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Telematics system for the intelligent transport and distribution of medicines

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Abstract: A growing demand for well-defined telematics systems in the intelligent transport distribution of pharmaceutical drugs is envisaged driven by legislative demands to enable the safe handling of medicines in automotive distributions. The provision is accomplished by providing virtual intelligence to vehicles designated for this form of smart freight transportation. The system provides anytime/anywhere assets tracking while on the move, from departure to destination, supporting reliable courier operation at low labour. The tracking and tracing system provides the vehicle with sufficient intelligence to: be located remotely, track and trace assets and provide incidence reports. The authors' architecture is intended to automatically broadcast adaptive logistic-distribution-plans between a central office and a vehicle. The proposed system represents an inexpensive and non-intrusive solution that exploits advanced technologies such as smart environment sensing, radio frequency identification, Wireless Fidelity (WiFi) and global positioning system, to support modern industrial needs. The authors describe and discuss the motivation and the benefits of using the system, including new hardware and software developments.

1 Introduction

Emerging demands for innovative pharmaceutical drug supply chains [1] require assets tracking solutions on moving vehicles alongside designated itineraries (pharmaceutical suppliers to end pharmacies). Enforced by the European Community (EC), the solution must provide traceability, secure delivery and healthy handling of medicines [2]. Owing to the associated costs increase and the highly competitive industry [3–5], the solution must be inexpensive to allow profitable operation with low margins. Competitors offering low-price and efficient services are highly successful in attracting and retaining new customers.

Among the important attributes of the solution is the ability to provide distributors with a reliable, high quality of service and satisfactory completeness of assigned freight distribution at a reasonable but nevertheless minimum time. In addition, the proposed telematics system should meet the European Union (EU) recommendations and provide relaxed human–computer interactions with simplified distributor's tasks.

To meet the above demands, a novel architecture is presented; in essence, it is envisioned as an inexpensive solution for the effective distribution of medicines that meets the requirements of the new regulations for the handling of medicines. It accomplishes this through the use of a range of relatively inexpensive technologies including typical mobile handsets (used by couriers) networked to a central office (CO). This allows for the traceability of journeys and assets remotely using human-to-computer interactions. Some potential applications of the telematics system include the ability to validate the cargo during distribution with minimum labour and the ability to identify and acknowledge responsibly any prospective failure of a committed distribution plan.

Following the introduction, the paper describes the key technical contributions of the proposed system and is organised as follows: Section 2 describes the intelligent system, Section 3 presents the radio frequency identification (RFID) system and provides details of the antenna developments, Section 4 summarises the key software advances and Section 5 validates the system.

2 Intelligent system

The growth of telematics systems can contribute to the development of vehicles with sufficient artificial intelligence. The system should ensure safe transport of medical containers as approved by the World Health Organization and be reusable [6] to minimise costs.

The vast number of containers that are expected in a warehouse would preferably favour an easy arrangement and low cost tagging solution; this is achievable using passive (uses no battery) transponders (tags). The containers are used in close loop with a value enhanced by their reutilisation to reduce waste and cost (permanent tagging).

In addition, the system must be capable of automatically reading the tags; the use of handheld interrogators (readers) can lead to reading delays compared with an automatic solution. Furthermore, it is essential to overcome any possible extended delivery and related expensive labour. For the solution, RFID technology is employed.

A high-level block diagram detailing the proposed intelligent system architecture is depicted in Fig. 1. A description of the blocks is now detailed. Ultra high frequency (UHF) RFID technology is employed; both the antenna interrogator and transponders are responsible for the wireless communication (the tracking and control of medicines). The interrogator is responsible for the requests and the processing of the replies made by the transponders allocated to individual containers; this is a more affordable technique than having each medicine tagged and is seen as an additional contribution to a cost-effective system. The 'embedded system (ES)' is primarily responsible for the communication exchange between the RFID system and a smartphone; the latter allows for real-time communications between the vehicle and a CO. The hub of the 'ES' provides the virtual intelligence to the vehicle (designated for this form of smart freight transportation) and interfaces the necessary hardware for the communication exchange. A simplified supply chain process of the intelligent system is given in Fig. 2, where, blocks marked as (*) indicate the origin-to-destination stages of the journey, and the halts otherwise.

