An IoT Framework for Assembly Tracking and Scheduling in Manufacturing SME

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Keywords: Industrial Internet of Things, IIoT, Internet of Things, IoT, Internet of Production, Assembly Tracking, Industry 4.0, Production Management.

Abstract: A universal RFID platform is presented, which is meant to be used as a building component of IoT integrated collaboration platform for manufacturing applications. The core element of the system is based on affordable Raspberry Pi modules, running on an IoT operating system. The main goal of this paper is to demonstrate an affordable IoT solution for manufacturing SME to improve productivity by measuring and adapting the assembly processes for a given product. To track the production chain, each part in the supply chain is equipped with an RFID tag, which will be recorded during its travel through the facility. In addition, each worker has his own RFID tag to localize himself and record the performed activities. The workstations are equipped with RFID scanners used to record activity and product flow through the stations. All the gathered data is collected on a server and the real-time status of the assembly line is processed and displayed to the dispatching agents. Upon this data analysis, the dispatchers can take actions, update the manufacturing setup and ultimately increase productivity.

1 INTRODUCTION

The Industrial Internet of Things (IoT) is a concept in which people are surrounded by objects that are all interconnected using embedded technologies – smart objects (Kortuem, 2010). In the IoT, these devices can exchange information and process it via network, providing a next generation of services to humanity. The environment is packed with systems that play the role of sensors and actuators (Gubbi, 2013). All these devices are spatially distributed, and communication between them may be established using a variety of technologies (Ebling, 2017).

These technologies have to be integrated with easiness of creating ad-hoc connections for seamless development and operation of the Internet of Things (Ray, 2018). Currently, most implementations of IoT-like solutions are being developed for business solutions affordable for large enterprises (Uckelmann, 2016), but there is an emerging need for extending it to the small and medium size enterprises (SME), with standardized and easy- to-use solutions.

The Scope of this paper is to make use of RFID technology to record live data of assembly lines, process this data and visualize it to facilitate decision-making, layout and scheduling optimization for the given assembly line. This will involve tracking the parts and workers of the facility, introducing a digital real-time interface for workstations and visualization of performance statistics for dispatching personnel optimizing the assembly processes.

The structure of this paper is as follows: the first step is to understand the challenges of manufacturing small and medium sized enterprises (SME). The second step is a to analyse the existing technological boundaries and introduce the RFID tracking to achieve an implementation strategy followed by the actual solution, which represents the development of the measurement and workstation unit and its deployment on the local assembly-line or on a smaller test assembly-line. Ultimately, the RFID-based system within the existing assembly line and provide new ways to visualize the assembly process, its bottlenecks and in the end provide useful statistics and analytics.

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Minoufekr, M., Driate, A. and Plapper, P.
An IoT Framework for Assembly Tracking and Scheduling in Manufacturing SME.
DOI: 10.5220/0007921805850594
In *Proceedings of the 16th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2019)*, pages 585-594
ISBN: 978-989-758-380-3

1.1 Background and State of the Art

Internet of Thing (IoT), concept of physical objects exchanging data through the Internet, is entering enterprise market bringing growth and profit. In order to function properly, IoT comprises of many different abstraction layers from tiny sensors detecting temperature change in individual objects up to huge server warehouses powering cloud- computing technologies. Before data coming from millions of 'real' physical objects can be processed, these objects have to be somehow mapped into virtual world. This is done by using sensor technologies that are able to transform physical properties into electric signals. One of the sensors, regarded as fundamental in IoT world is Radio Frequency Identification (RFID) technology. The RFID technology offers the ability to detect and distinguish individual objects from distance.

A big advantage of RFID is that it is affordable for any manufacturing SME by using modern RFID systems, which are based on commonly available technology (Bucciero, 2018). The approach presented here, can easily be adapted to new fields of application, such as pharma production or healthcare (Miorandi, 2012). Manufacturing companies are strongly moving away from a push- to a pull manufacturing, which requires highly flexible on demand assembly lines. Such lines feature the challenge of stock management and just-in-time supply management for the assembly lines. To stay competitive, manufacturing SME must produce with high quality standards and avoid scrap parts. The cost of reassembling, reworking products might quickly become higher than the cost of the product itself and result in direct waste.

