ScienceDirect

Procedia CIRP 72 (2018) 1009–1014

The 51st CIRP Conference on Manufacturing Systems

Smart Manufacturing Execution Systems for Small and Medium-sized Enterprises

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Abstract

Manufacturing Execution System (MES) plays an important role in supporting small and medium-sized enterprises (SMEs) for their daily production operations. SMEs' businesses traditionally rely on paper based system of operations. With the rapid increase in technology, it is almost guaranteed that this will be replaced by more efficient and reliable smart MES. This paper presents a RFID enabled real-time manufacturing system which will incorporate five functions. These five functions will be integrated into an android based interface which reads and writes data to a cloud based database in real time. NFC technology is also utilized to improve the ease of use. This aims to promote communication within a company, improve product quality, optimize data storage and reduce paper waste. A case study demonstrates the feasibility and practicality of the designed and developed system.

Keywords: Cloud; Internet of Things; Real-time; Manufacturing Execution System.

1. Introduction

Due to the increasing globalization, we are facing a rise in smaller manufacturing plants produce a wider range of products. Additionally, due to the Internet, E-commerce and a growing demand for product customization has led to an increase in hybrid manufacturing techniques, as opposed to the archaic, linear production line [1, 2]. Today's products are faced with a high level of critique from customers, and with competition between companies being fierce manufacturing facilities need to ensure that products are made to a high standard while operating at an optimum pace [3]. This is done by reducing machine down time, improving delivery times, optimizing production rates and managing schedules for both the workers and the tools they use etc [4, 5]. These functions form the basis of a manufacturing execution system (MES) which is defined by the Manufacturing Enterprise Solutions Association (MESA) by including eleven key functions [6].

Internet of things (IoT) is a term used to describe the interconnectivity between various devices and appliances via the Internet [7]. The concept applies to wide range of applications in life ranging from commercial and consumer applications such as smart homes, interconnected entertainment platforms and smart vehicles which can improve profits [8-12]. IoT is used beneficially in many sectors by providing an insight into a company's operations through the utilization of sensors, hardware, software and even the cloud network. Data gathered with the IoT network can then be used to optimize a company's performance and eventually lead to an increase in profits. The IoT network also enables company assets to be incorporated into the network, giving an insight to an individual asset which can be closely monitored. This can lead to large amounts of data generated from a single appliance, this data would be useless if it was not processed in real time, thus the use of cloud computing is used to process data, rather than a local server or a personal computer. Cloud computing enables fast communications within a network thus allowing real-time decision making [13, 14].

MES must have significant improvements due to the rapid development of technologies over existing examples in addition

10.1016/j.procir.2018.03.272

to creating a system which is suitable to small and medium-sized enterprises (SMEs). Three factors play a significant role in the improvement of a MES including transparency, responsiveness and cost-efficiency [15]. To increase transparency there must be a push to improve the integration of the business into the system. This should lead to improved communication between the finance departments and the production departments. The responsiveness of the system often denotes the rate of flow of data. Increased response times help detect problems and unexpected events faster, helping locate and resolve the issue before it spreads. Lastly the MES must offer optimization as an underlying tool for every MES function. This optimization saves resources and time, eventually reducing costs [16, 17]. This paper presents a RFID enabled smart MES which incorporates five key functions:

- Data Collection/Acquisition - This core function describes the way data is obtained from the factory floor automatically from equipment/workers in a real-time manner.
- Process Management - Oversees production by correcting and improving processes, done either automatically or by advising the use of information acquired from smart equipment.
- Resource Allocation and Status - A vital means to monitor the resources used by the company. Resources include, skilled labors, materials, machines and production tools. It also displays the status of the above resources.
- Operations and Detail Scheduling - A tool used to organize and plan operations based on its importance, its reliance to manufacturing equipment and the order it is required to follow.
- Performance Analysis - This is a key tool in manufacturing systems used to compare results with both the companies past outcomes and future business goals, aiding decision making, improving efficiency, and positive progress.

The rest of this paper is organized as follows. Section 2 introduces the different components of a smart Manufacturing Execution System and describes their importance on the shop floor. Section 3 describes the key services offered by the application. Lastly, section 4 introduces a case study which explains the integration of the system into a fictitious workshop environment.

