I-READ 4.0: Internet-of-READers for an efficient asset management in large warehouses with high stock rotation index

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***Abstract*—The I-READ 4.0 project represents an integrated and autonomous Cyber Physical System, for automatic management of very large warehouses with high-stock rotation index. Thanks to an internet of UHF-RFID readers, both fixed and mobile, it is possible to implement an efficient management of assets and forklifts operating in indoor scenario. The proposed solution can be employed independently on the warehouse sizes, the good types and the spatial resolution required for item localization by virtue of its low-cost, reconfigurability and scalability. The I-READ 4.0 system allows also to increase the safety levels of the human operators within the warehouse.**

Keywords—RFID Industry 4.0, Internet-of-Things, Internet-of-readers, I-READ 4.0, Pallet localization, RFID Warehouse, UHF-RFID Technology.

I. Introduction

Within the new paradigm of the Industry 4.0 [1] the Internet of Things, namely the network of items able to exchange their own information through internet, represents an enabling technology. In particular, the knowledge of item presence and location within the warehouse represents a key point when deploying automated solutions for smart factory. A real-time inventory allows improving the production activities with a proper planning based on the market demand. Besides, the position information allows optimizing the item placement during the storage and the forklift paths during the loading/unloading operations with a consequent improvement of operator work and safety.

In such framework, the Radio Frequency Identification (RFID) technology received great attention to develop smart warehouses [2]. In particular, the passive Ultra High Frequency (UHF) RFID technology represents a good solution to implement a real time inventory by virtue of its low cost and easiness of installation. Unlike RFID systems at lower frequencies, it guarantees a reading range of several meters. Moreover, the wide-beam reader antennas allow managing many tags at the same time thanks to the anti-collision algorithms implemented in the EPC Global Class1 Gen2 protocol [3]. Thanks to the last generation chip, the tag reading range can reach 10 meters and beyond, thus the passive UHF-RFID technology represents a promising solution also to

implement Real Time Locating Systems (RTLS) in indoor scenario.

The authors of this paper within the project I-READ 4.0 [4], funded by Regione Toscana, propose an integrated and autonomous Cyber Physical System, for automatic management of large warehouses. The system consists of an internet of UHF-RFID readers, hence the name I-READ, to implement an efficient management of assets and forklifts in very large warehouse with high stock rotation index. It allows also to increase the safety levels of the human operators within the warehouse.

The proposed solution is based on the implementation of a network of UHF-RFID readers, both fixed and mobile, able to collect automatically data related to identification code, position and status of pallets within warehouses at high rotation index. The main technological elements consist of UHF-RFID Smart Gates and UHF-RFID Smart Forklifts. The Smart Gates are fixed readers able to detect pallets entering or exiting from the areas of interest. Besides, the Smart Forklifts are equipped with UHF-RFID readers able to auto-localize themselves by exploiting data from UHF-RFID reference tags in the scenario and then to localize the tagged pallets in the indoor warehouse. The system is low-cost, reconfigurable, flexible and scalable independently on the warehouse sizes, the good types and the spatial resolution required for item localization.

The paper is organized as follow. Section II summarized the state-of-the-art of wireless technologies typically employed for indoor localization in warehouse scenario. Section III describes the infrastructure of the I-READ 4.0 project and Section IV shows some conclusions.

II. State of the Art

To implement indoor localization several technologies can be adopted [5].

A. Wi-Fi

The widespread solutions are based on Wi-Fi technology since they can exploit the infrastructure already present in any building. The Wi-Fi solutions can employ a fingerprinting approach based on the knowledge of the signal amplitude in a grid of points. In such case, the target position is determined as the position of the grid point with the closer received signal strength (RSS) value. Performance is strictly dependent on the density of the point grid, the greater the point number is, the higher the calibration cost becomes. Besides, any scenario modification requires for a new acquisition of RSS in the point grid. Among commercial systems there is that by *Infsoft* [6] which allows to get a localization precision between 5 m to 15 m, depending on the application scenario.