The main manufacturing tasks addressed in this paper are manual assembly processes. The assembly can vary strongly between applications and product to be manufactured. In general, the worker will manufacture the product by following a certain amount instruction, which guide him/her through the assembly process on the workstation. Those instructions are printed on paper separated into smaller steps. These steps are to be executed within a given time frame and with a defined quality that addresses mostly human errors. An assembly error can result in a rework or scrap product-creating waste of time and resources. Tracking the assembly steps enables crosschecks at each step and increases the chance that products are assembled correctly, reducing rework and production time.

2 PROBLEM DEFINITION AND SOLUTION

Before data coming from numerous 'real' physical objects can be processed for assembly tracking, these objects have to be somehow mapped into virtual world. This can be done by using sensor technologies that are able to transform physical properties into electric signals. One of the sensors, regarded as fundamental in IoT world is Radio Frequency Identification (RFID) technology. The RFID technology offers the ability to detect and distinguish individual objects from distance.

Current RFID systems are usually designed to gather data about recognized objects and to send them right away to a computer for processing. This solution might be enough for smaller number of RFIDs (e.g. timing marathon and races) but will be overwhelming for the computational unit in IoT domain with increasing investment and maintenance costs to the manufacturing company.

This problem can be solved by adding smaller computing units to each RFID reader. This computing unit would process the data on the spot and send results only when it is desired. This paper will concentrate on creating such a platform (computing unit with RFID reader, later called RFID platform) by assembling hardware parts and writing necessary software.

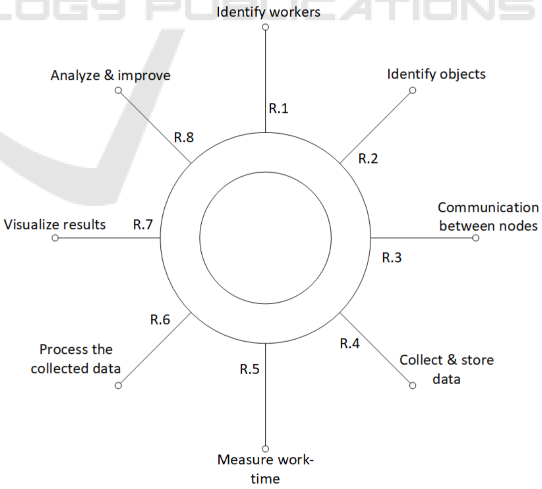


Figure 1: Requirements analysis addressing the challenges to the system.

In this paper, we present a solution based on low cost electronic tags that can easily be attached to physical objects, and do not require power source – reader in another device (Quan, 2018) initializes them. Emerging from the determined Factors, the requirements to the system are formulated in Figure 1. The different requirements are explained as follows:

Identify Workers (R.1): Each worker must be uniquely identifiable by the system. This will assist with building statistics over user productivity. Knowing the real-time activity and status of each worker is viable for tracking an assembly line. There are a multitude of ways to identify Humans which range from cheap and quick like a “user-password”-combination to highly secure and customizable solutions such as an iris-scanner. The most suitable option for identifying workers at their workstations is the RFID-Wristband which can be easily scanned contactless and with no further doing from the worker. The installation of a RFID sensor at each workstation is at a low cost of less than 10 Euros and directly compatible with the data-collection technologies of choice.

Identify Objects (R.2): Identifying objects means in this context to be able to identify parts, products, tools and other hardware required in the manufacturing process. These objects can differ greatly in shape, size and portability. It is important to therefore find reproducible and flexible ways to recognize objects throughout the assembly line. Recognizing objects cannot be done without further doing. Objects are more versatile in shape combinations than humans are. This eliminates options such as fingerprint scanners and leaves us mostly with option, which require the object to be marked.

Communicate between Nodes (R.6): Different nodes of the system need to be able to send data and triggers over a network to be defined. The less the latency and complexity of this network, the better the results.

Collect and Store Data (R4): In order to electronically process data, it first needs to be acquired and stored in the system. This process should be automatized and cost the least amount of time possible. Each fluctuation in the acquiring of timestamps will bias the dataset. The Raspberry Pi 3 device offers many possibilities, which are partly offered by other platforms too but the small form, factor clearly beats the other options when comparing compatibility and functionality/size.

