performances of RFID tags and readers when used in conjunction with fresh vegetables products, as well as the actual effectiveness of the proposed gapless traceability system.

1. Introduction

Track&trace is a critical part of the agro-food industry. In the European Union (EU) the import, sale and marketing of most fruit and vegetable products are regulated by the General Marketing Standard (GMS) (EU, 2011), which aims to ensure that the produce is clean, correctly labelled, of marketable quality and archive an appropriate quality class. To comply with legislation and to meet the requirements of food safety and food quality, each company along the supply chain must adopt internal traceability system and share information in a coherent manner. Global organizations encourage the use of traceability open standards and solutions, for example the EPCglobal standard (GS1, 2003), which improves efficiency and visibility in supply chains.

According to such strict requirements, the agro-food supply chain must monitor (track) a product in the food chain and allow the retrieving (trace) of its history from the producer to the consumer. Track&trace is therefore a preventive instrument of quality and safety management.

In such a context, the track&trace of fresh and ready-to-eat (RTE) vegetables is even more critical. RTE products such as buffet mixed salads, grab-and-go prepared salads, and packaged salad mixes, are gaining in popularity in urban areas because they are pre-washed and can be immediately consumed without additional preparation. For this kind of products, traditional traceability is not enough, as it does not represent a valuable add-on for consumers (e.g. people with special needs or patients affected by multiple intolerances) (Mainetti et al., 2011). To ensure public safety, RTE manufacturers must implement a more detailed traceability, with no gaps, i.e. "gapless".

The gapless traceability can provide the complete history of a product, from the seed to the shelf, including treatments and

* Tel.: +39 0832 297335; fax: +39 0832 297305.
E-mail addresses: luca.mainetti@unisalento.it (L. Mainetti), luigi.patrono@unisalento.it (L. Patrono), laura.stefanizzi@unisalento.it (M.L. Stefanizzi), roberto.vergallo@unisalento.it (R. Vergallo).

0168-1699/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.compag.2013.07.015

biological detections, even when the product itself is composed of different ingredients (e.g. mixed salads). In this case, the gapless traceability can return the history of each ingredient, separately.

The gapless traceability can also help maximizing the yield in the greenhouse. Tracking the products manufacturing, packaging and shipping processes can lead to business benefits (Guido et al., 2012); detailed tracking information, inputted in a business intelligence system, can furthermore suggest corrective operations for the crop (e.g. varying temperature and humidity to speed up or slow down the produce maturation).

According to the literature, the suitable technology for implementing track&trace is varied and it is present in a large number of experimental solutions. In recent years, the agro-food supply chain featured a growing interest in innovative Radio Frequency (RF) technologies like Radio Frequency IDentification (RFID) and Wireless Sensor Network (WSN) (Duan, 2011; Ruiz-Garcia and Lunadei, 2011; Vellidis et al., 2008; Santa et al., 2012; Costa et al., 2013; Gandino et al., 2009). Also Wolfert et al. (2010) notice that various pilot projects involving RF technologies have been set-up in the food industry, mainly for traceability and management purposes.

Maffia et al. (2012) and Calcagnini et al. (2012) demonstrate the suitability of RF technologies for a different critical sector, the drugs supply chains. They also analyze and discuss the effects of RFID over biological pharmaceutical products.

Many works propose RFID applications in the fields of agro-food production (Papetti et al., 2012; Chunxia et al., 2009). The EPCglobal standard itself highly encourages the use of RFID in supply chains. Case studies of combined EPCglobal and RFID implementation exist (Barchetti et al., 2009a,b). Nevertheless, RFID is insufficient for implementing the gapless traceability; it must be used in conjunction with a continuous monitoring technology. Anastasi et al. (2009) propose the use of WSN for monitoring high-quality wine production, but the gathered information is retained within the information systems.

What is evident from the available literature is that the development of a real gapless item-level traceability in the agro-food sector is still at an early stage. This is due to technical issues but also to cultural obstacles.

From the technical point of view, important issues are open: (i) vendor lock-in and lack of interoperability create barriers to adoption; (ii) the exclusive use of 1D optical barcodes is still deep-rooted; (iii) a strong EPCglobal industry adoption is still a goal to reach in most countries and organizations roadmaps; (iv) RF technologies costs are important constraints.