Other Wi-Fi systems exploit the knowledge of the access point positions [7]. In such case, the target position is estimated through the proximity techniques, the centroid method or the determination of a radio-propagation model. They are easier to apply and widespread despite of a worst localization accuracy.

B. Bluetooth

Bluetooth technology is a further solution to create indoor localization systems. The beacons are small and easy to install, they have a cost of the order of few euros. Furthermore, many modern devices (e.g. smartphones) support Bluetooth technology. The latest generation beacons have reduced power consumption (Bluetooth Low Energy, BLE) and the battery life reaches up to five years. Similarly, to Wi-Fi solutions, the localization occurs through fingerprinting or multilateration techniques by the knowledge of reference beacon positions. By using an appropriate beacon amount, the localization resolution can be in the order of the meter but in a greater time compared to Wi-Fi. Among commercial systems based on Bluetooth technology there is the *Goindoor* system [8]. It obtains a localization error of around 2 m by employing 121 beacons within an open space of around 10000 m^2, while by reducing the beacon number to 36 the localization error becomes 5 m.

C. UWB

The Ultra Wide Band (UWB) technology allows to get centimeter-order precision when deploying indoor localization system. Thanks to broadband transmitted signal, the UWB systems do not suffer from interferences of other systems in the scenario. Besides, the short-time pulses reduce the battery consumption of UWB tag. The main drawback is represented by the high cost of the UWB devices. Differently from Wi-Fi and Bluetooth systems, the UWB systems exploit the time-of-flight to determine the target distance through time-of-arrival or time-difference-of-arrival techniques. After distance estimation from several UWB anchors, the target position can be determined through multi-lateration or triangulation techniques. Localization accuracy is affected by the multipath propagation typical of a crowded indoor scenario, the synchronization between UWB anchors, the error in the determination of the antenna phase center (centimetric wavelength), and the sampling interval [9].

Among the main manufacturers of UWB devices there are *Time Domain* and *Decawave*, while among the commercial systems it is noteworthy the *OpenRTLS* [10] which guarantees a localization error of around 10 cm at a distance greater than 1 km with a cost of 3-11 € per square meter.

D. RFID

During the last years, the UHF-RFID technology is gaining increasing to perform indoor localization. The first systems involved active RFID tags, which allow a reading range of hundreds of meters. Among the most known solutions, we mention *SpotON* [11] and *Landmarc* [12]. However, passive UHF-RFID technology represents a more attractive solution for RTLS in virtue of its low cost and low-effort maintenance. Localization with passive RFID systems typically exploits the Received Signal Strength Indicator (RSSI) parameter. The main methods are based on “distance estimation” or on “scene analysis” [13]. In the first case, the RSSI model is related to the tag-reader distance and the mobile node position is estimated through a multi-lateration approach. In the “scene analysis” methods, a scenario map is built by measuring the RSSI parameter from several reference tags. Then, the position is determined using a *k-Nearest Neighbor* approach, despite of a long calibration procedure, which is scenario-dependent. Furthermore, all amplitude-based methods are strongly dependent on the tag typology and the multipath propagation with a typical localization error in the order of few meters.

Modern UHF-RFID readers are also able to measure the phase of the tag backscattered signal, which allows for applying new localization techniques capable to locate passive

