The Inte-Transit Management System: Utilising DGPS and RFID Technologies for Optimizing Container Tracking in Valencia Port

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***Abstract*—The Mediterranean (MED) Sea has been and will continue to be a vital space for the circulation of goods, with significance beyond the interest of countries directly involved. Nevertheless, the circulation of goods/capitals within the MED Sea faces a number of challenges. ICT technologies, such as the Differential GPS (DGPS) and RFID have proven of to be of great value in tackling MED/ EU port challenges regarding logistics and communication systems. The INTE-TRANSIT management system (ITMS) is a high accuracy client-server system, suitable for improving the efficiency of port terminals through an enhanced monitoring of the containers as well as of the yard equipment (trucks, straddle carriers, reach stackers, etc). The main purpose of the proposed system is to obtain information such as container identification, vehicle/yard equipment ID and positioning data from all relevant communication endpoints, namely Differential GPS receivers, RFID readers as well as GEO-location servers. The operation and functionalities of ITMS have been showcased in a pilot demonstration which has been performed in the Valencia Port Container Terminal, the largest MED port in number of TEUs.**

***Index Terms*—container tracking, RFID, DGPS, web-based visualization tool, valencia port terminal.**

I. INTRODUCTION

The INTE-TRANSIT project [1] focuses on strengthening communication links between i) ports and relevant authorities across the MED Basin, ii) all relevant actors in the maritime transfers and iii) ports and their logistic activities areas, through the use of modern Information Communication Technologies (ICT) technologies that will be used to enhance information management systems. In its framework, five pilot projects are implemented in order to demonstrate the improvement of logistic systems and port operations. The current paper refers to the ICT technologies based on DGPS and RFID which have been deployed in the Valencia port pilot. Specifically, the INTE-TRANSIT Management System (ITMS) which has been developed in this context uses RFID tagging technology for identifying the containers and Differential GPS (DGPS) technology to provide precise location information both for containers as well as for the monitoring of the yard equipment. These technologies are supported by an open-source, modular management server which is responsible to collect, store and represent gathered data (real-time or on-demand) to the responsible end-users, which is the port operations personnel. Automated processes and mechanisms for writing, reading tags, logging, alarms and data reporting enhance the real-time operational visibility and control of the containers and yard equipment as well as their management and utilization.

In prior work, [2] describes a four-layer architecture, consisting of a data collection, RFID network filter, RFID network process and business application layers; these provide the proposed system the ability to trace the container movement in real time using a network of RFIDs. The system is tailored for tracking containers along the supply chain, starting from the manufacturer's side by registering the EPC (Electronic Product Code) and ending within the distributor or retailer's EPCIS (Information Services) gets updated that the product has arrived. Moreover, [3] presents a case-study where RFID equipment for vehicle tracking inside the yard terminal is evaluated for different ranges, velocities and penetration levels (eg near containers as opposed to in free, open areas); several benefits of such a COTS (Custom-Off-The-Shelf) system were showcased, such as better operation management, tracking driver behaviour, as well as assisting yard equipment routing inside the terminal area.

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Finally, in [4], a vehicle terminal system is proposed, composing of an ultra-low power 16-bit microcontroller, an acquisition unit of RFID tags information, a GPS receiver, a GSM module and the HMI (Human Machine Interface); the system is relatively low-cost, yet exhibits the accuracy limits of COTS GPS receivers and also communicates with the back-end through GSM short messages.

The remainder of the paper is organised as follows: Section II presents the Valencia pilot conceptual design and requirements, detailing all steps of the pilot scenarios for both truck & yard equipment positioning as well as for an association of containers with trucks and reach stackers. Section III presents in detail the ICT architecture of the ITMS, describing the server, each modules, including an interactive visualisation tool, as well as the hardware client terminal developed in Valencia port. Moreover, in Section IV the pilot demonstrations main conclusions and lessons learned are outlined and, finally, Section V concludes the paper.

II. Valencia Terminal Pilot Design & Requirements

The Valencia terminal pilot aims at developing a solution to track and trace containers and equipment in the yard area of a terminal.

From the terminal process point of view, the objectives of this solution are:

- The automation and improvement of the productivity of the port operation and container/cargo traceability
- The enhancement of the existing container terminal management and control systems

They have been achieved by introducing modern positioning technologies in order to monitor yard and transfer equipment and the containers they handle. This has automated the location of containers and equipment within the terminal and has provided real-time information about the status of the stacks and the equipment that can be used for route optimization.

