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Development of Smart Mini Manufacturing System Model for Industry 4.0 Application

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ABSTRACT

The theoretical mini-smart manufacturing system makes use of connected sensors, machines, and gadgets across the production line for real-time data collection. In several facets of the manufacturing process, such as quality control, predictive maintenance, inventory management, and supply chain optimization, it enables proactive decision-making and continuous improvement. The mini-smart manufacturing system's conceptual design transitions from a conventional to a smart manufacturing system using Industry 4.0. To illustrate the notion, the physical model and remote model are created. The NodeMCU ESP32 and sensors utilized in the physical model of a conveyor belt allow for wireless data collecting and control. The dashboard is created using Google Spreadsheets for real-time monitoring, data analysis, and control. It permits automatic data-driven decision-making based on a performance analysis algorithm that evaluates the actual result with the intended outcome. These two versions are linked together using the Google Apps Script so they may communicate wirelessly. Case studies are used to test the interoperability of physical, remote, and data-analysis methods to make sure it satisfies the requirements. Automation processes, such as data gathering, analysis, and control, demonstrate the viability and core components of the smart manufacturing system. Overall, the idea of a smart manufacturing system signifies a radical change in how industrial processes are conducted. It offers increased efficiency, productivity, and flexibility by utilizing cutting-edge technologies and data-driven decision-making. The proposed smart manufacturing system offers a plan for a manufacturing ecosystem that is prepared for the future as the manufacturing sector enters the era of Industry 4.0.

1. Introduction

From the first machining techniques of the first industrial revolution to the automated manufacturing industries of today, the manufacturing industries have advanced significantly. After undergoing several inventions and repeated tests over the years, manufacturing systems have now entered their fourth generation of the industrial revolution [1]. However, the manufacturing sector faces a number of difficulties, including data integration, process flexibility, and process automation.

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The system’s core component, data, is used to reach a logical conclusion as opposed to one based on feeling or experience. The bulk of production systems generate and gather data via sensors on various machines. There are many different types of data, such as process data, which forms the basis for advanced analytics to increase productivity, quality, and quantity, logistical data, which includes all of the planning and service tasks required to finish manufacturing activities, product data, and quality data. Such data presents a number of challenges and calls for new management, processing, and storage strategies. New algorithms, models, and visualization techniques are required to make use of and benefit from the data so that the expert can recognize the relationship between data streams and draw a conclusion from the data [2].

Process manufacturers struggle with the need for increased flexibility in order to react quickly to volatile market demands, flexibility at the production level in a cost-effective manner, and the requirement to be able to identify potential problems early in order to make process adjustments for optimal performance given that the product life cycle is shorter now than it was ten years ago. Because historically many departments independently created and regulated processes and systems at the production level, the manufacturing technology now in use is unsuitable and does not support flexibility. As different manufacturing levels attempt different adjustments, the expenses rise. A further adjustment is necessary, but managing change at the production level will be challenging [2]. A change in one place will have an impact on the entire production system.

Automation of processes is driven by the goal to minimize human involvement in them in order to minimize human mistakes and prevent health risks. Higher accuracy, cheaper costs, and improved productivity and quality are all benefits of automation. Since human mistakes cannot be entirely avoided, it is acceptable for small-scale or individual errors to occur. Even one worker making one error per day might lead to a significant product rejection rate in the manufacturing sector, which is responsible for creating things in large quantities and with a variety of possibilities. Human mistake consequently becomes a barrier to growing industries and results in them suffering modest to major losses. The Internet of Things (IoT) is being employed in various types of systems as a result of historical technological improvements in order to simplify operations and reduce the need for human engagement in the automated system [3].

Industry 4.0 is the concept of "smart manufacturing," which integrates connectivity via the Internet of Things (IoT), machine learning, and real-time data processing [1]. Industry 4.0 is a concept that makes it possible for data to be gathered and analyzed across various equipment, enabling a speedier, more flexible, and more effective process to produce things of a higher quality while spending less money. It aims to promote industrial growth, expand production and logistics capabilities, and finally give every industry the chance to congregate on a single stage and compete on the caliber of their offerings [3].

In conclusion, the manufacturing sector has a number of challenges, including a lack of real-time machinery monitoring, the need for human intervention during the data-gathering stage, and the need to conduct offline data analysis. In order to solve the issues, Industry 4.0's central idea will be essential. Frameworks or fresh approaches are still needed for the future of the manufacturing sector because there is currently a lack of solutions that can address all of the industry's problems.

2. Problem Statement

Many manufacturers in the manufacturing sector still manually record the production rate, downtime, and loss using timers, pen, and paper, which are human-dependent, traditional data collection methods. Additionally, there is a lack of computer-aided technology, such as standalone software or Excel spreadsheets integration with machines, to give better data analysis. Manual processes are therefore exceedingly ineffective, prone to inaccuracy, and produce subpar decision-making.

