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# RFID and XBee based Automated Verification of Put-away Operation for Warehouse Management Systems

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***Abstract*: This study proposes a system using RFID and XBee technology to address and eliminate the problems resulting from human errors in put-away operations. The human errors in such operations are a serious problem that leads to a number of difficulties in production lines and supply-chain. The use of automated verification system in put-away operations in warehouses is rather rare. Therefore, the study draws from Information Technologies. Three modules -warehouse, racks, and forklifts - have been designed to ensure automated verification of error-free placement of goods. Also, a user interface is developed in Visual Studio C#.Net and SQL server is used for database management system. The developed system also provides monitoring of all steps of operation and enables real-time checking and supervision. Thus, it offers a reliable and transparent operation system, significantly contributes to effective management of supply chain and helps to improve high quality of fast and correct product delivery by minimizing the human errors. Thus, the study highlights the importance of automated verification system for an effective management of supply chain practices by establishing coordination among rack, forklift, warehouse modules, operator and product.**

***Keywords***: Warehouse Management, Put-away Operation, Put-away Errors, RFID, XBee Technologies, Arduino.

## I. Introduction

Logistics plays an essential role in enabling rapid, reliable and accurate transportation of products across the world in a global economy in which the production and consumption take place in different countries. Logistics gained more importance than ever in global economy as companies focused on cutting their costs and increasing their customer satisfaction [1]. The logistics in recent applications are composed of following tasks and functions [2]:

- Order processing
- Transport management
- Inventory management
- Warehousing
- Materials handling
- Packaging
- Information Technologies

All these logistics functions have a vital importance for leading firms and majority of them are also widely addressed by scholars and practitioners [2-6]. In this paper, the focus is on warehousing since any disfunctioning and mismanagement in warehouses can lead to a number economic consequences, including loss of time, increase in workload and delay in production line.

Logistics and Supply Chain Management covers various disciplines such as business, management and engineering and acts as an intersection of these fields [7]. The effective management of supply chain in business depends on use of IT technologies, including hardware and software components and identifying the effect of such technologies on chain performance. The supply chain management studies tease out the most significant problems as lack of product and information flow. Particularly, lack of accurate and real time information brings ambiguity and instability to supply chain. When the customer expectations are also taken into consideration, fast, correct, complete and faultless product delivery becomes more important. A significant way to offer a high quality of service is to use information technologies effectively in all stages of Warehouse Management Systems (WMS). Therefore, use of automated verification such as RFID or XBee based communication technologies play a crucial role in WMS [8, 9].

The location of products in warehouses is determined according to goods' features (such as dimension, weight, product value of SKU, demand frequency, pick density). This is usually conducted within the knowledge and expertise of operators and by pre-assigning the products to specific locations. However, in recent IT applications on WMS, it can be seen that few studies use smart decision support system

(SDSS) for an effective storage area management [10]. Unlike SDSS studies, in most studies, the controls of correct placement of products are based on the observation of staff. Such a method is very likely to involve human errors resulting from workload and bullwhip effect and takes more time than the automated verification [11, 12].

This study investigates a relatively unexplored issue and addresses a problem faced during the transfer of goods from a warehouse to the production line racks by local logistics department. Although few studies [11] looked into inventory record inaccuracy in supply chains, the focus has been on the role of workers' behavior without a concern for system improvement. Our study is located at the intersection of how an automated system can be developed and can run put-away operations smoothly. For instance, even if the forklift operator was informed correctly, he could misplace the good on the wrong rack. This may later on lead to delivery of a wrong product or cause loss of time in searching for the right product when it is needed in the production line. Since the possibility of misplacement will not be taken into consideration, the production line will also work in vain. So, to prevent such put-away errors, a recent IT-based system was developed to monitor all stages of a product from arrival to departure of a warehouse and to eradicate human psycho-behavioral errors.

This paper is organized as follows: The first part of the Section 2 scrutinizes the relevant studies in the area from a technological aspect; second part of Section 2 presents the common processes in a WMS. In Section 3, the proposed system is explained in detail. Following the design section, a conclusion section with some useful suggestions are listed to enhance the system.

## II. Literature Review

### *A. Use of Information Technologies in WMS*

Automatic identification systems such as Radio-Frequency Identification (RFID) and barcode are inherent parts of warehouse management. The common aim of these technologies is to get comprehensive information about quality and quantity of the goods when needed and to monitor product arrival time, current location of product and the process that the product has been through (packing and labeling). Thus, time loss at supervision and operational level will be prevented [13]. It could be seen that the barcode technologies are no longer used in current applications due to its disadvantages such as need of line of sight, short detection range, and single tag reading (one-by-one identification of products). So, RFID technologies are increasingly replacing the barcode system and being used for product tagging, monitoring and inventory controlling [13-16].

