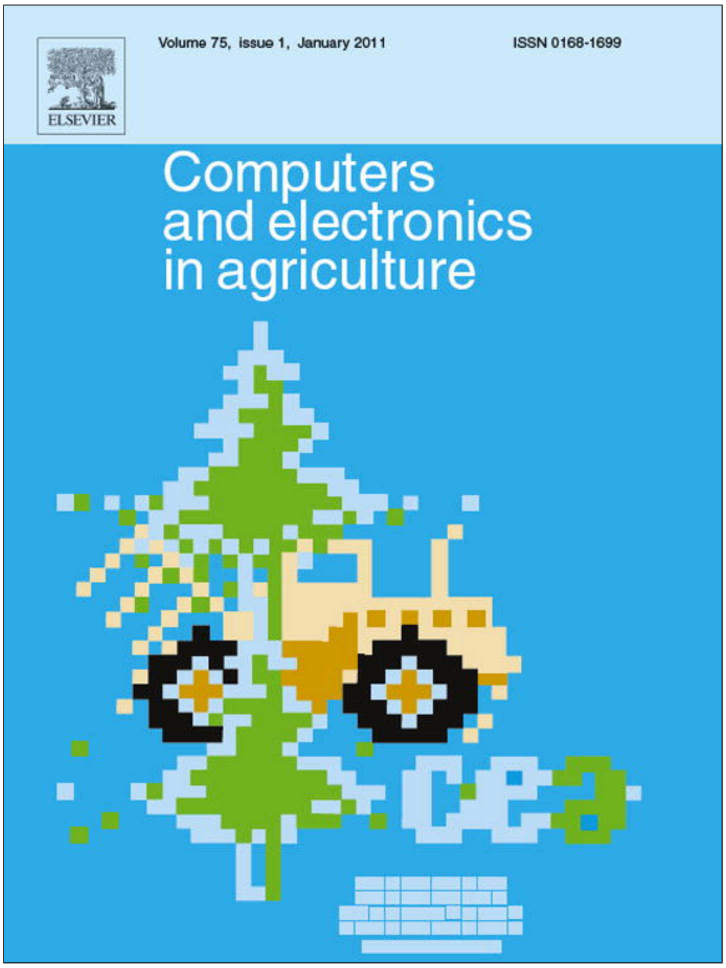
Volume 75, issue 1, January 2011
ISSN 0168-1699
ELSEVIER
Computers
and electronics
in agriculture

Computers and Electronics in Agriculture 80 (2012) 31–40

Contents lists available at SciVerse ScienceDirect

Computers and Electronics in Agriculture

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

Telematic platform for integral management of agricultural/perishable goods in terrestrial logistics

José Santa *, Miguel A. Zamora-Izquierdo, Antonio J. Jara, Antonio F. Gómez-Skarmeta

Department of Information and Communication Engineering, Computer Science Faulty, University of Murcia, 30100 Murcia, Spain

A R T I C L E I N F O

Article history:
Received 29 September 2010
Received in revised form 5 October 2011
Accepted 16 October 2011

Keywords:
Freight monitoring
Vehicle tracking
Vehicle telematics
RFID
ZigBee
Logistics

A B S T R A C T

At the same time as the Global Positioning System (GPS) has been applied to vehicle tracking and fleet management, other Information and Communication Technologies (ICTs) have also been proposed to improve supply chain efficiency. Among them, Radio Frequency Identification (RFID), and more recently wireless sensors, both currently dominate the research literature. However, many of these proposals lack realistic architecture, system integration in the supply chain, flexibility and cost-efficiency. In addition, several important research gaps need to be filled, such as driver identification, automatic management of journey schedule and security issues involved in wireless communications while collecting data. This paper copes with these issues by: proposing a telematic platform of an integral nature, enhancing tracking and tracing capabilities for vehicles and goods, giving a secure solution to the problem of installing wireless processing units in truck trailers and cabs, identifying drivers and journey itineraries, and assuring freight environmental parameters during the journey. Hardware and software prototypes have been successfully developed and tested in real vehicle case studies, including the transportation of agricultural products in the southeast of Spain.

1. Introduction

The vehicle comprises a recent ambit where new Information and Communication Technologies (ICTs) have been applied in the recent years (Giannopoulos, 2004). The combination of telecommunications and informatics, also known as "telematics", is of key importance for future vehicles. The research in this area is commonly included in the Intelligent Transport System (ITS) field.

One of the prime ICT-based applications in the transportation field during the last years has been the automation of the supply chain (Giannopoulos, 2004). Many commercial products and ad-hoc solutions have been developed for improving fleet management in logistics companies. These systems are mainly based on two technologies: GPS (Global Positioning System) and GSM (Global System for Mobile Communications). However, due to maturity of navigation and cellular communication technologies, tracking-only solutions for terrestrial vehicles are limited in the current research literature about location-based services (Sadoun and Al-Bayari, 2007). Instead, some works provide studies about the applicability of different technological alternatives in this field and analyze the real or expected impact to the supply chain. In Wang and Potter (2007), for instance, the authors present a tracking system for trucks, integrating GPS for vehicle location and GPRS (General Packet Radio Service) to send this information to a management center. Initial measurements about the impact reveal that the delivery ratio of goods and the number of vehicles in use slightly increase.

As a next step in the previous frame, ICT advances are extended to improve the management and monitoring of not only vehicles, but also products. The research world in ITS, electronics and food technologies has worked on the integration of technologies to improve freight tracking and monitoring during the past years. The interest in Radio-Frequency Identification (RFID) for detecting the presence of tagged goods is evident in current research literature these days (Michael and McCathie, 2005). In Tesoriero et al. (2009), an indoor tracking system is presented which reports a direct application of RFID on warehouses. This case study is followed in Ngai et al. (2007), with a decision support system to manage containers in a depot. However, when both tracking and tracing capabilities are needed during transport, RFID alone is not a cost-effective solution due to the necessity of deploying an expensive infrastructure of readers (Wang and Potter, 2007). This problem is also noticeable in the system presented in Siror et al. (2009). Here, a tracing system for reducing smuggling problems in Kenya has been implemented. Vehicles and freight are RFID-tagged, and readers are installed at transit points, such as ports or borders. In general, tracing resolution is directly proportional to the reader infrastructure deployed, which is expensive and does not support

* Corresponding author. Tel.: +34 868 888771; fax: +34 868 884151.
E-mail addresses: josesanta@um.es (J. Santa), mzamora@um.es (M.A. Zamora-Izquierdo), jara@um.es (A.J. Jara), skarmeta@um.es (A.F. Gómez-Skarmeta).

0168-1699/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.compag.2011.10.010

high (or even normal) traffic speeds when detecting tags. In Lefebvre et al. (2006) deployment costs of a similar solution are reduced, since RFID readers are installed only at warehouse entrances. However, this strategy diminishes the system functionality.

