
Leveraging IoT Technologies for Enhanced Human-Machine Interaction: A Case Study on Setup Time Acquisition

Uso de tecnologías IoT para facilitar la comunicación humano – máquina: un caso de uso sobre la adquisición del tiempo de preparación

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Abstract

Industry 4.0 is changing the industrial paradigm. The combination of cyber-physical systems (CPS) with 4.0 technologies has endless possibilities to improve the industrial environment. This article focuses on the combination of CPS and the Internet of Things (IoT) to facilitate communication between CPS and humans, a topic in which research is still lacking. In particular, this research aims to overcome the challenge of accurately knowing the setup time of machine tools. The machine tool's sensing system is not able to measure the setup time because it is switched off during this process. However, the incorporation of an additional device can solve this problem. This paper presents a case study that uses an IoT device with Radio Frequency Identification (RFID), so that the user can communicate with the CPS and know what the machine setup time has been, in order to calculate and compare the Overall Equipment Effectiveness (OEE) considering or ignoring the setup time. The results conclude that IoT improves the communication between the CPS and the user and shows the importance of setup time to correctly measure productivity and define improvement strategies.

Keywords: Cyber physical system, internet of things, setup time, real time.

Resumen

La Industria 4.0 ha revolucionado el paradigma de la industria. La combinación de sistemas ciberfísicos con tecnologías 4.0 ha supuesto la mejora del entorno industrial. Este artículo se centra en la combinación de sistemas ciberfísicos e IoT para facilitar la comunicación entre CPS y humanos, un tema en el que todavía no existen muchas investigaciones. En particular, esta investigación pretende superar el reto de conocer con precisión el tiempo de preparación de una máquina herramienta. El sistema de adquisición de la máquina no es capaz de medir el tiempo de preparación de la misma porque está apagada durante este proceso. Sin embargo, la incorporación de un dispositivo IoT adicional permite solucionar este problema. Este artículo presenta un caso de estudio que emplea un dispositivo IoT con RFID, de manera que el usuario pueda comunicarse con el CPS y saber cuál ha sido el tiempo de preparación de la máquina para calcular el OEE teniendo este tiempo en consideración o no. El estudio concluye que la tecnología IoT facilita la comunicación entre CPS y usuario y muestra la importancia de medir adecuadamente el tiempo de preparación para hacer una correcta evaluación del OEE, medir la productividad y poder definir estrategias de mejora.

Palabras clave: Sistema ciberfísico, internet de las cosas, tiempo de preparación, tiempo real.

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1. Introduction

At present, the industrial environment is constantly evolving, since the demands of profitability, flexibility, adaptability, stability, and sustainability are increasing (Spath et al., 2013). To face these challenges, the so-called “Industrie Initiative 4.0” was launched by Germany in 2011 introducing the idea of an integrated industry (Brettel et al., 2014). Industry 4.0 represents the comprehensive transformation of the entire industrial production through the combination of traditional manufacturing processes with Internet, and information and communication technologies (ICT) (Cohen et al., 2019). Recent research asserts that the combination between Cyber Physical Systems (CPS) and technologies, i.e., Internet of Things (IoT), Cloud Computing, and Big Data enables the implementation of Industry 4.0 concept in the industrial environment. For that reason, CPS is generating a big amount of research interest nowadays (Tan et al., 2019).

CPS can be defined as the systems in which the physical and cyber space are integrated, so natural and human made systems are merged with computation, communication, and control systems (Bagheri et al., 2015).

The IoT philosophy seeks for intelligent machines to capture and communicate data more accurately and consistently than humans do. The IoT allows communication between physical objects and their sharing to coordinate decisions. In addition, it allows more visibility and better knowledge of the operations and assets of a company (Ghobakhloo, 2018).