In WMS, wireless communication technologies such as XBee, Wi-fi, Bluetooth, Infra-red are generally used to connect RFID readers and database server [17-20].

When the relevant literature on the aforementioned technologies was analyzed, it could be seen that this subject was studied by both practitioners and scholars. Among all, the system developed for production line by Siemens in 2006 for Peugeot 206 draws attention [21]. In that system, a shelf tampon was formed for the car production components. Shelf tampon gives an automatic warning message when the number of components on the shelf decreases and also checks if they are placed on the correct rack. The products are tagged by using Moby-U RFID module and the main system management is conducted by Simatic S7. This system of Siemens resembles with our proposed study as they both automatically verify if the correct product is placed on the right rack. However, compared to the system of Siemens, the most important feature and superiority of the proposed system lie in the use of wireless communication technologies instead of a standard wired one such as ProfiNET.

The warehouse management system developed by Motorola firm based on real time warehouse and mobile warehouse concepts has a similar solution that could prevent human errors in put-away and increase put-away accuracy and crosscheck [22]. The system checks the accuracy between the barcodes of goods and shelves. The novelty of the proposed system is the technology used in the verification process. Instead of a conventional barcode system, a system based on RFID technology and wireless (XBee) communication was conducted.

When automation software developed by logistics firms are looked into, it could be seen all of them focus on topics such as inventory control, product placement strategy and order management. Some firms use RFID in labelling whereas others use barcode technology. However, none of the software has an application controlling whether the product is placed on the right rack. So, this article focuses primarily on automatic verification as well as inventory control, tagging, and product placement strategy [2-6].

The system offered by Said A. Elshayed et al. to increase traceability of supply chain resembles to the developed system proposed here in terms of hardware design. Yet they are both designed for different purposes. In both studies, communication between RFID readers and main server is enabled by Zigbee protocol [15]. In Said's study, a simulation environment is established for small and medium scale industrial enterprises to monitor the processes of insourcing chain before it reaches to market [15]. This simulation is composed of three stations. Each station involves an RFID reader and an XBee module. Thus, it could identify whether the products are delivered to the requested station or where the product got lost.

The work of T.C. Poon et al. can be given as another example for use of IT in warehouse [23]. In Poon et al.'s study (2009), the real time monitoring of the products is studied by using RFID technology. Additionally, during the transport of products to the assigned location or order- picking, the shortest route has been calculated by the developed software to help driver track this path. Indoor localization of vehicles and racks can be identified by RFID readers placed on the racks and forklifts. Yet, the put-away operation of goods is not verified by a system.

Furthermore, the study proposed in this paper and the research G.T.S. Ho et. al conducted for the solution of Storage Location Assignment Problem resemble in terms of hardware and software components. In the study of Ho et.al (2010) location of the products is determined by smart decision support systems [10] whereas in our system, location is determined within the operator's knowledge and experience through a user interface by fixed assignment. One last difference is that the study of Ho et.al (2010) optimizes the product placement but it does not check if products are correctly placed.

In the study of Ding et al (2008), a warehouse management system based on RFID and Wi-Fi technology has been established for an automobile company which has a large storage area. By using the proposed system, inventory management and goods' tracking are also provided. Ding et al.'s study shows great similarities with the proposed system in this paper in terms of technology and equipment. The guidance of the forklift to the relevant location is automated during goods' placement; but in the case of misplacement of goods, there is not a system function that can warn the operator by an audio alarm system (warning beep) or written messages [20].

Lastly, an ERP-RFID laboratory is formed and a simulation environment is prepared in a study that S.F. Wamba conducted to evaluate the role of RFID technology on supply chain. His study consists of two parts: In the first part, suppliers' operations were simulated whereas in the second part customer's receiver dock was simulated [12]. Among six cases handled in simulation environment, the third case focused on "The put-away of the inbound RFID-enabled products in a dedicated area on the warehouse shelves". This case quite resembles to the solution proposed in this study. Nonetheless, the study of Wamba does not offer an automatic verification system that could prevent human related put-away errors. Thus, our study aspires to fill this void by automated verification.

The similar studies on WMS and our proposed system are compared in terms of IT in Table 1.

### *B. WMS Processes*

Warehouse Management System is software which records all information of a warehouse and runs all the processes electronically [24]. A warehouse management is composed of the processes stated below:

- Goods receiving and tagging
- Location Assignment, put-away operation
- Inventory Control
- Order-picking
- Shipping

In this study, a prototype scheme of receiving, labelling, location assignment, inventory control processes are formed. Problems arising from the wrong placement of goods are particularly the focus of this research and the proposed system aims to produce a solution to dampen the negative effects of put-away errors.

