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IoT-based monitoring of environmental conditions to improve the production performance

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Abstract

In order to ensure long-term competitiveness of a company, an appropriate performance measurement is essential. While the introduction of KPIs focusing on the most important information represents an effective way to monitor and evaluate performance, KPIs do not directly provide reasons behind the current situation. As the strong effects of the environmental conditions in the production area on the human performance has already been proven, their incorporation is important for further production system's optimization. However, the basis for the required decisions builds the proper providing of relevant information. IoT application are considered as one solution for realizing an efficient and effective monitoring. Therefore, this paper first presents a concept for IoT-based monitoring of environmental conditions in the production area. Fulfilling the defined constraints scalability, adaptability and cost-effectiveness, a corresponding demonstrator has been developed and implemented in the LEAD Factory at Graz University of Technology. The demonstrator successfully enables real-time monitoring of the environmental conditions.

Keywords: Environmental Conditions; Monitoring; Internet of Things

1. Introduction

The survival of a company in the global market is strongly related to its long-term competitiveness. While Jovan et al. (2006) mentions the importance of providing high quality products and services, employing a flexible production

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to ensure a rapid response to changing demands and increasing the production effectivity and efficiency [1], Ante et al. (2018) argues that companies need production systems characterized by excellent performance in terms of reliability, sustainability, flexibility, and productivity [2]. Realizing performance improvements requires actual and relevant information about the current production provided to the management [3]. However, the huge amount of data hinders a fast and correct decision making of the production manager as the extraction of the relevant information still appears to be a major problem [1]. An effective way to monitor and evaluate performance represents the introduction of proper key performance indicators (KPIs) focusing on the most important information [1, 2, 4]. This requires selecting indicators appropriate to the specific intentions of the company [5]. However, KPIs do not directly provide reasons behind the current performance and thus, the decisions made for a production system's optimization could be detrimental in the long term [6]. Existing literature already shows that the environmental conditions of the production area strongly affect the human performance [7, 8, 9, 10]. Clements-Croome and Baizhan (2000) emphasize the importance of improving the work environment as it is the most cost-effective way of improving productivity, whereas already a small increase in productivity can have significant effects on the profitability of a company [9]. Besides that, an appropriate production environment positively contributes to the worker's health and thus, also to the company's profitability. This underlines the importance of real-time monitoring of environmental condition in production areas [11]. Monitoring systems provide the opportunity to improve the decision making for management dramatically. While the effective implementation of a robust monitoring and control system used to be a challenge [12], current technologies such as the Internet of Things (IoT) are considered to be a possible solution [13]. Gilchrist (2016) explains the need to implement IoT application as industrial systems are already very complex so that the abilities of human operators to understand, manage, and optimize their performance have reached their limits [14]. Collecting appropriate data and extracting relevant information followed by their analyzation enables gaining insight and new knowledge to realize optimization of production performance that is much harder to match for traditional methods [14, 15]. Therefore, this paper deals with the realization of IoT-based monitoring of the environment conditions to improve the production performance.

2. Theoretical Basis

KPIs provide quantitative information about the performance of an entire production system or specific parts of it [4, 5, 16]. In this context, a proper performance measurement, requiring well-defined indicators, provides not only information about the current state but also supports the identification of performance gaps between the desired and actual process as well as tracking the progress of closing these gaps [4, 16]. The selection of indicators appropriate to a specific production system strongly depends on the company's strategic intentions and its competitive environment. Independent from the industry, this results in an indicator mix different in almost every instance [5]. The performance areas to which the KPIs can be allocated are varying in the literature. Corbett (1998) classifies KPIs according to the four main constructs of manufacturing strategy: cost, quality, flexibility and delivery [17]. In contrast, Ante et al. (2018) categorizes indicators into supporting elements (information directly related to the production phase), quantity elements (information related to product quality and quantity) and maintenance elements (information related to maintenance and repair issues of machines) [2]. Ahmada and Dhafr (2002) split KPIs into 6 sections: safety & environment, flexibility, innovation, performance, quality and dependability [5]. However, KPIs do not directly provide reasons of the current performance and thus, the decisions made for production system's optimization could be detrimental in the long term [6].