RFID tags with decimeter accuracy in real scenarios [14]. In particular, the main techniques exploit the Phase Difference of Arrival (PDOA) of the tag backscattered signal, to mitigate the effects of the propagation channel [14]. The Time Domain PDOA method allows to estimate the radial speed of moving tags through phase measurements at different instants. This solution is robust in rich multipath scenarios, but a fine tag localization cannot be performed. The Frequency Domain PDOA method instead exploits the phase measurements at two or more frequencies to estimate the tag distance. It can be applied for both moving and stationary tags being similar to the Frequency Modulation continuous-wave radar [15]. However, it suffers from the limited bandwidth of RFID systems, especially in Europe (ETSI band 865-868 MHz). With the Spatial Domain (SD-) PDOA method, the Direction-of-Arrival of the tag signal can be measured by employing two or more antennas. As a result, the tag position can be determined from multiple distance/angle estimates, by applying multi-lateration or triangulation [16]. Among the SD-PDOA techniques, the methods which exploit the relative motion between the tag and the reader, the so called Synthetic Aperture Radar (SAR) approaches [17], are particularly effective. The antenna can be moved through a handling system [18], an Unmanned Grounded Vehicle [19] or an Unmanned Aerial Vehicle [20]. In the specific case of mobile node or vehicle localization and tracking, it is common to combine phase data coming from RFID tags together with measurements from other sensors such as encoders, accelerometers, magnetometers, or gyroscopes [21]. Such methods can be classified as *data fusion* methods, and rely on sequential estimators such as the Kalman Filter.

III. The I-READ 4.0 Infrastructure

The I-READ 4.0 system was designed to work in warehouses of area greater than 10000 m^2 and with an average handling of 1000 pallets per day, as for that of the *Sofidel* paper industry in Porcari, Lucca [22].

The framework of the I-READ 4.0 system is depicted in Fig. 1. The main technological elements are the Smart RFID Gate and the Smart RFID Forklift.