The labelled products are placed on the rack according to their properties. It is not possible for staff to know the location of each product in big warehouses. Therefore, there is a need for put-away operation assignment form. One of the systems used for location assignment is the random assignment. In this system, when a product arrives to a store, it is placed on

*Table 1.* Comparison of similar studies

| Reference | Scope | If the purpose of the studies are compared, it can be said that | Communication Technology used | Hardware Components of the System | Similarity with our study in terms of HW and SW components |
|---|---|---|---|---|---|
| Said A. Elshayed et al. | A simulation environment is established for small and medium scale industrial enterprises to monitor the processes of insourcing chain before it reaches to market. | Different | Wireless / Zigbee | RFID readers and tags | Yes |
| T. C. Poon et al. | Shortest route calculation to help driver | Different | | RFID readers and tags | Yes |
| G.T.S. Ho | Storage Location Assignment Problem | Different | | RFID readers and tags | Yes |
| Ding et al. | The guidance of the forklift to the relevant location is automated during goods' placement; but in the case of misplacement of goods, there is not a system that can warn the operator. | It shows great similarity | | RFID readers and tags | Yes |
| S. Fossa Wamba | It allows the automatic movement of goods from the receiving staging area to the dedicated put-away storage location; but It does not offer an automatic verification system that could prevent human related put-away errors. | Quite resembles the proposed system | | RFID readers and tags | Yes |

the most available rack and recorded to a computer. When there is as a product transport, the staff can find out where the product is placed and act accordingly.

Yet, a more preferred and commonly used method is fixed placement system. This means the rack on which each product should be placed is pre-determined within the staff's knowledge and experience. So the product ID is the most important parameter to identify location of the goods. Nonetheless, in such a system, it is assumed that operator places the product on the right rack. Since no automated verification is conducted during the put-away operation, it takes time to find the product in case of a possible misplacement. This causes production process to be halted, causes loss money and time and decreases performance metrics of WMS. Therefore, the automated verification system proposed in this research can play a significant role in increasing WMS performance.

The system is explained in detail below.

## III. System Design

The system presented in Fig. 1 is developed so that error-free put-away operation of the goods can be conducted to address the problems mentioned above. The modules, seen in Fig. 1, have been integrated to the racks and forklift to ensure automated verification of right placement of products and the traceability of the goods during the placement process.

Warehouse-pc server was set up to establish communication between modules. XBee based Wireless Communication Module (WCM) to establish the communication between forklift and racks has been preferred as it has low power consumption and it can support various wireless protocols, and encrypted communication. Arduino Prototype Development Card is used so that the system can be dynamic and upgradeable. This card includes Atmel AVR microcontroller and has its own C library to communicate with other peripheral devices.

To identify the products placed on racks, SM130 model 13.56 MHz RFID modules were used as it is a compatible component with Arduino. The reason why 13.56 MHz is chosen is its widespread use.

The most common method for product identification is standard barcode system. In this study, to address the disadvantages of barcode system and to create a dynamic and wireless system, RFID technology was preferred.

According to proposed solution platform in Fig. 1, goods arriving to receiving department from supplier first go through handling process and then are identified with a label indicating the products' properties. First, the goods are labelled by using passive tags, and then scanned by an RFID reader. Meanwhile product type is chosen by using developed windows' server software. Thus, the location of the product is determined according to the type of product. After "Goods receiving and tagging" process has been completed, the goods are loaded into forklift to be placed on dedicated racks. The RFID module mounted on forklift scans the label of the product, and then the location information of the product is requested from server via WCM, as seen in Fig. 1. Location of the product is obtained from database in the server. Then target location information is transmitted to the LCD screen of the forklift