Detail information on the intelligent system performance is now provided. First, a fully automated dispenser located at the CO receives prescription orders (from its enterprise resource

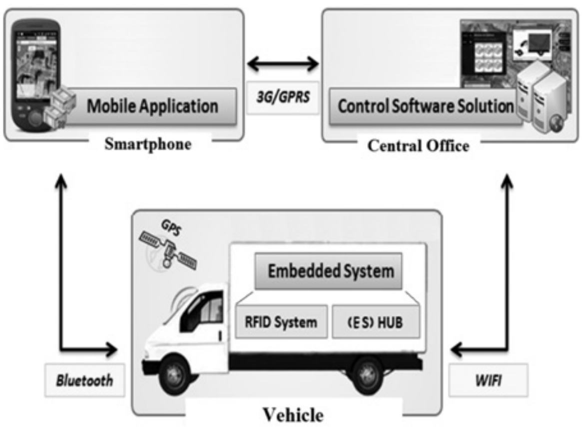

Fig. 1 *Intelligent system architecture*

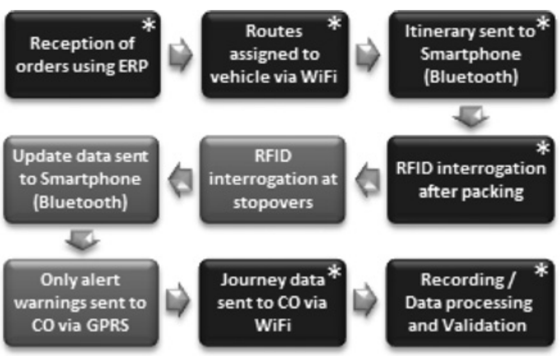

Fig. 2 *Supply chain process*

planning) system and rapidly coordinates the medicines for transportation. The intelligent system organises the requested medicines in containers that are dispatched immediately after validation.

WiFi – IEEE802.11b/g technology is used for the complete information provision of update itineraries from the CO to the vehicle; Bluetooth and general packet radio service (GPRS) complement the operation. Although fast growing automatic WiFi roaming can be used instead of 3G/GPRS, at present, the former is not as commonly deployed since it implies a large set of WiFi access points and therefore restricts the application to dense urban areas; 3G is typically a flat rate service used by couriers and therefore not seen as a cost increase. Although Bluetooth can in principle be replaced by emerging WiFi direct, the earlier incorporates very robust security mechanisms [7]. The containers are manually packed inside the vehicles and an RFID interrogator (inside the vehicle) reads the corresponding transponders during packing (while the vehicle doors are open) with no intrusion to the courier's tasks.

The hub of the 'ES', gathers, stores and delivers the data as collected by the interrogator; in addition, it continuously monitors the courier's performance. The data identifier is provided by an electronic product code (EPC) allocated to each transponder. Each ISO18000-6C compliant RFID tag holds the necessary numbering for a bunch of prescriptions (medicines contained in a container) including recipient (end customers) destinations.

Using EPC along with the system, the total number of containers and accurate reception acknowledgments are systematically updated during the freight distribution. This allows for up-to-date distribution routes and track record of medicines, verifiable location and assets tracing at unexpected situations.

Compared with other comparable solutions [3–5], the proposed telematics system is seen as non-intrusive since it allows the couriers to be detached from the tasks associated with the recording of the loading and unloading of freight, and supports virtual intelligence to vehicles assisted with the ability to identify accurately a malpractice and have it reported in real-time to the CO autonomously. Any misplaced consignment is automatically registered and acknowledged where 'lights' installed at the vehicle's carriage room (connected to the 'ES') respond; a red light in case of failure and a green light otherwise.

