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Advanced traceability system in aquaculture supply chain

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ABSTRACT

The paper presents a novel traceability system architecture based on web services, which are used to integrate traceability data captured through Radio Frequency Identification (RFID) systems with environmental data collected with Wireless Sensor Networks (WSN) infrastructure. The solution, suitable to be deployed in Small to Medium Enterprises (SMEs), is provided by integrating information collected along the entire food supply chain, tracking the products from the farm to the consumer. The results of the deployment of the novel system in two pilots in the aquaculture business are also presented, showcasing how business processes in the aquaculture supply chain can be improved by the architecture and flexibility of the new system, since the two companies involved in the project are of very different sizes. Additionally, we present an analysis of the benefits obtained by the introduction of the new system in the companies based on predefined objectives and the evaluation of KPIs. The evaluation of KPIs is presented as the time reduction of activities and can improve the Efficiency of the companies in 89–95%.

1. Introduction

Food sector has been affected by several food alerts and scandals in the past and even today (Schröder, 2008; Bánáti, 2011; Storøy et al., 2013). Their diffusion through the media and the market globalisation has resulted in lack of consumerś confidence and an increase in the concerns about the origin of food and the condition in which products reach the end consumer (Moretti et al., 2003; Thompson et al., 2005; Wang et al., 2011). The main tool that producers and consumers can count onto both increase confidence and solve food alerts in an effective way is food traceability (Regattieri et al., 2007; Costa et al., 2013a).

The concerns about food safety and quality in public administrations have launched new legislative initiatives that regulate the way information is collected and exchanged along the food supply chain: the EU directive 178/2002 (European Parliament, 2002) and the U.S. Bio-terrorism and Response Act (FDA, 2002) are both responses to these new concerns.

Within the food sector, aquaculture companies are not indifferent to these issues. Aquaculture is becoming one of the most important food sectors and its contribution to world total fish production climbed steadily from 20.9 percent in 1995 to 32.4% in 2005 and 40.3% in 2010; in addition, its contribution to world food fish production was 47% in 2010 (FAO, 2012).

Fresh fish is a perishable product in which environmental parameters, such as temperature and humidity, must be controlled and strictly maintained within established limits (Jedermann et al., 2009; Abad et al., 2009; Tingman et al., 2010). These parameters should be monitored during fish processing, storing and transport, and the quality and appearance of the fish depends on them (Costa et al., 2013b). Therefore, new specific standards have appeared describing the principles of traceability for the fish farming and the fish industries (CEN, 2003a,b) and for traceability of finfish products (ISO 12875, 2011). New regulations delegate the responsibility for traceability control and food security to producers, processors and retailers (Abad et al., 2009), hence, food sector companies and specifically aquaculture sector companies, have been pushed to make an effort to implement new internal traceability systems within their organisations. According to Pàlsson et al. (2000), first traceability systems in seafood industry were based on paper documentation. Although more recently Hsu et al. (2008) suggested that the traditional paper-based traceability systems are evolving to automate collection of information, many SMEs still do not have access to a traceability software and are still working with paper-based systems (Wang et al., 2011). The main reasons for this situation are the cost barriers and the lack of awareness about the benefits that these systems can bring to the companies (Sioen et al., 2007; Karlsen et al., 2011; Jakkhupan et al., 2011).

Traceability systems required to comply with the new food regulations can yield a huge volume of information and, therefore,

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data collection, storage and accessibility become critical. The evolution of traceability systems has been based on the introduction of Information Technologies (IT) and Enterprise Resource Planning (ERP) in the companies (Bevilacqua et al., 2009). Furthermore, the development of new technologies such as 2D barcodes, RFID and WSN is a key factor in the new food traceability systems, bringing new opportunities to improve safety and enhancing supply chain and process transparency (Kelepouris et al., 2007; Wang et al., 2011; Ruiz-Garcia et al., 2007).

In recent years, a great research interest about integrating RFID and WSN within the food supply chain has emerged. In fact, one of the most important research trends in the food sector is the electronic traceability and condition monitoring using RFID and WSN (Myhre et al., 2009). Thus, there have been some practical implementations in companies that are now using RFID for food supply chain in Italy, France, UK, Sweden, the USA and Canada (Angeles, 2005; Jones et al., 2005; Regattieri et al., 2007; Connolly, 2007; Launois, 2008; Kumar et al., 2009).