Measure Worktime (R.3): The time a worker spends on a product, a task or which an object in question is dependent on factors, which cannot directly be known. It is vital tough to track the assembly speed for each task and build statistics, which enable to better understand the challenges of each assembly line. The events registered when an RFID-tag is swiped will determine the time-window used for each operation. For operations, which do not incorporate any tagged object or product, a physical button will be introduced within the Users workspace, which he/she can operate to signalize the start and end of a timed event.

Process the Collected Data (R.5): The data, which is stored in the system, needs to be processed in real-time to be visualized for the assembly-line supervisors in time. This is taken over by an electronic component handling all the calculations of the system.

Visualize Results (R.7): The computed results finally must be transformed into human understandable and readable output. There are different media or transferring information to a worker. This depends on the complexity of the data and the capability of the worker. The latter is influenced by how busy the worker is or how susceptible he/she is to notice a change in information.

Analyze and Improve (R.8): Collecting and visualizing data does not mean the improve of the productivity. This stage is where you turn your measurements into insights and actions. Analyzing the data and knowing what is wrong and the parts of the process that need fixing, offer you the time to put improvements in place and get them stick. This is the best way for continuous improvement.

3 IMPLEMENTATION

This section shows how IoT can be realized to improve production efficiency by proposing an approach to support IoT-based assembly processes through integrating manufacturing data. In order to test the proposed approach and assess its impact on improving production efficiency, a pilot study was carried out in a discrete assembly line in our university’s Lean Lab. Several smart devices with sensor have been installed at assembly station level to collect production data in real-time, and then this data have been analyzed to see improvements of production efficiency. The IoT solution platform proposed in this paper, will address the challenges

Urgency, *Complexity* and *Security* by providing an approach which

- ➢ Can be easily introduced in existing production line (plug-n-play), without disturbing and interrupting the production capacities,
- ➢ Is easy to use and based on standard components and thus affordable for producing SMEs and working with low configuration efforts, hiding technological details from the users

- ➢ Is using standardized security protocols and assures (at least) the same safety measure to protect user and customer data like the one given by the company's IT infrastructure

The lack of understanding of manual assembly process behavior "who", "where", "when", and "how" is the essential reason of the difficulty in evaluating and improving production efficiency. In order to improve production efficiency, significant attention and efforts have to be made to obtain process data from smart devices, sensors, and other tools (Saeid, 2017), and then integrate this data in production management. As a result, the approach to build a model for supporting IoT-based production management in sustainable smart factories can be summarised as follows:

1. Understanding assembly processes and current manufacturing management practices

2. Monitoring and analysing manufacturing progress in real-time using IoT technology (e.g. smart sensors)

3. Integrate process data into factory's tools for improving production efficiency

4. Define sustainable strategies and practices in production management to improve production efficiency

The first phase involves the understanding of the production processes, the evaluation of the current production management practices and the definition of key performance indicators (KPIs). The second phase focuses on collecting (possibly) real time data by means of IoT technology and then analysing them to understand current practices and limitations. Here it is required to define and model the assembly stations to be monitored, define the monitoring devices for each station, the communication system and where and how the data will be stored and analysed. Moreover, the production processes must be identified (e.g. assembly sequence, processing time for each product under different configurations), so as to link and understand the process behaviour and make the efficient decision. After collecting and analysing the data, the third phase is to integrate this data into production management tools to enable the decision makers to define the waste, where improvement can be achieved, also select the most sustainable configuration mode of assembly setup with considering the production planning. The fourth phase encompasses the upper level, i.e. the definition of strategies and practices to improve the production efficiency of the smart factory "by design", for example by integrating production data in production management practices.

The IoT platform proposed in this paper majorly consists of four main components and is based on the architecture proposed by Kranz (Kranz, 2017):

Sensors / Actuators: RFID Sensors collect data from parts and workers in each assembly station and measure useful data like process time. Actuators intervene to change the process flow, for example by alerting the worker at the assembly station in case of process errors.

Edge Devices: The device systems build the control element of the sensors and feed data for data aggregation on the server. In our case, Raspberry PI3 are used as edge devices, which are physically attached to the RFID sensors and logically connected to adjacent gateway device or server for data forwarding and processing.

Gateways: A gateway provides connectivity between all elements in the physical world and digitalized cloud data. In our use case application, we use a standard Wi-Fi gateway switch.

Cloud/Server: Although edge IT processing systems may be in remote locations, our server backend application is in our Lean Lab facility.

