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A Model for Indoor Product Localization Based on the Internet of Things

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Abstract

Modern automated systems require integration of devices, products and systems to form a unique interconnected information system, referred to as the Internet of Things, which should enable constant tracking and data exchange among the connected objects and systems to provide adequate and timely information and enhance the possibilities for system control and supervision. One of the necessary requirements for the Internet of Things is knowing the location of objects. This paper presents a model based on the Internet of Things for estimating the location of products in industrial conditions and focuses on the implementation of RFID (Radio Frequency IDentification) technology and wireless sensor networks for object localization.

Key words: *Internet of Things, Localization, RFID, Wireless sensor networks*

1. INTRODUCTION

The Internet of Things (IoT) is a paradigm for a connected world of objects, where each object (product, device, system, etc.) has sensor, processing and communication subsystems that enable connecting and communicating among different objects [1]–[4]. Such objects are often referred to as “smart objects” or “smart devices”. The goal of the IoT is the creation of a unique network of smart objects, which would enable better and easier object identification, tracking, localization, and would lead to better utilization and optimization of the existing systems. Today many systems are being researched and developed to help the IoT paradigm, aiming to ease the living and working conditions, by providing adequate and timely information, easier tracking, monitoring and control of various systems. One of the prerequisites for the IoT systems is knowing the exact location of the object, especially when the required data is insignificant if it is not connected to a certain position, e.g. when measuring the environmental conditions in the object’s proximity [5], [6]. Localization systems for the IoT are also necessary in industrial conditions, during production, assembly, packaging, transport, storage of semi-finished products and products, distribution and retail, in order to provide accurate and precise information about the product’s position in real-time. There are many IoT technologies that can be applied for product localization, but today a great deal of localization systems rely on contactless and wireless technologies, such as RFID (Radio Frequency IDentification), Bluetooth, wireless local area networks (WLAN) or wireless sensor networks (WSN) [7]–[13].

The model presented in this paper provides a framework for a product localization system based on the IoT, and ways for integration of this system into the existing processes and the entire environment. The model is primarily designed for product storage locations, but with slight modifications it is applicable in production systems, assembly systems, transport systems, retail objects, etc. It could also be implemented for general localization of various objects, people or animals in an indoor environment. This paper presents the model in its basic form, i.e. for product storage locations. The proposed model is based on the IoT Reference Model, which is presented in section 2. Section 3 of this paper describes the proposed model for product localization based on the IoT, and section 4 gives the final comments and conclusions.

2. THE INTERNET OF THINGS REFERENCE MODEL

The IoT Reference Model [14] was presented at the Internet of Things World Forum in 2014. It is comprised of seven levels (Fig 1.) that provide a global reference frame regardless of the specific components and the application context, and shows how tasks at each level should be handled to maintain simplicity, allow high scalability and ensure supportability of the systems.

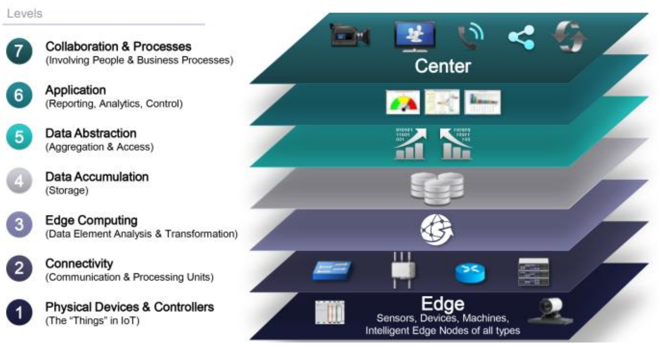

Figure 1. The IoT Reference Model [14]