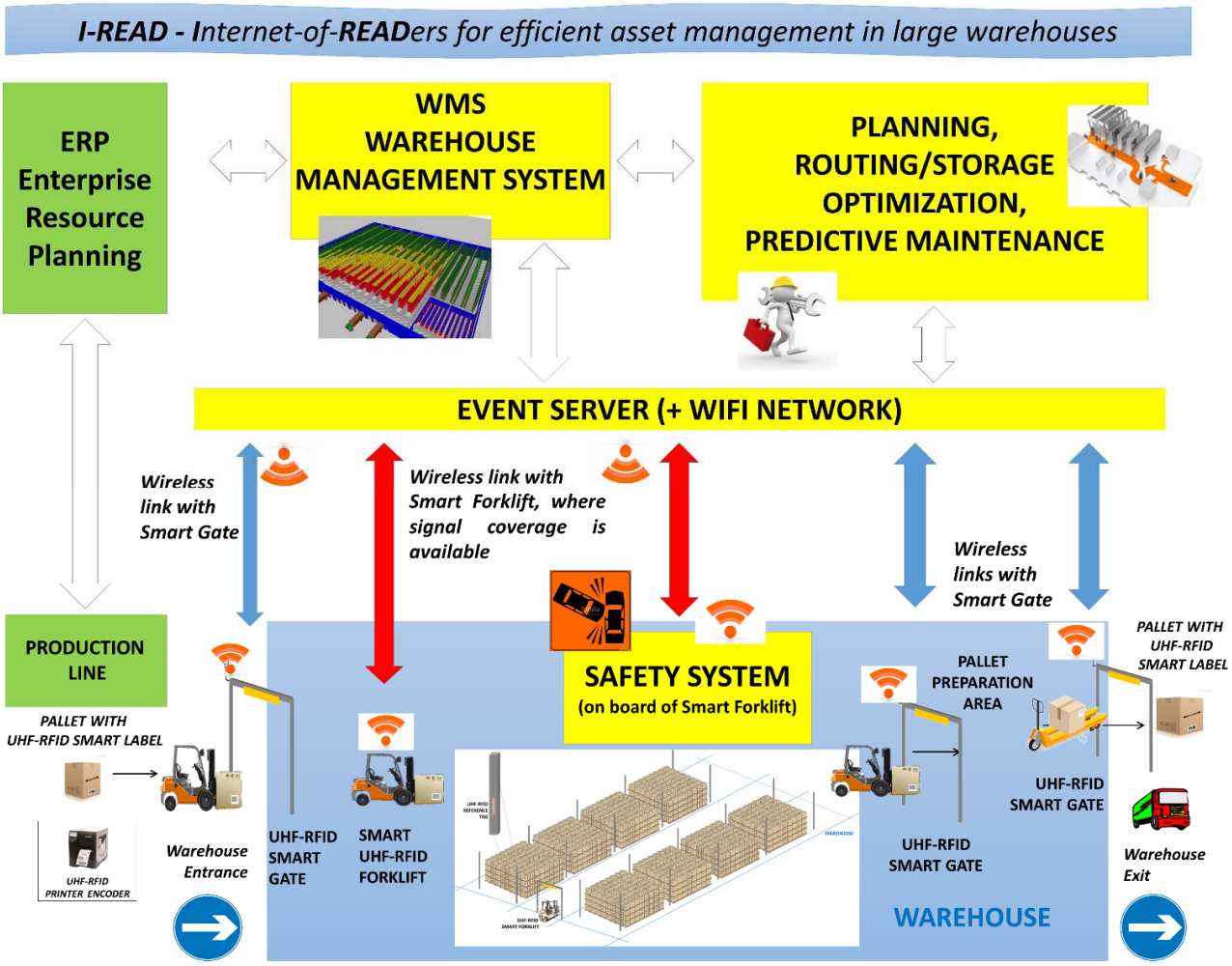

Fig. 1. The I-READ 4.0 infrastructure.

A. *Smart RFID Gate*

The Smart RFID Gate (SRG) consists of a UHF-RFID reader connected to a single wide-beam antenna (Fig. 2). It is placed in several points of interest within the indoor warehouse scenario: at the entrance of the warehouse storage area, at the entrance of the preparation area in front of each loading bay, and in correspondence of each warehouse loading doors. The SRG implements a classification algorithm able to discriminate the pallets entering, exiting or passing close to the gate without crossing it. At the main entrance, the SRG task is to certify the real entrance in the warehouse of the pallets coming from the production stage. At the entrance of the preparation area the gate has to certify the pallets which are prepared for the delivery by avoiding a manual scanning of the operator typically employed when using barcode system. At the entrance of the loading doors, the SRG has to certify the real loading of pallets in the truck. While in the first two cases, pallets are transported by the forklift, in the last case, they are carried out by the human operator with the trans pallet. Ultimately, the SRG allows the determination of the pallet state that could be "in entrance" to the warehouse, "in the preparation area" or "loaded" in the truck. A processing unit is also present within the SRG which implements the classification algorithm and send the data to the Event Server through the Wi-Fi infrastructure.

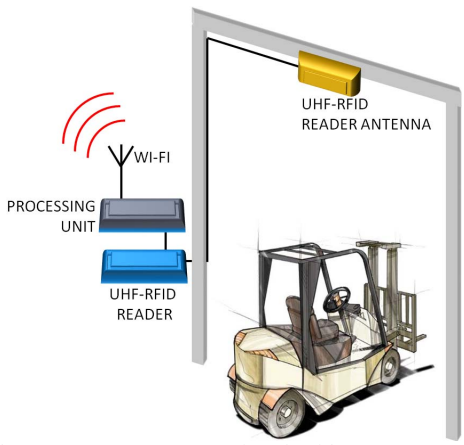

Fig. 2. The Smart RFID Gate equipped with UHF-RFID hardware, a processing unit, and Wi-Fi infrastructure.

B. *Smart RFID Forklift*

The localization system is realized by employing the forklift already present in the warehouse scenario and regularly used for pallet handling. To realize the Smart RFID Forklift (SRF), the latter is equipped with commercial UHF-RFID hardware, kinematic sensors, a processing unit, an interface with the operator (*i.e.* touch screen display) and a wireless device for data transmission through the Wi-Fi infrastructure. In particular, a UHF-RFID reader is installed on the forklift and connected to two antennas. The antenna placed close to the forks has a limited detection range and it is used to detect the tagged pallets during the loading/unloading operations. The antenna on the rooftop is a wide-beam antenna employed to detect the reference tags placed at the ceiling (Fig. 3) and employed for the localization system.