The implementation is focussed on the assembly process of a paper puncher tool. The according assembly line is composed of seven stations: chassis assembly – base assembly – marriage – QA & shipping – receiving product and dismantling 1 – dismantling 2 – material handling. Each station consists of many individual sub-assembly tasks. The last station (Material handling) involves motion, storage, and delivery of materials throughout the process.

In the proposed IoT framework for puncher assembly processes, the overall objective is to complete a well-defined life cycle, which will result in the assembly of a target paper puncher device. To accomplish this objective, a set of distributed IoT components and devices including cyber physical resources and modules collaborate. A well-defined set of functional activities are accomplished, and they include the following:

1. Creating the assembly plan
2. Creating of the 3D assembly instructions
3. Analysis of assembly alternatives using prediction models to assess the assembly
4. Physical assembly of target parts using IoT

These resources are linked via the Internet using a cloud computing approach. The components of this cyber physical framework for micro assembly are shown in Figure 2.

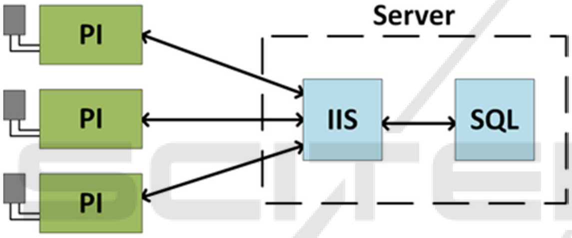


Figure 2: Overall system design and approach.

In our implementation of our IoT framework and the associated remote collaboration protocols, a remote client-server approach is realized that is based on standard Windows setup as a server and Windows IoT platform (Sabanal, 2016) Provisioned on bare Raspberry Pi3 hardware for the assembly node clients.

This application hosts the assembly planning and real-time tracking (created using C#, Windows IIS) that would be the target for remote clients interested in the collaborative analysis in our IoT framework. Remote users with thin clients are able to connect to the server applications. Users from different geographical locations are able to collaborate using thin clients to propose assembly plans and study assembly plans.

We will now present implementation of the previously discussed aspects. The setup is shown in Figure 2. Each station consists of a combination of one IoT device (Raspberry Pi3) combined with an RFID sensor, which is assembled on a PCB, attached to the top part of the 3D printed frame holding the IoT device. Each IoT device is equipped with a touch display to interact with the worker. The communication between the Pi and the sensor via the SPI protocol (Spi et al., n.d.).

The basic workflow of one station is as follows: after an initialization phase, a worker can login and then start the execution of a task (Figure 3). The worker moves from one-step of a task to the next, using one of several methods, as discussed later. At some points in the workflow, there are interactions with the server, specifically for validation before proceeding. The instructions are displayed to the worker with both text and images, to facilitate the understanding of the tasks and to ensure a smooth and productive operation. The application was developed according to the following structure chart, in which all basic activities and their correlations are shown, see Figure 3. When a RFID tag is detected at the sensor, a request is sent to the server to identify to which group it belongs (workers, parts, etc.). After receiving the answer, the station sends a login request. Finally, it proceeds when receiving a positive answer.

Figure 3: Sequence for logging in a worker.

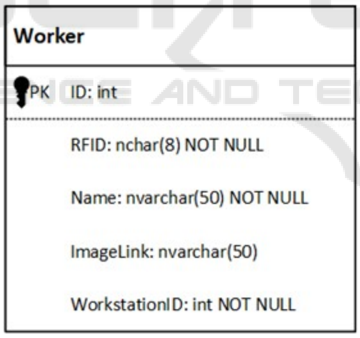
The main menu consists of four buttons, which can be used to place orders, register, search for products and navigate through the application. In the activity “new job”, two buttons can be used to decide for which factory the order is to be created. When the activity is started, an RFID tag can be scanned. The RFID code displayed on the contains the component’s data and the according instructions, which are displayed on the screen.

Figure 4: Structure of the application.

The second important part of the implementation is the centralized data communication, see Figure 4. It is the central element of the assembly network, interacting with all involved devices, be it for the storage, validation or retrieval of data. The secure data communication between the app and the database is realized by a web server regulating the communication between the app and the database and making the data available directly in a suitable form. The production data in the production system are stored in an SQL database in tables, which are divided into customer data and order data. Both the database and the web server are located on one server, running independently. Only a single interface enables communication between the web server and the database.