A. *Valencia Pilot Scope*

For the accomplishment of the objectives presented above, the Valencia Pilot is based on deploying the ITMS made of two main subsystems, the Intra-Terminal Truck Positioning System (TPS) and the Container Positioning System (CPS). This platform is software that collects aggregates and manages positioning and ID data.

The data is principally obtained from DGPS and RFID technology, which also need to be installed for the pilot.

Therefore, the scope of the Valencia Pilot consists of applying the ITMS, but it also includes the implementation of: hardware components installed on port equipment, IT hardware infrastructure, software based tools and applications, network infrastructure and tagging elements installed on containers.

B. Valencia Pilot – Conceptual Design

The Valencia Pilot deals with the yard operations (the reader is referred to Fig. 1), and involves the interaction of the storage equipments – Reach Stacker (RS)-, with the interconnection equipment -Terminal Trucks (TT)-. It has been deployed in Noatum Container Terminal Valencia (hereinafter, Noatum).

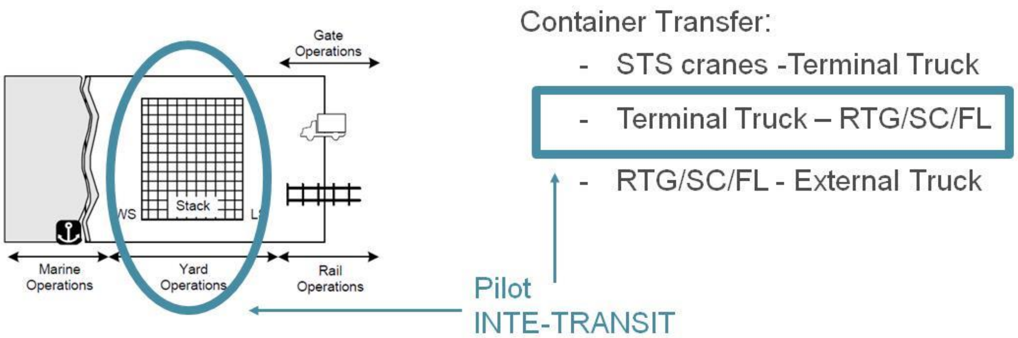

Figure. 1. Operation areas for the generic terminal (Valenciaport Foundation based on [5])

In order to understand how the Valencia Pilot works, it is important to bear in mind that the ITMS interacts with a client terminal hardware solution provided by the Valenciaport Foundation and Noatum, hereinafter called the Valencia Solution. The Valencia Solution is in charge of capturing and transmitting the necessary data about the equipment status and positioning. For this purpose, it integrates DGPS and RFID technology, as well as some interface devices such a screen to display the job orders.

1. The first phase tackles the Intra-Terminal Truck Positioning System (TPS), specifically:

1.a_The decision-making regarding the TTs assignment depending on their proximity to the target container

1.b_The temporary linkage of the target container identity (ID) to the TT identity which transports that container

2. The second phase of the Valencia tackles the Container Positioning System (CPS), specifically:

2.a_The transmission of the target container ID from the TT transporting it to the RS assigned to stack it

2.b_The target container positioning in the stack

All stages of the first phase are described in detail in what follows:

1.a_The decision-making regarding the TTs assignment depending on their proximity to the target container

The first part of the Valencia Pilot for the truck positioning allows automating the operational decision-making of TTs assignment depending on how near they are to the target container, minimizing the distance travelled by the TT fleet. This part of the Valencia Pilot consists of the following steps (Fig. 2):

1) (2 or more) TTs are fitted with a DGPS receiver and a screen (integrated in the Valencia Solution)
2) The DGPS receiver transmits the position of those TTs in real-time to the ITMS
3) The ITMS manages that information in order to identify the closer TT to the target container (of which position is also known by the ITMS) and assigns it to carry out the operation.
4) The ITMS sends the job order to the assigned TT (position of the target container)
5) The ITMS updates the status of the TT (now assigned, previously free)
6) The assigned TT executes the job order (goes to the target position)
7) The status of the TT can be: free, assigned or loaded.