Typically, couriers use smartphones (no cost increase). Making use of the integrated Bluetooth technology (typical ranges of 10 m) and a computer engineering solution (described in Section 4) the 'ES' communicates to the smartphone. This provides immediate up-to-date freight distribution information and stage progression to moving couriers who are warned in case of inaccuracies. Only the latter is immediately (real-time) reported to the CO via GPRS, Fig. 1. In addition, the intelligent system indicates which containers must be either collected or dispatched at the upcoming destinations. Once the freight distribution is completed, data is reported to the CO upon arrival, where WiFi is used for the communication exchange; the use of widely deployed WiFi in-stores (no additional cost involved) guarantees high reliability (goods can be tracked at the CO independently of GPRS). The data is accordingly recorded in the developed 'control software solution' for further analysis; this is introduced in Section 4.3.

Using existing global positioning system (GPS) technologies, an assisted GPS (A-GPS) receiver, Fastrax IT310 [8], is connected to the hub of the 'ES' for

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traceability, monitoring and itinerary predictions. The 'ES', in addition, includes a variety of atmospheric sensors inside the vehicles to monitor and control the temperature, pressure and humidity of medicines; this is significant to preserve medicines in good conditions.

3 RFID system

To meet the EU Governments strive for ensuring reasonable finances and fiscal sustainability in health care [9], the use of consistent and reusable (for economy and permanent tagging) containers for the transportation of goods are essential. This creates a perfect scenario for the attachment of RFID tags needed for the intelligent delivery of medicines to end customers.

The RFID system encompasses two basic communicators, a reader or interrogator and a tag or transponder. Specifically designed low-cost antennas for the application (reader and tag) are presented in the next sections; inexpensive antennas play a key role for maintaining a low-cost intelligent system.

3.1 RFID transponder design

Certain materials pose challenges to passive RFID tagging, for instance metallic objects cancel electric fields and liquids absorb electromagnetic waves. In both cases passive tag antennas may not receive sufficient power to excite the RFID chip and suffer significant degradation in performance.

For use in this application, the UHF–RFID transducer should be thin, insensitive to detuning when attached to medicine containers, cheap, flexible, reliable and small in size (dimensions as low as $125 \times 52 \times 0.4\ \text{mm}^3$). A candidate tag has been presented in [10], Fig. 3, and has been filed as patent P40909GB. The tag was designed for optimum performance on the surface of any object, regardless of whether it is conductive or has high dielectric constant or loss, Fig. 4. This allows for read ranges close to the maximum quoted for a given system even when attached to the containers. For additional reliability, a Datamatrix (printed onto the tag label) can be used to complement the intelligent system in case of RFID failure. The tag is now customised to read at the 865.6–867.6 MHz frequency band according to the EPC global Gen2 air interface and has 4.3 dBi directivity. A reading range of 2 m using a 500 mW (27 dBm) reader was measured on all mounting surfaces (i.e. metal and water container) in the laboratory environment and is adequate for the dimensions given by the vehicle.