The first level of the IoT Reference Model is the physical level, and includes objects that are “things” in the IoT, i.e. various end devices, sensors, actuators, machines, etc. The devices should be capable of A/D conversion as required, generating data and being queried and controlled over the net. The second level is the connectivity level that ensures communication between the devices. This level is also responsible for implementation of various protocols and translation between protocols, in order to ensure communication between different devices and parts of the system. The third level is the level of edge computing, and includes distributed processing and data transformation as early and as close to the edge of the network as possible, which is one of the prerequisites in IoT systems, where there are possibly high-volume data that should be filtered, cleaned up and aggregated in order to allow the higher levels of the system to deal only with the needed data. The fourth level provides data accumulation and storage, for parts of the system that do not need to process the data in real-time. The fifth level includes data abstraction, aggregation and access control. This level merges various formats of data and assures consistent data among the data sources, confirms that the data is complete, enables the data authentication and authorization in order to provide data protection, etc. The sixth level is the application level, which enables control of the system, analysis of the data and the system state, supervision and monitoring activities, reporting, etc. The highest, seventh level involves collaboration and sharing of the data between people and inclusion in the business processes.

As most IoT systems require bidirectional data flow, the IoT Reference Model assumes that the data for control of the system flow from level 7 to level 1, and the data for system monitoring flow in reverse, from level 1 to level 7.

3. THE MODEL FOR PRODUCT LOCALIZATION BASED ON THE INTERNET OF THINGS

The model for product localization based on the IoT is compliant with the IoT Reference Model, but includes specific technologies and methods for product localization in an indoor environment. Fig 2. shows the basic hierarchical structure of the model with the seven levels declared in the IoT Reference Model.

The lowest level of the model, the physical level (Fig 3.), defines the specific technologies and the devices required for the product localization. Analysis of different IoT technologies led to the proposal that two systems should be used in combination, an RFID system and a WSN. RFID technology is proposed since currently there are many products that are already labelled with RFID tags for product identification, thus there is often no need for attachment of additional labels to the products. Moreover, RFID systems are suitable for localization purposes as they allow contactless data acquisition within the antenna range, and there is no need for additional power supply as the RFID tags are passive and allow long-term functioning of the system without the need for maintenance of every tag. The model proposes individual labelling of each product with an UHF RFID label, as UHF systems have the largest read range. On the other hand, wireless sensor networks allow distributed data acquisition and transfer among large spaces, which is required when the products move through the system. Furthermore, WSN nodes can provide measurements and monitoring of the required parameters in their environment. The model proposes attaching a WSN node to each group of products, such as a pallet, container, transport systems, etc. Furthermore, if the products are transported through the system on longer distances, and the position does not have to be very accurate, then the system can use only the WSN data to track the group of products, in order to lower the cost of the system.