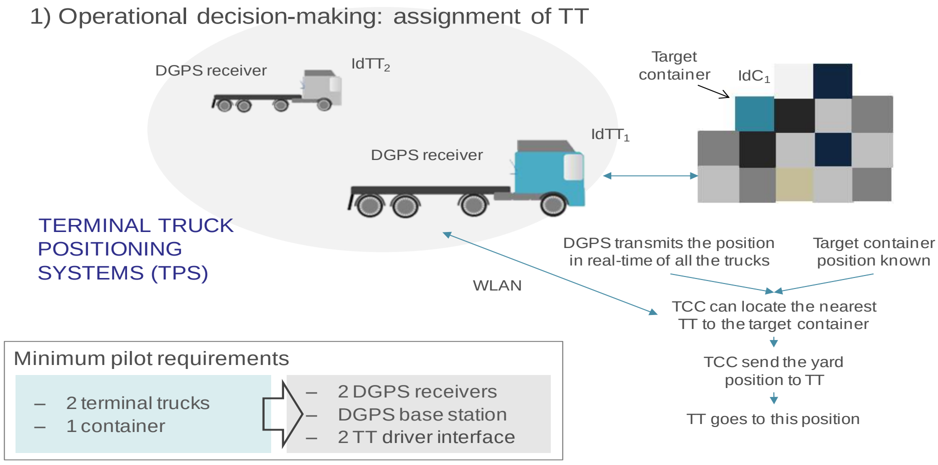

Figure. 2. Decision making: assignment of the TT

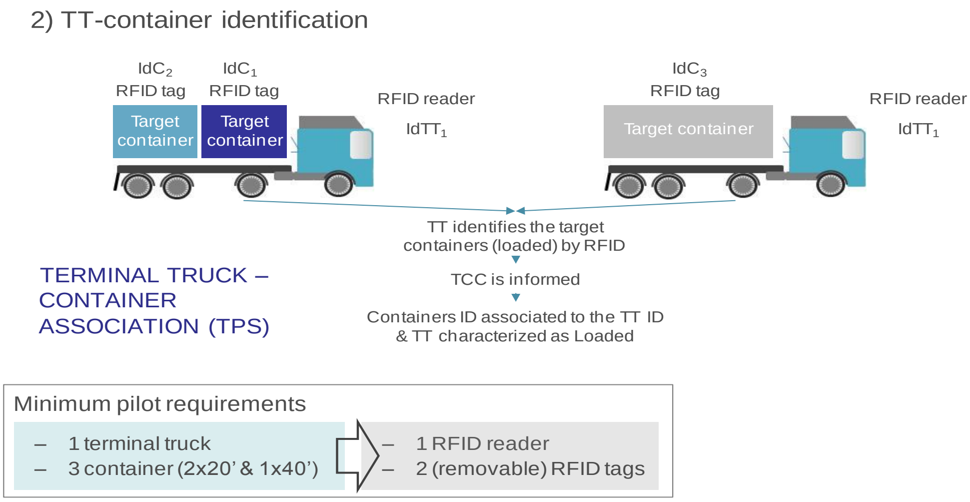

Figure. 3. Temporary linkage of the target container ID to the TT ID which transports it

1.b_Temporary linkage of the target container identity (ID) to the TT identity which transports that container

The second part of the Valencia Pilot for the truck positioning allows automating the linkage of the target container identity (ID) to the TT identity which transports that container, improving the traceability of the container inside the terminal facility. This part of the Valencia Pilot consists of the following steps (Fig. 3):

1) The assigned TT is fitted with an RFID reader (integrated in the Valencia Solution)
2) The target container is provisionally fitted with a RFID tag and the tag is temporary linked to the target container ID
3) The RFID reader of the TT identifies the target container and transmits this data to the ITMS
4) The ITMS links the target container ID to the TT ID which transports it
5) The ITMS updates the status of the TT (now loaded, previously assigned)

2.a_Transmission of the target container ID from the TT transporting it to the RS assigned to stack it

The first part of the Valencia Pilot for the container positioning allows automating the transmission of the target container ID from the TT transporting it to the RS assigned to stack it, avoiding errors and guaranteeing the traceability of the container inside the terminal facility.