Moreover, many approaches which also monitor the product status by means of sensor systems can be found in the literature. These systems should take into account three key challenges for managing goods (Ruiz-Garcia et al., 2007): Tracking, Tracing and Monitoring (TTM). The most extended one, tracking, focuses on the ability to locate vehicles and freight at any time. Tracing allows both logistics companies and final consumers to know product movements from source to end users. Finally, the most recent challenge is monitoring, which enables logistics companies to assure product quality during transportation. The integral TTM approach has been especially relevant for perishable and agricultural goods, as can be seen in the proposals presented in Jedermann and Lang (2007) and Jedermann et al. (2009). The first proposal describes a monitoring system based on wireless sensors deployed in a truck trailer, and the second one proposes a temperature monitoring platform based on active RFID sensors. Among the different sensors that could be installed in the trailer, that study pays special attention to temperature, since it determines the quality of perishable and agricultural goods. These sensors can be wired with a processing unit or connected through a wireless link (Shan et al., 2004; Wang et al., 2006), by means of ZigBee, an implementation of the IEEE 802.15.4 standard, or Bluetooth, which also provides a short-range data communication channel but less suited for sensor environments.

Although one can notice that there are solutions to help automate TTM tasks in the supply chain, with some of them commercially available (although mainly centered on the tracking part), we find several drawbacks and gaps in the field:

- Flexibility of solutions from the architecture point of view. Moreover, open platforms that comply with current normalizations and standards are necessary to make interconnecting and updating tasks easier.
- Security issues, since short-range communications applied in transportation require specific authentication and privacy measures.
- Driver identification and profiling are not considered in many designs, and this could be used, for instance, to enable different drivers to share a truck and avoid vehicle thefts (García et al., 2009).
- Real-time freight tracking based on radio-frequency identification of products. This tracking is usually done only at warehouses and checkpoints, decreasing the confidence on freight TTM information during the whole travel.
- Real-time freight monitoring. European traceability normatives (EC/178/2002, 2002; COM(1999)719, 2000; Coff et al., 2000) must be considered to ensure the quality of products such as medicine, perishable and agricultural goods.
- Management of freight and trailer configuration. The driver usually checks the freight and loads/unloads manually.

The above issues are considered in this paper by presenting a platform that gives an integral TTM solution with novel advances while also considering previous achievements in the area, such as vehicle tracking or freight identification. The system collects identification and sensory data from the freight and vehicle, and processes this information at three levels: trailer, truck and core infrastructure. A ZigBee link connects an On-Board Unit, which is integrated into the truck cabin, with an interchangeable trailer. The trailer hosts a Wireless Sensor Network (WSN) to monitor freight status. The system also proposes two RFID solutions to, on the one hand, detect changes in the load by means of RFID-UHF and, on the other hand, identify drivers, save trailer's WSN configuration, and maintain the delivery schedule and desired environmental requirements during transport, by means of RFID-HF. As a result, goods can be tracked, traced, and monitored from the source (garden market, slaughterhouse, winery, etc.) to the sending point.

The rest of the paper is organized as follows: Section 2 begins with an overall description of the proposed platform. Next, Sections 3–5 detail the most interesting parts of the architecture, while at the same time introducing the developed prototype. Section 6 details two application examples of the system and, finally, Section 7 ends the paper with some concluding remarks and future lines. Additionally, a list of important abbreviations used in the paper has been included in Table 1 for efficient referencing

2. Overall architecture

The general architecture of the platform is presented in Fig. 1. Three main components can be identified: On-Board Unit (OBU), Trailer Control Unit (TCU) and Distributed Collection Logic. TCU collects monitoring information from trailer/container sensors and freight entrance/exit notifications from the RFID-UHF reader. Some sensors can be wired with TCU, while others can be part of a Wireless Sensor Network inside the trailer. Additionally, monitoring cards with sensors and communication capabilities can be inserted in product boxes or pallets. In Fig. 1, temperature, humidity and light sensors are shown for both wired and wireless cases, while the door-opening sensor has been affixed and wired in the trailer. This is used for detecting when the trailer door is opened, in order to switch on the RFID-UHF reader.

A number of sensors can be added to the trailer and some others attached to the freight by means of the WSN. All data collected by TCU is filtered and stored in a temporal buffer, since spurious and repeating reads can be obtained. This process comprises the *first processing stage* of the system.

OBU is the most intelligent component of the vehicle on-board equipment. It receives freight information from TCU and data from on-board sensors and the on-board RFID-HF solution. The link with the trailer uses a query protocol that works over ZigBee. The

Table 1
Main abbreviations.

3DES	Triple data encryption algorithm
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
AES	Advanced Encryption Standard
ERI	Electronic Registration Identification
CAN	Controller Area Network
CRC	Cyclic Redundancy Check
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HF	High Frequency
ICT	Information and Communication Technology
IP	Internet Protocol
ITS	Intelligent Transport System
JNLP	Java Network Launching Protocol
M2M	Machine-to-Machine
NFC	Near Field Communication
OBD(-II)	On-Board Diagnostics (second version)
RFID	Radio Frequency Identification
SMS	Short Message Service
SSL	Secure Sockets Layer
TTM	Tracking, Tracing and Monitoring
UDP	User Datagram Protocol
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
WSN	Wireless Sensor Network