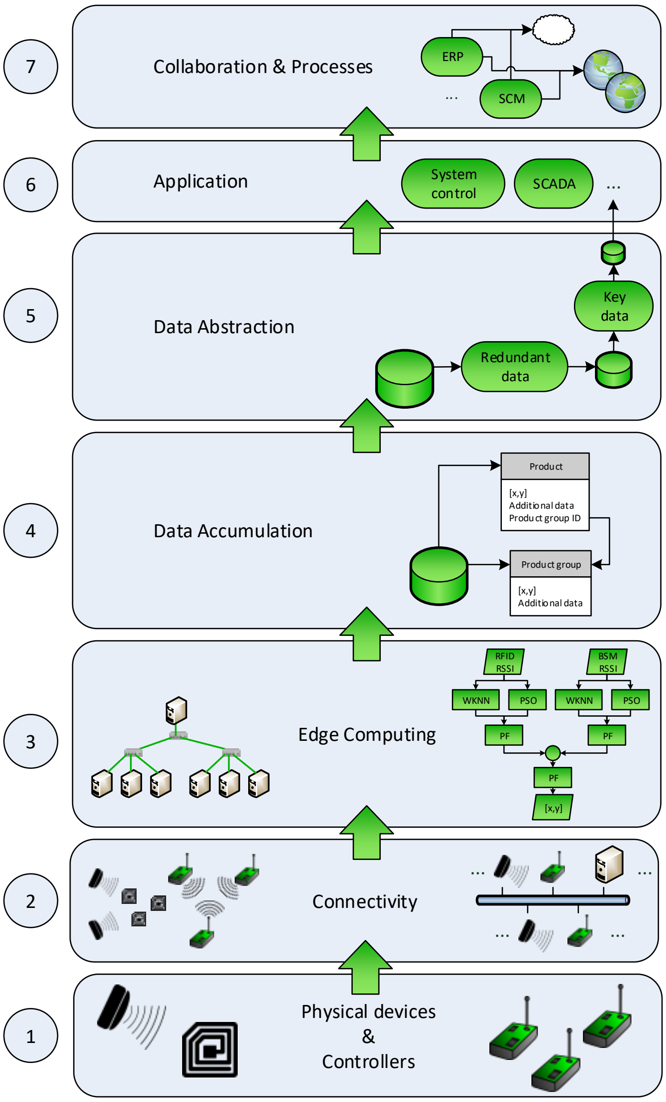

Figure 2. Basic hierarchical structure of the model for product localization based on the IoT

The first level of the model proposes installing stationary RFID reader antennas and WSN nodes which serve as reference points for communication with RFID tags and WSN nodes attached to the products. The reference points should be placed in corners of the square space in order to cover the corresponding square area for localization. If the space where the localization takes place is larger than the RFID antenna range, the space should be divided in smaller areas and new reference points should be set for each subspace.

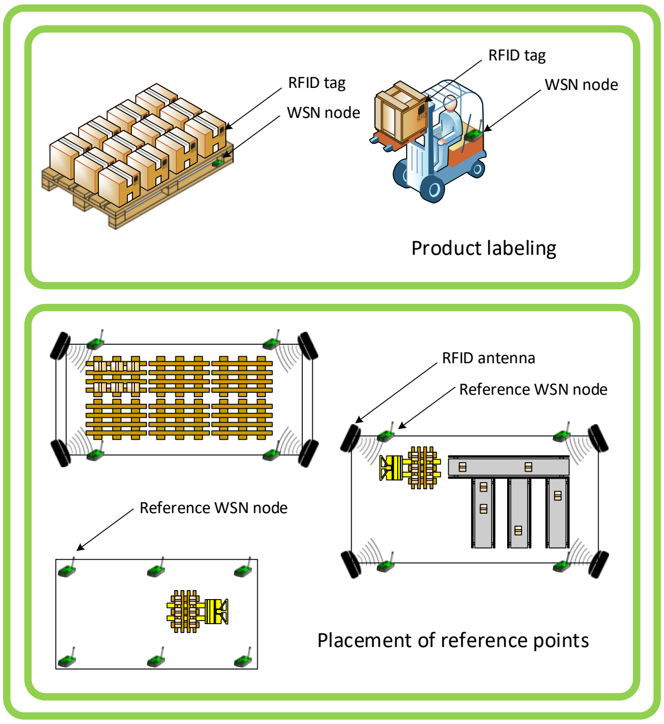

Figure 3. The first level of the model for product localization based on the IoT – Physical devices and controllers

The second level of the model, the connectivity level (Fig 4.), relies on communication between the reference points (WSN nodes or RFID reader antennas) in known stationary locations and the mobile WSN node attached to the group of products or the RFID label on the product itself that need to be localized. In the WSN each reference node communicates directly with the mobile node and receives the RSSI values along with the additional data if needed. In the RFID system, each reference RFID reader antenna reads the RSSI value from the tag attached to the product, as well as the additional data.

Furthermore, communication between the reference points and the control unit must be provided. This communication can be wired or wireless. The control unit communicates with the WSN nodes through a WSN collector, and with the RFID readers directly through a supported protocol.