The integration of CPS with IoT technology is key for Industry 4.0, as it enables the connection of people, things (such as machines and products) and data, creating new ways of organising and conducting industrial processes (Hermann et al., 2016). This close communication between humans, machinery, transport systems and products could change the logic of the existing production (Hofmann and Rüsçh, 2017). Moreover, the communication and integration between cyberspace and man-made physical space is essential for CPS being able to achieve stability, security, reliability, robustness, and efficiency in the system (Madhan et al., 2019). CPS-based environments have many heterogeneous intelligent, autonomous and communication mechanisms that are closely integrated with humans. Therefore, the human being has a fundamental role in the CPS development environment (Franke et al., 2016). In Pticek et al., (2016) is researched the development of systems that interweave humans and machines, stating that this study is only the beginning of an investigation in which researchers, companies and governments should collaborate. Yilma et al. (2019) considers that in the communication between humans and CPS, cognitive interaction should be studied in addition to the execution of tasks (Yilma et al., 2019).

In order to improve communication between humans and CPS and expand re-search in this field, the aim of this article is to use an IoT device following the philosophy of many supply chains that use these de-vices to optimise their value chains (Lelli, 2019). Specifically, the IoT device is used so that the CPS operator can indicate the setup time required to prepare the machine for the manufacture of parts. This communication makes it possible to im-prove the calculation of productive Key Performance Indicators (KPIs) in real time that was being carried out, thus, the operational performance could be improved, and costs could be reduced. Both topics are gaining importance due to increased competitiveness between them. In that sense, manufacturing companies are working on the improvement of both issues, productivity and cost. Reducing or even eliminating setup times has many advantages, such as increasing production or reducing costs (Ahmadov and Helo, 2018). Burtseva et al. (2010) proposes a decomposition of manufacturing time which includes setup time. This author divides the total time a product spends in a machine in three parts: setup, production and remove (Burtseva et al., 2010). After that, the study of setup time reduction has gaining importance, as an example, the research of Pinedo (2012) shows that the efficiency of the machines could decrease by more than 20% if that time were ignored (Pinedo, 2012).

To highlight the importance of accurately measuring the setup time, this paper presents a case study in which the most popular productive KPI, Overall Equipment Effectiveness (OEE), is calculated by a CPS in real time considering or not the setup time acquired by using the IoT technology.

As a result, this research proposes a solution to communicate human and machines through an IoT technology and an RFID system. Furthermore, the case study shows how that communication is crucial for a better and more accurate calculation of the Key Performance Indicators and how it affects to productive and economic issues in manufacturing enterprises.

Regarding paper structure, this section introduces the main topics covered in the paper. It goes ahead describing the methodology, the CPS implementation, the IoT device which is use and how OEE is calculated in real time. On that note, the case of study compares OEE calculation before and after IoT device implementation, which results, and discussion are shown in the following section. The paper ends with conclusions and proposals for future studies.

2. Methodology

This article proposes the use of an IoT device for communication between human and CPS to establish the machine set-up accurately and in real time. An RFID (Radio Frequency Iden-

tification) sensor is used for the IoT device to detect the start and end of the set-up time. The operator will pass an RFID card at the beginning of the preparation and when finished. Then, the IoT device will record the exact duration of that set-up in seconds (see Figure 1). Once that information is collected, it will be sent to the cloud along with the rest of the information and variables of the machine collected by the CPS to be used in the calculation of the OEE. This idea is based on the fact that applying IoT technology to RFID allows RFID cards to be identified remotely, allowing systems to react to these devices. The possibilities of these devices are infinite and allow communication with each other and with machines or workers (Fernandez-Carames & Fraga-Lamas, 2018), as is sought in this case. between CPS and IoT.

2.1. Description of CPS and IoT technology and communication

This section describes the CPS and the IoT device which are used in this study.

On the one hand, CPS is composed of a physical and a cybernetic space. The physical system of the CPS with which it works is composed of a machine tool (HAAS VF-3), which is a five-axis vertical milling machine; Three of the axes (X, Y, Z) and the other two (A and C) were added incorporating a Trunnion 160 double-cradle table. The TR160 is a dual-axis trunnion rotary table that offers maximum rigidity and accurate performance for obtaining a full 5-axis machining of small to medium parts (Haas, 2022). The cybernetic part consists of a monitoring machinery system, connected to an industrial computer that allows data capture in real time and stores it in the cloud. Thus, transforming the machine tool into a CPS. This implementation could be seen in a deeper and more extensive explanation in (Morella et al., 2021a).