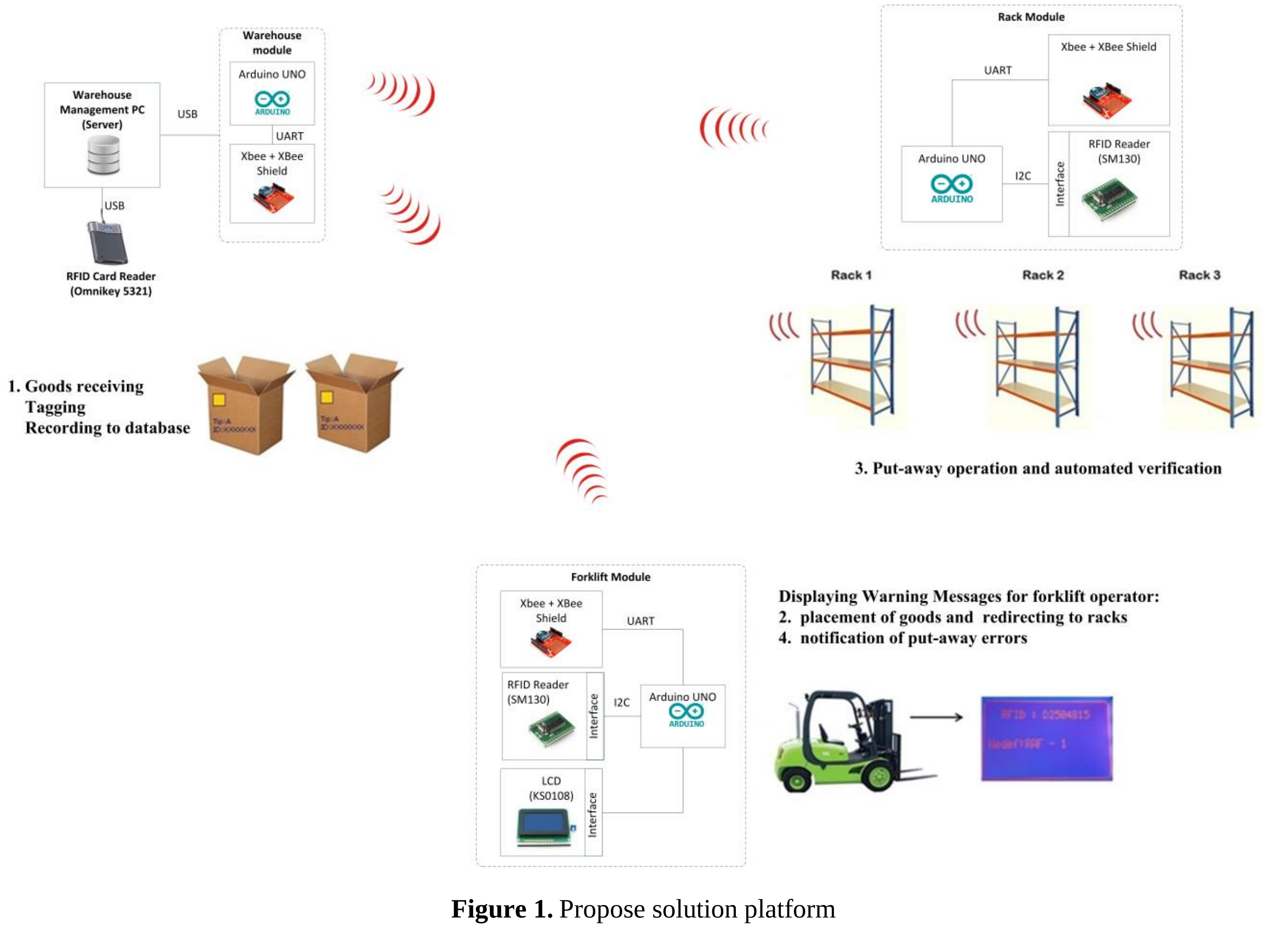



**Figure 1.** Propose solution platform

through WCM. Thus, the operator is informed. Forklift operator takes the product to the location indicated on the screen and puts away it. Put-away verification is done automatically during the placement. Each location (rack) has modules called rack module. So, if the product is misplaced, error message appears on the LCD panel of forklift and operator gets informed that the product is not placed on the right rack.

This entire process is shown in Fig. 2.

