Smart Multi-material Weight Tracking Resource Bin

Puneeth S. Kannaraya, S. Dilip, Chandana S. Deshpande, Manish Arora, and Amaresh Chakrabarti

Abstract Smart Manufacturing or otherwise Industry 4.0 as known in Europe has been the latest technological trend in all industry domains. The components being cyberphysical system (CPS), Industrial Internet of things (IIoT), Big Data are major key technologies in improving the overall performance of the factory. In this paper, a case study is done to understand the resource management for medical device manufacturing company and with bringing smartness into manufacturing. A smart multi-material tracking resource bin that measures the quantity of the waste materials is designed and developed which can send real-time information across the stakeholders using the components of smart manufacturing. The application of the resource bin will then may result in the cost-cutting and increasing productivity which are important measures for Micro, Medium, and Small-scale Enterprises (MSME).

Keywords Smart manufacturing · Waste · Weight · IIoT

1 Introduction

Smart manufacturing systems include instrumentation systems, condition monitoring systems, manufacturing execution systems, and process control systems [1]. Smart

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manufacturing promises quality at greater safety and productivity [2] at a lower cost and environmental impact.

The overall goal of our research is to understand the major manufacturing challenges in the medical device industry in India, especially in Micro, Small, and Medium Enterprises (MSMEs), and develop means to support these typically conventional enterprises to adopt smart manufacturing. A large number of MSMEs in India are in shortage of funds and have limited access to relevant information. By trying to reduce costs and minimizing capital expenditure, the MSME sector is dormant when it comes to the use of the latest technology and knowledge [3]. In accordance with the provision of Micro, Small and Medium Enterprises Development (MSMED) Act, 2006, the MSMEs are divided into two classes: Manufacturing Enterprises and Service Enterprises. The manufacturing enterprises are defined in terms of investment in plant and machinery. The limit of investment for micro, small, and medium enterprises is up to 10 Crore INR. Similarly, for enterprises engaged in providing or rendering services, the investment in equipment limited to 5 Crore INR [4].

As part of the objective, this paper reports a detailed case study conducted in an orthotic footwear manufacturing MSME, which manufactures customized footwear for people suffering from diabetic foot, corns, calcaneal spurs, heel pain, heel cracks, metatarsal pain, arch pain, obesity, height difference, low back pain, and flat feet. Manufacturing companies typically procure huge quantities of raw materials; when these raw materials flow into the production line, the factors such as keeping track of materials, accounting the raw materials consumed, and waste materials generated becomes crucial in terms of cost [5] and efficiency in any manufacturing industry. MSMEs in India, especially its micro variety is highly cost-sensitive; hence there is a need to introduce an affordable technology in the production line to monitor the usage of raw materials. Affordability to high-end technology becomes a challenge and often results in using nonstandard practices.

Medical device manufacturing industry generates various types of waste in its manufacturing sites, research institutes, and health care facilities. These include the types of waste generated by medical footwear manufacturing unit, including raw material waste during production activities. Over the last two decades, the footwear sector has placed significant effort in improving material efficiency as well as eliminating the use of hazardous materials during the production phase [6]. However, unsustainable consumption patterns of raw materials in its production lines generate considerable waste.

There are several methods to supervise the waste generated; the most common method would be to track the weight of waste material produced; an example being, use of weighing scale in beehive monitoring [7], and being accountable for the same. There are, however, no appropriate methods used in the MSME for this purpose, let alone tracking the weight of waste on a continuous basis in an accurate and stable manner.

Henceforth, in this paper, a highly economical solution for multi-material weight tracking has been presented; the solution uses an industrial-grade weighing system, around which the functionality of tracking different types of waste materials which are being generated, measured on a single weighing platform has been developed.

2 Case Study

As mentioned earlier, the intent of this work is to study and understand the processes and activities involved in the micro/small/medium scale medical device manufacturing industry, carry out time study for their value-added and non- value-added activities, so as to find out the existing bottlenecks in their processes and help them to improve the productivity of the enterprises using smart manufacturing technologies.