On the other hand, the IoT device is an M5Stack Core 2. “The microcontroller unit (MCU) is an ESP32 model. Wi-Fi and Bluetooth are supported as standard. The deve-

lopment platform and programming language supported by M5Stack Core2 are Arduino or UIFlow (using Blockly, MicroPython language)” (m5-docs, 2021). In this case, the M5Stack has been programmed with MicroPython in UiFlow because of its easiness. An RFID sensor is connected to this device, which has an RFID MFRC522 chip inside. “The MFRC522 operates in the 13.56MHz frequency band and uses the modulation and demodulation principle to interact with the proximity RF card” (m5-docs, 2021).

CPS and IoT are communicated through MQTT. MQTT is the Message Queuing Telemetry Transport. This works through a protocol based on publication or sub-cription, known as TCP/IP. The terms of this type of communication are: Connect, Subscribe and Publish. Additionally, the client ID, topic, username, and password are en-coded in UTF-8 strings (Upadhyay et al., 2016). The IoT device publishes the setup time in the MQTT broker to which the CPS that collects the information is subscribed. The communication structure can be seen in Figure 2.

2.2. Calculation of OEE

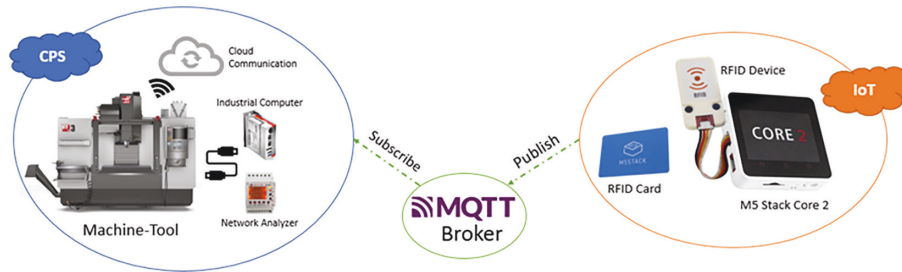
As it has been explained in the Introduction, this paper presents a case study comparing the calculation of OEE considering or not set-up time. In this subsection, it is explained what the OEE is and how can be calculated in real time by a CPS.

The OEE is the quantitative tool most used to measure productivity for industrial purposes for years (Sonmez et al., 2018). The OEE is obtained as a result of multiplying three parameters (equations 1, 2 and 3). These parameters are based on the Nakajima classification of the six big losses (Jonsson & Lesshammar, 1999).

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Planned Operating Time}}, \quad (1)$$

Figure 1. Communication.



Figure 2. Communication scheme between CPS and IoT.

Availability is associated with breakdown and adjustment losses caused by material and personnel and waiting time losses, i.e., set-up and adjustments, where the IoT implementation of this study is relevant. Therefore, Operating Time is the result of subtracting from the Planned Operating time the time associated with these two losses.

$$\text{Performance} = \frac{\text{Net Operating Time}}{\text{Operating Time}} \quad (2)$$

Performance is related with reduced speed losses and minor stoppage losses; thus, Net Operating Time is obtained taking off these time losses from Operating Time.

$$\text{Quality} = \frac{\text{Conforming Pieces Operating Time}}{\text{Net Operating Time}} \quad (3)$$

Finally, quality refers to rework losses and reject losses, so, quality is acquired obtaining the time of rejected or reworked pieces and deducting it from Net Operating time (Morella, et al., 2021b).