The third level of the model, the edge computing level (Fig 5.), requires distributed data processing and transformation on the edge of the network. In order to achieve this, the model proposes a separate control unit for each subarea that could function as a distinct unit, which would provide the data acquisition and processing for product localization within the subarea, and then forward the data to the neighbouring control units and the central control unit of the system. This approach provides the modularity of the system, simple addition of new subareas or activating/deactivating parts of the system as needed. Moreover, this makes the subsystems independent of each other, thus allowing integration of equipment from different vendors and different communication protocols.

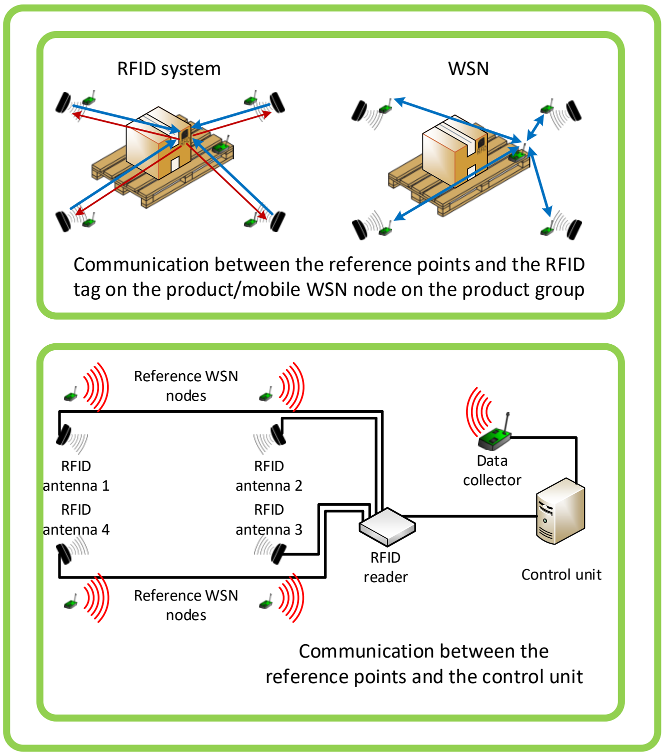

Figure 4. The second level of the model for product localization based on the IoT – Connectivity

This level also defines the method for data acquisition and processing, i.e. the method to be used for product localization. A hybrid method is proposed, which estimates the product's position separately in the RFID system and the WSN, and then performs data fusion of the acquired data. In each of the two systems, the hybrid method first fuses data acquired by two different methods – a weighted *k* nearest neighbour (kNN) method and a localization method based on particle swarm optimization. The proposed method for data fusion is the particle filter, which additionally integrates the previous estimated positions and thus improves the localization precision and accuracy.

The fourth level of the model, the data accumulation level (Fig 6.), includes integration and storage of the localization data from level three into a central database of the system. This level makes a systematization of data acquired from different parts of the system, and enables further access to the higher levels. The database in this level allows transition from the real-time data from the first three levels into stored data that can also be accessed later by different applications in higher levels, as needed. The database is also directly connected to the central control unit.