From a cultural perspective, agronomists do not highly regard the adoption of RF automatic sensing technologies. They distrust full sensor-based automations because they think they own the right knowledge and experience needed to manage the field.

In this work we discuss an EPC-based gapless item-level traceability model implemented for a fresh RTE vegetables Italian company; in contrast to the available literature, we pay particular attention to preserving the role of agronomists and reducing the costs of adoption. In our solution, not sensors but humans perform the EPC style tracking in the greenhouse. The company's agronomists use Android smartphones with bundled Near Field Communication (NFC) RF technology for linking plants and tracking information in the greenhouse. In the transformation factory, a classic EPCglobal architecture uses both passive Ultra High Frequency (UHF) RFID and the less expensive DataMatrix technology. We achieve low costs by using DataMatrix tags for item-level tagging, while restricting the use of UHF RFID to coarse-grained grouping levels (cases and pallets). Considering the low cost of the product, it is not worth applying an RFID tag on each individual package. By using DataMatrix codes we are still compliant to the standard, while it will be possible to trace the product history by exploiting any 2D barcode reader, e.g. a common smartphone connected to the Internet.

We deployed both traditional and innovative services in an Enterprise Service Bus (ESB) in order to grant flexibility and scalability while preserving compatibility with legacy applications.

We carried out an intense experimental campaign following the Living Laboratory approach, i.e. we exploited a controlled test environment whose hardware and software features reproduce faithfully the main business processes. We identified the most suitable model of RFID tag by conducting two kind of tests; these allowed to evaluate the recognition accuracy of 11 pre-selected tags when used in conjunction with cases and pallets containing fresh RTEs products.

The rest of the paper is structured as follows. Section 2 reports a deeper overview about the fresh RTE vegetables supply chain processes; in Section 3 materials and methods adopted in our experimentation (both hardware and software) are described. In Section 4, the results are shown; in Section 5, we discuss our results and sketch future research.

2. Analysis of the fresh RTE vegetables supply chain

Jentu is a novel fresh vegetable producer recently established in the South of Italy. The cultivation processes in Jentu's greenhouses follow some practices of the biological approach, e.g. the least amount of pesticides and fertilizers is used. Main Jentu's products are: lettuce, spinach, chicory, arugula, radicchio, endive, carrot, zucchini, radish, and sauerkraut, packaged singularly or in mixes. To date, the cultivation of the farm extends to 36 acres of land and more than 60 ha of greenhouses for a total of 6 greenhouses, but soon new greenhouses will rise up. Jentu pays the same attention to the transformation processes; the factory avails itself of high-tech equipment and extreme attention to hygiene matters.

Next we analyze the fresh RTE vegetables supply chain from Jentu's perspective in two different phases: produce cultivation and products manufacturing.

2.1. Produce cultivation

To date, the agronomist manually performs the sensing activity; he notes on paper the presence of plant diseases, the field humidity and other qualitative aspects at each check visit. After the check, the agronomist saves the information to a digital system called "Field Log", which is part of a suite specialized in the greenhouse management. A Field Log is a software able to record warehouse movements, sowing, growing, harvesting, irrigation, the use of chemical products, the scheduling of goods collecting, weighing and shipment, all accompanied by a detailed report and in compliance with all applicable regulations. The Field Log supports the automatic importation of data related with the compositions of commercial formulations and active ingredients, provided by the Italian Ministry of Agriculture and Forestry.

The agronomist also defines the portions of land/greenhouse ready to be cropped. He also decides whether the product must be fully cropped (because it is adult) or it can be mowed. It is clear that the activities performed by the agronomist are highly exposed to human errors and imprecisions, mainly due to the need of transcribing the gathered data into the Field Log.

Pallets are used to move the crop from the greenhouses to the transformation factory. The crop is placed into bins, which are placed over the pallet. The division in bins is needed in order to allow partial use of the crop in the production steps, depending on costumers' orders.

Before being processed, the crop is weighted, classified and made identifiable by an attached form. Jentu requests outsource