This CPS is capable of capturing variables, such as machine time (the time that the machine is on), what number of tool is being used each second (tool number) and when it is changed (tool change), the number of parts produced (number of parts), and spindle rotation (spindle rpm). However, there are parameters that cannot be obtained on their own and must be hypothesized. In this case, the number of reworks and rejections was hypothesized, and the difference between stoppage and minor stoppage was established in five minutes (Morella et al., 2020). In the case of set-up time, it was hypothesized before implementing IoT technology. At this time, it is obtained as a real parameter thanks to human machine communication. When the operator performs a preparation or adjustment task (set-up), he brings the RFID card closer to the IoT device, which begins to count the time (seconds) that the operator is working until it ends and passes the card again, stopping the counter. Once all the data has been acquired, the combination of time with other variables allows us to know

the time associated with each big loss and, therefore, to calculate the OEE (see Figure 3).

3. Results

This section presents the case of study and the results and discussion derived from it.

Our study consists of two cases in which five equal parts are machined from aluminum blocks, whose dimensions were 100 mm × 100 mm × 20 mm (see Figure 4). As hypotheses in both, it has been assumed that there has been a rejection and a rework, for each case. Case 1 (prior to the IoT implementation) neglects the set-up time, in Case 2 this set-up time is obtained from the IoT system, as previously explained. Our CPS collects the case data in real time and processes it with a Python program to obtain the OEE.

The results obtained from both case studies are shown below (Table 1). The difference between both cases is based on whether the set-up time associated with availability losses is considered, so the difference in OEE in this case is due to that block of losses.

Figure 5 shows that the difference between OEE in case 1 and 2 becomes from the availability rate. It can be concluded that the set-up time measurement affects directly to availability, but it has no effect on performance or quality.

The results shown in Table 1 highlight the importance of measuring the set-up time supported by authors such as (Ahmadov & Helo, 2018; Burtseva et al., 2010; Pinedo, 2012). It can be easily seen how by not considering the set-up time the results obtained from the OEE can be misinterpreted. Case 1 shows a performance lower than availability, therefore, when trying to improve the OEE, performance would be considered before availability. However, case 2 with a more precise calculation by including the set-up time shows that the availability is much lower than the performance. Therefore, this study allows to realize that the availability is really the parameter that must be attended first in the search for improvements in OEE and therefore productivity.

Figure 3. Flow chart of the OEE calculation.

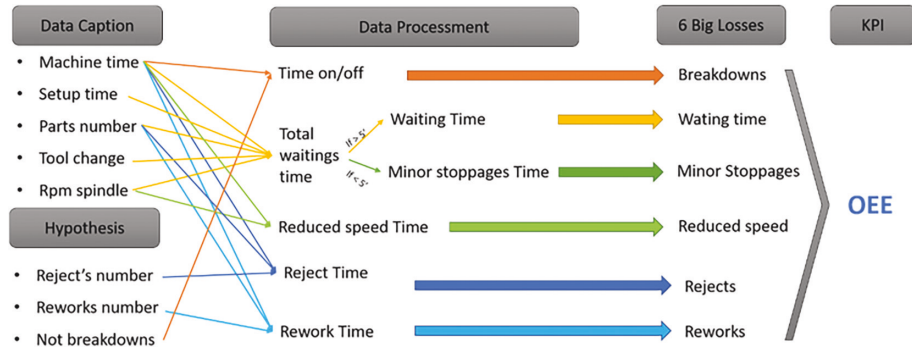
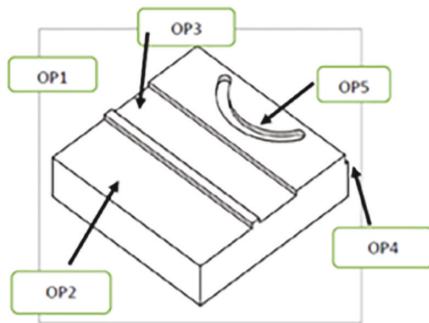