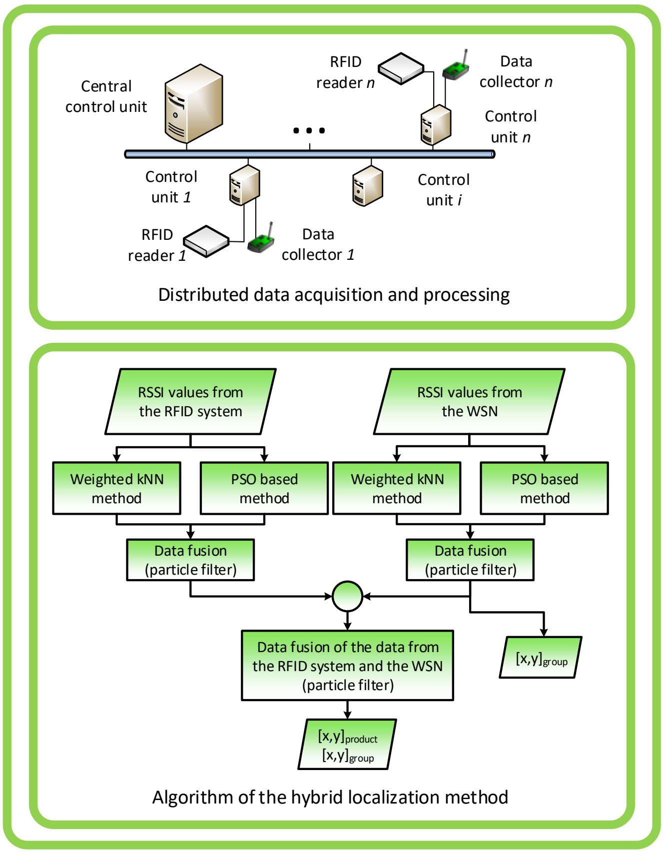

Figure 5. The third level of the model for product localization based on the IoT – Edge computing

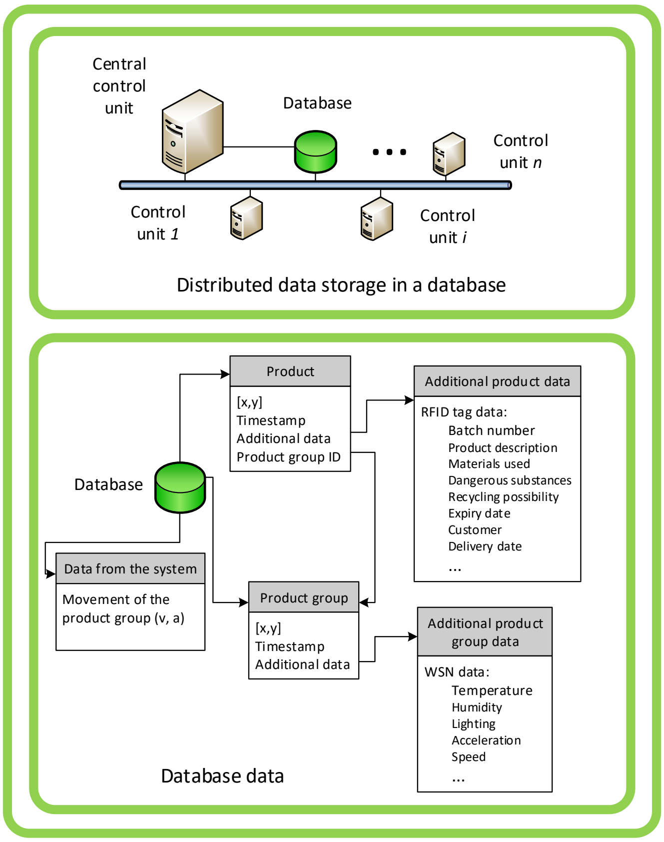

Figure 6. The fourth level of the model for product localization based on the IoT – Data accumulation

The database must contain location data for all products along with the timestamps, and can contain additional measurement or identification data. Furthermore, the database should also link this data with other data about the products which are already available in the existing information system, which is required in order to establish the true IoT. If the system contains data on movement of the products or the product group, they should be integrated in the method for product localization in level three in order to increase the accuracy and precision of the localization system.

The fifth level of the model, the data abstraction level (Fig 7.), includes data abstraction, extraction of key data and setting the access to the data. Since not all of the higher applications request all the data from the database, the quantity of the data should be minimized for each application. In order to achieve this goal, this level needs to balance and unite all the available data in the database, especially if there are different formats originated from different data sources, and to perform the aggregation of redundant data as needed. Furthermore, this level extracts the key data for higher level applications and sets authentication and authorization of applications and users for access control to the data.

