IOP Conference Series: Materials Science and Engineering

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To cite this article: Timo Rautio and Antti Järvenpää 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **964** 012013

IOP Conf. Series: Materials Science and Engineering **964** (2020) 012013 doi:10.1088/1757-899X/964/1/012013

Overall Equipment Efficiency Measurement System Based on Raspberry Pi

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Abstract. A complete system with the associated hardware, software and graphical user interface for Overall Equipment Efficiency measurement was developed in this work and then thoroughly tested on a factory environment for a period of over three years. The system was designed to be easily utilized on a typical production line, where the products can be identified with a simple sensor, which could also be deployed without interfering the line itself and the related electronics. This work shows that an extremely cost-effective solution based on popular Raspberry Pi architecture can be effectively utilized for all the required tasks needed for a functioning independent system. Data collection electronics with the related database for storing the data and a web server for the graphical user interface and reporting, were all integrated on a single enclosure. In addition, an analysis software was developed to get the benefit from the collected data, and the software was further developed along with the graphical user interface based on the feedback from the collaborating factory. During the test period, over three million products were correctly detected, and all the stoppages were recorded. The developed system revealed important bottle necks on the production line.

1. Introduction

To survive in the harsh competitive environment, every manufacturer must optimize their production to get the maximum efficiency and to minimize cost. Every reasonably sized company has a way of measuring their efficiency in real time, but SMEs (Small and Medium-sized Enterprise) do not necessarily have effective means to get accurate data about their day-to-day effectiveness. Today, one of the most widely used methods for measuring the production line efficiency is the Overall Equipment Efficiency (OEE) that was first introduced as a metric for Total Production Maintenance (TPM) by Nakajima [1]. In its simplest form, the OEE represents the percentage the production line was running in relation to the available time it should have been running. To give a better and more detailed view of the production process, Nakajima proposed six big losses categorized in three groups. These are collected in Table 1, where the relation of the losses to the efficiency components (availability, performance and quality) is referenced and defined in terms of equations based on the production metrics. While the OEE can be used to develop the production, some pitfalls need to be considered first. While it may be intriguing to compare the OEE between different machines and platforms, it is only a measure of internal efficiency and should not be directly compared to other production lines [2]. It is important to keep the focus on the production development and not to get carried away by nice graphs easily acquired with an OEE system [3]. There is also some variation in the definition of OEE, which makes comparing the OEE of one plant to another even more dangerous and pointless [2]. The big picture of the whole process should be carefully considered when planning actions to improve one OEE component [4]. Improving the quality by one percent can lead to bigger loss in the performance, for example.

Table 1. The definition of OEE components by production line metrics and 6 big losses defined in [1].

Efficiency component	6 Big losses
$Availability = \frac{Actual\ production\ time}{Planned\ production\ time}$	Breakdowns Setups/Adjustments
$Performance = \frac{Total\ number\ produced}{Planned\ number\ produced}$	Reduced Speed Idling / Minor Stoppages
$Quality = \frac{Accepted\ quality\ produced}{Total\ number\ produced}$	Defects / Rework Yield

Measuring the availability, performance and quality of a given production line can be utilized to define a more representative figure for the OEE. This is obtained by multiplying the components using the equation:

$$\boldsymbol{OEE = Availability * Performance * Quality} \quad (1)$$

In this equation, OEE can never be more than 100% like any of its products. Availability is the actual running time in relation to the planned production time. This is reduced by breakdowns and unplanned setups and adjustments. Planned maintenance breaks or the workers' break times agreed on the employment contract do not affect the availability but everything in addition to them does. Performance is defined similarly as the actual number of products produced in relation to the planned number of products.

If the production line is running its maximum speed with no idle run, the performance will be 100%, but every minor stoppage or reduction in speed will decrease it. Quality factor considers all the faulty products that have had to be reproduced. This is defined as the ratio of accepted quality products to the total number of produced parts.

Many new automated production lines are readily equipped with necessary software capable of giving the most important metrics of the production in real time. Depending on the customer requirements, these might also include the OEE measurement. Many times, especially in older systems, the amount of information can be extremely limited. In these cases, a specially designed system for the OEE measurement is required. Such a system usually involves building some sort of sensoring and related data acquisition, capability to store and analyze the data from the sensors and implementing a user interface to utilize the whole system. Collecting the data accurately and identifying the production losses will define how accurately the OEE can be calculated [5].