2. Smart MES

2.1 Smart Machines

The architecture of smart MES is shown in Fig. 1. Physical layer includes several sub-layers which are consisted of various categorized components. Firstly, high frequency RFID tags are deployed into various components and machines. Secondly, critical components, cutting tools, machine controllers, and data acquisition devices are included in this layer. They may carry different sensors so that their status could be real-time tracked and traced. Typical machines and robots may use different tools (e.g. cutting tools) for different processes. Thus, they are identified by RFID devices. For example, RFID tags are attached on each individual machine so that it can be uniquely identified [8-10].

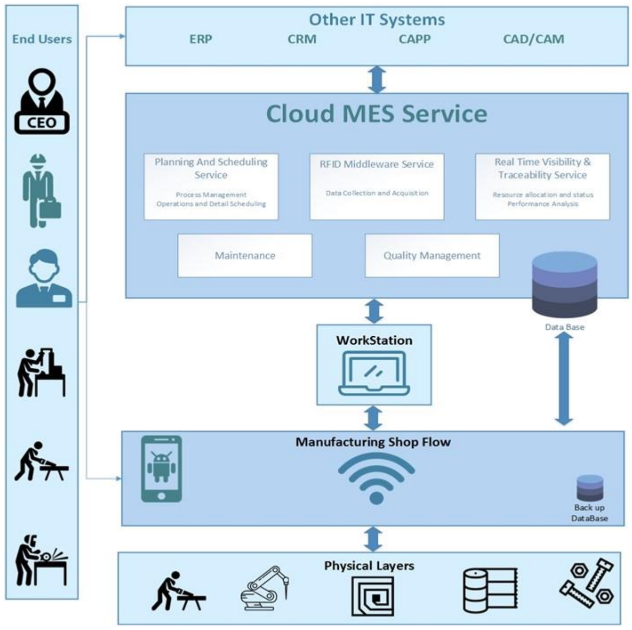

Fig. 1. Architecture of Smart MES

E-statistics report services enable the production progresses to be monitored via his/her smartphone. Customized interfaces could be designed per different applications and conditions such as peak season production planning and scheduling evaluations. The third sub-layer includes all the fundamental materials and resources used to create the final product. These materials however need to have a set size and finite number in order to have a RFID tag associated to it. Materials are usually delivered to a workshop with a set size in bulk. Bulk materials can then be grouped in batches and associated with tags, ready for use. Raw materials often reside in irregular or large shapes and sizes, with an unknown quantity. This may require a worker processing a raw material to a set size and grouping them in manageable quantities before linking them to a RFID tag. For example, a worker could cut uniform pieces of a carbon-fiber fabric, and organize the pieces in batches of a certain quantity, before linking each batch to a RFID Tag. Each batch could then be used to create a finite number of composite boards, without any leftovers. The RFID tags play a critical role converting materials and resources into smart objects so they can be used in a MES. Therefore, their decision-making procedures and operational flows could be reengineered and rationalized by the IoT-enabled solution.

2.2 Manufacturing Shop Floor

The entire framework is composed of tangible and intangible elements. The manufacturing shop floor represents one of the tangible elements required by the end-users, specifically the shop floor workers and their managers. These include a smartphone, equipped with an RFID reader/writer and which is running on an android operating system and a wireless internet connection which connects the phones to the cloud. It also contains a backup database which can record information if there is a breakdown in the network connection to the cloud, the backup Database may store the Job list for several days. The manufacturing shop floor serves as the central hub of connection, linking the End Users and the Physical Layers to the Cloud based MES.

2.3 End Users

The end users are all the persons that can influence and utilize the cloud based MES, this is generally the workers and the workshop managers. Workshop managers have additional tools and settings which can be used to make changes and improve workshop performance. Managers have the ability to add new jobs to the job list and edit existing jobs. Managers can also view performance analysis indicators for different aspects of the production process. Executive members of the company could use performance reports created by the MES to understand trends in production which they can use to shape the future of the company. Employees in the financial sector utilize other IT systems such as an Enterprise Resource Planning software, which is used to control the company's resources, reduce cost and enhance productivity. A cloud based MES could easily synchronize with other IT systems, increasing the connectivity within a company.

3. Key Services

3.1. RFID middleware

RFID middleware is one of the most important features of the MES. It is responsible for services that manage raw data as well as inter-device communication. Two key functionalities are associated with this service - data collection/acquisition and maintenance management. The latter will not be discussed in this paper as it is not yet implemented.