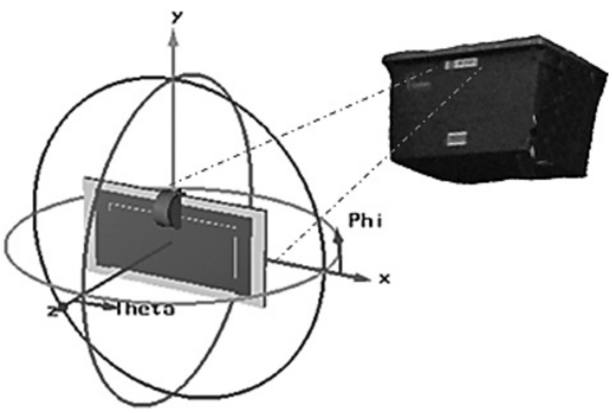

Fig. 3 *RFID tag attached to the container*

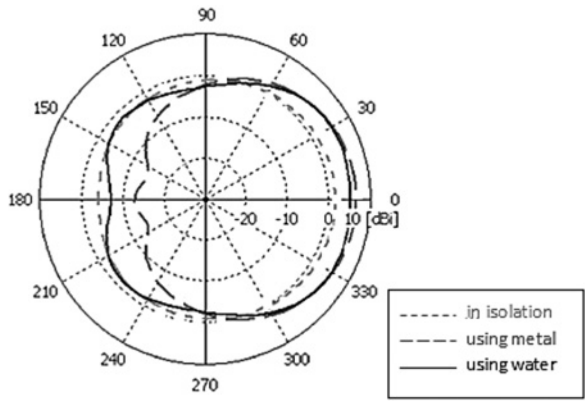

Fig. 4 *Simulated radiation pattern of the tag*

3.2 RFID interrogator antenna design

The RFID interrogator was located inside a vehicle. An RFID Mercury5e development kit (DVK) from Thing Magic [11] was used as a base for the experiments. The DVK uses the UHF 865.6–867.6 MHz frequency band, provides a maximum power of 30 dBm (1 W) and a −65 dBm receiver sensitivity; this is in accordance to the EU regulatory body European Telecommunications Standards Institute (ETSI) [12].

UHF is the preferred broadcasting approach to provide an effective interrogation zone as it is less restricted by line of sight compared with other higher bands. It supports ranges longer than those supported at other available low frequencies. To provide optimal interrogation zones within vehicles, interrogator antennas were designed and the strategic location inside the vehicle identified. Initial predictions using commercial software Zeland IE3D, based on the method of moments (MoM) [13], indicated that an interrogator antenna, described in Section 3.3, is preeminent when located in the middle of the ceiling inside a vehicle.

The MoM was preferred over a ray tracing technique [14] since the first method accounts for any possible antenna performance deviation when implemented in a realistic scenario.

To meet with the demands of the RFID interrogator introduced in Section 3.2, and the economical constraints placed on the telematics system, Section 1, a customised interrogator antenna is intended to be low cost.

Among the devices that are capable of transmitting and receiving electromagnetic waves efficiently, miniature printed – planar inverted F antennas are in great demand because of their relatively low-profile design, easy fabrication and low cost [15]. Typically, high gain antennas imply larger sizes when compared with less bulky but nevertheless efficient low-profile antennas.

Presented simulated results indicate that optimised antennas having gains of 2 dBi (measured at 1.92:1 voltage standing wave ratio) are adequate for in-vehicle applications. They can deliver a sufficient radio propagation field (within an interrogation zone) inside a vehicle, having a complete shield carriage room of $1.8 \times 2.6 \times 1.4\ \text{m}^3$ with maximum power budget, Fig. 5; this assumes full power transmission at the transceiver [11]. The antenna interrogator was set in the middle of the ceiling of the car as a preferred location in vehicles [16]. This ensures good power distribution to likely RFID tag locations within the car while minimising field exposure to the occupants (those assisting in the inventory distribution of goods). Antennas inside a metal shielding can in theory confine the antenna's radiated power within the car body with no power loss, no

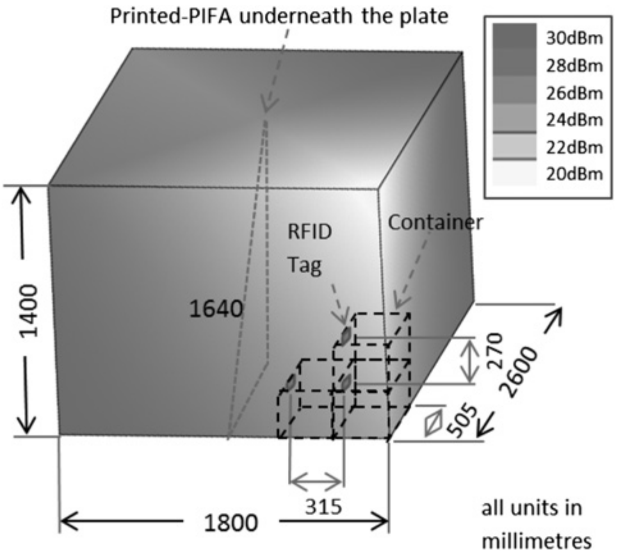

Fig. 5 *Received power at the boundaries of a car body*

Doppler shift on moving vehicles. The power strength seen at the boundaries of the room, Fig. 5, guaranties RFID field coverage in all the corners of the vehicle.