Existing literature already shows that the environmental conditions of the production area strongly affects the human performance [7, 8, 9, 10]. Wyon (1996) argues that thermal conditions can reduce the individual human efficiency for simple tasks by 5-15%. Similar affects have been identified with poor air quality and inappropriate humidity [8]. Clements-Croome and Baizhan (2000) mention that crowded workspaces, thermal problems, as well as bad air quality and pollution are principal complaints about unsatisfactory environments [9]. Especially in the manufacturing industry some processes might cause high temperatures, loud noises or other irritating environmental condition. Study results have shown that high temperature do not only negatively affect the worker's performance but also their health in terms of illnesses or headaches. While the noise level directly affects productivity, the lightning does not. Furthermore, both have no significant impact on the worker's health [10]. However, the evidence still shows that an appropriate production environment positively contributes to the worker's health and thus, also to the company's profitability [11]. Considering the company's competitiveness, it is important to reduce the manufacturing cost by minimizing the energy consumption for factors not affecting the productivity such as lightning. This is possible by the implementation of a real-time monitoring of environmental condition in the production areas.

Currently, companies have the strong belief that technologies within the Industry 4.0 paradigm such as IoT, big data, machine learning, etc. represent an essential opportunity in terms of greater flexibility and competitiveness of the manufacturing system [18]. Syafrudin et al. (2018) considers IoT application as one solution for providing efficient and effective monitoring and thus, to improve the decision making for management dramatically [13]. However, this requires a proper employment of the data value chain, which describes the process of transforming raw data (lowest value) into applied knowledge (highest value) [15]. Collecting appropriate data and extracting relevant information followed by their analyzation enables gaining insight and new knowledge to realize optimization of production performance that is much harder to match for traditional methods [14, 15]. Besides that, additional factors facilitate the use of IoT for monitoring. Hwang et al. (2017) argues that the technology can be easily installed in a limited area such as a production area [9]. In addition, Gilchrist (2016) explains the quick increase of IoT applications also through the recently reduction of sensor technology regarding cost and size [14]. Some research currently deals with the introduction of IoT and related technologies in different industries. For example, Mörth et al. (2020) presents a design perspective for IoT-driven analytics in intralogistics, based on a Cyber-Physical Systems (CPS) approach, to unlock new capabilities for enhancing the performance in intralogistics [19].

3. Demonstrator Concept

The first step in realizing an IoT-based monitoring of the environment conditions is the development of an appropriate concept. While gathering the necessary data within production facilities using IoT Technology was the main aim, several additional requirements are to be met in order to make the solution applicable in industry. One requirement was to ensure scalability. This enables an application in different facility sizes as well as the later adjustment to any size changes. Besides that, the system should also be easily adaptable according to the predominant environmental conditions in the production area. This is possible through the quick and simple exchange of the employed sensors. Using common sensors also supports cost-effectiveness as another requirement.

The developed concept consists of 3 layers:

- Measuring nodes: Micro controllers with sensors
- Message Broker: MQTT
- Data Storage and Visualization

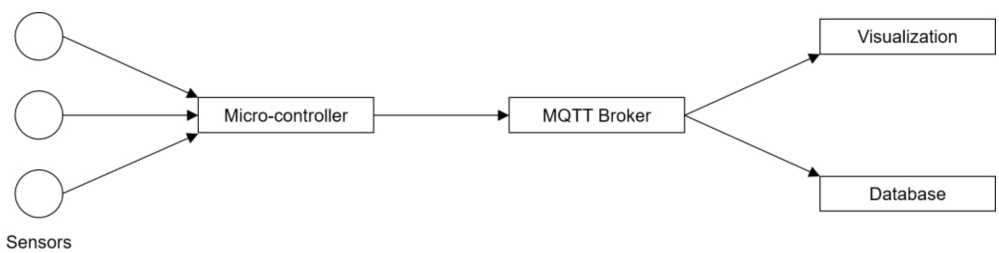


Fig. 1. Concept Graph.