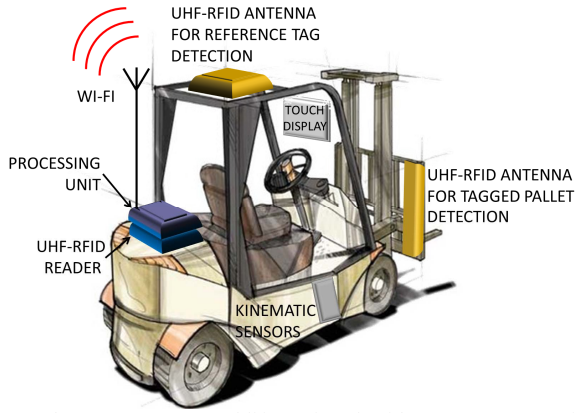

Fig. 3. The Smart RFID Forklift equipped with RFID antennas for the detection of reference tags and of tagged pallets, RFID reader and inertial sensors.

In more details, the complex backscattered signal by the reference tags are combined with the data of acceleration and velocity measured by the kinematic sensors. Through a *data fusion* algorithm, the forklift position during its journeys and operations is determined. Thus, the pallet position within the warehouse is determined by the forklift position at the time of pallet unloading. The localization algorithm is implemented within the processing unit. Each SRF sends its position to the Event Server together with the status and position of all pallets detecting during its operations, in a completely transparent way to the operator. Such data are temporary stored in the processing unit and send when there is the Wi-Fi coverage.

The main advantage of the proposed RFID-based localization system is that it does not required a fixed infrastructure of active devices with high density, but only a grid of passive reference tags at low spatial density.

It is noteworthy that the data related to the forklift routes and loading conditions can be employed to also perform predictive maintenance.

Besides, the RFID technology, the I-READ 4.0 project foresees also to employ the UWB technology as a further solution for SRF localization. In such case a fixed infrastructure of UWB anchors is installed within the indoor warehouse. Such alternative localization system will allow for a benchmark determination, to evaluate the benefit-cost ratio of the RFID localization system.

C. *Event Server*

The Event Server (Fig. 1) collects all data related to the forklift routes and to the pallet status and position, from SRG and SRF. In high-rotation warehouses, such server is designed to collect a very large amount of information in real-time. After that, the server sends the received data to a framework able to elaborate and format them for the other systems or business applications, at regular time intervals. Based on particular events, such a framework is also able to generate alarm signals or other events for warehouse management.

The Event Server exchanges information with the Warehouse Management System (WMS) connected to the Enterprise Resource Planning (ERP) and also with a system which deals with the optimization of pallet storage and forklift routes.