Directly printing (i.e. electrically conductive paint) antennas onto suitable surfaces are encouraged as a desirable approach to provide relaxed and relatively inexpensive mass-produced antennas.

In addition, antennas that can be straightforwardly sprayed onto the coating of a vehicle body would further simplify the fabrication and costs; this is exciting to the automobile industry and for use in this application.

Owing to the reduced costs that are mainly achieved by the easy manufacturing process and the reduced amount usage of paint composite (i.e. copper) needed for the deposition of the electrically conductive elements of the antenna, directly printing a radiator over the car body seems to be an efficient method for realising a cheap antenna prototype. Recent advances in electrically conductive paints [17] can provide adequate sheet resistance for the development of cost-efficient antennas. Among the most remarkable conductors, silver and gold-based inks are expensive; copper is a more cost-balanced solution while providing a better electrical conductivity than gold. Other cheaper inks, such as aluminium and nickel can be used at a compromised performance.

The geometry of the proposed sprayed antenna (paint substrate 2 mm) design is presented in Fig. 6. It depicts a relatively simple structure that enables easy fabrication.

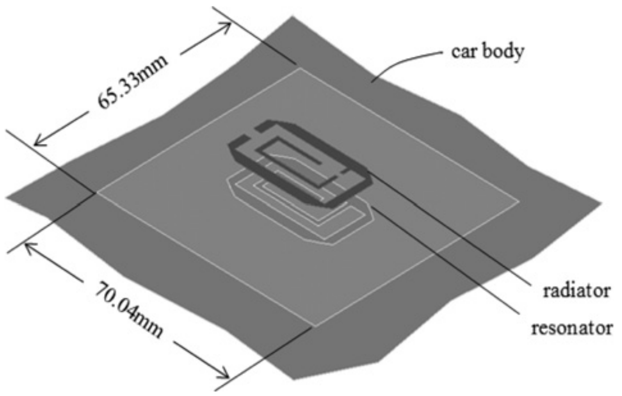

Fig. 6 *Miniature antenna design printed onto the car body*

The antenna can easily be fed via-through a metal plate of the car body. The practical miniature antenna design is designed to be directly patterned onto the car body inside the carriage room of a van and is suited for use in RFID networks using the unlicensed RFID sub-band b2 (865.6–867.6 MHz) of the ETSI standard [12]. As the antenna can be sandwiched in between paint layers, this can favour hidden antenna applications. In return, there would be no immediate information of the antenna interrogator location. Simulated results predict an antenna having a bandwidth of 2 MHz (with tailored rejection to unwanted neighbouring frequencies) measured at the −10 dB reflection coefficient and a 2 dBi gain (this is a 46% radiation efficiency) when using copper ink. Recent studies show a similar performance using silver and a lower efficiency antenna using other conductive paints such as nickel [18]; copper is therefore the preferred ink for the antenna application. Radiation patterns having 60° beamwidth for both the azimuth and elevation planes are expected to positively contribute to effective radio coverage over the required interrogation zone; this directional antenna characteristic can be useful for indoor applications [19] where the optimised pattern enhances the system coverage inside the vehicle, Fig. 5.

The results, Fig. 5, indicate an optimal radio propagation performance with potential reading range for the application; multipath present in the enclosure (vehicle) is conjectured to have contributed positively.

In multipath scenarios, the RFID interrogator antenna receives a direct component when the tag is directly visible and a great number of echoes with different amplitudes, phases and random arriving times otherwise [16]. Owing to the expected reflections in multipath, the tags are likely to be seen by the interrogator for any possible antenna orientation and Section 5 corroborates that all the tags were read.