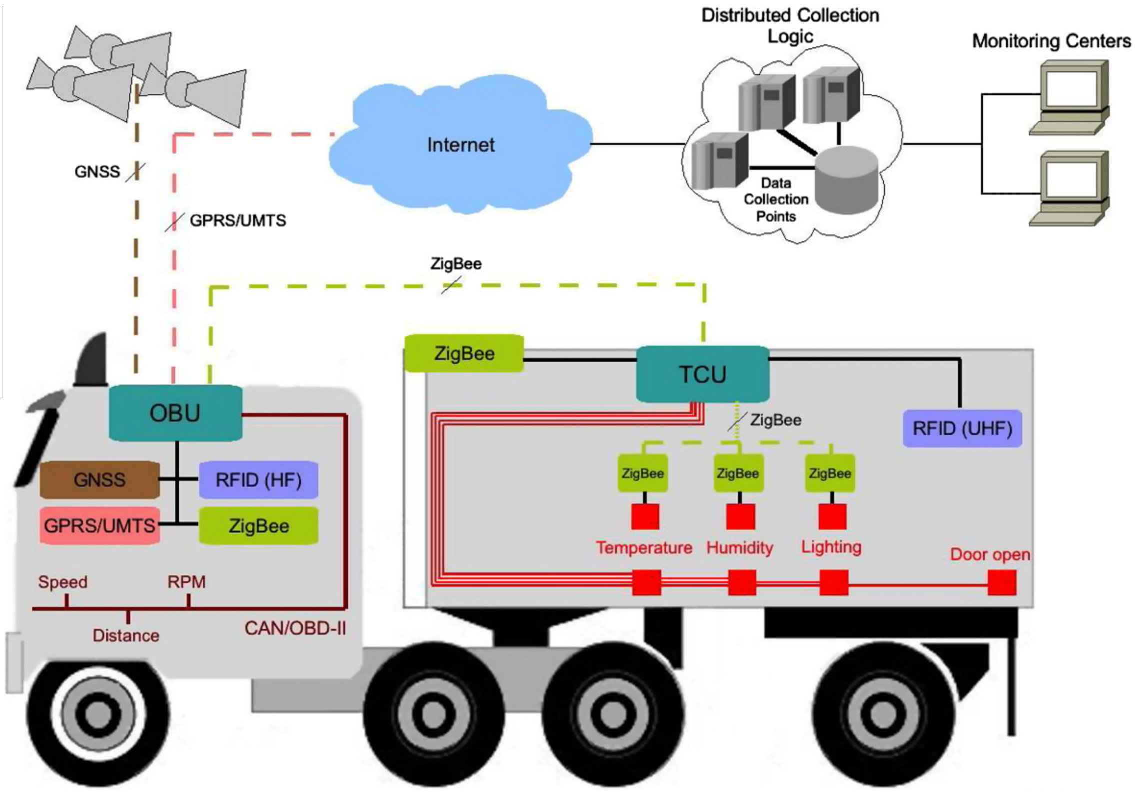

Fig. 1. Architecture of the telematic TTM platform. On-Board Unit (OBU), Trailer Control Unit (TCU) and Distributed Collection Logic are the main modules of the system. Wired links are drawn with continuous lines, while wireless links are drawn with dotted lines.

RFID-HF reader of the cab is also compliant with NFC (Near Field Communication) and it is used both to identify the driver and the trailer, and to configure freight requirements (humidity, temperature, light, etc.) and delivery schedule. Regarding in-cab sensors, information about vehicle location is collected from a GPS-based navigation system, and the odometer of the vehicle is accessed by means of an OBD (On-Board Diagnostics) interface. All the TTM data collected from on-board sensors and TCU are useful in tracing the vehicle and freight conditions during transport. These collecting and processing tasks carried out by OBU comprise the *second processing stage*.

Information generated by the vehicle is then sent to the Distributed Collection Logic. A reliable data collection system is accessed by means of GPRS or UMTS (Universal Mobile Telecommunications System – 3G). When there is no GPRS/UMTS coverage, the system caches all information to be sent, until a data link is available. Moreover, a pool of Data Collection Points exists, as is illustrated in Fig. 1, and each OBU can alternate among these depending on the observed performance. All of these collection points can be distributed in the Internet and they share a synchronized database, which stores logs about each journey. Finally, a set of Monitoring Centers accesses this data to present a friendly human-machine interface to operators and users. All the tasks carried out at the core infrastructure, including data filtering processes, comprise the *third processing stage*.

The next sections give more details about the architecture and operation of the most important parts, describing in parallel the developed prototype.

3. Truck On-Board Unit

An embedded OBU prototype has been designed with the capabilities described above. This can be seen in Fig. 2, jointly with the different antennas used. In the photo the OBU board is provided with a backup battery. Additionally, an intelligent power-aware mechanism has been developed in order to avoid wasting energy when the truck is not moving or if there is no new data from on-board sensors or TCU. Movement information is obtained from the odometer or motion sensor, to detect whether the vehicle has stopped.

Fig. 2. OBU prototype. An independent battery, and the RFID-HF (square), GPS/GPRS (round) and ZigBee antennas are also shown. The last one is directly connected to the ZigBee transceiver.

A low-cost 16-bit processor controls the OBU board. This offers a cost-effective and reliable solution. Apart from an internal and limited memory, an external memory is used to cache the status of the truck (GPS coordinates, goods, freight status, driver identifier, etc), since the power could eventually be disrupted or the GPRS/UMTS link might not be available for some time. Additionally, the microcontroller's firmware can be remotely updated through the GPRS/UMTS link. This functionality has been implemented in a special OBU service.

The data flow among the various modules integrated in the vehicle and the internal software processes carried out in OBU are depicted in Fig. 3. The next subsections detail this logic.

3.1. Navigation system

A low-cost navigation system has been integrated in the OBU prototype by means of an NMEA 0183-compliant GPS device. In case higher positioning necessities are needed (e.g. when transporting dangerous or expensive goods), a more powerful navigation solution can be used. A hybrid navigation system has been designed to provide location information even under periods of GNSS signal obstruction. This navigation system, which is also illustrated in Fig. 3, integrates information from the GPS receiver, odometer, and inertial sensors (gyroscope and accelerometer), by means of an Extended Kalman Filter. Further information about this navigation unit can be found in Toledo-Moreo et al. (2007).

3.2. RFID/NFC-based driver authentication and extra management features

As can be observed in Fig. 3, the RFID-HF/NFC module is used to authenticate the driver and the trailer while also to configure freight transportation requirements and maintain the delivery schedule. This hardware is plugged into the OBU board, precisely where the RFID antenna is connected, as can be seen in Fig. 2. It works at 13.56 MHz (HF range) and, according to performed tests, it detects tags up to five centimeters away from the antenna. This reader is compatible with NFC tags, which are increasingly being integrated in mobile phones and identification cards. In this way, the driver could be identified without the need of an extra tag.

Fig. 4 presents the information stored in the RFID-HF card. The card structure has been defined using techniques for reducing access latency, optimizing capacity, and guaranteeing integrity, as described in a previous work (Jara et al., 2010). This scheme includes: driver identification details, vehicle information based on the schemes defined for ERI (Electronic Registration Identification) in the ISO standard 24534 (Segura et al., 2008), WSN parameters to set up the communication and pairing between OBU (cabin) and

