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Performance analysis of the RFID system for optimal design of the intelligent assembly line in the learning factory

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Abstract

New industrial revolution, called Industry 4.0, is based on the evolution of information and communication technology. It creates new challenges for the scientific and industrial community, but it also creates a specific challenge to demonstrate this new industrial platform in the learning factory environment. A significant and interesting topic for a demonstration of Industry 4.0 is to track the manufacturing execution by using the RFID (radio-frequency identification) system. Thus, creating a system called RFID-enabled Manufacturing Execution System (MES). RFID technology is interesting, because it enables, not just identification of some product like barcode technology, but also writing the data on the RFID tag attached to the product (data about process times, ERP product data~~,~~ or similar). This kind of live tracking of manufacturing execution can significantly improve production planning, especially for the small-lot and single-item production. Learning factories are, in the most cases, oriented to this type of production. However, RFID technology has its limitations. In this research, a performance of the industrial RFID system has been experimentally tested. Presented results give guidelines for the design of the intelligent assembly line in the learning factory at University of Split, regarding the limitations of the RFID systems.

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Keywords: Learning Factory; Industry 4.0; RFID

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1. Introduction

The introduction of the Information and Communication Technology with the Internet of Things and Services into the manufacturing environment has started the fourth industrial revolution, called Industry 4.0 [1]. This new type of industry is based on a Smart Factory model. The Smart Factory has a completely new approach to production based on Smart Products [2]. Furthermore, Smart Factories allow individual customer requirements to be met and make single-item production profitable.

Smart Products are unique (single-item), therefore they need to be identifiable, may be located any time and know their own history, current status and alternative routes to achieving customer [2]. The technology that can enable these requirements is radio-frequency identification (RFID) technology [3]. This technology is based on RFID tags for storing data into their memory, and RFID antennas to read data from the tag or write data to the tag [4]. RFID technology is already well-known technology, therefore it could be implemented into Manufacturing Execution System (MES) with ease, thus creating RFID-enabled Manufacturing Execution System [5]. This kind of live tracking of manufacturing execution [6] connected with Enterprise Resource Planning (ERP) system can significantly improve production planning [7], especially for the small-lot and single-item production, making them more profitable [1].

The main aim of RFID-enabled Manufacturing Execution System is to have real-time manufacturing execution data [8], i.e. to have Real-time MES [9]. The main layers of the Real-time MES that create MES framework are [8]: shop-floor layer with various hardware devices (RFID readers, RFID tags and other communication devices like Wi-Fi network, or similar); MES layer containing three core services (communication service, planning and scheduling service and visualization service); interface layer that aims at real-time intercommunicating with other enterprise systems (with ERP in general); and decision-making layer consisting of the information systems: ERP (Enterprise Resource Planning), PDM (Product Data Management) and CAPP (Computer-aided Process Planning).

However, it represents a significant challenge to demonstrate RFID-enabled MES in the Learning factory environment [10].

2. Design of the intelligent assembly line in the Learning Factory

As an answer on the challenges set by Industry 4.0, a new intelligent assembly line has been designed in the 'Lean Learning Factory @ FESB at the University of Split [11]. The main idea was to demonstrate all main aspects of the smart production, emphasizing vertical integration of production system. A special product, called 'Karet', was designed based on Design for Assembly. The industrial RFID system and Windows tablets have been installed on the workstations. The main aim was to connect MES and ERP, thus creating Pull-based production system (Figure 1).

