A Reliable ICT Solution for Organ Transport Traceability and Incidences Reporting Based on Sensor Networks and Wireless Technologies

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Abstract This paper describes an ICT solution based on an intelligent onboard system which is able to trace the organs inside a medical van during delivery routes to the hospitals, without altering the carriers daily tasks. The intelligent onboard system is able to ensure the safety of the cargo by means of a sensor network who permanently evaluates their status. The van understands its environment, including: its location, the temperature and the humidity of the transported organs; and can report incidences instantly via wireless communications to anyone interested. It is a non-intrusive solution which represents a successful experience of using smart environments in a viable way to resolve a real social and healthcare necessity.

Keywords: medical traceability, transportation of organs, incidence management, sensor networks, wireless technologies.

1. Introduction & Related Work

Traceability provides the historical location and trajectory of a product or batch of products along the supply chain. Traceability commercial systems are adapted to areas in which governments establish minimum traceability requirements: mainly food and pharmaceutical industry, or those sectors in which large industries are those than indicate the parameters that determine traceability to suit their demanding quality systems, such as electronics or automotive [1].

The importance of tracking goods has reached such a point that is being regulated by law in some countries. For example in Europe, Regulation 178/2002 requires the traceability of all food from farms to the end of the supply chain. This is one of the reasons because most of the projects about tracking are focused on the food industry, as for example the Trace FP6 project (http://www.trace.eu.org) or those ones based on RFID or ZigBee technology and described in [2] [3] [4].

There are other critical sectors as the pharmaceutical one. Thus, the PharmaX initiative is proposed to shed light on the pharmaceutical traceability and overall-process regulation. This system ensures that all pharmaceutical supply chain participants can integrate with each other, resulting in information sharing, consistency checking and anti-counterfeit [5]. All these projects are seeking the following benefits: processes automation, turnover increase, and stock management improvement [6].

This paper describes an ICT-based solution that meets the needs of a specific scenario: transportation of organs and biological samples. In this environment, the decisive factors in industrial environments such as the cost of deployment and return of investment are replaced by others that lead to system reliability. Maintain organs in optimum conditions since the certification of brain death of the donor to its reintroduction in compatible receivers is a critical process. Any incident that affects the environmental conditions of the packaging must override the transplant process to the enormous risk involved in the receiver [7]. The proposed system constantly monitors the environmental variables immediately reporting any change in them which endangers the transport process.

The use of this kind of ICT tracking solutions in the medical sector is innovative due to the lack of previous references adapted to this scenario. Despite that, the proposed architecture adapts to any other sector that requires sensitive freight. The result of our work is an innovative ICT solution with real-time tracking for improving the incidence recovery timing in the transportation of organs and biological samples.

2. Functional Description

There are two well differentiated parts in the proposed solution: the onboard system and the control software solution. An architecture schema of the complete system is shown in the graph below.

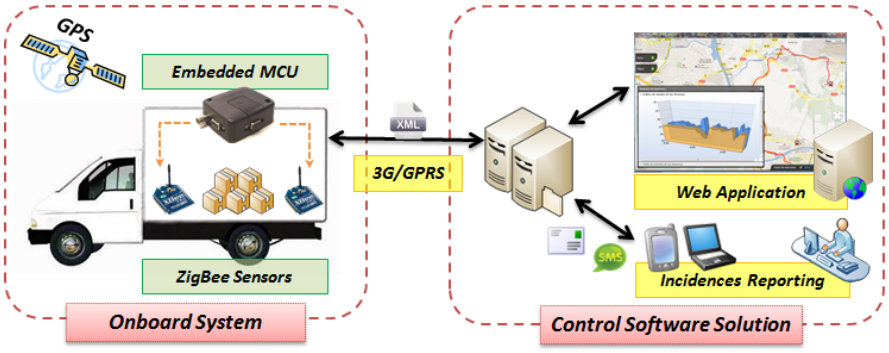

Fig. 1 System Arquitecture

2.1. Onboard System

Responsible for managing the proper transport and delivery of organs to the hospitals, is a key element for the functionality of the whole system. Its function is to monitor by humidity, brightness and temperature sensors the state of the refrigerators in which organs are transported. Likewise, and by geolocation technologies, it will send the position of the cargo to guarantee traceability at all times.