4 Computer engineering solution

A ubiquitous computer engineering solution aimed at supporting the necessary components of the intelligent system architecture of Fig. 1 is given in this section. For the solution, the ES set-up and related software control is subsequently explained.

In addition, a developed mobile application (designed for the smartphone) and control software solutions (for governing the CO) are, respectively, given in Sections 4.2 and 4.3. Both, the mobile application and the control software are seen as relatively cheap solutions since they are deployed on typically encountered computers (handsets and desktops).

4.1 Hub of the ES

The hub of the 'ES', Fig. 7, is given by a common shared commercially available stand-alone computer-on-module IGEPv2 from ISEE [20] and utilises existing interfaces to provide connectivity to the WiFi, the open-and-close of the vehicle's door (using detectors) and control of the 'lights' (using the general purpose inputs and outputs), the RFID, the GPS and the Bluetooth.

Other commercially available DVKs might be used, however, the above was carefully chosen for its suitability and moderate cost. Specific embedded software was implemented to control the hub interfaces, Fig. 7. The solution is responsible for the control of the intelligent system with responsibilities already described in Section 2

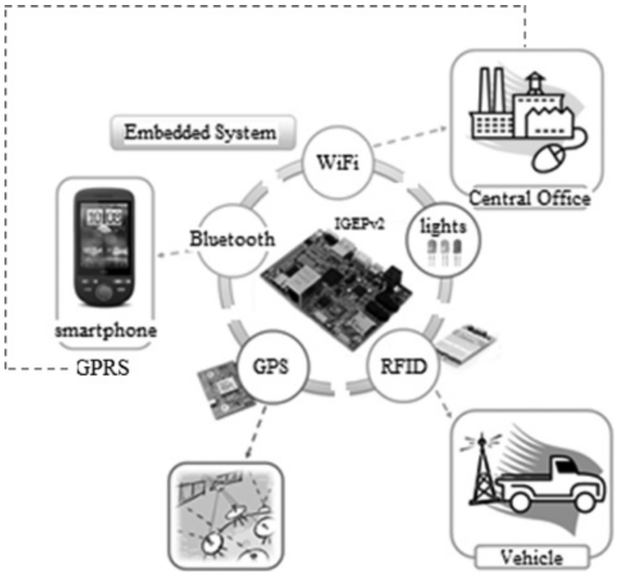

Fig. 7 *'ES' hub*

and allows for the data compilation of the 'track and trace' in an Extensible Markup Language (XML) file format; any assigned itinerary is download and encapsulated in the XML. The proposed mobile application is next introduced.

4.2 Mobile application

The mobile application has the responsibility for presenting update data information regarding the containers and the prospective itinerary on the handset screen. For the realisation, a service-oriented architecture is proposed; this provides maximum functionality distributed over a main server at the CO. Distributed simple object access protocol messages (text commands), based on the XML syntax are sent across the Internet using Hypertext Transfer Protocol; this allows relieve capacity processing for the terminals (smartphones) accessing the logic of the control software solution, Section 4.3, in the CO via 'web services'.

Even the market changes rapidly, at present smartphones are being customised on android 'software stack' solutions. For this reason, the android's mobile operating system, based on Linux kernel, is used for the solution and the resulting application design is presented in Fig. 8.

Following the establishment of a journey route, the smartphone, receives the necessary data (via Bluetooth, from the embedded application) for the predicted journey (efficient distribution of medicines), including: distance, duration, stopovers (pharmacies), addresses and further information. At stopovers, EPCs containing detailed identity of every container are downloaded and sent uplink for processing; the data is accessible via the mobile application interface, Fig. 8.

Among the potential functionalities of the mobile application are the management of incidences and the navigation assistance. These are described next.