The Database access via the web server takes place in four steps:

1. The app sends an http request to the web server. The http request contains the information what is requested (order, customer, events). Furthermore, the http request contains attributes that are necessary for the web server to search (for example, an order number when requesting an order).
2. The web server checks the syntax of the request. If the syntax is correct, the web server queries the desired data in the database using an SQL statement.
3. If there is an entry for the attribute passed (such as the order number), the web server gets the data back and creates an xml document. If there is no entry for the attribute, an empty document will be created.
4. The web server responds to the http request with the created document containing the desired information. These are encrypted for security reasons.



Worker

PK ID: int

RFID: nchar(8) NOT NULL

Name: nvarchar(50) NOT NULL

ImageLink: nvarchar(50)

WorkstationID: int NOT NULL

Figure 5: Database table representing a worker.

Objects are identified by RFID stickers (R2), see Figure 6. Another aspect to be considered in this context is the detection range of RFID tags. The latter increases both with the size of the RFID tag and sensor and with the power of the sensor. A trade-off between shape, size and power has therefore to be found, tailored to the specific situation on the shop floor. It is therefore important that the system can be adapted to different configurations and types of sensors.

The components are represented using an SQL database. The basic structure of the tables involved is shown in Figure 5. Moreover, each performed step is associated with an entry in the AssemblyInstance table. The main information are the start and the end time of the step. Furthermore, each workstation is associated to the instructions performed on it, the workers on that workstation and the scanned objects (StationFlow table). The latter allows regrouping all the steps for one specific instance of a product.

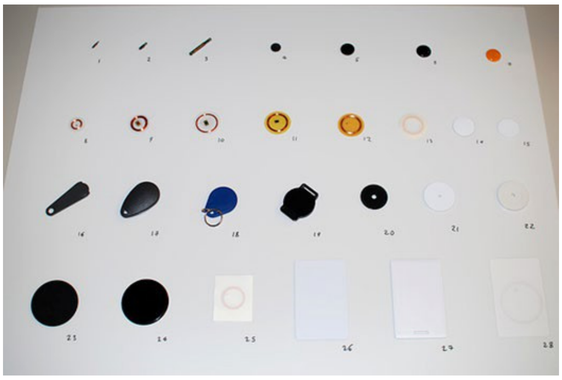


Figure 6: Tagged object and several tag alternatives.

The sequence of steps when scanning an object is like the identification of a worker, with first the identification of the “owner” of the tag, before sending a request to the server. When validated, the station shows the next step of the task. If at any point in time there is an error, the user receives a visual feedback, as illustrated in Figure 7. The screen flashes green in the case of a success.

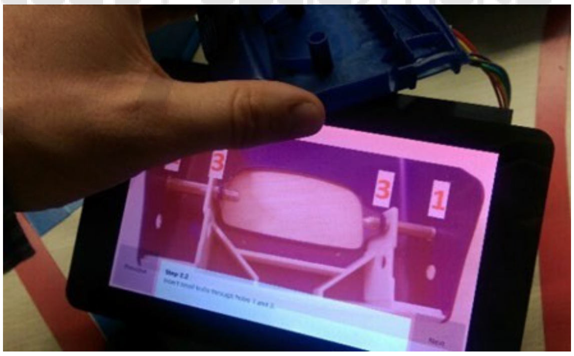


Figure 7: Visual feedback for user if scanning a part was a success or an error.

The measurement of the time a worker spends on a given task is measured for each step. To indicate that a step is finished, the worker either presses a button or scans an RFID tag. In both cases, the station directly sends a request for the validation to the server. When the server acknowledges the completion of the step, the station goes on to the next step or starts

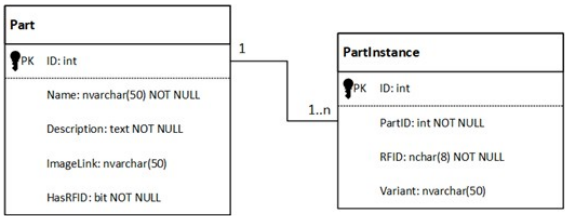


Figure 8: Database tables for saving process data.