Data collection is essential to the proper implementation of manufacturing execution systems. Traditional paper-based style of operations, are often error prone and unable to cope with dynamic shop-floors, among other things. These problems arise mainly due to the untimely gathering of information which can be achieved through proper deployment of RFID enabled smart devices such as workers, machines and resources. Figure 1 shows how the smartphone app bridges the connection gap between the RFID devices and the cloud MES. Appropriate usage of this at key stages, would enable data to be frequently updated, allowing location and status, among other things, to be known. Once this data is collected, it is organized into information that can be used so that appropriate feedback can be sent back. Due to the nature of RFID many security measures need to be put in place to prevent the loss of any data

3.2. Planning and scheduling service

Planning and scheduling services provide proper guidance in the optimization of processes and operations. This service addresses two functionalities – process management and, operations and detailed scheduling. Process management is the method used to define the process that raw material would have to undergo as it becomes the final product. Whereas operation and detailed scheduling is used to determine when and for how long the process should occur.

When jobs are registered, managers would input information such as priority, importance, machining process to use, etc. The middleware service would then collect and organize this data so that an optimal method can be computed. This would be formulated for each instance using a set of rules or logic governed by the input parameters as well as real-time data. Once the process method is known, the operations and detailed scheduling can be generated and sent to the workers. This would take into account constraints, such as due dates, placed by clients or otherwise and automatically adjust current and future schedules.

3.3. Real-time visibility and tracking

The purpose of this service is to provide improvement in the exchange of information for decision making related to the real-time planning and control of materials. Several steps must be undertaken for this to be successful. This includes the timely collection of data and the useful interpretation and feedback of information.

The timely collection of data is managed by the middleware service and aided by the proper deployment of RFID tags. The organized information collected by the app is used to create meaningful information that can be presented in a graphical manner. Managers, or other authorized users, can view the current situation of the shop floor and, track or edit resource allocation, inventory levels, worker performances, etc. to ensure that any decision made, can be made on a real-time basis.

4. A case study

4.1. About the case

The case study chosen is a fictitious company which produces jewellery using resources unique to New Zealand and its heritage. The Workers in this company are experienced jewellers, who rarely need to follow an instruction sheet. These Workers may specialise in certain materials and techniques however can complete every task. The Jewellery produced is then sourced to several retail chain stores around the country. These stores generally place large orders for various products, which have a long-term deadline. The company is placed in a tourist prominent area, and frequently has customers inquire about jewellery that can be custom made. Custom orders generally have a shorter deadline, and the difference in deadlines means that some tasks greatly influence the job list compared to other tasks. This case study provides an excellent example of small scale, customized production.

This company uses three main resources for their jewelry catalogue - jade/greenstone, paua shells, and silver. Because each of these materials have unique properties, different machines would be utilized to ensure that detailed and quality work is done consistently. Each type of jewellery would also have a different manufacturing process that it would follow till completion.

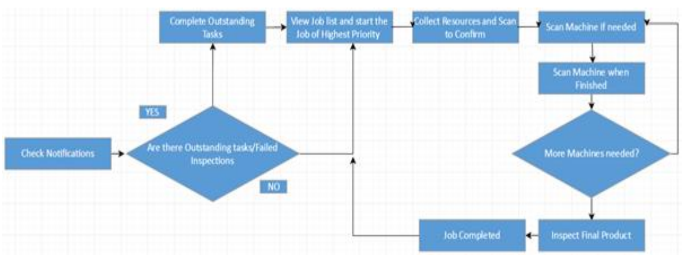

Fig. 2. Process Flow

The process for making silver earrings usually starts with the rolling of the silver into sheets which are then ready to be laser cut (Fig. 2). Silver rings are all produced on site, in a forge. This starts with the hand carving of a wax replica, which is used to create a reusable rubber mold. The mold is used to create wax duplicate, which is a key component in hollow wax casting. The wax blanks are then covered in a heat resistant plaster and when it has set the molten silver is poured in. The molten silver melts away the wax and takes its place. When the cast has cooled, the plaster is broken away and a silver ring is left behind.

The Paua shell materials are delivered in their raw state. Paua has a hard scale which must be removed to expose the attractive layers underneath. The workers then cut the paua to appropriate sizes to work with and then begin carving them to the desired shape. Similarly, the greenstone is delivered in large sections, which need to be cut to an appropriate size before cutting and shaping the stone.