Raspberry Pi computer has become widely known, and its sales have reached 25 million units already by March 2019 [6]. The small size accompanied with a reasonable performance and ability for wireless networking make it an attractive solution for many different applications. Its performance has increased gradually after the first launch of the Raspberry Pi 1, and at the time of writing, the newest version is the Raspberry Pi 4. This has created even more possibilities and innovations. Raspberry Pi 3 was used as a basis of an autonomous robot that could be controlled by an android application on phone [7]. Salih & Omer used a Raspberry Pi 3 model B as a video server that was able to store video with audio [8]. The first version (Raspberry Pi 1) already had the capability to work as a station to count people based on face recognition [9]. Small size and price have made Raspberry Pi an attractive solution for home automation requirements as well [10].

2. Measurement System for the OEE

After an evaluation of the requirements for the system, a Raspberry Pi 2 computer was decided as the basis for the system. Raspberry Pi 2 was the latest version of the Raspberry Pi family at the time this system was designed. It had all the necessary I/O-connections and the capability for ethernet and wireless networking and some additional hardware already at the market like an inexpensive 7" display. It was estimated to be powerful enough to handle the data collection in addition to the required web server and data analysis software. A simplified block diagram of the system consisting of a printed circuit board (PCB), enclosure with the display and the Raspberry Pi itself are presented in figure 1. The associated hardware, software, and user interface development for the OEE measurement system will be presented on the following chapters in more detail.

a) b)

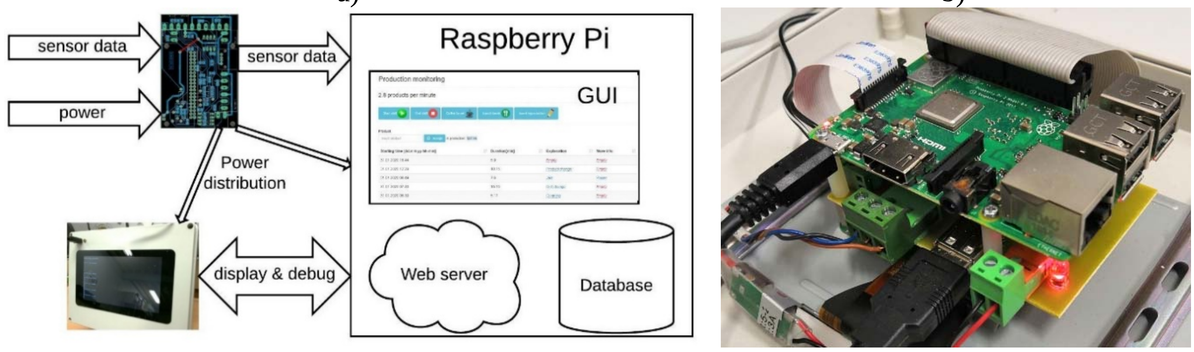

Figure 1. a) A simplified block diagram of the measurement system b) Raspberry Pi with the circuit board for sensor connections connected at the back of the 7” display.

2.1. Data Collection Unit Hardware

Basic settings for the OEE measurement can be made with just one sensor, but some additional inputs were added at the PCB for possible future expansion needs. These wouldn’t have to be directly related to OEE measurement but could be temperature or other condition monitoring etc. All four inputs were optically isolated and the power supply for the system was settled at 12 volts to support a wide range of sensors. It was intended from the beginning that the system could be installed to any manufacturing line without interfering the electrics or electronics of the factory in any way so that only a power connection would be needed.

The complete system was assembled on an enclosure with only a power supply cable and a sensor wire as the outside wiring. For the evaluation and development purposes, this enclosure was also equipped with a 7” touch screen and a USB connector to connect a mouse or a keyboard. The screen has been specifically designed for the Raspberry Pi and has mounting points ready for securing the computer on top of pillar supports. The PCB for this work was designed so that it could be also connected to these same mounting points and the Raspberry Pi on additional pillar supports on top of it, resulting on a sandwich type installation shown in the figure 1b. This way the measurement unit size could be minimized, and it can be fitted in a very small enclosure when the screen is not needed.

2.2. Analysis and Reporting Software

MySQL database was installed on the Raspberry Pi for the data storage purposes, and a simple command line program was developed to catch and store the sensor data to the database. The program was automatically started when the computer was switched on. To get the benefit from the collected data, an analysis software is needed to calculate the figures associated with the OEE measurement and all other relevant metrics that can be obtained with the system. Most importantly, it is used daily to monitor the production and is an essential tool for the decision making on how to improve the production. A Windows desktop application was developed for this purpose and the main window is presented in figure 2. The two calendars are used to select the dates of interest and the program calculates the OEE with its components and various other metrics for the range automatically. Graphics show the daily or hourly (if only one day chosen) number of parts produced, the length of stoppages and the reproduction numbers at one glimpse.