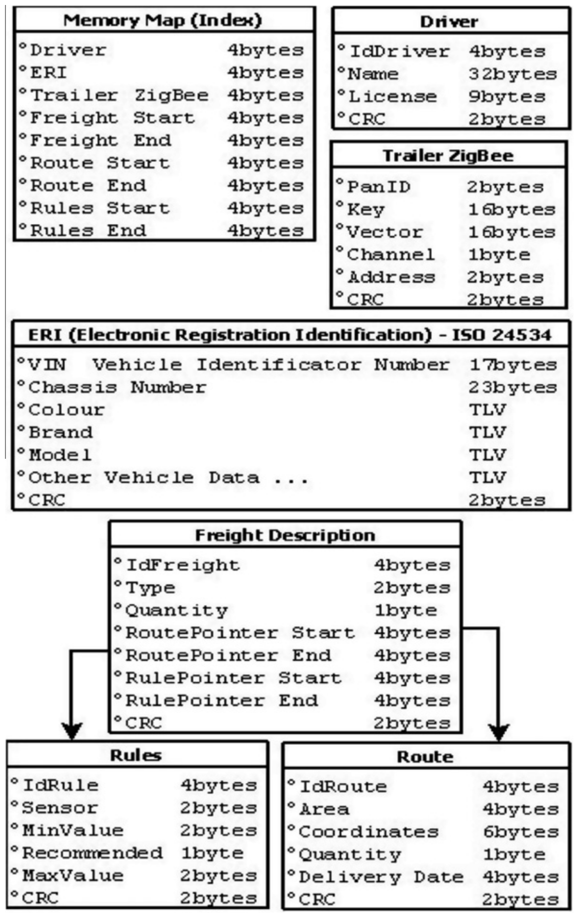

Fig. 4. Data structure of the driver RFID-HF card for system starting and management.

TCU (trailer) through the ZigBee link, and finally, the freight details and desired transportation conditions, jointly with the expected delivery schedule. In this way, the freight description is linked to its route and a set of rules to ensure optimal conditions for the freight during the journey. These are mainly oriented to special goods, such as agricultural/perishable products or drugs. Therefore it is possible to check that light, humidity and temperature are within safety limits (EC/178/2002, 2002; COM(1999)719, 2000; Coff et al., 2000). On the other hand, routes allow for the detection

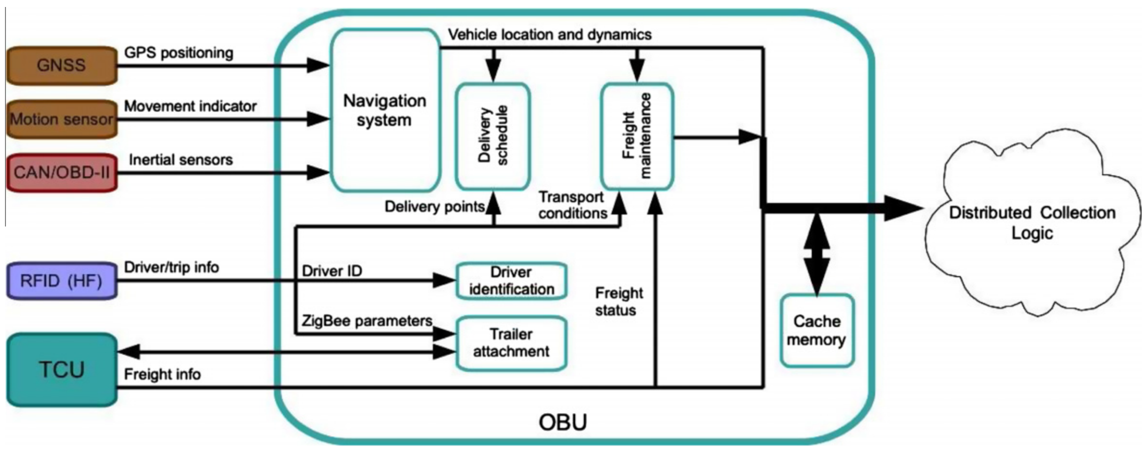

Fig. 3. Data flow in On-Board Unit (second processing stage).

of delivery mistakes by checking that the freight inventory follows the expected delivery schedule.

3.3. Wide-area communications

The GPRS transceiver is plugged into the OBU board, next to the connection of the GPS/GPRS antenna, as can be seen in Fig. 2. It is used together with an IP/UDP communication stack provided as a software library. On the basis of this stack, a specific high-level protocol (UDP-based) between OBU and Data Collection Points has been developed: the Superior Home Automation Protocol (SHAP) (Zamora-Izquierdo et al., 2010), which was initially conceived for domotics solutions. This is also used to remotely update the microcontroller's firmware.

3.4. ZigBee module

A ZigBee transceiver has been added to the OBU board to communicate with the trailer equipment. This module supports a family of antennas, such as integrated ceramic antennas, which are used in sensor boards, but an external antenna is used in this case, together with a high power amplifier for assuring the TCU-OBU communication. This module can be seen in Fig. 2, just over the RFID-HF module, plugged into the left most part of the OBU board.

4. Trailer Control Unit

The base architecture of the TCU board is the same as the OBU one, but some elements have not been included. The RFID-HF module, the GPS receiver and the GPRS transceiver are not integrated in order to reduce costs, since they are not used in the trailer. The same ZigBee module that is used in OBU has been integrated in TCU.

Data exchanges among trailer sensors and TCU can be shown in Fig. 5, together with the main software modules of TCU. Apart from collecting sensor data, TCU is in charge of managing the RFID-UHF reader and the WSN, since the ZigBee module included in the trailer acts as the controller of the network. The following subsections give more details about these data flows.

4.1. Detecting RFID-tagged goods

An external RFID-UHF reader is connected through a serial RS-232 interface with TCU, although it is also feasible to establish this link via a wireless interface, by means of the WSN. This module works within the frequency range of 865–960 MHz (UHF) and is able to detect tags at distances of up to 10 m, according to performed tests. Moreover, it is compatible with EPC Global and ISO/IEC 18000-6; thus a wide range of tags can be detected.

The RFID-UHF installation in the trailer is based on a rack of antennas installed around the loading door, which are connected to the RFID reader. This set-up improves the ratio of detected tags when the freight blocks the RFID signal. Fig. 6 shows the reader and the antenna rack mounted in a testing gantry. This set-up has been used to measure the performance of the system in laboratory.

4.2. Freight monitoring

TCU collects the environmental data from the sensors directly wired with the TCU or the sensors connected to ZigBee, as is depicted in Fig. 5. These sensors are deployed in the trailer with the freight, integrated in small boards that include a ZigBee transceiver, as can be seen in Fig. 7. The current implementation of these sensor boards contains humidity, temperature and light sensors.

Fig. 7 also shows the deployment of these sensors in the various supply chain stages, from the market garden to the final distribution point. It is also important to note that current algorithms at TCU specifically send information under significant environmental changes, although periodical messages are sent at predefined times (between 1 and 5 min).

4.3. Cab-trailer attachment and communication

Since the communication between cab and trailer is performed by means of a wireless link, communication conflicts could appear at places where several trucks are present, such as warehouses or transit points. Under these conditions, OBU might not be able to determine the correct TCU, which acts as the ZigBee coordinator to establish the communication link. This problem has been solved by means of an initial attachment process. The RFID-HF/NFC card model presented in Section 3.2 is used to both identify the trailer and save the ZigBee network configuration details, such as the network identifier, the cipher key and the communication channel. At the beginning of the journey, the driver takes the preconfigured RFID/NFC card and brings it near the OBU RFID-HF antenna placement to perform the attachment. As a result, a security wireless link is established by means of the AES (Advanced Encryption Standard) algorithm.