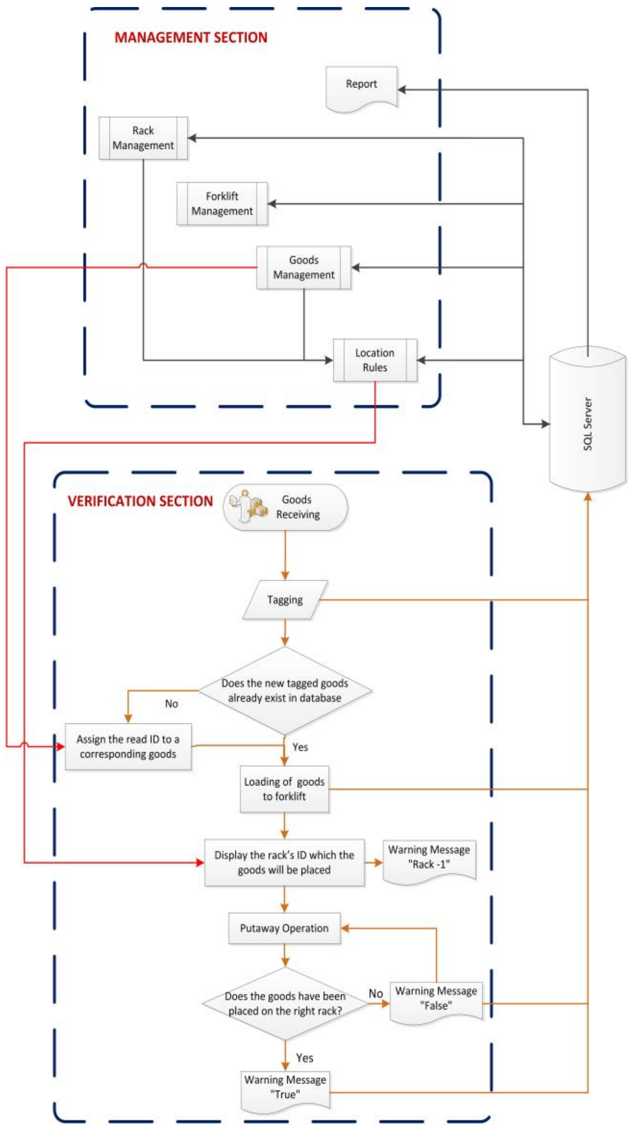



**Figure 2.** System flowchart for put-away operation

The proposed system is composed of hardware and software parts:

Hardware part includes three modules:

- Warehouse Module
- Rack Module
- Forklift Module

Software is composed of two sections; Microcontroller software and user interface design:

- Microcontroller software includes:
  - Forklift Module Software
  - Rack Module Software
  - Warehouse Module Software
- User interface design.

### A. Hardware

Hardware component has 3 main headings. As seen in Fig. 1, warehouse module is the only module connected to the server with a cable. Forklift and rack modules communicate with the server through WCM. Features of each module and sub-units are presented below:

#### 1) Warehouse module

Warehouse module is composed of 2 sub-units:

- Arduino Unit
- XBee Shield Unit

This module forms an interface between racks and forklift by the help of server and microcontroller software. When a label is scanned by any forklift or rack module, the product ID is transmitted to warehouse module via WCM and necessary inquiries are processed. If the product ID is scanned by a forklift, warehouse module sends the rack ID to LCD panel for put-away operation. Yet, if product ID is scanned by a rack, first it is controlled if such a rack exists and then verification result of product placement is sent to LCD panel on forklift module.

In this study, Arduino Uno design was used. There is AtMega328 model microcontroller on this design, including warehouse module software. This microcontroller acts like a bridge between this software and WCM. It transfers the information obtained from USB port to WCM via UART and thus establishes a connection with other modules.

XBee Shield is a system which enables wireless communication between Arduino XBee and other wireless modules [25]. This study enables peer to peer communication of warehouse-rack and warehouse-forklift by XBee modules. There is no communication between racks and forklift modules.

Modules called XBee Series 1 uses IEEE 802.15.4 network protocol and allows point-to-multipoint or peer-to-peer communication. Series 1 modules are recommended to be used in peer-to-peer communication as they give better results and faster results [26].

XBee Series 2 modules are called Zigbee because these modules are used in Zigbee protocol. Mesh network can be established by these modules [26].

Any series terminal program can be used to configure XBee modules for required roles. When setting up modules, the target address of main module should be assigned as end-device's source address and end-device's target address should be assigned as main module's source address. Thus, uninterrupted communication can be established between two modules. In this application, XBee in warehouse module is assumed as the main device (XBee can be assumed to be connected to database) and a fixed address is assigned. Each module (all modules excluding the main module) has a different address and the main module address is assigned as a communication address to other modules. Thereby, all modules can send data to main XBee in warehouse module and the main XBee can also send data to other XBees (rack and forklift). In this way, a peer-to-peer communication is produced [26].

### 2) Rack module

Unlike warehouse module, an RFID reader has been added to rack module for automated verification process (scanning of products on racks).

Therefore, SM 130 RFID reader compatible with Arduino was preferred. This module is composed of 3 sub-units:

- Arduino Unit
- XBee Shield Unit
- RFID Unit (SM130 module and antenna)

When a product placed on any rack is scanned by a module of corresponding rack, the product ID is sent to microcontroller via serial communication interface. Microcontroller sends the data to XBee module via serial communication and then finally the data is received by warehouse module.

### 3) Forklift module

This model is composed of 4 sub-units. Unlike rack module, this module has GLCD as seen in Fig. 3a.

- Arduino Unit
- XBee Shield Unit
- RFID Unit
- GLCD Unit

After scanning the product ID and identifying the product, this module sends ID to warehouse module and requests the information about the rack on which products will be placed. In addition, this module displays a warning message on LCD indicating whether the product is on "right rack" or "wrong rack" to prevent put-away errors. If a product is placed on a right rack, an approval message appears on forklift screen as seen in Fig. 3b. If it is placed wrongly, an error message is displayed to the screen as seen in Fig. 3c.