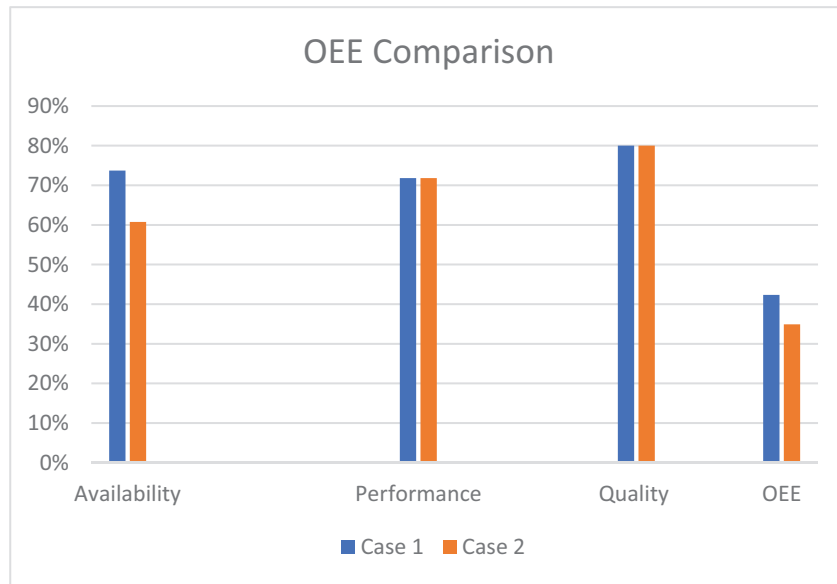
Figure 4. Machined part design during testing.



- OP1: face milling on the top side with an octagonal plate of Ø80 of five plates.
- OP2: face milling at 90 degrees with a plate of Ø63 with five plates.
- OP3: slot milling with two plates with a cutter of Ø25.
- OP4: shoulder milling with cutter of Ø14 of three cuts and a cut to the center; in other words, the tool has an edge toward the center and low cutting.
- OP5: circular slot milling with a fast steel cutter of Ø10 HSS (High Speed Steel) with three cuts and a center cut.

Table 1. OEE Results.

Time (seconds)	Case 1	Case 2	OEE (%)	Case 1	Case 2
Planned Operating Time	1405	1705	Availability (equation 1)	74%	61%
Breakdown and adjustment Time	-369	-369			
Set-up Time	0	-300			
Operating Time	1036	1036	Performance (equation 2)	72%	72%
Minor stoppage Time Losses	-198	-198			
Reduced Speed Losses	-94	-94			
Net Operating Time	744	744	Quality (equation 3)	80%	80%
Rejected and Reworked Time Losses	-148,8	-148,8			
Conforming Pieces Operating Time	595,2	595,2			
OEE				42%	35%

Figure 5. OEE comparison.

4. Discussion and Conclusions

This paper takes advantage of the 4.0 technologies, particularly IoT, to allow the communication between human and CPS. Often the information acquired directly from the CPS is not sufficient for the calculation of indicators. Therefore, the use of IoT devices attached to the CPS will solve this difficulty, using devices that do not involve a high cost for the acquisition of specific variables. This communication enables the acquisition of new parameters to measure. These variables enable the measurement of KPIs with more accuracy. It can be seen that IoT technology can enhance this kind of communication, pointing out a topic for researchers that try to fill the gaps around it, e.g., (Franke et al., 2016; Pticek, et al., 2016; Yilma et al., 2019).

The presented case study supports the importance of measuring correctly the setup time to improve efficiency of machines, increase production and therefore reduce costs. The case study brings out this fact. It is shown how ignoring the setup time means misinterpreting the OEE and therefore performing the wrong up-grade tasks. Having improved the OEE calculation, this KPI is useful to identify the machine activities that are worsening the efficiency of the machine and to act on them. In addition, knowing the setup time is useful to apply in the future techniques that help to reduce this time, such as SMED (Single Minute Exchange of Die) techniques.

This case study is carried out in a real industrial environment which could be replicated by other researchers or companies. It establishes the methodology and the de-vice

needed to improve the communication challenge between humans and CPS. It would be necessary to train operators in device use to ensure a right communication.

As future research is proposed the use of IoT to continue improving KPIs. For example, using it to notify the CPS when parts are rejected, improving quality parameters. All things considered; future research will be based on the use of IoT to improve the human-CPS communication.

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