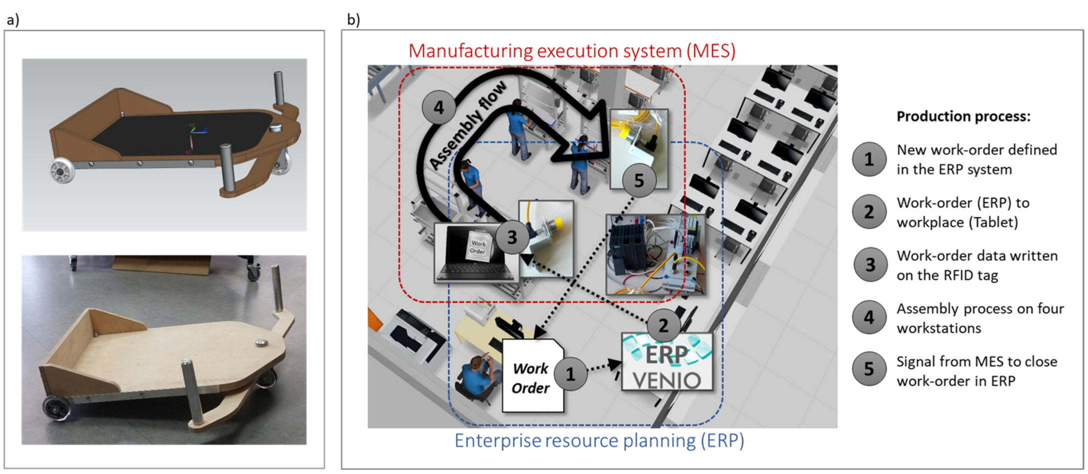

Fig. 1. Intelligent assembly line: a) Product ‘Karet’ for assembly; b) Production process with ERP and MES integration

The design of this intelligent assembly line represents a simple, yet realistic, demonstration of complete vertical integration of production system. However, since RFID technology has its technical limitations [12], a performance analysis [13] of the RFID-enabled Manufacturing Execution System has been made in this research. The results give guidelines for the design of the assembly line in the 'Lean Learning Factory @ FESB at the University of Split.

3. Performance analysis of the RFID-enabled MES

3.1. Methodology

The aim of this research was to test the performance of the industrial RFID system (from TURCK Company) in a case of manual assembly workstation. Manual assembly is specific because worker and the part are out of the range of the RFID R/W-head antenna. Therefore, a worker needs to bring the RFID tag, attached to the part, near RFID R/W-head to read or write some data on it. However, it takes some time to read or write data to the RFID tag, so the worker mustn't do it too fast. The official TURCK Company's RFID system simulator (Figure 2) was used to collect the data about the read/write speed (linear velocity of the RFID tag passing through the range of the RFID R/W-head antenna) possible and distance of the RFID R/W-head and RFID tags. One type (13,56 MHz) of the RFID R/W-head was used (TN-M30-H1147) and two types of RFID tags were used: EEPROM memory type (TW-R16-B128) with the capacity of 128 bytes and FRAM memory type (TW-R20-K2) with the capacity of 2048 bytes. Three different sets of experiments, made in this research.

The first set of experiments was with EEPROM type RFID tag: the data quantity was constant (20 bytes) and six variations of the distance from R/W-head were used. EEPROM type has different read and write speed, therefore different maximal speeds (velocity of the RFID tag passing near R/W head) were determined: 1,09 m/s for reading the 20 bytes of data was achieved on the 20 mm distance from the R/W-head, and 0,73 m/s for writing the 20 bytes of data on the same 20 mm distance. The second set of experiments was with FRAM type RFID tag: the data quantity was constant (20 bytes) and six variations of the distance from R/W-head were used. FRAM type has the same read and write speed, therefore the same maximal speeds were determined: 3,19 m/s for reading the 20 bytes of data was achieved on the 15 mm distance from the R/W-head. The third set of experiments was with FRAM type RFID tag: six variations of the data quantity and five variations of the distance from R/W-head were used. The maximum speed of 0,60 m/s for reading the 250 bytes of data was achieved on the 40 mm distance from the R/W-head.