Consider a normal day at this company without the RT-MES as the base case. Workers start with existing Jobs that have not been completed from the previous day before moving on to other jobs. The current system has employees create a single product from start to finish, processing the raw materials into manageable shapes. Additionally, Clients are met as they arrive throughout the day. Each client will have their own specific requirements and designs which are written on paper forms. These would then be manually inputted into the system and job schedules would be manually allocated to suit the worker's skills.

Current problems the company faces are an inadequate method of tracking the resources used and the time taken.
The company also requires a method of optimizing the job list for each worker, and the ability to track various resources in real-time. Additionally, the company is trying to reduce its carbon footprint by lowering its paper consumption.

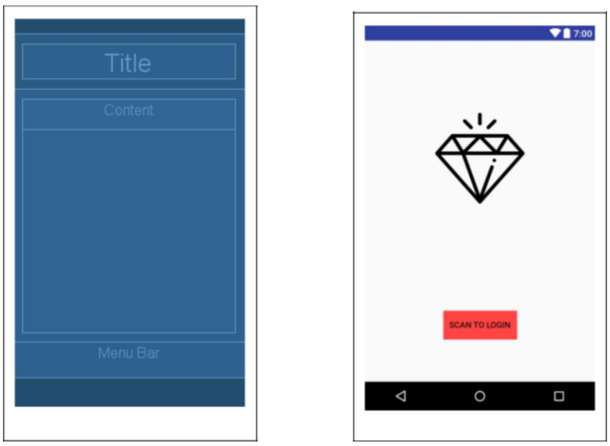

Fig. 3. User Interface Design

4.2. User interface

The user interface was designed to be simple and intuitive as most of the users are typically older persons who may not be familiar with technology. There will be two versions of the app, one for the general worker and one for manager and higher level employees. Both versions are essentially the same, however the key difference is that managers have to ability to add, edit, and view more information, such as assigning job priority, viewing performance, etc. The different screens were initially designed on BlasamIQ, an interface design tool. Each screen follows the same basic layout where possible see Figure 3. This along with the expected daily use of the application is expected to increase familiarity which serves the principle of memorability, which promotes usability. The following subsections will discuss the login and job specific overview page, employee resource screen, and job list screen. These pages will address a portion of the MES functionality namely, data collection/acquisition, performance analysis, and process management/operations detailed scheduling respectively.

4.3. Login

The first screen that the users will see as they start the application is the login page. This ties into the security aspect of Firebase in that it will compare the RFID information from the employee's ID card, with the information in the database. It will then either log in to the app, or display an error message with more information. Other details such as date, time and location are also logged. This increases the robustness of the application as it means users cannot try to cheat the system by logging in at home or at a later time. Location parameters were not set as it would rely on the specific business.

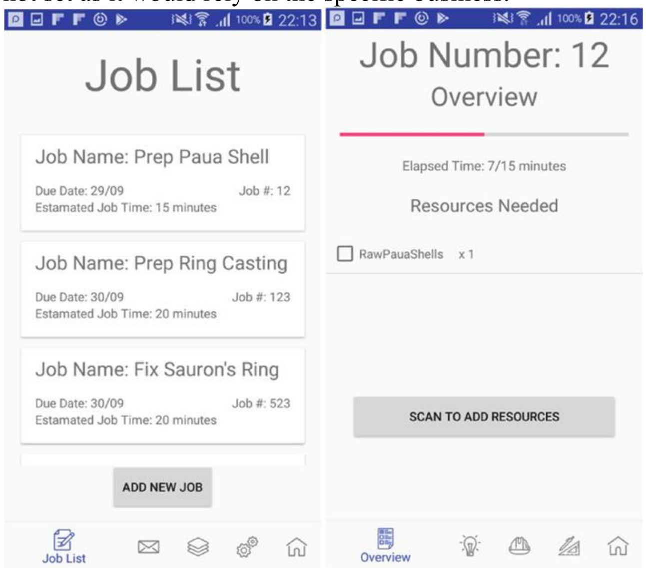

Fig. 4. Job list

4.4. Job list

Fig. 4 displays the next major screen is the job list page. This page utilizes the basic layout mentioned previously. The Content instead lists the specific jobs that are assigned to the logged in user. The job information is displayed in cards, which are populated by using customized adapters. These adapters take in arrays of job information obtained from the database, which will be ordered using the simplified formula.

$$n = 0.8d + 0.2p$$

Where d is the number of days since the job was assigned, and "p" is its priority number. A higher n value would mean that the job would be higher on the list. The above formula puts emphasis on the "d" as it is bad for reputation if the customer is kept waiting for long. This relates to operations scheduling, whereas the process management can be seen as the items in the list are not necessarily for a complete job. For example, Job 12 is "Prep Paua Shell", an intermediate step in creating a paua earing.