5. Distributed data collection

The Distributed Data Collection Logic comprises a key part of the TTM telematic platform. It collects freight data, sensor measurements and driver information from vehicles in a reliable

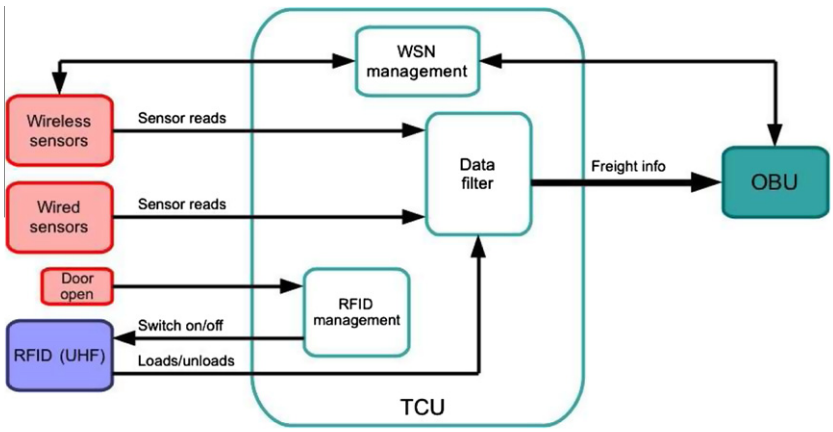

Fig. 5. Data flow in Trailer Control Unit (first processing stage).

Fig. 6. RFID-UHF reader and antenna rack of the trailer, mounted for testing purposes in laboratory.

Fig. 7. Integration of the ZigBee RFD node (marked in red), with humidity, temperature and light sensors in three supply chain stages. Left: sensors attached to the artichokes immediately after being harvested from the market garden. Middle: sensors affixed to a pallet of tinned peaches. Right: sensors affixed to a pallet of pepper jars. (For interpretation of reference to colors in this figure legend, the reader is referred to the web version of this article.)

way, and provides processed information to Monitoring Centers. Its architecture is shown in Fig. 8. As can be seen, data from vehicles is collected by a set of Data Collection Points (DCPs) by means of the SHAP protocol. Vehicles choose one of these DCPs according to the observed performance and an initial priority list. All data collected by DCPs is then sent to Data Base Proxies, in charge of turning OBU measurements into data records. Several Data Base Proxies provide reliability to the system for accessing the database. Finally, an intermediate stage for providing a buffered and synchronized access to the database is provided by DB Writer. All this information flow provides a fault-tolerant design against eventual problems in the different modules.

As can be seen in Fig. 8, two management modules have been included in the data collection system: OBU Manager and System Manager. OBU Manager is used to keep track of all vehicle connections, and it enables administrators to remotely upgrade the OBU firmware. System Manager is an always-on service that monitors the operation of all modules. It periodically reads status information of all modules (DCPs, DB Proxies, etc.) from the database, since each new record also includes status stamps of each system module.

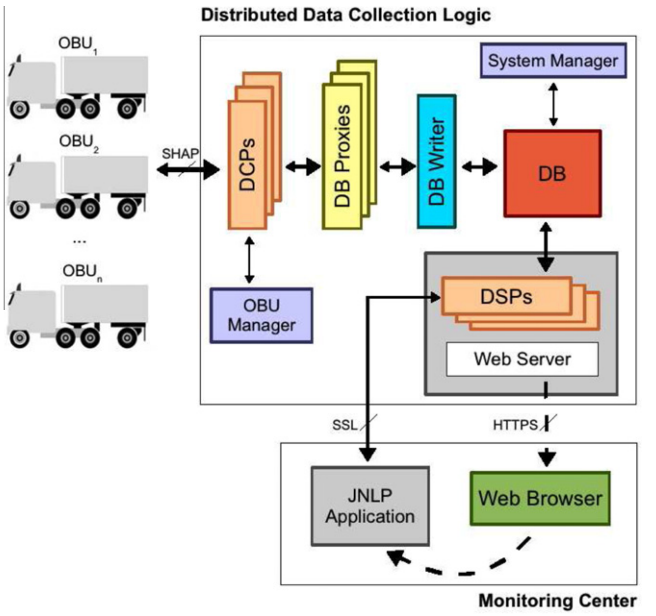

Fig. 8. Architecture of the Distributed Data Collection Logic. Data is collected from vehicles through Data Collection Points (DCPs), and TTM information is accessed by means of Data Server Points (DSPs).

All collected TTM information is finally provided to users at Monitoring Centers. This is also illustrated in Fig. 8. By means of a PC platform, operators use a common Web Browser to access a URL of the system. After the user is authenticated, a secure HTTPS link is established. At this moment, a JNLP (Java Networking Launching Protocol) application is automatically downloaded. This software operates at the client side, and provides a graphical front-end to access TTM information of all tracked vehicles and freight. A screenshot of this application, used in the two study cases included in Section 6, is shown in Fig. 9. This software enables operators to identify trucks and drivers, be aware of the vehicle status (speed, engine temperature, accelerations, etc.), monitor the status of the freight (loaded goods, temperature, lighting or humidity), track the vehicle path and stops and search for data of past journeys. Moreover, as can be seen in the lower part of the application window, the operator is informed about sensor measurements which fall out of specified bounds; for example, when the trailer temperature, humidity or lighting is too high for the transported freight or when the engine temperature is above threshold.

All TTM information is available for the JNLP application by means of an SSL (Secure Socket Layer) link with a Data Server Point, which access the database. This feature also improves system reliability when TTM information is accessed. Moreover, the JNLP technology offers flexibility to the system, since monitoring centers dynamically download the Java (platform-independent) application from a Web server, but only when it is accessed for the first time or a newer version is available at the server.

6. Application examples

The platform described in previous sections has been installed and tested in a transportation company truck and a fleet of University of Murcia vehicles.