In cases when the goods are not placed on the dedicated rack, the operator is notified. Thus, misplacement of product is no longer left to initiative of operator and an automated inquiry process is developed.

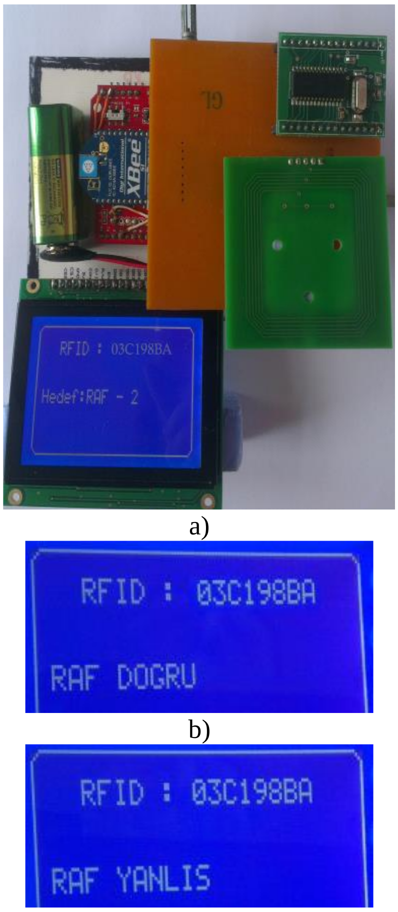
## B. Software

### 1) User interface development

User interface is developed in Visual Studio C#.Net. SQL server is used for database management system.

As seen in Fig. 4, the user interface of WMS has two parts. First section is Management section. It has sub-management forms in which product, rack and forklift data are entered. It also has location assignment rules form. If there are any changes in data, necessary amendments can be re-entered. Second part is the report section. Data and reports of inventory control, product tracking and placement are stored in this section.

Rack management form is developed to add a new rack or to cancel unused racks. Placement of products is done according to rack IDs.




c)

**Figure 3**. Forklift module and screen shots in Turkish, a) General view, b) When the product is placed on a right rack, c) When the product is misplaced.

As seen in Fig. 5, Rack management form consists of "arduino_kod" column used for establishing the connection

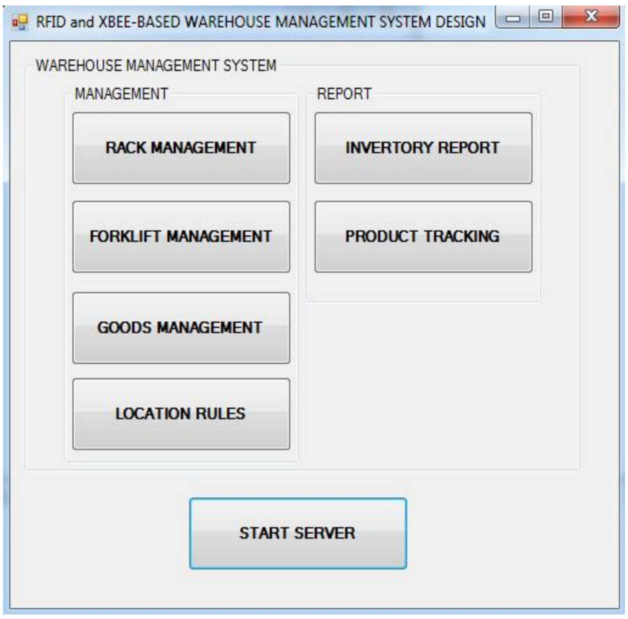



**Figure 4.** Warehouse management user interface (Control Software)

between the rack names on the production line and microcontrollers. It also includes “id” and “location id” columns. The number of these columns automatically increases as a new rack is added to the database.

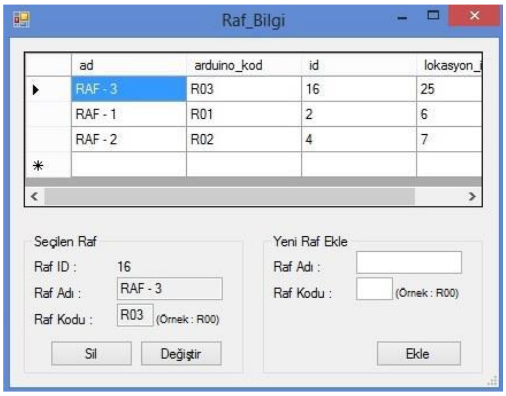



**Figure 5.** Rack management user interface

Forklift management form records the forklifts in use and it is also responsible for updates. As seen in Fig. 6, Forklift management form consists of “arduino_kod” column used for connection between forklift names on production line and microcontroller, “id” and “lokasyon id” columns used for controlling.