This part of the Valencia Pilot consists of the following steps (Fig. 4):

1) The target container ID is previously linked to the TT transporting it (part 1.1.b of the Valencia Pilot)
2) The TT transporting the target container is fitted with a DGPS receiver and a screen (integrated in the Valencia Solution)
3) The RS assigned to the operations is fitted with a DGPS receiver, a CAN Bus reader, a RFID reader and a screen (integrated in the Valencia Solution)
4) The ITMS sends to the TT transporting the target container and the RS assigned to the operations their respective job orders (target position for the target container)
5) The TT transporting the target container and the RS assigned to the operations go to the target position in order to execute their respective job orders
6) The DGPS receiver transmits the position of the TT and the RS in real-time to the ITMS
7) The RS assigned to the operations takes the target container initially loaded on the TT
8) The CAN Bus reports to the ITMS when the RS twistlocks are closed
9) The ITMS saves the TT and RS position when the RS twistlocks are closed
10) The ITMS links the target container ID to the RS and releases the TT thanks to the temporary “coincidence” of coordinates (X, Y) of the RS and the TT on the terminal map
11) The ITMS updates the status of the TT (now free, previously loaded) and the RS (now loaded, previously unloaded)
12) Additionally, since the RS is also fitted with a RFID reader (integrated in the Valencia Solution), the target container ID can be double checked by a process similar to the one described in the section 1.1.b
13) If the double check shows that the container being stacked differs from the target container, the ITMS displays there is an exception that needs to be managed.

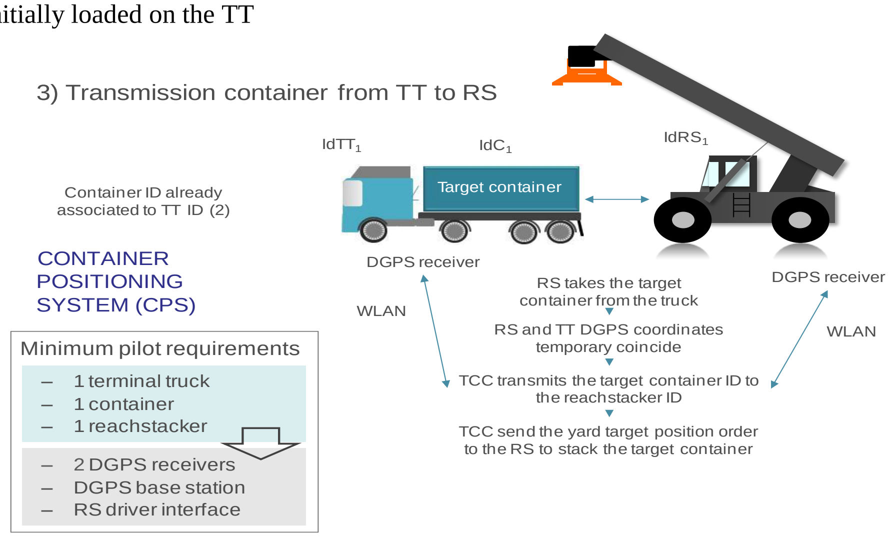

Figure 4. Transmission of the target container ID from the TT transporting it to the RS assigned to stack it

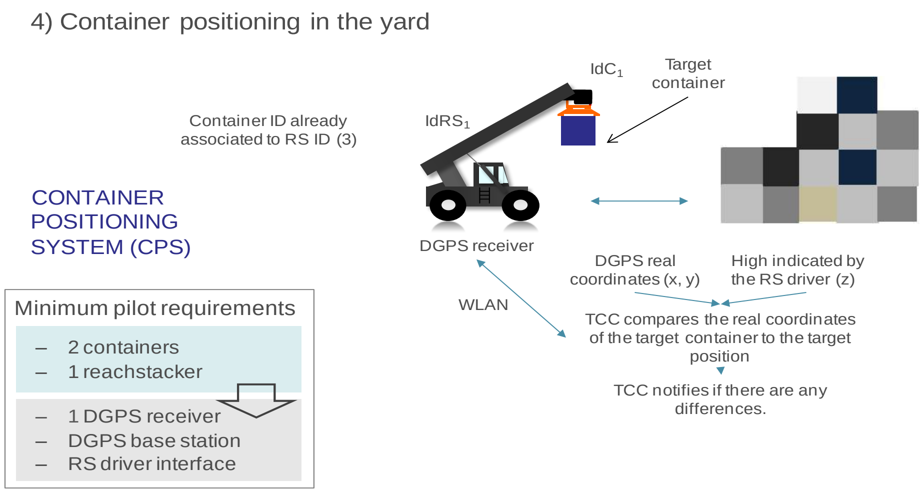

Figure 5. Target container positioning in the stack

2.b_Target container positioning in the stack

The second part of the Valencia Pilot for the container positioning allows automating the Target container positioning in the stack, avoiding errors and guaranteeing the traceability of the container inside the terminal facility.