The following step was to determine how fast worker could move the part (with RFID tag attached to it) over the RFID R/W-head. The aim of the measuring was to capture the normal speed of the worker that he/she will use to pass the part over the R/W-head. In order to calculate his/her speed, one meter marker was placed on the table and high frame rate video was captured. After that, it was easy to calculate the worker's speed using the one meter marker and captured times. Two different workers made 30 movements each. The average speed of a worker was 0,95 m/s, the minimum was 0,67 m/s and the maximum was 1,23 m/s, the normal distribution perfectly fits the data.

3.2. Results

The final step to determine the performance of the RFID system was to compare the distribution of the worker's speed with the range of reading speed of a RFID R/W-head, as it is presented in Figure 2.

The results of this research have shown that for higher quantity of data an RFID could result in very bad performance, i.e. very small percentage of successful readings (Figure 2c). But, for the small quantity of data, like lot number or product ID only, a performance of the FRAM type RFID readers (Figure 2b) is better than the EEPROM type RFID readers (Figure 2a).

However, it must be mentioned that unsatisfying performance of the RFID reader for higher quantity of the data is caused by the low range of the RFID R/W-head, thus decreasing the time that RFID tag will spend in the range of an R/W-head. Antennas used in this research (13,56 MHz) could have range up to 1000 mm, but they are limited to below 100 mm, because of the fear that a long-range antenna could put a worker under the influence of its radiation. It is a non-ionizing type of radiation, but some researches show that it could have a negative impact on the human body in a long-term period. So, for the safety reasons, manufacturers of the RFID systems have limited the range of the RFID antennas used in their systems.