Refrigerators, specifically designed to the organ transportation, will be provided with wireless sensors able to measure its temperature, brightness level and humidity. With the ZigBee technology used, whose actual operation is detailed in Section 4.1 of this paper, the solution is capable of generating a mesh network autonomously so that the addition of a new refrigerator in the van with its corresponding sensor is performed transparently to the communications system.

Another component present in the onboard system is an embedded microcontroller that is connected to the ZigBee coordinator. With the processing power and communication interfaces of this device the solution will be capable of collecting and processing data which will be subsequently sent to the central server. This data shall consist of the values of the set of sensors present in the medical van providing the transport, as well as geolocation values obtained through the GPS capabilities of the microcontroller module.

By processing the raw data received by the embedded system from the ZigBee coordinator, the system will generate relevant alerts or incidents, taking into account the maximum or minimum values established for that specific transport.

2.2. Control Software Solution

Installed on the servers of the control center, it is composed of two different applications, integrated and designed as part of the solution. The applications complement each other for the treatment, management and dissemination of the data collected and received from the onboard systems installed on the medical transports.

Communications Management Server
The communications manager is the server side of the distributed system that comprises the solution. The clients (the medical transports on route) will request access to the server so it will generate dedicated processing threads to meet these requests dynamically increasing the QoS offered by the application in important aspects such as reliability, performance, transparency and scalability.

Traceability Web Application
It is used to track the medical transport vans and the transported organs as well as monitor and keep track of their status at all times. The information received will be displayed through a web application designed to facilitate usability and present data in an attractive and complete way.

The functionality offered by the web application can be subdivided into three distinct areas according to their purpose. These are: the traceability of the medical transports, the freight status monitoring and the incident management.

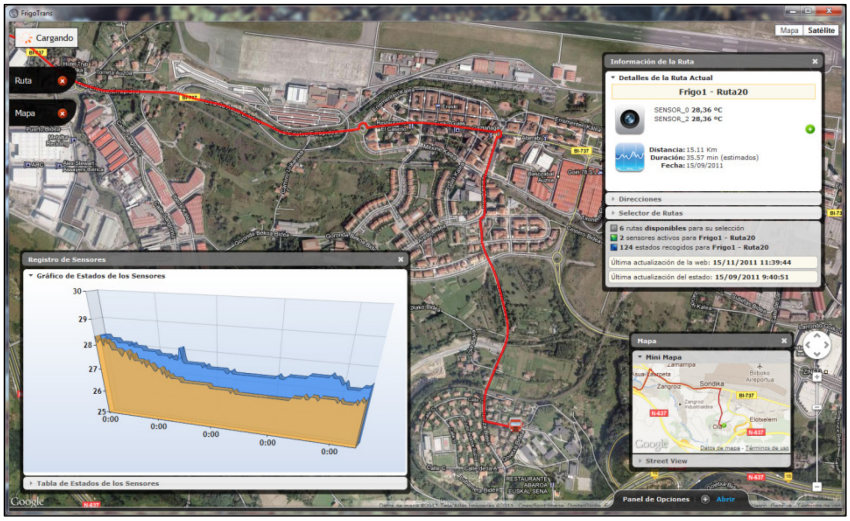

Fig. 2 Web Application Snapshot

1. Freight Condition Monitoring

The system has a robust database where all route information is stored. It keeps a record for both finished and real-time routes with all the information collected on the status of the sensors that monitor each refrigerator. That is, once the interval of data sending is defined in the application itself , the system stores the status of sensors and GPS position data during all the course of the route.