This part of the Valencia Pilot consists of the following steps (the reader is referred to Fig. 5):

1) The target container ID is previously linked to the RS loading it (part 2.a of the Valencia Pilot)
2) The RS assigned to the operations is fitted with a DGPS receiver, a CAN Bus reader and a screen (integrated in the Valencia Solution)
3) The RS assigned to the operations has already received its job order regarding the target container from the ITMS (target position for the target container) (part 1.2.a of the Valencia Pilot)
4) The DGPS receiver transmits the position of the RS in real-time to the ITMS
5) The RS releases the target container in the target position in the stack
6) The CAN Bus reader reports to the ITMS that the RS has released the container: twistlocks opening and Z coordinate
7) The ITMS saves the coordinates (X, Y, Z) of the spreader of the RS when it has released the target container
8) The ITMS calculates the position in the stack belonging to those coordinates
9) The ITMS compares the final position of the target container in the stack to the target position
10) If both positions agree, the ITMS links the target container ID to that position in the stack and releases the RS.
11) The ITMS updates the status of the position in the stack (now occupied, previously free) and the RS (now unloaded, previously loaded)
12) If the final position in the stack differs from the target position, the ITMS displays there is an exception that needs to be managed (back to step 10)

III. INTE-TRANSIT MANAGEMENT SYSTEM

The INTE-TRANSIT management system (ITMS) is a low-cost, yet high accuracy client-server system, suitable for improving the efficiency of port terminals, such as the Valencia port terminal, through an enhanced monitoring of the containers as well as of the yard equipment (trucks, straddle carriers, reach stackers, etc). Its ultimate objectives are an efficient and accurate management of the storage procedure of containers inside a port terminal area at a minimal cost and an always up-to-date inventory of the stored containers. These functionalities are combined with a user-friendly visualization tool for yard equipment positioning and jobs, which offers various and configurable mapping capabilities, a container search functionality and remote access for the system operator in almost real-time.

In order to meet the aforementioned requirements, the ITMS consists of several well defined layers of operation; each of these layers of operation should operate independently, while also having the ability to robustly communicate with its neighbouring layers, designed to ensure efficiency and reliability under heavy workloads. The architecture layers are described in what follows:

- **The user management endpoints** consist of all GUI enabled client software, designed to support all management and monitoring activities of the ITMS remotely or locally, through a secure connection to the ITMS via a middleware (secure web service provider). In Section IIIA, a detailed functionality of the visualisation/GUI software is described.
- **A middleware gateway** is designed to maintain all information exchange activities between the user management endpoints and the core software of the ITMS through the utilization of secure web service calls.
- **A core software agent** implements the "business" logic of the ITMS, maintains a connection to a Data Base Management Server (DBMS) in order to store and manage container and yard equipment positioning and identification information. It also implements all the required communication interfaces for the exchange and translation of data between all data sources (RFID, DGPS, DBMS, GUI).
- **The hardware management endpoints** include all the client software required to maintain the interconnection between the hardware elements that retrieve information (DGPS receivers, RFID readers) and the core software of the ITMS.

A. ITMS Server GUI

The ITMS server GUI presented in **Figure 6** has been developed in such a way so as to provide the end-user with useful information and the same time to be user-friendly in its usage. For that reason, the GUI has been organized into five sections:

1) **The "Connectivity Status" area:** In this area the user is being provided with information about the current network connection status of the server. Both the Control and DGPS modules are referenced in this area. Also, in this section the server provides the user with information about the connected client terminals as well as the connected DGPS modules. The user has the option to select between the connected client terminals and view specific information about a particular vehicle.
2) **The "Drawing Bay" and the "Map Settings" area:** In this area the Server provides the user with the options of drawing the Bay Areas of the selected Container Terminal as well as moving the GIS Map's view to that particular Terminal. The drawing procedure of Bay Areas is based on the actual coordinates of every Bay, giving maximum viewing and calculating accuracy.
3) **The "GIS Mapping" area:** In this area the Server displays the GIS Map where all the current activity of the entire ITMS is displayed. Every connected vehicle is spotted on the GIS Map in real-time and the user is provided with information about a vehicle's current job status, location, assigned container etc.