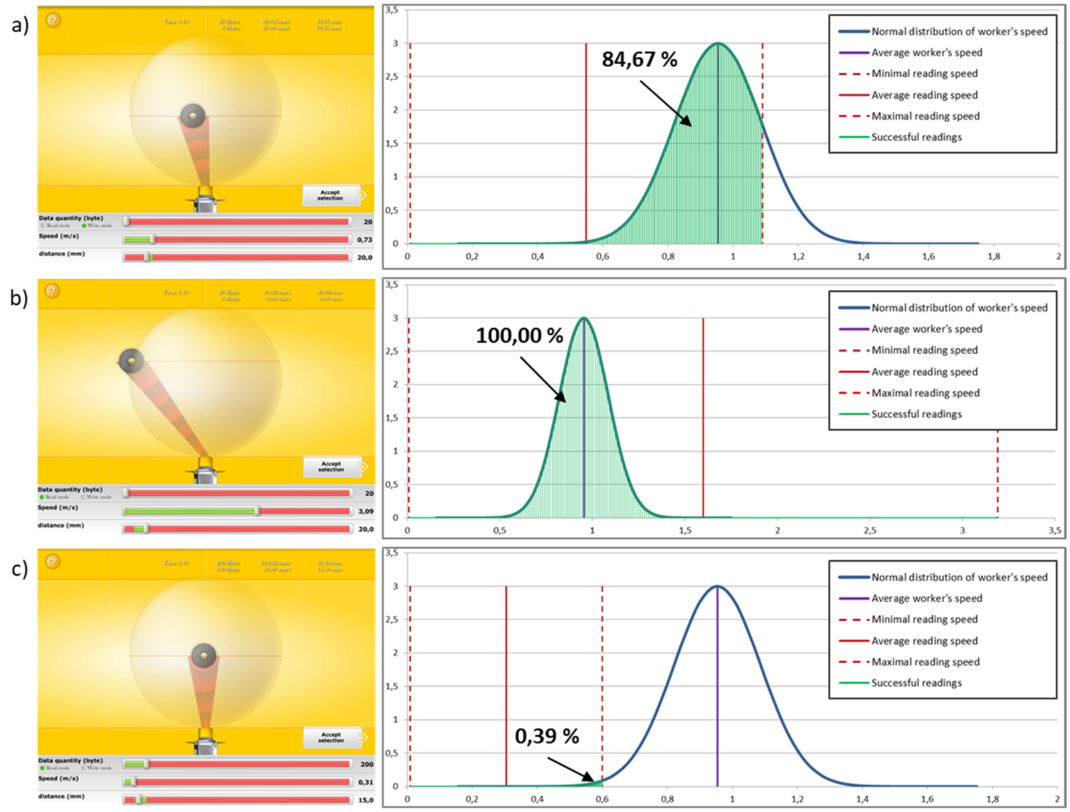

Fig. 2. Presentation of the most successful readings for each of three sets of experiments: a) Percentage of the successful readings of the 20 bytes from EEPROM type RFID tag on 20 mm of distance; b) Percentage of the successful readings of the 20 bytes from FRAM type RFID tag on 15 mm of distance; c) Percentage of the successful readings of the 250 bytes from FRAM type RFID tag on 40 mm of distance

4. Improvement of the design of the intelligent assembly line regarding the limitations of the RFID system

The results of the performance analysis of the industrial RFID system showed significant limitations of the system. These limitations need to be taken into account in the selection of the optimal design for this assembly line. The possible suggested improvements of the design of the intelligent assembly line regarding to the limitations of the RFID system should enable the reliable behavior of RFID system.

These suggested improvements contain additional visual and textual guidance for the workers. As LCD displays are planned on all assembly working stations in order to provide workers with assembly guidance and used parts needed for current product to be assembled, these displays will guide workers what to do posterior to finished assembly process. The displayed guidance screen will schematically show the finished product, the working station and the specially designated location on that working station with RFID reader. The procedure to properly execute the RFID reading activity will be presented to workers in the following steps:

1) Display guidance system will switch to the display page showing the necessity for RFID reading activity according to time sequence defined in advance.
2) RFID reading activity page will confirm adequate product position after it receives signal from RFID.
3) When RFID system read tag data in full content, display page will confirm that RFID reading activity is done successfully.
4) Display guidance will switch to assembly guidance screen for the following product to be assembled.

In the case that RFID system did not successfully recognize and read the tag, the RFID reading activity page will still wait for a tag to be read. Therefore, the worker will be warned by a display screen that RFID reading activity of current product should be successfully executed prior to assembly of the following product. The RFID reader will be positioned in right corner of assembly working station. Additional physical guides and constraints will be installed to increase the locating speed of the product (Figure 3, left side).

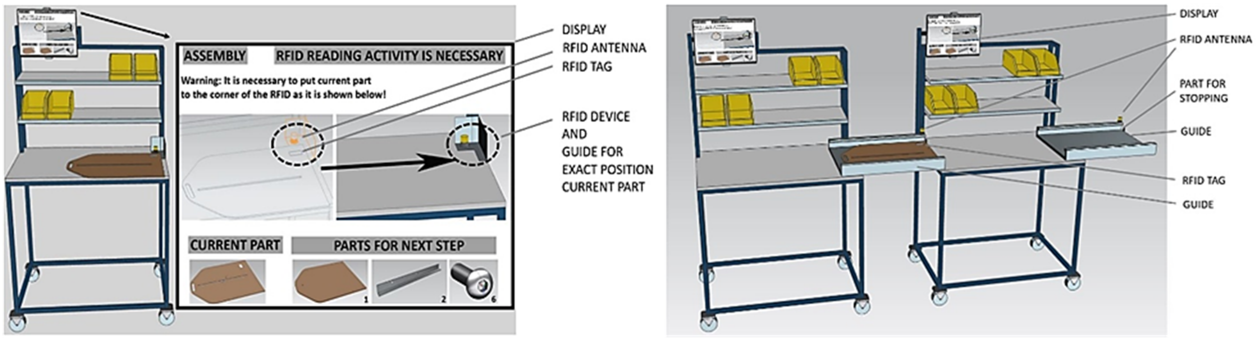

Fig. 3. Working station equipped with RFID reader and guidance displayed on tablet (left side) and design of guide for one working station equipped with RFID reader (right side)

It is assumed that the reader will read the tag during short time frame necessary to full stop the product on designated location, and therefore no additional waiting time will be needed to remain product on the location for the successful reading. Nevertheless, the disadvantage of suggested improvement is the prolongation of the necessary process time, for about 4 seconds in case that the reading activity is executed according to the display guidance, and even more if reading process is omitted in the first place. The prolongation will be caused by the worker, and the worker will be additionally loaded with one more work element, which is reducing the perception that RFID system will increase productivity and reduce workers' effort.