2. Medical Transports Traceability

The fleet management system provides trace and tracking of moving medical vehicles using a web-map. The computed routes with corresponding times (including stopovers) are recorded to assist in the prediction of appropriate time intervals for successive freight distributions which is of great importance considering that time is a critical factor in the field of medical transportation. This leads to optimized routes with improved delivery time, traffic monitoring and a preventive transport distribution.

3. Incidences Management

Although you can perform a complete monitoring of the state of the transport and its cargo via web, it is also necessary to include a complete incidences management system to notify to anyone interested about the possible deviations when they occur.

All this incidences are managed from the incidences reporting tab, where incidences are displayed at the instant they occur in the form of warning. There is also an historical record of incidents in which we can seek them ex post using search filters for transport, date, route, etc.

Another required functional feature that belongs to the incidences system is the ability to subscribe to alerts for a particular route or transport and for a certain time. This subscription allows the user to receive notifications via email or SMS depending on the configuration chosen. Upon receipt of an incidence the system takes care of consulting the list of subscribers and then sends via SMTP server or SMS server the appropriate notice to all of them.

3. Technical Solution

All features explained in the previous section have been developed thanks to the use of different technologies. At this point, we are going to describe the functionality of the system from a technical point of view. Information is structured here in three parts to facilitate the exposition of the technological and implementation aspects of each of the hardware and software solutions presented in the system.

3.1. Onboard System ZigBee Sensor Network

ZigBee is a low-cost, low-power, wireless mesh network standard. The low cost allows the technology to be widely deployed in wireless control and monitoring applications. Low power-usage allows longer life with smaller batteries. Mesh networking provides high reliability and more extensive range [8].

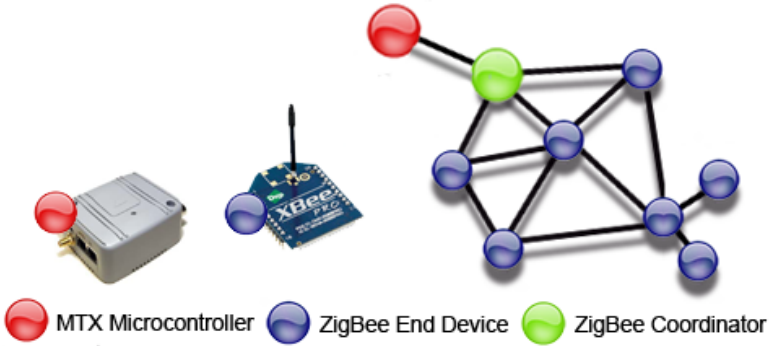

Fig. 3 Onboard Sensor Network

The ZigBee mesh sensor network that conform the devices that are arranged both in the conditioned refrigerators and in the medical transport allows the system to know the status of the organs transported at all times.

As shown in Figure 3, the network is composed of two types of ZigBee devices (the End Devices or ZEDs and the Coordinator) and a Microcontroller unit.

- ZigBee End Device (ZED): Contains just enough functionality to talk to the parent node (either the coordinator or a router); it cannot relay data from other devices. This relationship allows the node to be asleep a significant amount of the time thereby giving long battery life.
- ZigBee coordinator (ZC): The most capable device, the coordinator forms the root of the network tree and might bridge to other networks. There is exactly one ZigBee coordinator in each network since it is the device that started the network originally.

The use of the proposed ZigBee network will allow the system to meet the specific requirements of the healthcare field as the reliability, as well as desirable non-functional requirements such as low cost, high durability or auto configuration. All these features encourage the use of this type of networks in the proposed field.

3.2. Embedded Microcontroller & Communications Device

MTX-65+G embedded microcontroller is connected to the ZigBee coordinator. This terminal is a GPS receiver combined with a GSM-GPRS for data, voice and SMS connectivity. It is made with a SIEMENS XT65 modem, with a high sensitivity and low consumption GPS receiver integrated into the GSM module that can be controlled with AT commands, not being necessary to know the NMEA plot.