As Fig. 1 shows, a measuring node consists of a micro controller and multiple sensors. Micro controllers allow the use of a wide variety of low-cost sensors. Therefore, it is possible to configure each measuring node to the predominant environmental conditions in the production area. Furthermore, micro controllers require low power and can be easily deployed in different locations. The addition of a Wi-Fi module enables simple integration of measuring nodes in existing networks. Through the use of Wi-Fi, measuring nodes can also be placed anywhere in the production facility without the need for additional network cabling [20]. This strongly enhances the deployment of the system in hard accessible areas. Same examples of environmental conditions that can be monitored with low-cost sensors are temperature, humidity, air pressure, air quality (carbon monoxide, liquid petroleum gas, smoke), lightning and noise. Measuring the temperature, air quality and noise is very important as the literature has proven that these factors directly affect the human productivity. However, also measuring and monitoring factors such as the lightning is favorable as they might support the optimization of the energy consumption.

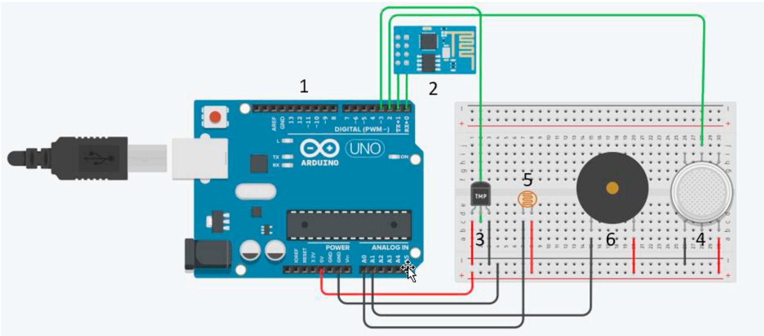
In the developed concept, the measuring node uses the MQTT protocol to publish the sensor data. Message Queuing Telemetry Transport (MQTT) is a lightweight protocol that uses a Publish/Subscribe model. Therefore, MQTT is often used for data transmission in IoT applications. Clients can either subscribe to one or multiple topics (subscriber) or publish messages (publisher). The MQTT broker broadcasts messages to all subscribing clients [21]. The MQTT protocol enables a very scalable solution as multiple measuring nodes can be added as clients. This allows concurrent measuring and monitoring on different locations throughout the facility. Having a server subscribed to the sensor data topics, the data can be stored in a relational database for later analysis. Regarding the data value chain introduced in the theoretical basis, up to now the proposed solution enables gathering and storing necessary data. The additional processes that might be required to extract the relevant information from the data can be performed through a software program on the micro controller. The next step includes analyzing this information, whereas an appropriate visualization is essential when performed by human operators. As already mentioned previously, this analysis enables gaining insight and new knowledge to realize optimization of production performance that is much harder to match for traditional methods.

4. Implementation in the LEAD Factory

This section presents the implementation of a demonstrator for an IoT-based monitoring of the environment conditions in the LEAD Factory at Graz University of Technology. Although the presented demonstrator represents only one possible solution, it is indicative of other possibilities. The LEAD Factory is a learning factory as it is already employed at several universities. Abele (2016) defines a learning factory as *"A Learning Factory in a narrow sense is a learning environment specified by processes that are authentic, include multiple stations, and comprise technical as well as organizational aspects, a setting that is changeable and resembles a real value chain, a physical product being manufactured, and a didactical concept that comprises formal, informal and non-formal learning, enabled by own actions of the trainees in an on-site learning approach."* [22] Consisting of eight (in the initial state) or five (in the future and digital state) work stations, the LEAD Factory represents a miniature industrial manufacturing site including an assembly line of a market available product, a scooter. Through the hands-on application of specific techniques and methods, participant can learn how to transform the initial assembly line into a lean, energy efficient, agile, and digital one. While the digital state already enables monitoring of particular KPIs such as the throughput or the cycle time, the environmental conditions in the production area have not been incorporated yet.