The detailed study carried out in the orthotic enterprise spanned from the event when an order is received all the way to the packaging of the product. Once an order is raised, raw materials from the inventory are issued to the production stations where manual cutting and stitching and gluing are carried out. There are around 40 different materials used in the manufacturing of a shoe [8]. Typically, shoes are cut from large sheets into patterns, leaving 30% or more material to be discarded [6]. There will always be some waste that cannot be prevented at the source. Where waste material is produced, an optimal end-of-life treatment option must be selected with the lowest possible risks to human health and the environment. Table 1 shows the footwear waste generation for different materials in India.

At present, the waste collected is discarded to the landfill, leaves a major carbon footprint on the environment. Landfill sites can result in serious environmental pollution of groundwater and rivers, caused by landfill leachate [8]. But for optimal usage of the raw materials and recycle and reuse of the wastes by following a scientific procedure can reduce the effect on the environment.

For cutting the upper part and the insole materials Ethyl Vinyl Acetate (EVA) sheets are used; during each of these stages, waste is generated (see Fig. 1 for the different parts of footwear). In a similar manner, waste is generated at most of the manufacturing stations. Based on the study of the shoemaking process in the above manufacturing unit, it has been clear that raw materials are currently not used to the maximum due to inefficient, manual intervention in the unit. If the amounts of materials wasted, their locations, and associated processes can be tracked across the production lines, the costs associated with the material losses can provide motivations for devising and implementing measures for their improvement, in particular, by

Table 1 Condition of footwear waste in India (Contribution of various elements in generating waste) [8]

Footwear materials	Percentage (% wt)
Leather	25
Polyurethane (PU)	17
Thermoplastic rubber (TR)	16
Ethylene vinyl acetate (EVA)	14
Poly Vinyl chloride (PVC)	8
Rubber	7
Others (adhesives, metals, etc.)	7
Textiles and fabrics	6

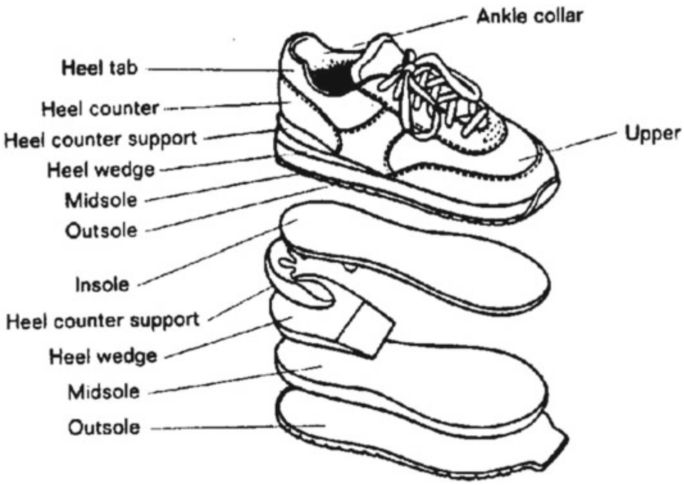

Fig. 1 Parts of footwear (reference image)

avoiding material losses. One way to tackle this challenge is to develop a high-quality weight tracking system that is also highly affordable.

3 Methodology

By the emergence of fourth industrial revolution or smart manufacturing, the manufacturing processes have opened to broad ways by allowing advanced technologies with the use of IIoT, CPS, Big Data, etc. These technologies which have the capability of data transformation and informatics will help manufacturers to expose to the competitive market with better business strategy. Also, it allows to penetrate the market with cost-effective products and also improve the efficiency of production.

One such approach was decided to apply for the tracking of waste materials and to quantify it so then the information can be used to extrapolate the efficient use of raw materials as per the interest of stakeholders.