An "add job" button is also available for the manager's version of the application. This adds flexibility as it enables the manager to react to sudden jobs or if jobs are cancelled unexpectedly.

When the user selects a job, they will be redirected to a page containing information specific to that job. The first screen specific to the job is the Overview screen (Fig. 4 right), this page displays a progress bar, the resources needed, and a scan button. When the user clicks the scan button, the application will start searching for RFID tags, if it reads a tag pertaining to the allocated resources it will check the box. As the resource becomes checked, it will then update the database shifting the desired amount from "INVENTORY" to "WORKINPROGRESS". It also sets the location of the resource to the users ID, thus providing real-time updates that be tracked.

As soon as the last resource is selected, the progress bar will begin and an internal timer will start. The progress bar will follow the expected time that the job should take, as determined by the ERP software, while the internal timer logs the actual time it takes. This information can then be used to update the user's performance.

Other screens include instructions, safety, quality, and home. Of note is the quality screen, which will have a "Finish" button that, when selected, starts the RFID scanner after checking if the quality parameters are fulfilled. The final product is scanned which updates the used resources status, e.g. from work-in-progress to inventory (finished product).

Fig. 5. Employees Performance

4.5. Resources Management

The resources page will feature three cards: inventory, work-in-progress and employees. By click the card, the user will be taken to that respective page Figure 7 show the employee page which can only be accessed by a manger level user. On this page, a graph will be displayed depending on the three options chosen by the user. For example, if the manager was interested in user id "04950F4AE53F80" and wished to see their daily performance compared to the estimated performance, then the output would be as Figure 7. The manager can then look through previous days as long as the data is available. An example of how it can display real-time information can be seen in how the graph ends suddenly in Figure 7. The problem with this is that since this application relies on the upper ERP software, the required data would need to be sent as a file to the database storage where it will be downloaded from and parsed into usable information. The data supplied by the ERP software can be in a variety of formats which would need to be individually handled. For simplicity, we has assumed that the information is in JSON. This does hinder the real-time ability of information and may mean a bigger download when the datasets become larger, however this would be after more than a couple of years of use.

4.6. Discussions

The cloud based android application interface developed above, supports many key MES features. Utilizing RFID technology makes it easier to digitize resources and store them in a database. The Job list page displays the Jobs in order of their priority. This organizes the worker's timetable and insures the worker follows the most optimized schedule. When the worker accepts a job, he/she uses RFID to scan to collect resources. When a resource is collected, the database is updated in real time. Adding safety features related to the Job keeps the safety of the worker as a priority. An instructions page was included to display a detailed method needed to complete the job, and the job is concluded after the worker completes a quality analysis of the job completed. Utilizing RecycleView and Firebase Storage allows the application to display a variety of content, such as pictures, videos, and audio files. This gives the interface a highly modular design, allowing the company to display the information they believe is most important.

4. **Conclusions**

This application is a smart manufacturing execution system (MES) aimed at small and medium sized manufacturing enterprises (SMEs) to gain the most are those that rely on manual and paper based data collection of shop floor information, and do not have the spare funds to invest in the costs associated in fully setting up an ERP system. This paper contributes to several aspects related to the IoT enabled smart MES. Firstly by proposing a mobile RT-MES, that can be used by workers as well as managers to mitigate and accurately respond to the dynamics of the shop floor. Secondly, the use of a decentralized cloud server allows the information provided by multiple ERP systems to on one database. Enabling the proposed application to be modular in nature and adaptable to any business, whether they partly use an ERP system or not.

The recommended future work can be split into two distinct paths. The first would focus on the modular or adaptability of the application which was not fully implemented due to time and cost restrictions as well as limited coding knowledge. This requires the compressing and integrating the information provided by multiple ERP systems so that business are not limited in their providers. The second path focuses on shifting from only an interface only application towards a more self-reliant MES application. Much more research would be required from this pathway as it would require the formulation of mathematical models for real-time planning and scheduling and process management.

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