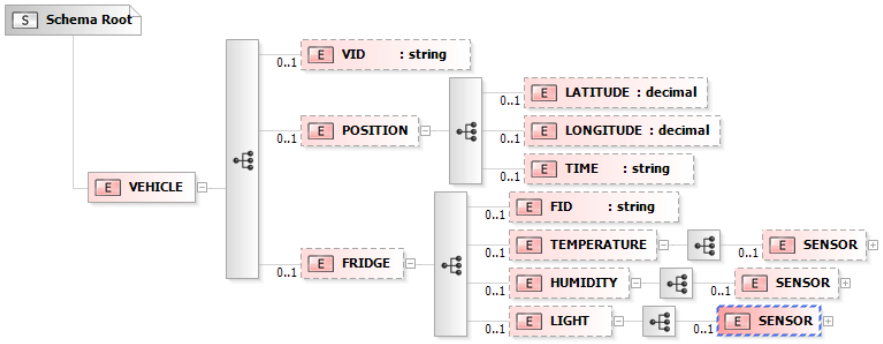

Fig. 4 Status Message XML Schema

The embedded microcontroller is responsible for collecting and transforming the data which will be subsequently sent to the central server. Fig. 4 illustrates the XML schema generated and sent to the central server. As shown in the graph, the file is composed of the values of the set of sensors present in each of the fridges carried in the medical transport (temperature, humidity and light levels), as well as geolocation values (latitude, longitude and time) obtained through the GPS.

3.3. Control Software Solution

All the functionalities described in Section 3.2 have been developed on a Rich Internet Application (RIA), Fig. 2. Below are listed the technical characteristics of the business logic, data management and graphical components that conform the web application.

Business logic and Services
In this module is contained all the logic needed to meet the functional requirements set by the application proposal, outlined in points 3.2.1 to 3.2.3. Thus, we find the necessary logic for the treatment and management of the routes or buckets, as well as the user and incidences management. It also has all the required data about the geolocation of the routes, obtained through external services, in this case using the Google Maps Javascript API.

Data management
"Microsoft SQL Server 2008" was used for the data storage of the applications related to the ICT Solution. The data is stored during the entire transport distribution by generating the necessary entries in the Database Management System (DBMS) of the server.

Web application
The development of the control solution is completed with the web application which offers features beyond the typical application of fleet management. This application has been developed taken into account two fundamental characteristics: (1) to maintain a friendly and attractive interface, (2) without prior installation or further configuration. This Web application approaches usability to a modern desktop application but with all the advantages that such implementation offers, being available globally via the Internet to a vast number of devices supported.

The Control Panel, based on asp.NET development framework, has been made extensive use of technologies designed for creating Rich Internet Applications (RIA): JavaScript, CSS3, HTML5, Ajax and jQuery, along with the use of the tools offered by Google for displaying and processing of geographic and positioning information. This feature improves not only the final visual aspect of the application but also the overall usability. The whole site is based on an asynchronous behavior, so interaction eliminates the sense of loading data and responds instantly. All kind of choices as routes, transports or incidences, represent a dynamic and transparent loading of data and an almost immediately response to their interaction.

4. Conclusion

The work presented in this paper provides a comprehensive solution that can detect environmental anomalies that affect the organs and biological samples during the transport process. Temperature, humidity and light are continuously monitored since organs are collected in any of the extractors centers network of organ and tissue until they are deposited in the immunology service of the nearest certified laboratory or in the center linked to the selected receiver. The system can detect trends that may lead to the loss of an organ, generating autonomously a warning before jeopardizing its integrity. Furthermore, the system provides real-time geolocation for transported organs allowing the medical teams to plan the intervention with maximum accuracy.

The inclusion of the ZigBee motes, responsible for the acquisition of environmental variables on the inside of the refrigerator where organs are transported, so as the installation of on-board system in the medical transport vehicles allows carriers to run their transport actions in a non-intrusive way without causing any alteration in the transport process, fully established by the protocol for the transport of biological samples and transfer of organs and/or tissues.

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