6.1. Prototype truck

The system installation in the real truck is illustrated in Fig. 10. An IVECO Stralis AS Super3 truck has been used to install all trailer

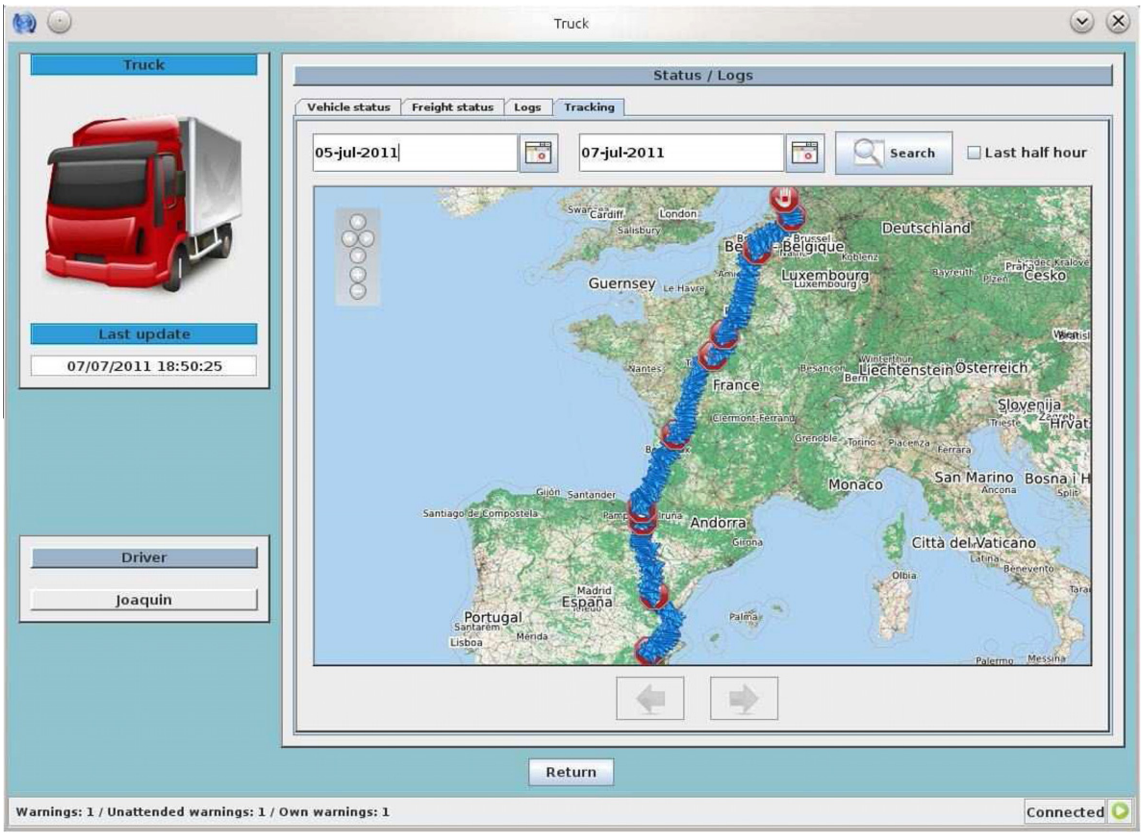

Fig. 9. Screenshot of the application used at the monitoring center. The operator can track both vehicle and freight status in realtime during the trip and access historical data of ongoing or past trips.

and cabin elements of the TTM architecture. As can be seen, the OBU has been integrated into the lower part of the dashboard, connected to the electrical system of the truck. The RFID-HF antenna has been installed in the same place, while the GPS/GPRS-UMTS antenna has been affixed on the dashboard near the windshield. Since a small speaker has been integrated in the OBU board, a short beep is emitted when the driver is correctly identified and the OBU-TCU link has been established.

Regarding the trailer RFID-UHF system, it has been installed near the rear door, as can be seen in Fig. 10. The rack of antennas has been placed around this door, and they are connected to the reader. Finally, the reader is connected to the TCU, which has also been affixed to the trailer wall. The TCU has additionally been provided with a small LCD to facilitate debugging tasks by means of text messages during operation. It has been proved that goods are correctly detected by testing the trailer with various types of packages and RFID tags during loading trials. The ZigBee communication link has also been widely tested to assure that messages sent by TCU are correctly received by OBU, even though electromagnetic noise is generated by the cooling unit of the trailer.

Fig. 10. Integration of the system prototype in a truck. On the left the cabin elements are seen as integrated into the truck dashboard: the GPS/GPRS antenna (up) and OBU (down). On the right the deployment in the trailer. The RFID antennas have been installed around the rear door, near the RFID-UHF reader and the TCU.

The core infrastructure of the TTM platform has also been installed in a publicly accessible server to receive data logs from the truck. At the moment, the Distributed Data Collection Logic set-up considers three DCPs, two DB Proxies, and two DSP, since usually only one operator is connected to the system. The same core infrastructure is used in the deployment scenario described in the next section.

This setup, with the equipped truck prototype, the core infrastructure and the client application presented in the previous section, has been tested in a real working trip. The equipped truck was used to transport juice from citric fruits from the southeast of Spain to The Netherlands. The TCU showed in Fig. 10 was covered with a transparent watertight box to protect electronics, and two external temperature and humidity sensors were wired to the TCU. The light sensor is integrated in the TCU, and it is the same that is used in the ZigBee nodes that can be affixed to the freight. The TTM platform was used to trace and monitor the status of both the vehicle and the freight during the travel. The screenshot provided from the monitoring application in Fig. 9 shows the path followed by the truck, from Archena (Murcia, Spain) to Delft (South Holland, The Netherlands). This software has also been used to obtain a log of the trailer sensor measurements during the travel. These values are plotted in the charts given in Fig. 11. As can be seen in the results, most important changes in measurements are obtained at the beginning and the end of the trip. At the beginning of the journey the trailer had been just loaded and the cooler started, provoking the temperature to fall. Since relative humidity is highly dependent on the temperature, it also rises as temperature falls. The cooler was kept on during the two and a half days of the trip, as can been seen in the results. Finally, when the freight is unloaded, the cooler is switched off and the temperature rises to the external local environment temperature. A difference of almost 10 °C is observable between the departure and arrival locations. Observing the temperature and humidity results, it can be noticed when the cooler corrects the temperature and the direct impact on relative humidity.

The cooler was supposed to maintain temperature around 2 °C, with a maximum variation of 2 °C; however, as can be seen in the results, the system logged temperature measurements between 5 °C and 10 °C during the trip, with high variations (for instance, between 40.000 and 80.000 s). The transportation company was informed of this cooler malfunction by a system warning, but the juice was eventually transported. Since the product was bottled, there were no humidity limitations and a temperature below 10 °C was acceptable for the freight. An adjustment problem in the cooler was repaired when the truck returned to Spain. As can be seen in the histogram plots, most of the temperature and humidity measurements are maintained within ranges of 5–10 °C and 50–75%, respectively. Temperature values higher than 20 °C and humidity measurements below 40% are due to loading/unloading. These periods are also noticeable in lighting results, since rear doors were opened at these moments. Some intermediate values between dark (doors closed) and bright (doors opened) results are obtained, between 200 and 300 lumens. These values were obtained while the two doors of the trailer were being opened or closed.