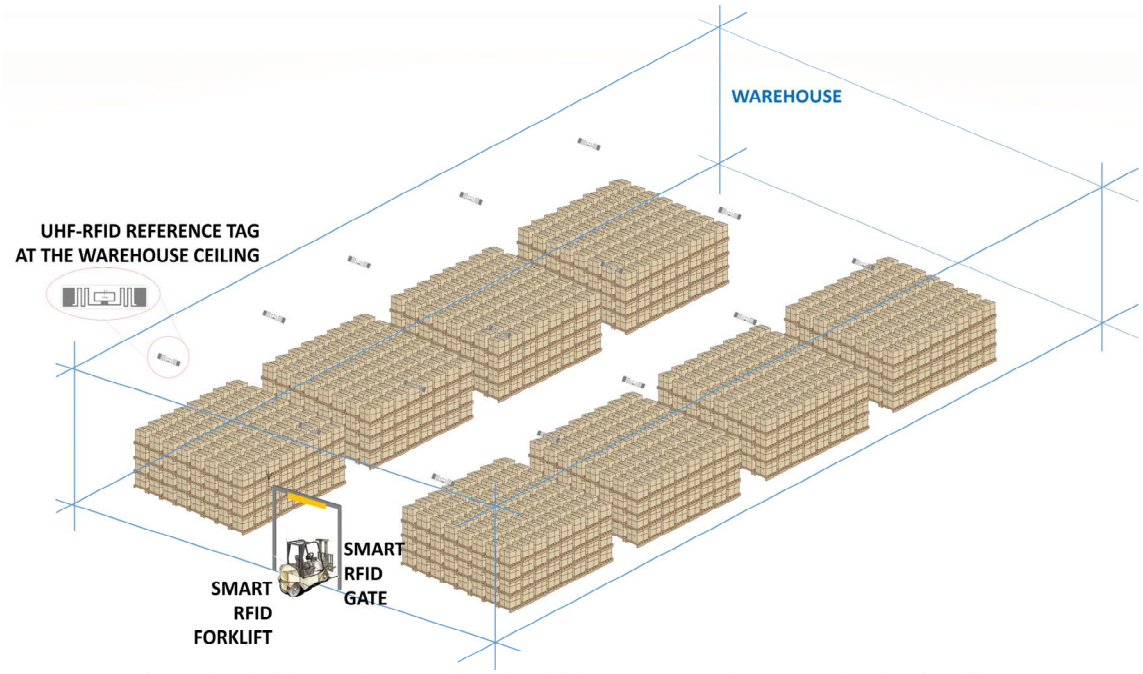

Fig. 4. Sketch of the warehouse (not in scale) with the UHF-RFID reference tags placed at the ceiling.

D. Safety system

Beyond the optimization of logistic processes within the indoor warehouse, the I-READ 4.0 project aims to improve the safety of human operators. The SRF is also equipped with safety devices developed by the Italian Company *AME* [23]. Such active sensors are able to detect a possible collision, namely near-miss, with walking operators also equipped with active devices and with other forklifts. The near-miss data are shown to the operator on the forklift display. Besides, they are sent to the WMS through the Event Server. Such near-miss events together with the knowledge of forklift locations are processed to elaborate statistics with the aim to determine the dangerous areas with high-collision risk.

Furthermore, the indoor localization system allows the development of advanced functionality as the geo-fencing. It is based on the definition of a virtual enclosure within which the forklift operations can be modified by sending messages on the display or by setting up the forklift speed. Such enclosure can be definable through the WMS and dynamically reconfigurable on the basis on warehouse status or day hour.

E. Partners

The I-READ 4.0 project was born from a need of the paper industry *Sofidel* [22], which is leader in the world trade. Besides several research groups of the University of Pisa, the partner network consists of small and medium enterprises such as *Ingegneria dei Sistemi Elettronici* (ISE) [24], *CAEN RFID* [25], *3logic MK* [26], and *Advanced Microwave Engineering* (AME) [23].

F. I-READ 4.0 features

The I-READ 4.0 system main features can be summarized as follow:

- Monitoring and control of warehouse management operations in a completely automatic way, through a constant information exchange with the ERP system.
- Optimization of forklift routes, pallet storage and warehouse housekeeping operations based on the company planning (production, shipments, arrivals) and the minimization/maximization of appropriate objective functions (e. g. forklift mileage, average time of pallet handling, etc.).
- Statistical analysis of near-miss events obtained from data on forklift localization and subsequent corrections on warehouse management to reduce the risk of collisions.
- Bidirectional transmission of data to the system involved in the real-time management of deliveries with low error rate.
- Predictive maintenance on the basis of data on forklift routes and their loading conditions.

The I-READ 4.0 system is actually under implementation and experimental results related to the Smart RFID Gate and the Smart RFID Forklift will be shown at the conference.

IV. Conclusion

In the framework of the Industry 4.0, the I-READ 4.0 system represents an integrated and autonomous Cyber Physical System, for automatic management of very large warehouses with high-stock rotation index. The proposed solution is based on an internet of UHF-RFID readers, both fixed and mobile, to implement an efficient management of assets and forklifts operating in indoor warehouse. Besides, it allows to increase the safety levels of the human operators within the warehouse.

The application scenario is a warehouse of the paper industry *Sofidel* with a warehouse area greater than 10000 m^2 and with an average handling of 1000 pallets per day. However, the proposed solution can be employed independently on the warehouse sizes, the good types and the

spatial resolution required for item localization by virtue of its low-cost, reconfigurability and scalability.

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