4) **The "Message Log" area.** In this area, the Server keeps a log file with information about the exchanged communication protocol frames between the Server and every connected Client. The operator of the ITMS server may hide this area or make it visible depending on whether they want to operate it in debugging mode or in a normal operations mode.
5) **The "Container Search" area.** This feature gives the ability to an administrator user to collect information about a specific container through the ITMS Server's GUI and can be used for container planning, tracing and monitoring purposes. The Container Search engine is implemented through an interactive form where the user has the following options:
6) **Apply Search Filters** : The user is given the option to apply search filters based on their needs. Depending on the applied filters the search engine will make queries from different points of the database (i.e. stored or pending containers). Furthermore, the search engine can make queries for currently assigned / on-going containers.
7) **Enter a keyword:** The search engine asks the user for a specific keyword to look for (i.e. a container ID).
8) **Search by Container or Location ID:** The user is also given the option to search either by Container ID or by Location ID. In this way the search engine is more flexible and the user can retrieve information like which container is stored (or is to be stored) at a specific location of the Bay Area.

B. ITMS Server Core Software Agent and Middleware Gateway Modules

The core software agent which is the 'brain' behind the ITMS server encompasses different functionalities. In particular, it maintains, through threads, a set of socket network interfaces responsible of connecting with local and remote data sources. This module maintains permanent socket connections with the terminal clients as well as socket connections that expire after a certain time.

Moreover, it includes a TPS module, which is responsible for assisting the positioning of trucks and reach stackers inside the port terminal yard. In particular, it coordinates (by correlating the retrieved location and identification data to actual coordinates and equipment IDs) the terminal client devices inside trucks and reach stackers during their operation of assisting the proper storage of containers inside the designated areas of the port. The positioning data received by DGPS modules and the container identification information received by the RFID readers is cross-referenced with block/bay/row grid data and equipment ID information stored in the database.

In addition, the core agent includes a 'business logic' module which is responsible to make optimised decisions for the best use of inventory space and management of cargo containers. Moreover, a storage controller module ensures the storage of data in the Data Base Management Server (DBMS) as well as performs integrity checks (prior to storage) so that erroneous or corrupt data is discarded. Finally, an auditing/logging functionality is supported, offering to the server administrator different levels of detail.

On the other hand, the middleware gateway is actually in its most part a web application server written in Java, implementing SOAP [6]-based web service calls. The motivation between using web service calls in the gateway is that any part of the application outside the port authority's ITMS closed network and wishing to access it, will need to invoke (after passing through OpenSSL [7] based authorisation) web service calls in order to complete the transactions. Moreover, the gateway also serves in this application server in order to do so. Data conversion module: Responsible for data formatting and conformance. This module is responsible for the necessary conversions between different data formats to avoid misinterpretation of data. This module will provide the required functions to convert data when necessary to the end user or the system itself.

C. ITMS Valencia Pilot Terminal Client

The client terminal hardware designed for the Valencia Pilot (also referred to as the Valencia Solution) consists of several modules interconnected to allow the correct and efficient work of the Valencia Pilot. Those modules have the following features:

- A screen terminal
- A RFID reader
- GPS or DGPS receiver
- CAN Bus reader
- Storage system for data
- AC/DC I/O port
- Wi-Fi transmission technology; plus complementary GPRS

Apart from those modules, the Valencia Solution includes the development of the software client which exchanges messages and commands with the ITMS. Apart from the requirements detailed in the description of the Valencia Solution modules, it also has to fulfill the ones described in Table I:

TABLE I. VALENCIA SOLUTION MODULES REQUIREMENTS

Module	Requirements
Touchscreen terminal	Robust industrial touchscreen terminal (IP65[1]), operating with Windows CE, 7 and XP.
RFID reader	RFID technology with range enough to read a tag deployed on the second 20' container loaded in a TT. Able to eliminate noises coming from other RFID tags inside the RFID reader range, but not belonging to the containers the TT is transporting, if any. Advisable to combine the RFID reader with a complementary detection technology that notices the presence of the containers on the TT platform, such as a laser sensor. Therefore, the RFID technology works in a more efficient mode since it is not continuously reading and transmitting information; just when the detection technology is

[1] Degree of protection provided according to the International Standard IEC (International Electrotechnical Commission) 60529.