The main concern when using the tutorial for workers is a possibility that workers accidentally skip RFID reading activity. Although display screen will warn worker, there is a possibility that worker does not notice warning due to its' unconsciously repeatable assembly of products in series without checking display screen at all. Therefore, guides could be installed on working stations in order to substantially guide product between two working stations. The guides will define the product's orientation and position suitable for RFID reading, and using guides will require enough time for successful RFID reading activity. Guides should have physical stopping device or lever which will stall the product transfer until RFID reading became successful. Design of guide for one working station is shown in Figure 3 (right side). The main disadvantage of this solution is that guide enlarges working station and assembly line layout.

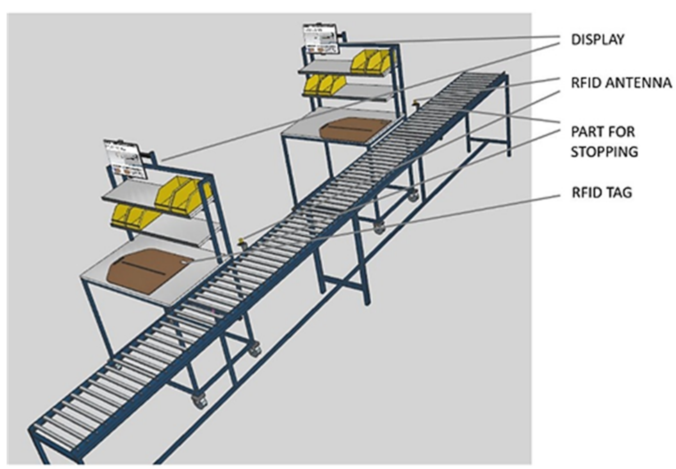

Fig. 4. Conveyer with RFID readers

The disadvantages of product guide installation lead to a necessity for a robust solution. It could be achieved in the form of a conveyer passing by the working stations. The workers will be guided to take products base from the conveyer, to do the necessary assembly activities and to put back finished product on the conveyer. Conveyer should enable RFID reading activities as it will have installed RFID readers between every two successive working stations. The position of the RFID readers across the width of the conveyer will be standardized, together with the position of RFID tags on products. Working stations and conveyer with the position of RFID readers are shown in Figure 4.

5. Conclusion

Although the RFID technology was seen as a platform that enables real-time tracking of the manufacturing execution, the industrial RFID system analyzed in this research showed limited performances. The read/write range of the 13,56 MHz RFID R/W-heads antenna is below 100 mm and it takes more than few seconds to read or write some data in some cases. However, these antennas could have range up to 1000 mm, but that would put workers under the influence of the radiation of the RFID antenna, especially in the manual assembly processes. So, it is very important to take into account limited performance of the RFID R/W-heads when designing a workstation for manual assembly. In this research three different workstation designs which should provide reliable RFID reading activities are suggested. For every working station design, the disadvantages are listed, and a possible solution is presented in the following design. Nevertheless, using RFID technology definitely minimally reduce the processing speed on shop floor level, but it has many advantages in MES, ERP and other production planning and control activities.

The future work will enable selection of optimal design by multi-criteria decision-making methods, which should take in consideration company preferences, financial and human resources, product variability and plant layout constraints. For the Learning factory purpose, four station assembly line with the RFID readers will be developed in 'Lean Learning Factory @ FESB' at the University of Split.

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