An example of recorded data is shown in Figure 9. It is important to note that this is only the raw data that must be processed before using it to analyze the process performance. This basic data can be used to obtain a lot of different information, a simple example being the cycle time or identifying the best/worst station.

The processing and visualization of the recorded data is highly interlinked. Information is extracted out of the data at the moment it is requested, in order to always have the newest information available. The chosen technology for displaying results is an HTML page, as this makes it easily deployable across different platforms and media.

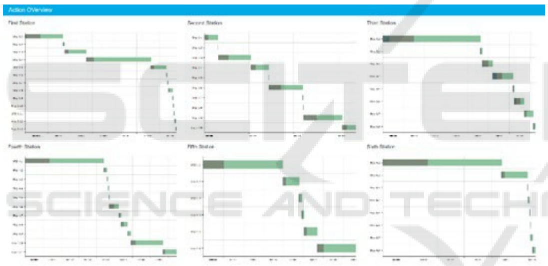


Figure 9: Example process data.

When the IIS server receives a request, as illustrated in Figure 10, a controller first extracts the data from the database, before passing it on to a view to setup the page. This is done via data objects that are independent of the exact visualization of the data. This allows for an independent development and testing of both components as well as an easy exchange of just one part of the program. After receiving the data, the view then transforms the data into the exact form it needs it to be, before generating the whole page with the aid of the Razor technology. Finally, the page is being returned to the client.

Currently two main pages are in use. Both display their information per station. The first one presents some basic statistical information about the process performance. It includes the average cycle time, the last cycle time, the number of products finished as Well as an indication in which state the station is in (e.g. operational or error). Furthermore, it displays the stations with the minimum and maximum on the cycle time and the number of products finished. The second page displays the times of the different steps for each station via a Gantt chart. It includes three bars per step, indicating the minimum, average and maximum duration of that step. This is a useful tool to evaluate which steps for one specific station take the longest, whereas the first page is more useful to compare between stations. Both pages can be seen on figures in the next section *Discussion and Result*.

As previously discussed, the connection method between the server and the stations is done via WiFi, which allows for a flexible rearrangement of the stations, without needing to pay attention to the extra effort of placing network cables. The topology of the network is a star-based, with the server in the centre of a “cloud” of stations. The client displaying the information pages can be any device with a browser. It is important though that the display attached to it is big enough for proper of rendering of the information.

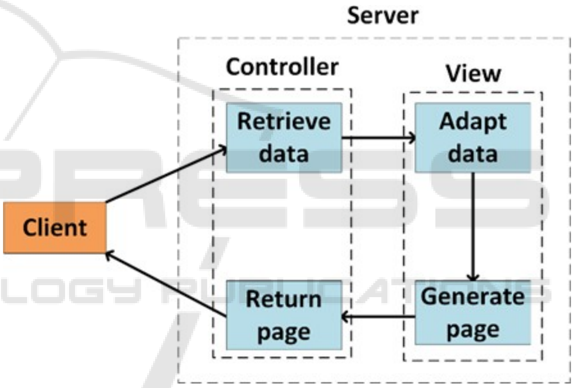


Figure 10: Structure of a request to display live data.

4 RESULTS AND DISCUSSION

The “Lean Assembly Lab” at the University of Luxembourg is a testbed to practice concepts of Lean manufacturing and basic concepts of Kaizen. Both concepts are state-of-the-art methods in industrial application to help increase efficiency in production. In this section, we present some results, which shows the advantages, in terms of efficiency, productivity and scalability, of using the proposed IOT platform. Two experiments have been carried out at the lean assembly lab. Both tests have been performed in the same environment: process of hole punching tool, six stations, one worker per station, same process layout, and same product (Table 1).

Those experiments are aimed to distinguish between effects resulting from the paper-based assembly process and those resulting from a more comprehensive, systemically transformation by digitalization of an Assembly process.

The key question we investigate in this section is: "Given a lean process, what is the impact of applying the described IoT framework to that process regarding process improvement?"

The Layout design is an important component of an assembly line and other operations, both in terms of maximizing the effectiveness of the production process and meeting the needs of employees. The basic objective of layout is to ensure a smooth flow of work, material, and information through a system.

Table 1: Conditions of the experiments.