	activated.
GPS or DGPS receiver	GPS or DGPS technology with accuracy of 1 m (enough to differentiate 2 consecutive container positions in parallel in a stack) and reliability of 90% minimum to determine the spreader position. Located on the spreader, to avoid using a gyroscope to convert the receiver coordinates to the spreader[2] coordinates.
CAN Bus reader	J1939 CAN Bus reader to decode information regarding the RS operating, such as the boom extension and angle in order to calculate the Z coordinate of the spreader, and detect the opening and closing of the twistlocks so it is known when the container is released.
Storage system for data	Capacity enough to storage the data produced for a month.
AC/DC I/O port	In case it is necessary to incorporate lights, sensors or buttons for the Pilot demonstration, such as the laser sensor for the RFID readers.
Transmission technology	Wi-Fi technology, plus complementary GPRS technology to solve the potential lack of Wi-Fi signal due to the shadow projected by the stacks. Data acquisition time less than 0.8 s and time between transmissions less than 1.5 s.

IV. Valencia Pilot Results & Lessons Learned

The main challenges faced in Valencia Pilot were:

- Valencia Pilot aimed to test the available technologies for container traceability and interaction with a central server that manages and controls operations
- A DGPS system has been tested in real conditions inside a difficult environment (high bulk metallic canyons).
  To sum up, both AGPS (Assisted-GPS) and DGPS have been deployed for improving positioning challenges in real environment. As a result of preliminary tests, industrial AGPS has been chosen. In both cases however, a 2.5m error is expected most of the time
  Position of the GPS antenna is a real challenge as far as the Reach Stacker is concerned because of its telescopic boom. In addition, a local DGPS station has been mounted in the terminal for improving local correction of GPS disturbances. A 1m error is expected most of the time. Nevertheless, problems expected when the GPS antenna is enclosed between high metallic surfaces
- Analyzing and selecting between active RFID or passive RFID. Testing the number of tags and RFID antennas which were necessary as well as their positions.
  Active RFID has been discarded for this pilot due to its inherent need of maintenance (batteries).
  One passive RFID tag per container is a low cost solution and could be economically viable. As a result of identification of a container with only one RFID tag attached, more than one RFID antenna per machine was needed.
  Furthermore, the maximum range (more than 10 meters) with RFID passive tags is reached with high power UHF tags (2W @ 865-868MHz).
  Considering than, it is necessary to attach RFID antennas without compromising the machine's operation.
- An industrial Panel PC with a 3G router + WiFi client has been connected to external Server and internal Terminal Operator System (TOS), achieving uninterrupted but low-cost communications.
  The WiFi layout could have “shaded” areas for small moving machinery like TT and RS between metal canyons, whereas 3G mobile communication is available but could be expensive if heavily used (due to data traffic charges).
  Therefore a dual parallel communication has been tested: a 3G router, an Ethernet switch and the WiFi client working at the same time
- Translation to a cartographic system of new layers for container location. A GUI interface was proposed for human operators of the yard equipment that includes a cartographic presentation of the locations involved in the process (target position, current position…)

As a conclusion, it has been demonstrated that low-cost RFID passive tags can be used for containers identification. When all the containers of the terminal will be tagged, simple software algorithms would refuse tags detected but not being involved in operation and with a proper Management System this working method will produce big improvements in container's traceability and intra-port movements.

V. Conclusions

The primary objectives of container tracking are physical localisation and consequently terminal process optimisation. Nowadays, this inspection is mainly performed by human operators. In the framework of the INTE-TRANSIT project, the hardware solution adopted for the implementation of the client terminal in Valencia Port pilot was implemented and presented in this paper, based on a low-cost implementation of (D)GPS and RFID technologies. On the other hand, the software architecture including all architectural elements of the ITMS designed for the purposes of INTE–TRANSIT was presented in detail, illustrating the open and modular system design principles followed. The main purpose of the ITMS is to obtain-retrieve data (container identification, truck id information, positioning data, control actions status) from all communication endpoints such as DGPS receivers, RFID readers, CAN Bus readers; managing the storage procedure of a container inside the storage areas of the port authorities and also keeping a detailed inventory of the stored containers while also providing the ability to a remote user having all this information properly displayed and visualized inside a GUI.

[2] The spreader is the part of the RS that captures the container, so the container coordinates are the same as the spreader coordinates.

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