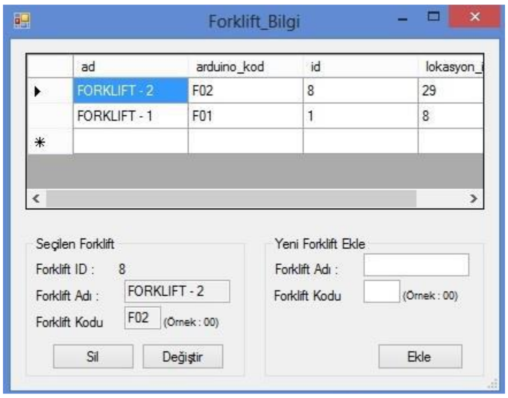



**Figure 6.** Forklift management user interface

Product management seen in Figure 7 is the interface that records all the products delivered from supplier. Firstly, all products arriving to warehouse is recorded in database. Then, they are tagged.

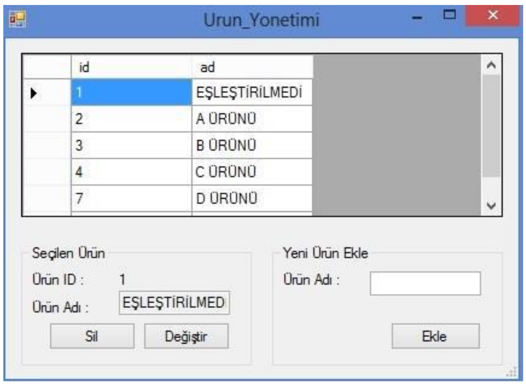



**Figure 7.** Goods management user interface

When a new product arrives the warehouse or when a product is cancelled, add, update and delete functions can be performed in this interface. If a product have not been previously recorded in this form at the time of tagging, “Eşleştirilemedi - Not Matched” message will be displayed and operator will be asked to enter product details (see Fig. 7).

As seen in Fig. 8, Location assignment rule screen provides information on placement of products on the related rack within the knowledge of operator. The product placement is conducted according to pre-defined rules. One product can be placed on more than one rack.

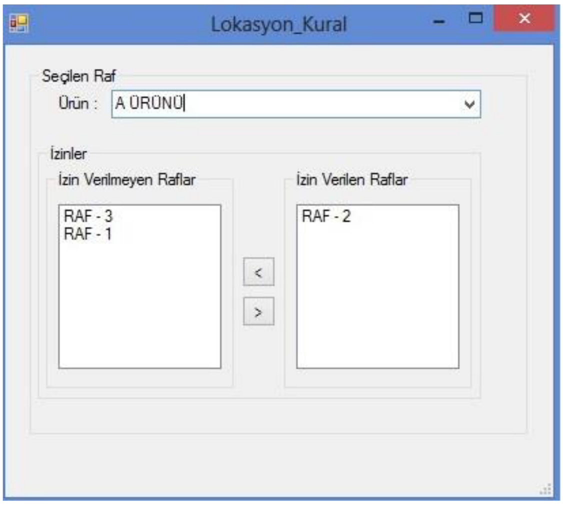



**Figure 8.** Location assignment rule interface

For the selected product, all the racks available in warehouse will appear automatically in the list on the left side of location rule interface. Moving the rack to the list box on the right side is enough for product placement. Assigned rack appears on the operator’s LCD screen when the product is scanned.

As seen in Fig. 9 Inventory Information Screen is an interface that could monitor product types, RFID codes and rack ID. Placement of products on racks, the number of products on a certain rack or inventory volume of a product in warehouse can be enquired. Product monitoring screen is the interface that records all the processes a product goes through after it has arrived warehouse.

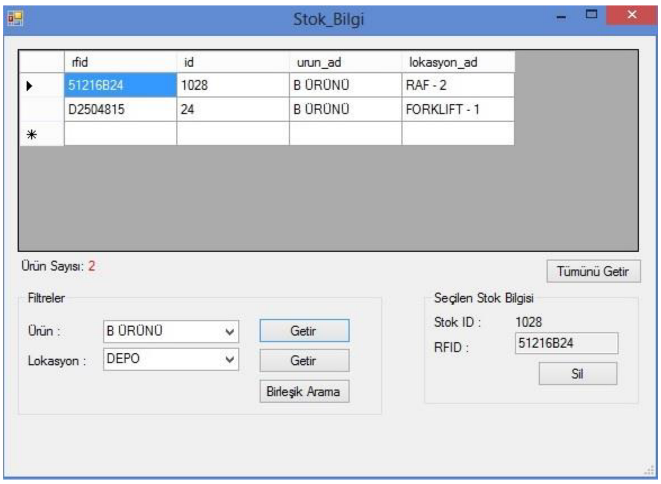



**Figure 9.** Stock information interface

Product Tracking screen in Fig. 10 is an interface that records all the processes since the arrival of the product to warehouse. The id column is a primary key defining the order of the process. Since the product code “D2504815” is being filtered in the figure, some line numbers are missing. This is because these line numbers may belong to other products.