6.2. Deployment of the platform for fleet management

A fleet of 48 vehicles at the University of Murcia currently uses the TTM platform presented above, in the frame of the SATELITES research project. Currently, this deployment is considered to test the scalability of the solution over a fleet of vehicles in terms of tracking and tracing capabilities. Internal staff of the university can book these cars by means of a reservation process in a Web application. Before using the TTM system, the university did not have any information about the usage of the vehicles during the time the cars were not in the garage. This could have led to driving outside of the authorized area, traveling excessive distances, or aggressive use of the car.

The OBU set-up in the vehicle fleet can be seen in Fig. 12. Here, the OBU integration is detailed in one of the vehicles, although it is equivalent to the truck case. The car is a Seat Ibiza with a hybrid gas/gasoline engine, which reduces pollution. The OBU board has been installed in the glove compartment, taking advantage of an unused space on the left part, hidden by the plastic case. The power source has been taken from the electrical system of the car. As can be seen, the GPS/GPRS-UMTS antenna has been placed over the dashboard, in front of the passenger seat, in order to improve the signal quality. The RFID-HF antenna has been placed under the steering wheel, thus the driver can easily authenticate when the car has started. An optional OBD-II reader has been considered in the solution, as can be seen in the lower right corner of Fig. 12, to read monitoring information of the vehicle. From this module the OBU obtains information from the tachograph, such as speed, traveled kilometers or revolutions per minute.

During the year that the system has been running, some technical modifications have been applied. For example, in order to

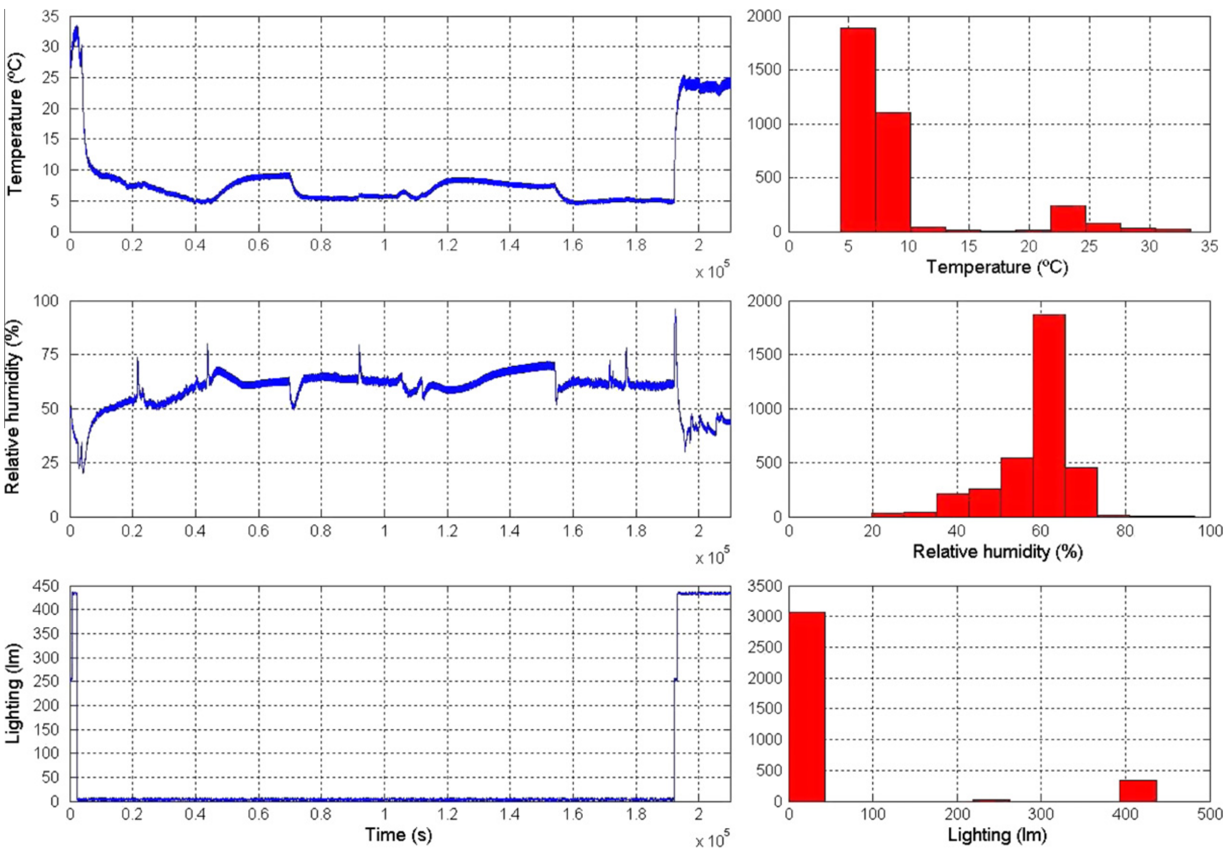

Fig. 11. Freight monitoring results obtained while transporting juice from Spain to The Netherlands. Most relevant variations are due to the loading/unloading periods, but temperature corrections of the cooler also imply noticeable changes in both temperature and humidity values.

Fig. 12. Integration of the system in a real vehicle fleet. The emphasized elements are listed in clockwise order: the GPS/GPRS-UMTS and RFID-HF antennas, the OBD-II reader, and the OBU module.

reduce the GPRS/UMTS bill and power consumption, the modem is turned off when there is no GSM coverage or if the vehicle is stopped. This avoids continuous communication attempts when the network availability conditions do not change. The motion sensor included in the general architecture has been installed in the vehicles for this purpose. Moreover, a filtering process detects when the vehicle is moving at low speed, to reduce the amount of interesting positions to be sent to the infrastructure. This improvement is especially noticeable in cars which are driven in urban environments or those used for loading/unloading tasks. Additionally, an OBU communication manager has been developed to decrease GPRS/UMTS traffic, for example, by sending positions only when a complete packet can be filled. Regarding the core infrastructure (which can be better tested in this case of study rather than the truck example), we have checked that only one of the replicated modules has been used (one DCP and one DB Proxy) during the last months; hence, this configuration currently offers more than enough performance for the vehicle fleet.

7. Conclusions

The paper shows how Information and Communication Technologies, jointly with integration of electronics in vehicles, can be used for improving logistics tasks in the supply chain, in terms of efficiency, management and assurance of product quality. The platform presented comprises a secure and flexible platform for Tracking, Tracing and Monitoring vehicles and goods in terrestrial transportation. Three main data collecting and processing stages have been identified at three subsystems: Trailer Control Unit, On-Board Unit and infrastructure. An attachment strategy decouples the OBU and trailer parts of the system, saving costs in a complete monitoring solution and solving the problem of trailer exchange. Moreover, RFID-UHF has been used to detect/identify goods, and new RFID-HF/NFC advances have been carried out to authenticate drivers, attach trailers with truck cabs, manage unloading points, and adequate trailer environmental parameters.