There is a certain amount of research has been gone through for waste management in various municipal infrastructure services, for smart cities. But we don't see much usage of waste management techniques by using smart manufacturing concepts in the industrial sector. Although the idea of sensors-based waste bins [9–11], capable of notifying waste level status, is not new to its entirety, however, to quantify the collected waste on the basis of the material is what concerned. Use of Radio Frequency Identification (RFID) technology for the bin identification has also been used [11, 12].

The difficulty in the maintenance of the RFID tags post-production in our case study is another issue. So the usage of barcodes which can easily be printed onto the

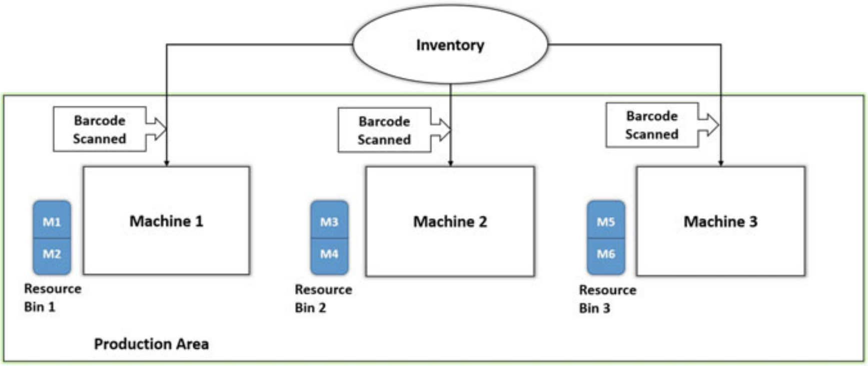

Fig. 2 Activity flow in factory layout

paper, allowing to be assessed by a worker for a particular job order with material and human information, was decided. Whenever the job order is issued and materials are collected from inventory the barcodes are to be scanned. This enables the traceability of the materials at the cutting stations. Figure 2 shows the resource bins placed beside the cutting machines and barcode reading activity happens before raw material enters into the production line.

4 Design

4.1 Hardware Design

The smart multi-material resource bin is designed to be placed at one of the cutting stations, where large sheets of 1.5 m × 4 m are placed on the table and a hydraulic press shear off the sheets into soles of sizes determined according to the shearing die placed beneath. The waste generated is then put into the nearby bins designated for that type of material.

In order to identify the type of material used during any part of the production, barcodes are attached to each batch of raw materials. To scan these barcodes, a barcode scanner is used, which scans the encrypted data and sends it to the visualization platform, the Node-RED.

As mentioned earlier, during the manufacturing process of these orthotic shoes, different types of raw materials are used. There is a need for different materials to be tracked on a single weighing platform so that variants of the same resource bin can be developed and placed according to the disposal flow with appropriate barcodes to facilitate the materials associated with each bin at each location as shown in Fig. 2.

The weight of the two sets of waste materials tracked independently on a single weighing platform is given by the following equation:

$$T1 = w - p - T2 \tag{1}$$

$$T2 = w - p - T1 \tag{2}$$

where

$T1$ weight of material type 1
$T2$ weight of material type 2
p tare weight
w applied weight

The smart resource bin has been designed to collect two different types of waste materials (and can be extended for collecting more types if needed) with two separate bins for waste collection. The parting door provided for the resource bin ensures that a given waste can be slid into its designated bin by the door closing the other bin. A DC motor is used to operate the door with two limit switches attached on either side of the motor. The limit switches, once pressed, restrict the door from moving further. This way, the movement of the door is controlled. Figure 3 shows the concept generated in the CAD environment and Fig. 4 shows the final setup of the resource bin.