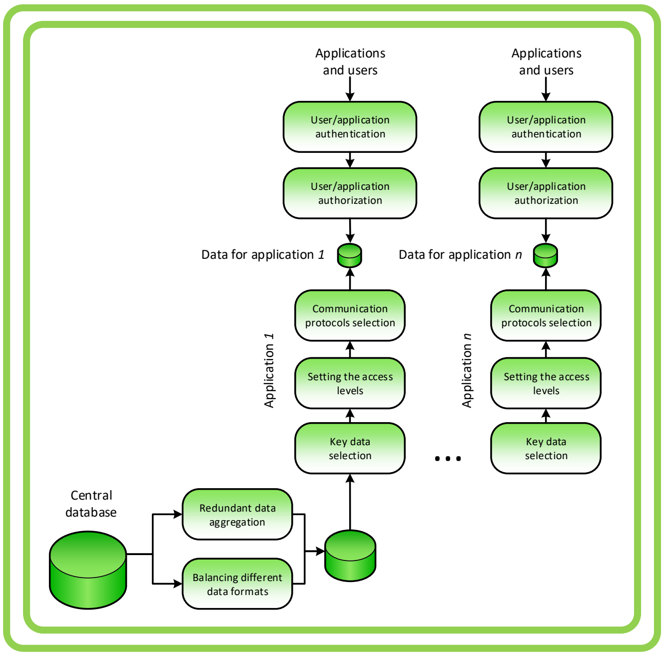

Figure 7. The fifth level of the model for product localization based on the IoT – Data abstraction

The sixth level of the model, the application level (Fig 8.), provides practical application aspects for the localization system. The applications in this level communicate with the database by taking the key data extracted for the specific application in level five. This level performs the essential interpretation of the data. The localization data, along with the environmental data for specific positions, allows setting of a quality supervision system, enables system control optimization and data analysis, reporting, alarm handling, etc.

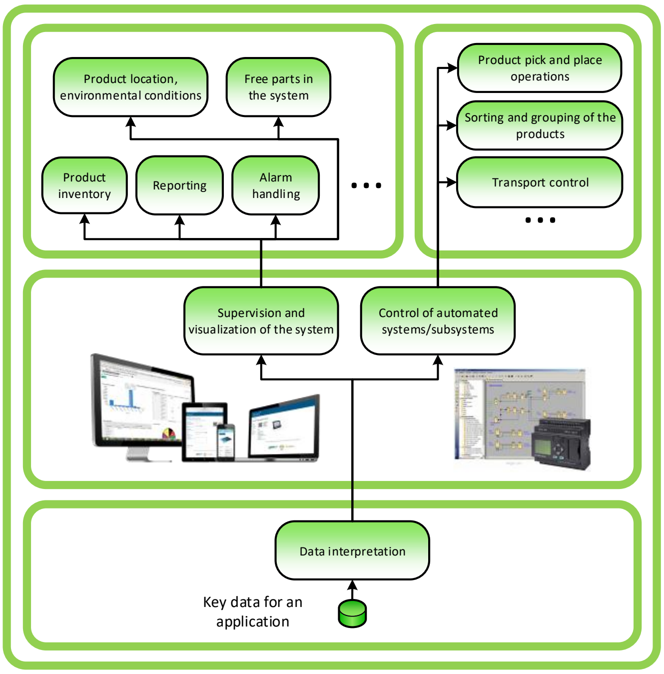

Figure 8. The sixth level of the model for product localization based on the IoT – Application

The seventh level of the model, the level of collaboration and processes (Fig 9.), supports the integration of the localization system into other business processes in the system and inclusion of the people in the processes, as well as further connectivity with the internet in order to fully reach the IoT paradigm. The sixth level involves specific applications for various requirements, on the other hand the seventh level is about connecting diverse applications and involving all the participants in the process, in order to get improved business processes and easier collaboration and decision making. This level provides integration of the localization system into the existing information systems, such as WMS (warehouse management system), SCM (supply chain management), ERP (enterprise resource planning), etc. Moreover, this level enables connectivity with external systems, where the data can be exchanged with other systems directly, or through the increasingly popular cloud computing. This way, the model provides the integration of the data, processes, systems and people, which enables traceability of the products through their lifespan, as well as quality product lifecycle management.