More detailed view of the stoppages for the chosen period can be seen with a click of a button. The report presents them in a descending order with the total time and number of stoppages for each reason. These can be utilized to get a detailed view of where the time was consumed when the production was not running. Weekly reports will show if the actions followed have had the desired outcome or if there is a need for further development. Real time view of the production can be seen with the help of takt time and current day’s production numbers.

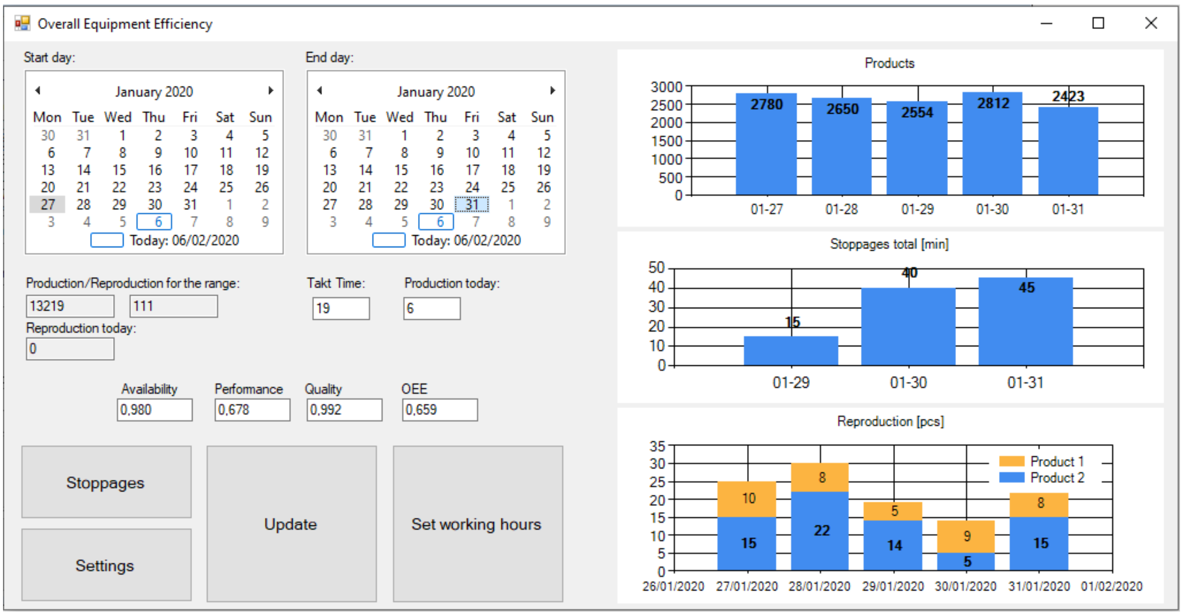

Figure 2. The main window of the OEE calculation and analysis software.

2.3. Graphical User Interface

Lighttpd web server was installed with PHP packages as a basis for the graphical user interface (GUI) development. One of the key features of a high usability OEE measuring system is a clear and intuitive GUI, which can be effectively used to collect the data from the users and to relate it to the sensor data. Such an interface needs to be designed to minimize the interferences to the daily work and the effort to feed the necessary input to the system. After some optimization, the GUI took the form shown in figure 3. Web page interface was chosen since it is easily accessed by handheld devices like tablets or mobile phones, also reducing the time needed to interact with the system.

The most important feature is the list of the latest stoppages. If no production is observed after a predefined time, the system creates a new event on the list indicating the user needs to interact. To minimize the time needed to feed this information, a ready-made list opens when a new stoppage is clicked. This list (editable by the management) includes the most common reasons for the stoppages and only in special cases they need to be manually typed. Only the last five stoppages are listed (uncertainty of the input increases if a lot of time has passed since the stoppage), and the reasons can be fed at any point while the stoppage is showed at the list. Forgotten or incorrect inputs can be corrected by the management from the analysis software presented earlier.

Quality component calculation is handled based on the number of reproduced parts stored by the users. The factories that took part in this study, made all the reproduction only once a day, usually at the end of last shift. The GUI was designed so that the reproduction numbers could be given at any time of the day, again interfering as little as much the production itself. The reproduction could be also counted automatically, but this would require user input anyway as the sensor cannot separate reproduction.

The interface shown in figure 3 also shows some of the optional elements designed. These include the buttons that can be used to follow the shift time and the length of coffee and meal breaks. Takt time can be also presented if it is desirable that the workers see the speed of the production at any time. Finally, the system can be also used to store the production with product numbers, a feature that is not necessarily readily available on the production line, especially in an aged one.