A complete prototype of the platform has been developed and tested in our laboratory. The application of the system in the agricultural field has been demonstrated through several applications of our monitoring prototypes in south-eastern Spain's vegetable industry. A real set-up of the system in a truck has been completed and tested in real working journeys. Moreover, a deployment of the platform for fleet management purposes is currently in use to track and monitor vehicles lent to university staff.

One of our next steps is oriented to extending the architecture towards Internet of Things. For that purpose, connectivity and identification capacities, based on ZigBee and RFID/NFC, are being extended with 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks), which is envisioned to replace ZigBee in the area. Consequently, the system is being prepared to support end-to-end communication between the monitoring center and on-board sensors, and then providing an M2M (machine to machine) support with the rest of external systems. This outlook is not being used in the current system deployment, since existing security capabilities of 6LoWPAN are not suitable for a real operation yet. For that reason, the system will be enhanced with further security extensions. Specifically, an asymmetric cryptographic strategy based on Elliptic Curve is being developed to secure data transfers over 6LoWPAN when communicating with sensors or the truck trailer. Moreover, a semantic layer at the Monitoring Center is envisioned for identifying driver behaviors, analyzing delivery rates and determining the quality of perishable goods.

Acknowledgments

This work has been sponsored by the European Seventh Framework Program, through the ITSSv6 Project (Contract 270519); the Ministry of Education and Science, through the SEISCIENTOS Project (TIN2008-06441-C02) and the FPU Program (Grant AP2009-3981); the Spanish Ministry of Transportation, through the SATELITES Project (FOM/2454/2007); and the Region of Murcia, through the Excellence Researching Group Program (04552/GERM/06) and the project "Modelización Hidrológica en Zonas Semiáridas" (PCTRM 07/10).

The Authors would like to thank the transportation company "Campillo Palmera" and the fruit, vegetable and canned food produce packing company "Paco Portero", for its cooperation in the development of the truck prototype and all tests carried out with its participation.

References

Coff, C., Barling, D., Korthals, M., Nielsen, T., 2000. The European Union and the Regulation of Food Traceability: From Risk Management to Informed Choice? The International Library of Environmental, Agricultural and Food Ethics, Ethical Traceability and Communicating Food, Brussels, Belgium.

COM(1999)719, 2000. White Paper on Food Safety and Sets out a Farm to Table Legislative Action Programme. Commission of the European Communities.

EC/178/2002, 2002. Regulation EC/178/2002 – General Food Law – Traceability. Commission of the European Communities.

García, L., Pinart, C., Lequerica, I., Alonso, A., Rodríguez, J., González, J.M., Quesada, D., 2009. M:VIA, smarter vehicles and roads by using new generation ITS concepts and IMS capabilities. In: 16th ITS World Congress Stockholm, Stockholm, Sweden, pp. 1–8.

Giannopoulos, G., 2004. The application of information and communication technologies in transport. European Journal of Operational Research 152, 302–320.

Jara, A., Alcolea, A., Zamora, M., Gómez-Skarmeta, A., 2010. Analysis of different techniques to define metadata structure in NFC/RFID cards to reduce access latency, optimize capacity, and guarantee integrity. In: 10th IFAC Workshop on Intelligent Manufacturing Systems, Lisbon, Portugal, pp. 1–8.

Jedermann, R., Lang, W., 2007. Semi-passive RFID and beyond: steps towards automated quality tracing in the food chain. International Journal on Radio Frequency Identification Technology and Applications 1, 247–259.

Jedermann, R., Ruiz-Garcia, L., Lang, W., 2009. Spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. Computers and Electronics in Agriculture 65, 145–154.

Lefebvre, L., Lefebvre, E., Bendavid, Y., Wamba, S., Boeck, H., 2006. RFID as an enabler of b-to-b e-commerce and its impact on business processes: a pilot study of a supply chain in the retail industry. In: 39th Hawaii International Conference on System Sciences, Hawaii, USA, pp. 1–10.

Michael, K., McCathie, L., 2005. The pros and cons of RFID in supply chain management. In: International Conference on Mobile Business (ICMB 2005), Sydney, Australia, pp. 623–629.

Ngai, E., Cheng, T., Au, S., Lay, K., 2007. Mobile commerce integrated with RFID technology in a container depot. Decision Support Systems 43, 62–76.

Ruiz-Garcia, L., Barreiro, P., Rodriguez-Bermejo, J., Robla, J., 2007. Review: monitoring the intermodal, refrigerated transport of fruit using sensor networks. Spanish Journal of Agricultural Research 5, 142–156.

Sadoun, B., Al-Bayari, O., 2007. Location based services using geographical information systems. Computer Communications 30, 3154–3160.

Segura, J., Jordan, J., Jaen, M., Soriano, F., 2008. Implementation of the ERI standard and evaluation of applications with several low-cost technologies. In: 11th International IEEE Conference on Intelligent Transportation Systems, Beijing, China, pp. 490–494.

Shan, G., Liu, Y., Prosser, G., Brown, D., 2004. Wireless intelligent sensor networks for refrigerated vehicle. In: IEEE Sixth Circuits and Systems Symposium on Emerging Technologies: Frontiers on Mobile and Wireless Communications, Shangai, China, pp. 525–528.

Siror, J., Huanye, J.K., Dong, W., Jie, W., 2009. Application of RFID technology to curb diversion of transit goods in Kenia. In: 2009 Fifth International Joint Conference on INC, IMS and IDC, Seoul, Korea, pp. 1532–1539.

Tesoriero, R., Gallud, F., Lozano, M., Penichet, V., 2009. Tracking autonomous entities using RFID technology. IEEE Transactions on Consumer Electronics 55, 650–655.

Toledo-Moreo, R., Zamora-Izquierdo, M., Úbeda Miñarro, B., Gómez-Skarmeta, A.F., 2007. High integrity IMM-EKF based road vehicle navigation with low cost GPS/SBAS/INS. IEEE Transactions on Intelligent Transportation Systems 8, 491–511.

Wang, N., Zhang, N., Wang, M., 2006. Wireless sensors in agriculture and food industry: recent development and future perspective. Computers and Electronics in Agriculture 50, 1–14.

Wang, Y., Potter, A., 2007. The application of real time tracking technologies in freight transport. In: Third International IEEE Conference on Signal-Image Technologies and Internet-Based System, Shangai, China, pp. 298–304.

Zamora-Izquierdo, M., Santa, J., Gómez-Skarmeta, A., 2010. Integral and networked home automation solution towards indoor ambient intelligence. IEEE Pervasive Computing 9, 66–77.