Condition	Value	Units	Symbol
Net time available to work	60	min	Ta
Customer demand	20	units	D
Number of worker / station	1	NA	NA
Number of stations	6	NA	NA

One worker is required on each station to complete the job and minimum two auxiliary workers are needed to support the production while supplying the raw material and retrieving the finished products. A manager controls the whole assembly production according to the order and priority of product. On each station, there is a small buffer to continue the stream production and to overcome the bottleneck and starving condition for the successive one.

a) Collected Data of Paper-based Assembly Process

The initial assembly process is based on paper instruction. Different paper-based work instructions are provided to each station. Assembly is followed by the instructions mentioned on the paper. The papers explain some critical steps as well. The data was manually collected in this case, using chronometer. The workers record the start as well as the end as precise as possible (Table 2).

Table 2: The manual collected data

	S.1	S.2	S.3	S.4	S.5	S.6
Station Time(s/unit)	159	451	263	243	197	224

b) Collected Data of Assembly Process using IoT Framework

After having the results of paper instructions, new modifications are introduced on the lean assembly line. Instructions are followed by using the IoT Framework. All these disparate parts of the assembly are connected via the IoT Framework including RFID sensors. In the digitized assembly line product, flow and layout are the same as in paper-based process. The only parameters changed are the use of RFID tags, display screens and paperless instructions. An RFID system is linked with every station, which is connected to main server and saves the progress of the assembly. The software records the deviations and processes the data by showing different process parameters i.e. cycle time and lead-time. On every station the RFID tag of a part can be read. After successfully detecting the tag, the instructions are displayed on a screen explaining the assembly necessary steps. At the same time, the station records the relevant process parameters (Table 3).

Table 3: The collected data of IOT-based process.

	S.1	S.2	S.3	S.4	S.5	S.6
Station Time(s/unit)	159	451	263	243	197	224

Takt Time: the rate at which you need to complete a product in order to meet customer demand.

$$Tt = \frac{Ta}{D} \qquad (1)$$
$$Tt = 3\ (min)$$

Cycle Time: The maximum station time of an assembly process.

$$Tc = \max S_{i,}\ i \in \{1 \dots 6\} \qquad (2)$$

Cycle time for paper-based instruction is higher than the digitalized instruction, which is mainly caused by the work needed at station 2. Station 2 creates a bottleneck in the whole process, which leads to high flow time and causes line balancing. Figure 11 shows the irregularity of both methods. The paper-based method has higher irregularity than the digitalized one. In addition, in the digitalized method, quality checking is a pacemaker step. Pacemaker steps create a pull flow in the whole process, which results in less inventory and less bottlenecks.

Throughput rate: it measures the movements of outputs within the production process.

$$Tr = \frac{Ta}{Tc} \qquad (3)$$

Ta Is the net available production time and Tc is cycle time as explained in Equation (2).

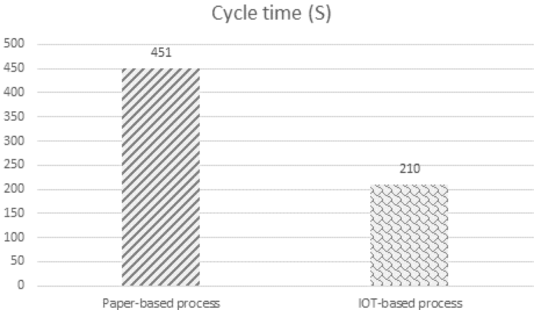


Figure 11: Cycle time comparison.

Eight products were assembled in one hour, but only five products were useful, three products defected in the case of paper-based process. On the other hand, seventeen products were assembled and only two of them defected. Throughput rate for digitalized instruction is high because of less cycle time and less bottleneck. The digitalized process has a pacemaker with less disorder, see Figure 12.

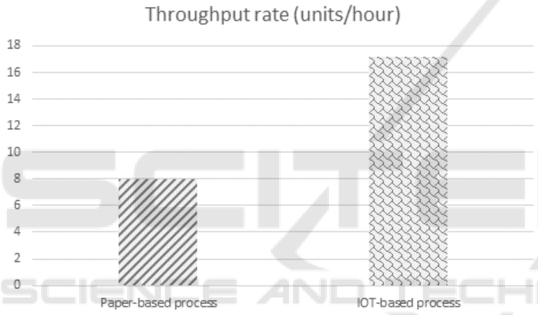


Figure 12: Throughput rate comparison.