4.2.1 Management of incidences: The management of incidences is responsible for the control of activities and warning of possible failures during transportation; this includes variations in the estimated time of a journey and left-behind containers. The alerts are sent to the courier (smartphone) and the CO via GPRS.

In the system architecture, we assumed $a \geq 10\%$ deviation in the estimated time or any mislead container, for the system to automatically report an incidence. The warning alerts provide with the most recent number of containers.

4.2.2 Navigation assistance: The navigation assistance (uses Google Maps) is responsible for the alert warnings between the vehicle and the CO and is feasible using Bluetooth and GPRS, Fig. 7. It uses the smartphone to provide the courier with any possible variation in the scheduled delivery immediately and assists the courier with real time and diverge routes (when necessary) and first-hand stopovers; and was highly accepted by the drivers.

Fig. 8 *Mobile application interface*

4.3 Control software solution

The control software solution was developed for the monitoring and tracking of assets and centralised at the CO. It comprises the development of a control panel (web application), Fig. 9, with the following functionalities.

1. *The traceability of medicines:* The traceability system comprises a robust database with stored data information of the freight.

This includes the distribution itinerary, the dispatch location, the batch number and the expiry date of nomadic containers at anytime/anywhere.

2. *Fleet management and optimisation:* The fleet management system provides trace and tracking of moving vehicles using a web-map, Fig. 9. The computed routes with corresponding times (including stopovers) are recorded to assist in the prediction of appropriate time intervals for successive freight distributions. This leads to optimised routes with improved delivery time, traffic monitoring and a preventive transport distribution.

The architecture of the control software solution and corresponding architectonic layers (presents a modular arrangement prepared for ease reuse, minimise coupling and prospect functionalities) is given in Fig. 10. The technical features of the layers are detailed next.

1. *Business and service layers:* This module contains the logic (treats and manages the routes) of the traceability of medicines and the fleet management. In addition it manages and give the necessary permissions (i.e. user/password) to likely users at the vehicle and the CO, and makes use of the Google Maps Javascript Application Programming Interface (API) external services, Fig. 10, to provide with the itineraries.
2. *Persistence data layer:* 'Microsoft SQL Server 2008' was used for the data storage of the applications related to the intelligent system. The data is stored at the completion of the entire transport distribution by generating the necessary entries in the Database Management System of the server. An XML file is automatically generated and sent from the 'ES' hub to the main server at the CO. The file includes both, the completed itinerary of the vehicle and any detected incidence.

Fig. 9 *Web application interface at the CO*

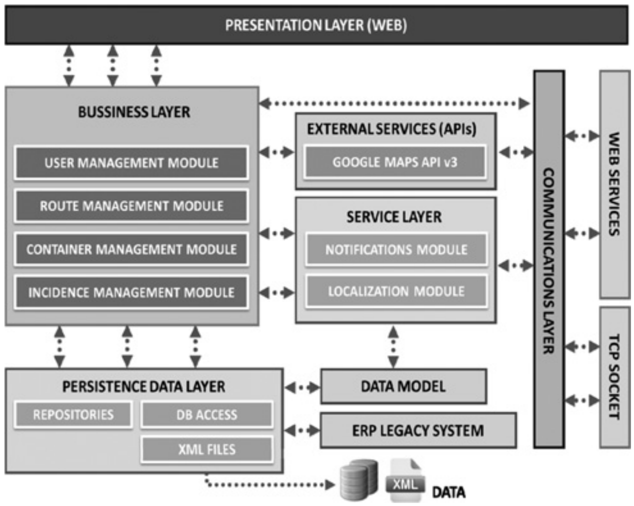

Fig. 10 *Control software solution architecture*

3. *Communications layer:* The communications layer utilises 'web services' to retrieve the data (system information) as provided by the DBAccess, Fig. 10. The latter was developed using Windows Communication Foundation technology. This ensures a high security, scalability and interoperability, and enables the access to the persistence data and the business (the logic) layers. Access to the control software solution is similarly made using a Transmission Control Protocol (TCP) sockets gateway operated by the communications layer; this enables XML files (with complete routes) to be driven via File Transfer Protocol.
4. *Web presentation layer:* A user-friendly graphic web application, Fig. 9, offers an easy use tool with unnecessary programming expertise. The application is aimed for use in contemporary computers and is intended to be accessible worldwide via the Internet.