When a given batch of raw materials is received from inventory at the shop floor, the batch consists of a barcode that must be scanned before starting the in-process work. The information on the barcode includes material types and properties. This

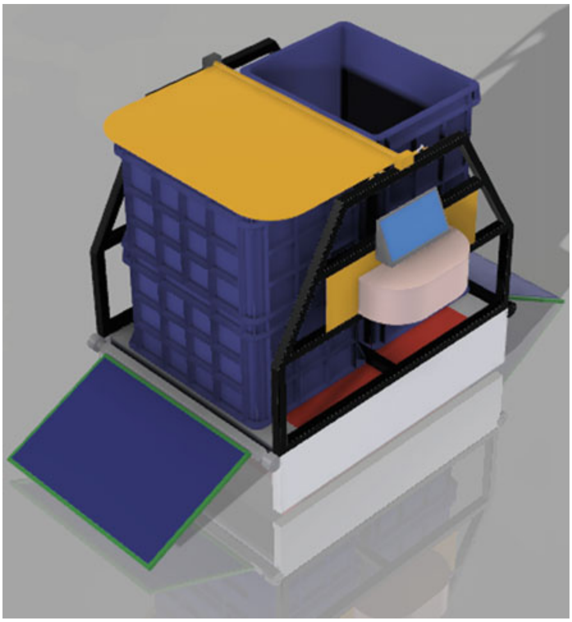

Fig. 3 Concept design of the resource bin

Fig. 4 Smart multi-material resource bin setup

information is utilized to open the designated side of the weighing scale and making the other side of the bin inaccessible.

4.2 *Architecture and Working*

A 200 kg capacity load cell is fixed to the industrial weighing scale platform of 0.6 m × 0.6 m, which is then connected to the Node MCU with HX 711 ADC by an I2C communication protocol. As each material gets accumulated in the respective bin, the weight of the material and the material type are stored in the computer and displayed on the screen, so that the worker can monitor the activity.

Barcode scanner is connected to the Raspberry Pi which scans the details of the type of the incoming material at that manufacturing station. The data is visualized on a dashboard. The architectural block diagram of the smart resource bin is shown in Fig. 5.

The visualization dashboard is built on the Node-RED platform; the dashboard displays the details of the material type and provides virtual buttons for (changing) material selection, visualization of weights of the material, and flow of material over time as shown in Fig. 6. The MQTT protocol is used to communicate Node MCU and RPi 3, which makes the connectivity wireless.