4.1. Demonstrator Setup

Fig. 2 shows the setup of the demonstrator measuring node deployed in the LEAD Factory. The Arduino acts as a connection hub and distributes power to the sensors via the 5 Volt power pin. A BME 280 sensor measures temperature (°C), humidity (%) and air pressure (hPa). It is connected via a digital pin to the Arduino as well as the MQ2 sensor. This sensor measures carbon monoxide, liquid petroleum gas and smoke content of the air in ppm. Furthermore, a photodiode and a microphone are connected to analog pins of the Arduino, whereas these analog signals are transformed into lumen and decibel through a software program running on the micro controller. A Wi-Fi connection is established via the ESP8266 Wi-Fi module and used to periodically publish the sensor data via MQTT. Having completed the hardware, an Arduino IDE is used for programming the micro controller. Besides that, the open source Eclipse Mosquitto MQTT broker is used for the implementation. However, gathering the necessary data and extracting the relevant information represents only half of the data value chain. Therefore, PostgreSQL serves as database management system and the Visual Shop Floor from Solunio serves as visualization platform.



Components:

1. Arduino Uno Micro Controller
2. ESP8266 Wi-Fi Module
3. BME 280 Sensor (Temperature, Humidity, Air Pressure)
4. MQ2 Sensor (Air Quality)
5. Photodiode (Lightning)
6. Microphone (Noise)

Fig. 2. Circuit Graph.

4.2. Visualization and Testing

The information of the environmental conditions in the production area of the LEAD Factory can be visualized in real-time on its Shop Floor Management Board. Fig. 3 shows a sample visualization of the humidity and temperature over time. While a rather constant value course can be seen at the beginning, two sudden drops in temperature and two rises in humidity at the same time can be seen. At the time of the first temperature drop, a window near the corresponding sensor was opened. During the period of tilted windows, temperature slowly declines and humidity slowly rises. Finally, the last drop in temperature visualized in the below graph represents another window opening. In order to evaluate the system, the points in time of the performed actions described above were compared with the timestamps of the peaks and troughs in the graph. Due to the minor time differences, the developed demonstrator successfully represents a solution for real-time monitoring of the environment conditions in the production area.

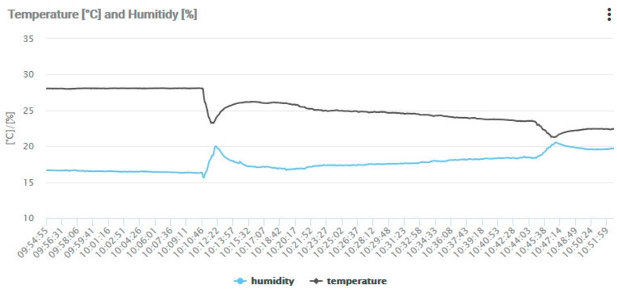


Fig. 3. Circuit Graph.

5. Conclusion

Several studies have already proven that the environmental conditions in the production area strongly affect the human performance. Combining the necessity to incorporate these conditions to realize further improvements of production systems with the current opportunities provided by IoT applications, the need for an IoT-based monitoring of environmental conditions has been shown. This paper has introduced a corresponding concept including three defined constraints namely scalability, adaptability, and cost-effectiveness. As the measuring node consists of a low-cost micro controller and multiple sensors, it is possible to easily configure the system to the predominant environmental conditions in the production area. Through the use of Wi-Fi, measuring nodes can be placed anywhere in the production facility without the need for additional network cabling. The developed demonstrator measures temperature, humidity, air pressure, air quality, lightning, and noise. Measuring the temperature, air quality and noise is very important as these factors directly affects the human performance. However, also measuring and monitoring factors such as the lightning is useful as they might support the optimization of the energy consumption. The information of the environmental conditions can be visualized in real-time on the Shop Floor Management Board of the LEAD Factory in order to enable and support further analyses. Hence, the developed demonstrator represents a successful realization of an IoT-based monitoring of the environmental conditions in a production area. The provided information builds the basis upon which a production system can be improved. Possible next steps include focusing on larger scale implementations as a precursor to industry adoption. As different sensors can be employed, the demonstrator is also applicable to monitor information different to the environmental conditions. Future work might therefore include its adaption based on the specific needs in different industries.

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