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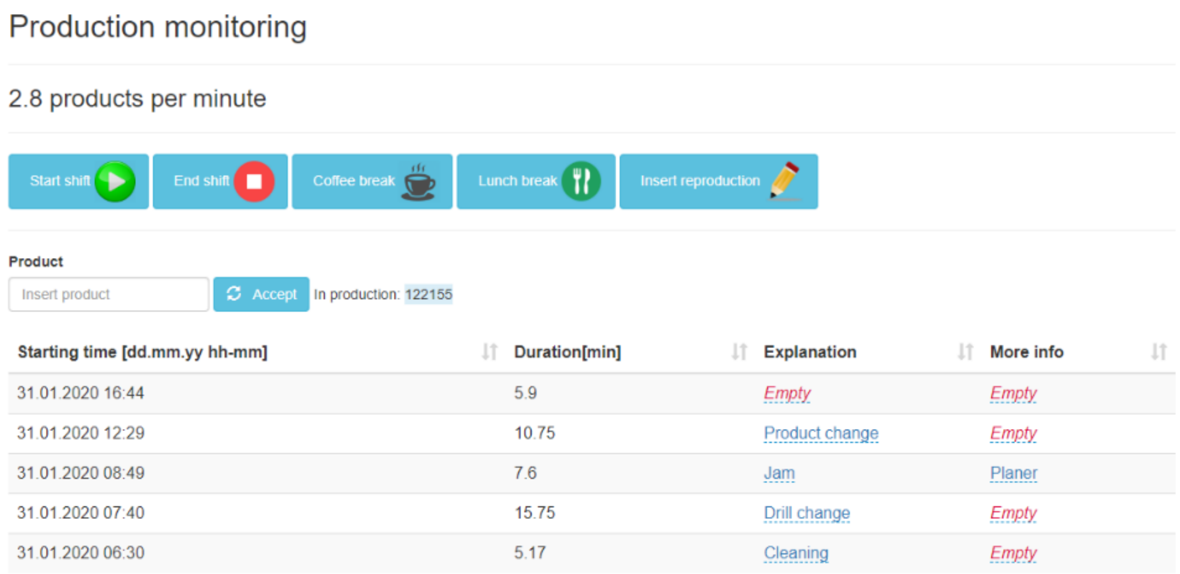

Figure 3. User interface to collect data from the stoppages, breaks and reproduction.

3. Experimental Runs at Factory Environments

Both factories we had the opportunity to run the system in were wood processing lines, where the products move on conveyor belts. This made the installation easy for the measurement system as only the availability of power at the installation location was needed to be confirmed and only one sensor was needed to follow the products in the production line. A bracket was fabricated for the sensor and it was installed at the end of the production line on both cases to record every product passing by. Stoppage at any point of the line stops the whole line making one sensor feasible to monitor and count simultaneously. The enclosure was secured to a wall so that it was not in the way of daily operations on the line.

One of the systems was left on a factory line and has now been running for over three years recording over three million products during the years. Uptime of the system has been well over 99.99% as only one instance was recorded when the system had stopped for a reason that was left uncertain. The issue was fixed by a simple power off – power on maneuver and has not repeated since. Another issue emerged after the system had registered over two million samples. All products were stored in one database table, one line each, and at that stage the select statement from the table took several seconds and was impairing the user experience. This was solved by converting the data to hourly when the day ended. This way no relevant data was lost, and the table size reduced by 99% making the select time about 0.3 seconds.

Both the GUI and the analysis software were developed during the first couple of months of use with the operators and the management to reach the versions presented earlier in this paper. This is the way most software development should be made, in close contact with the end user listening and reacting to the feedback. One of the biggest changes to the original GUI was how the reproduction numbers were collected. At first, there was a button which was used when the reproduction was started and stopped, but it was noted that it was forgotten on some instances and it would be easier to just type the daily numbers as they were already precisely known by the workers. An option to the software settings was also added, enabling the management to change the number of working hours planned for each week to get an accurate presentation of the availability component from the system.

As a result of putting the measurement system to use, the factory could find some of the underlying reasons for the stoppages and found ways to enhance the production. Unfortunately, these cannot be discussed here in detail due to a non-disclosure agreement.

4. Conclusions

A complete system with the associated hardware, software and GUI for the OEE measurement was developed and then thoroughly tested for a period of over three years in real factory environments. This work showed that a very cost-effective solution such as Raspberry Pi can be used in a factory environment successfully. The system was found to be extremely reliable and able to handle all the processing related to data storing, analysis and updating the GUI. The main purpose of the work was to help the factory to analyze their own production in a cost-effective manner. It was shown that no special and expensive hardware or complicated software development is required to build a system that can be used to improve the efficiency of manufacturing industry.

Acknowledgements
The authors would like to acknowledge the financial support received from the Council of Oulu Region and the European Union (European Regional Development Fund) for the "KuTuA" project.

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