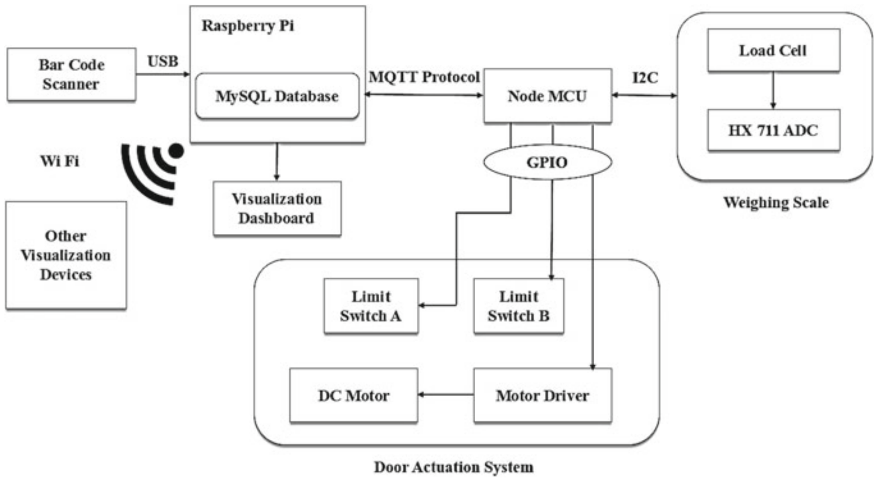

Fig. 5 Architectural setup and connectivity

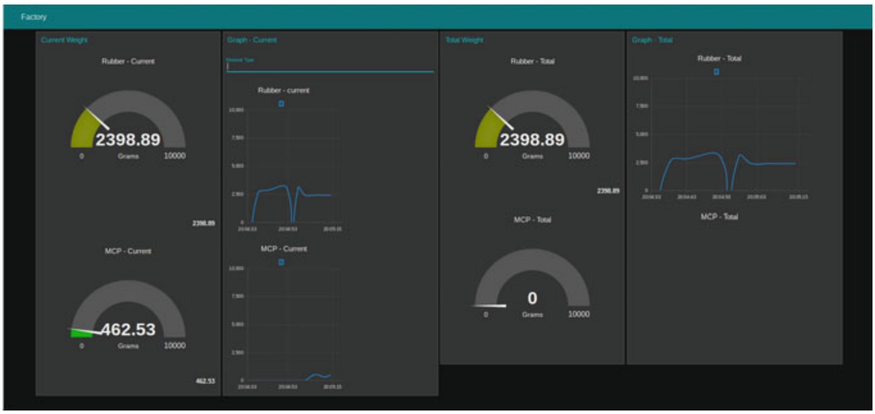

Fig. 6 Visualization dashboard

5 Execution

The smart multi-material resource bin was tested in the development environment for its performance by adding waste materials at different intervals of time, with the data stored in a local MySQL database, which could be retrieved in different file formats.

The dashboard displays information about the material type and its real-time weight and provides a graphical representation of the waste that is being continually dumped into the bin with appropriate timestamps. The above visualization is also possible to be provided on other devices, by connecting to a common Wi Fi network to which the RPi 3 is configured.

Using the system developed, a supervisor or top-level management can have real-time visualization of the waste generated at a manufacturing site and can remotely monitor the quantitative values of the waste. An email will be sent at the end of the shift/day to a top-level manager, which updates the wastes being collected.

5.1 Field Trial Observations

The smart multi-material resource bin has been successfully deployed at a live shop floor of the orthotic footwear manufacturing industry. During the field trial at the factory, we observed the following challenges which are being considered as feature enhancement in the upcoming version of the product.

Challenge I: The shop floor of the industry used two materials—rubber and Multi-Cellular Polymer (Chemically known as EVA) for the orthotic footwear design and they are cut at different work stations. The wastes from these stations are to be segregated and discarded individually but due to space constraints between these stations, the leftover materials were discarded at the same place and then manually segregated because of which there a mix up of materials was being discarded into wrong bins, which caused a misinterpretation of weights of materials being segregated.

Challenge II: The waste materials were supposed to be dropped inside the designated bin. The bins will be closed alternatively depending on the scanned barcode information. Once if the barcode is not scanned, even though with labeling on the bins the worker dropped the wrong material to the wrong bin. The post realization of the mistake made the worker scan the barcode and drop it again into the designated bin. This activity did not provide continuous data and it was difficult to identify the outlier.

Challenge III: There is regular power shut down in the factory, which interrupted the activities of the resource bin and the system needed a reboot. This also affected the analysis of the performance of the system, due to non-continuous data.

6 Conclusion

A smart multi-material tracking resource bin has been designed for meeting the challenges in MSMEs in Low and Medium income countries; it is intended to help track the quantity and type of materials being wasted. The historical data collected thus is then available for review. Integration into a Manufacturing Execution System (MES), and for performing data analytics, which should help in optimizing material usage and improving the efficiency of a manufacturing plant, resulting in revenue for the enterprise provided the operator is duly trained on the usage of the product, which we found to play a significant role in Industry 4.0.

The resource bin should help manufacturing enterprises at every stage of their operations for measuring and remotely monitoring waste, in the following manner:

- Tracking of the weight of the waste materials
- Segregation into reusable and non-reusable materials
- Tracking of the different types of material being used
- Data visualization and storage

We plan to deploy such smart multi-material resource bins at large scale manufacturing sites and test the performance in the near future with necessary upgrades. This should provide further insights into the sensitivity and reproducibility of the resource bin in the real-world applications, and their efficacy in supporting the reduction of waste and cost and improvement in productivity and sustainability.

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