Flow time = total time a unit spends inside a system.

$$A = \sum_{i=1}^{6} Si \tag{4}$$

Flow time (Figure 13) also depends on the bottleneck step. Due to bottleneck process in paper-based method, the overall flow time is quite big. Higher flow time results into the less production.

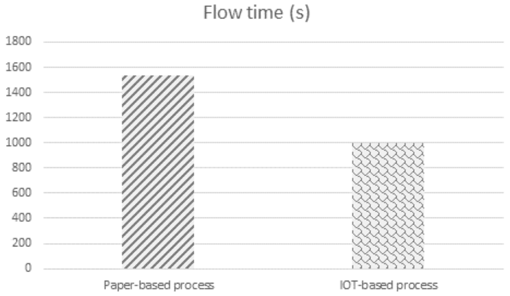


Figure 13: Flow time comparison.

Efficiency is very often confused with effectiveness. Efficiency determined by the ratio of useful output to total output. Effectiveness is being able to achieve a desired customer demands.

$$Ecy = \frac{Tw}{Ta} \tag{5}$$

Tw: useful total working time, *Ta*: net available work time

Table 4: Efficiency comparison.

	Paper-based process	IOT platform based process
Efficiency (%)	62.63	87.5

In total, our experiment showed for that for theconcrete application, the digitalized instructions were more efficient than paper-based instructions, see Figure 14.

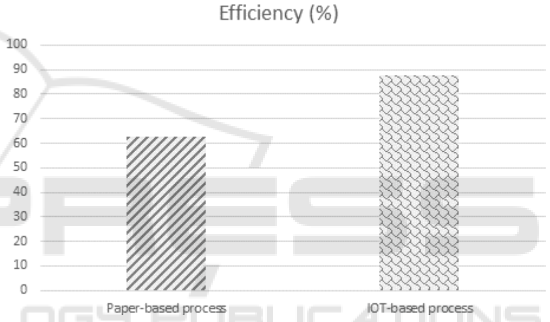


Figure 14: Efficiency comparison.

Defected Parts: During the whole process, three defected parts were observed in paper-based instruction. Whereas in digitalized based method only two parts were defected. More defected partsresult in the unclarity of the process steps in the paper-based instructions. Defected Products If defective articles are not discovered in an early stage it can create valueless work and quality shortages on products that lead to increased cost. If the defected articles are found before, transferring them to assembly line it will minimize the valueless work. This can be received by implement earlier quality controls.

5 CONCLUSIONS

Considering how industries instruct inexperienced operators today regarding manual assembly tasks, it is often expensive, time consuming and involve many personnel. Especially when toady's products become more complex and customized, the need of operators learning new manual assembly tasks increases when having more product variants in production. If they utilize instructions, which do not involve humans, they often use improperly designed paper instructions consisting mostly out of text, which is not the most appropriate way of designing assembly instructions considering human cognitive processes. Instructions could be designed by using many different technologies, but it is about how you design the instruction that is of most importance. To fully reach the most benefits, instructions should be effectively designed, considering both planning and presentation of instructions. The technology for designing instructions should be digital, using screens or smart tablets, to fully utilize the benefits of digitalization.

Regarding instruction performance, assembly time and achieved product quality, of the two instruction types (paper & digitalized), it can be concluded that differences between the instructions are small. The digital instruction seem to have better performance than the other regarding both assembly time and product quality based on our experiments. The most impressive result of the digital instruction was its low variation in both performance parameters, which is reliable and consistent.

Connected to the results from the objective quantitative measurements from the case study, with a trend of slightly more positive results towards the digitalized instruction regarding understanding the instruction technology and usability during assembly. It is therefore recommended, based on our experiments that industries use a properly designed digitalized instruction on a screen for inexperienced operators, since it guides the operator how to accurately place the hands and the technology is familiar, easy to understand and use. Looking at the future of manual assembly, technology within digitalized field will be developed at a rapid pace and will therefore be interesting to follow within the upcoming years. Switching instruction technology into more digital solutions is not a large investment for companies in general, though it may have a large impact on future business and it constitute an opportunity for industry to reach higher competitiveness globally and become a leader within the digitalization field.

ACKNOWLEDGMENT

The authors would like to thank the INTERREG V A de la Grande Région for the support of the depicted research within the PRODPILOT project.

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