The control panel (web application) is based on the asp. NET development framework, and makes extensive use of the latest technologies for the Rich Internet Application.

The technologies include JavaScript, CSS3, HTML5, Ajax and jQuery, along with several tools offered by Google for the processing and display of the geo-spatial positioning of vehicles.

5 System validation

As part of the evaluation of the system, the following set-up was arranged. The complete 'ES' was installed inside an own vehicle, and the 'mobile application' and 'control software solution' debugged, respectively, in the smartphone and the computer at the back-end of a CO.

The arrangement was made and vehicles run their daily itineraries (a real case) with arbitrarily distributions depending on pharmacy requests. A vehicle distributed a total of 97 containers [21] (dimension $665 \times 415 \times 315$ mm^3) along the distributed routes (26.4 km total when all the pharmacies were covered) and was made 1–3 times/day, independently to the diverse destinations. The average time for a complete distribution was 1 h–37 min and the total number of stopovers (pharmacies) was 1–12. For consistency, the measurements were repeated over six consecutive days. The validation process was made gradually with the following progressions. First, the 'track and trace' scheme was validated by successfully retrieving the data information of a previously recorded positioning of the moving vehicle in an XML file; for the test, software was implemented in the 'ES', Section 4. The resulted XML file provided with the necessary information to characterise uncovered areas of the GPS and the optimised location of the end customers (pharmacies). Second, the freight identification was validated by confirming the total number of containers contained inside a vehicle (non-intrusiveness to the courier was met). During the vehicle halts (pharmacies), the hub of the 'ES' received the XML file containing the number of containers that remained inside the vehicle; only once a single mislead was encountered and was because of a faulty tagged container. Finally, the complete solution as a whole was validated. In this case, the experiments were performed three times/day, were using the previous set-up and repeated for 2 days for consistency. For the first two attempts, the courier was given corresponding instructions to spot for any improper distribution of the freight; no discrepancies were seen as compared to the proposed system functionality. From the results, the system showed no misplaced consignments during the freight distribution; this was indicated (in green) by the 'light' installed in the vehicle's carriage room. For the third attempt, the XML file containing the itinerary was intentionally modified with the following inaccuracies: a wrong order, a misplaced container and a wrong delivery; this was done intentionally to gain credibility in the results. All inaccuracies were tracked and subsequently received at the CO (on screen). There was no apparent delay in receiving the messages; however, the time response required by an operator (for misleads during the loading and the freight distribution) at the CO was not seen as a great impact when compared to the effectiveness in using the proposed system.

6 Summary

A relatively cost-effective telematics system for the intelligent transport distribution of medicines has been presented. The solution meets with the EC regulations and standards for the traceability, secure delivery and healthy handling of medicines. The proposed system was detailed and experimentally validated and is currently deployed in a small and medium enterprise pursuing the urgent delivery of medicines.

The application can be tailored tiny towards other distribution schemes (as long as using the tagged containers) with potential market possibilities, e.g. the transportation of groceries.

The intelligent system exploits existing communication technologies and original software developments to provide an inexpensive solution. Advanced antennas were designed to further reduce the total costs of the system. For the validation, the intelligent system was set-up (using commercially available antennas) and tested accordingly.

The medicines were traced over a prearranged transport distribution itinerary showing no apparent disconformities; this verifies the system and validates the advanced hardware and software developments.

A future development will see us design cost-effective and advanced intelligent systems to automatically broadcast update distribution plans between a CO and a vehicle and with the capability to trace individual medicines that are packed inside a container (i.e. Datamatrix that is at present cheaper than RFID tags). Inexpensive RFID tag antennas (including the transducer chip) can guarantee the solution.

7 Acknowledgments

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