In the seafood sector some electronic chain traceability systems have been proposed, such as the one in Frederiksen et al. (2002) that proposed an internet based traceability system for fresh fish. Seino et al. (2004) proposed a similar system for fish traceability by using QR codes after discarding the use of RFID due to the costs of this technology at that moment. Grabacki et al. (2007) introduced the concept of using RFID for the seafood industry in Alaska and they remarked how this will be the key technology in the supply chains of the future. More recently, some research has been performed in demonstrations of RFID applications in the live fish supply chain (Hsu et al., 2008), in intercontinental fresh fish logistic chains (Abad et al., 2009) and for monitoring the temperature of fish during cold chain using RFID loggers (Tingman et al., 2010). The benefits of using RFID in the fish supply chain were also recognised in the Scandinavian fishing industry, with the main objective of developing and evaluating a traceability system (Thakur, 2011). With regards to WSN systems, Lin et al. (2011) proposed a WSN-based traceability system for aquaculture that can automate many monitoring tasks and improve the information flow.

All these studies conclude that the introduction of RFID in the food traceability is beneficial for improving management of perishable products by tracking quality problems, improving management recalls, improving visibility of products and processes, automate scanning, reduce labour, enhance stock management and reduce operational costs (Sarac et al., 2010; Regattieri et al., 2007; Michael and Mccathie, 2005). Some studies have also highlighted drawbacks, mainly caused by the high cost of the technology, the reluctance of the companies to invest in its implementation and the immaturity of the technology (Huber et al., 2007).

In the above context, the paper presents a novel system based on the EPCglobal Architecture (EPCglobal, 2013) and developed under the framework "RFID from Farm to Fork" (RFID-F2F, 2012), to improve traceability in the aquaculture sector. For the first time, the system integrates different technologies and standards to efficiently combine traceability data in the form of events, with WSN data for monitoring the environment. An innovative architecture based on web services is deployed to collate traceability information with relevant environmental information captured with the WSN infrastructure deployed. Furthermore, the paper presents the results and evaluation of the system in two different pilots featuring RFID and WSN technologies in aquaculture companies in Slovenia and Spain.

The paper is structured as follows: Section 2 first presents the proposed traceability architecture, the methodology used to implement and deploy the pilots, and finally, the proposed evaluation methods used in the analysis of results. In Section 3, the results of the tests performed in the pilots and the evaluation of the improvements and benefits through the definition of key objectives and KPIs are discussed and finally, Section 4 concludes the work.

2. Materials and methods

2.1. Architecture of the traceability system

The new traceability system is based on the EPCglobal Architecture Framework allowing to exploit data derived from the use of Electronic Product Codes (EPC) and RFID technologies within business processes (EPCglobal, 2013). To achieve this, RFID and WSN technologies are in use in all stages, starting from fish farms up to the delivery to the retail.

The novel architecture is divided into four main components as shown in Fig. 1. The first component comprises of RFID Readers, Sensors and Data Input devices to implement traceability operations in the supply chain. In general, this includes fixed or handheld RFID readers, antennas, tags and barcode readers. To control environmental conditions, sensors include different WSN components and RFID data loggers collecting relevant parameters such as temperature in the processing environment, during transport or warehousing (Abad et al., 2009; Jedermann et al., 2009, Lin et al., 2011, Wang et al., 2006; Zhang and Wang, 2006).

The second component is the set of capture and query applications that act as a connector to the traceability repository of the physical data received from the hardware devices and, at the same time, they allow external software to perform queries.

The third component is the traceability repository which is used to store the relevant traceability data generated during the company operations. This is composed of an EPC Information Service (EPCIS) compliant repository, running on the Fosstrak Open Source RFID Platform (Fosstrak, 2012), and a Sensor Database to store the sensor data. The traceability system collects a large number of data along the supply chain and stores it in the form of events in the EPCIS repository (EPCIS Standard, 2007). In addition, various sensors measure the supply chain conditions and store the data in the Sensor Database. In order to relate traceable units with their monitoring sensors or RFID data loggers, each EPCIS event is linked to the information stored in the Sensor Database using the timestamp and the unique identification (ID) of the sensor.

The fourth component is the set of web services which provide the product information to the customer through a web browser or a mobile application. For this purpose, we chose a RESTful web service architecture to implement the system, allowing to integrate traceability information with the information gathered by the wireless sensor network (Sandoval, 2009).

2.2. Methodology for pilot implementation

The aquaculture industry represents a food sector with specific characteristics and requirements in the supply chain due to the importance of freshness and quality of products. The development of an electronic traceability solution meant to replace paper documentation requires a complete understanding and description of existing business processes. Many well established methods were already described in research papers presenting pilot implementations of traceability systems (Karlsen et al., 2011; Costa et al., 2013a). In this context, we propose a new traceability architecture for the aquaculture sector whose performance has been assessed by the deployment of pilots in two SMEs in Spain and Slovenia. The pilots have been implemented following the methodology proposed in Karlsen et al. (2011) that is divided into four stages: *Mapping, Planning, Implementation and Analysis.*