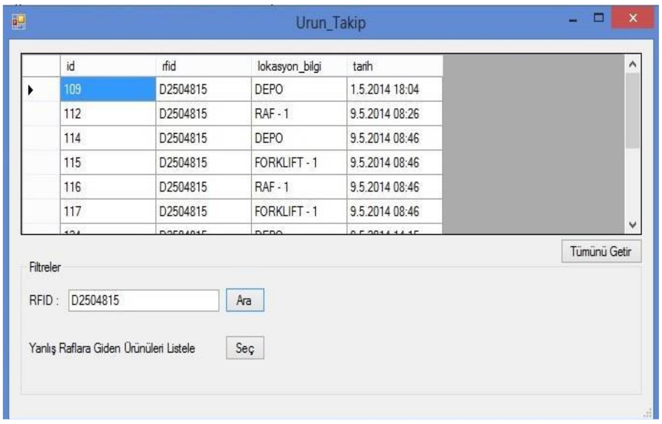



**Figure 10.** Product tracking interface

When “Start Server” button is pressed, “warehouse-pc” server interface appears, as seen in Fig. 11. This interface enables connection between microcontroller and USB RFID terminal, scans the product tag, sends the location information to the operator and checks the connection among all three modules (forklift, rack and warehouse). All operations conducted by an operator are recorded in Recent Process tab.

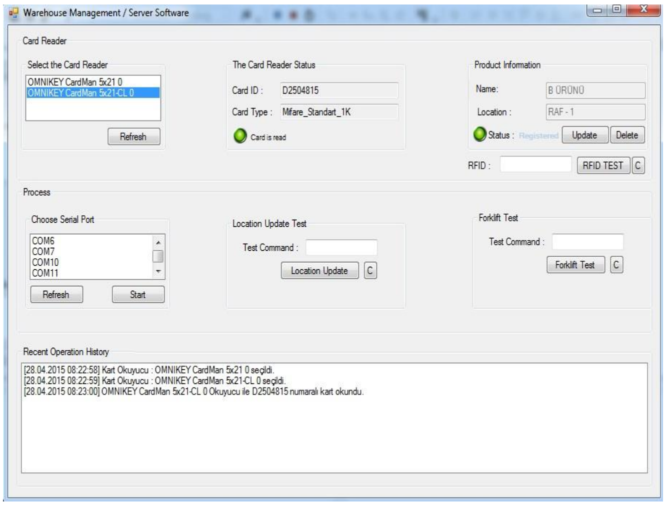



**Figure 11.** Warehouse- PC (Server) interface screen

### 2) *Programming of microcontroller*

Arduino unites used in this study has Atmel ATMEGA 328 microcontrollers on them. During the programming of microcontrollers, a Java based compiler provided by the supplier is used instead of assembly. Microcontrollers are programmed in C language. Communication functions of RFID and WCM modules are integrated to microcontroller software in accordance with series communication protocol.

## IV. Conclusion

In this study, products are tagged and monitored by using RFID technology. The system can monitor all the process of a product from arrival to the warehouse to the use of it in production line or distribution process. Identifying the location of the goods or inquiry of how and when the goods are transported can be monitored by the use of wireless technology. The main aim of the study is to address and eliminate the delays resulting from human errors such as misplacement of products in production line. It is assumed that system will provide following advantages:

- Automatic verification in processing and rule implementation.
- Developing a warning system for misplacement
- Enabling real-time control and supervision
- Reducing human related errors
- Enabling monitoring of product, operation and staff.

## V. Suggestions

The proposed system provides a solution for put-away errors. However, there are some limitations involved in choosing hardware components to make the system more affordable. Due to limited budget, this study is conducted with 2 racks, 1 forklift and 5 product tags.

With its current form, detection range of RFID reader is short. Also, the reader used in the project can scan a single tag and this causes scanning process to take longer than expected. Lastly, since RFID tags are passive, system developers cannot assign any ID other than the pre-defined ID to the product. This means they have to work with the pre-defined IDs.

The current system can actively work within a 100-meters area but this distance can easily be increased up to 1.5 km if a higher powered module is used. In addition, use of active tags and high range reader modules can address the problem of reading range. Alternatively, multiple tag reader can be added to the system to shorten the scanning time.

Rules on the types of transportation vehicle according to product type can also be defined. For instance, small objects cannot be transported by a hollow trolley.

The software is upgradable and therefore enables to add new forklift and racks. The change in technical specification of modules does not pose a problem for software.

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