4. CONCLUSION

The model for product localization based on the IoT relies on the IoT Reference Model, but includes the specific requirements for the product localization problem. The model levels include the required devices, technologies, methods for localization, ranging from very specific in the lowest levels to general in higher levels. The possibilities of the implementation of the proposed model were experimentally tested in order to check whether the use of the proposed technologies and devices is justified. The model was tested in two test beds, a classroom and on a test assembly line at the Faculty of Technical Sciences, University of Novi Sad, in order to check the appropriateness of the model in real world conditions, in the presence of metal objects and industrial devices which can greatly influence the communication in RFID systems and WSNs. The experiments evaluated the possibilities for adequate placement of the reference points, the RFID tags and the mobile WSN node in real world conditions, and tested the possibilities for communication and data transfer within these systems. The experiments showed that it is possible to set a system as proposed by the model and provide adequate communication, data acquisition and processing for the localization system.

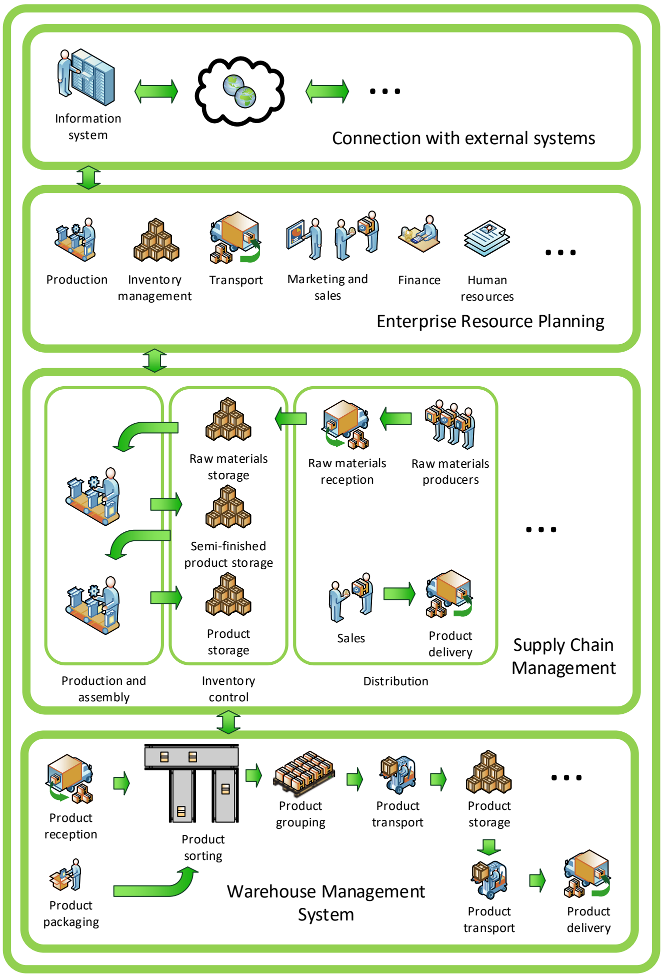

Figure 9. The seventh level of the model for product localization based on the IoT – Collaboration and processes

The proposed model provides better control of the system, by enabling automation of the product distribution, inventory, processes that require knowing the product location, product handling, etc. By knowing the product location, it is further possible to monitor and track the conditions in the product's environment, which increases the possibilities of the system control, as well as the product tracking during its lifecycle, and eventually increases the value of the products and the whole system. Knowing the product's location along with the environmental conditions is a prerequisite for providing product traceability, which is today a very important competitive factor, especially with food, medical and chemical products, which have a limited lifetime and require storage in strictly defined conditions.

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