When operators manually record variables and parameters on paper, productivity suffers. Every handwriting motion results in a timely reduction in operational time. The problem still exists during analysis because all of this data must be manually assembled into clear reports and visuals. Additionally, since manual data collecting requires a lot of labor, less labor will be available for other projects.

Simple errors like misreading numbers, having bad handwriting, and failing to record information are what lead to human error. The likelihood of inaccuracy increases with the complexity of the data that must be recorded. The operator is also under a lot of stress in unpredictable situations. The operator will be overworked as a result, increasing the chance of mistakes.

Reduced productivity, incorrectly documented data, and an overworked workplace all contribute to poor decision-making. Real-time data is recorded straight from the machine utilizing devices and sensors, and the data-collecting procedure is automated. Utilizing Google Spreadsheets, the acquired data are put through the data analysis process. The operator devices receive wireless data transfers of both the gathered and the analyzed data, enabling them to work anytime, anyplace. Better decision-making, more production efficiency, a decrease in human mistakes, less overloading, and industrial process optimization are all benefits of this.

3. Objectives

In order to demonstrate the capability of remote communication, this project aims to create a smart manufacturing system that enables wireless connection between the field side of the manufacturing system and end-user devices. It also aims to create a system for real-time monitoring and manufacturing operation execution that can adjust to changes in the status parameters of the machinery and integrate data analytics to identify the best manufacturing parameters. The following lists the project's goals:

i. To develop a prototype of the system that connects the physical model and remote model through an IoT system.
ii. To create a system that can perform real-time monitoring and controlling.
iii. To provide real-time visualization of sensor data on the dashboard user interface.
iv. To develop a decision-making algorithm that can perform automatic data analysis using the remotely collected data to provide the optimal value for the manufacturing parameter.

4. Literature Review

4.1 Industry 4.0 (Smart Manufacturing System)

The input and output of the production line, which is the process that turns raw materials into finished goods, are primarily the focus of the traditional manufacturing system. The production line can be managed more effectively, though, using a smart manufacturing framework [4]. The cloud, data analytics, and networking technologies are combined in the smart manufacturing system to exchange information and enable end users to make informed decisions. The smart manufacturing system enables the constant observation and management of crucial parameters [5].

Manufacturing systems for Industry 4.0 must function, be kept up with, and have the finest scheduling. The widespread usage of numerous different sensors has made smart monitoring possible by gathering information from all points along the supply chain. For example, real-time data on a range of manufacturing items, such as temperature, energy use, machinery status, and speed, can be collected. To facilitate better decision-making based on predictive operation, smart monitoring provides a graphical representation of these data [6].

The manufacturing system known as Industry 4.0 offers adaptive production control, commonly referred to as smart control. Using mobile devices with internet access, end users can manage the parameters of the machinery as well as turn it on and off. In order for front-line production to function, the choice will then be swiftly executed [6].

IoT and Node-RED are the two main technologies that support smart monitoring and control in smart manufacturing systems. Node-RED is one of the greatest platforms for creating IoT systems because it is based on Node.js and has an open-source JavaScript environment. It facilitates the development of data processing logic and the transfer of processed data to systems at a higher level. With the use of its Dashboard interface, Node-RED can build a user interface to present different sensor data as a graph or value without the need for specialist HTML and CSS knowledge. Before dedicating a significant amount of resources to the development, new or current technologies can be developed and tested on the Node-RED platform [7].

4.2 Internet of Things (IoT)

The Internet of Things, or IoT for short, is a broad concept in which "things" including all locations, objects, and environments can be connected to one another online [8]. The idea of the IoT makes it possible for anything with a unique identity anywhere in the globe to be connected at any time. The phrase "being connected" is frequently used in reference to technological apparatuses like servers, computers, and smart devices. The Internet of Things (IoT) integrates sensors and actuators that are embedded in physical things using wired and wireless networks and a standard communication protocol to join the Internet [9].

Microcontrollers, sensors, and actuators are often used to connect Internet of Things (IoT) devices to the Internet. The most well-known protocols used in the Internet of Things are Representational State Transfer (REST) API and Message Queuing Telemetry Transport (MQTT) [10]. The MQTT protocol is frequently used in Internet of Things applications for data transmission due to its lightweight communication characteristic. The publisher and subscriber-based MQTT protocol allow several devices to communicate with one another across a wireless network without having to mutually recognize one another. All of the devices that have subscribed to that topic will receive the information attached to any application messages that the publisher sends on that topic. An MQTT connection consists of a client and broker server, where the client is any connected networked hardware such as mobile devices and sensors. In contrast, an MQTT broker is a server that distributes messages across clients [11]. REST API is a more flexible protocol that is simpler, uses less bandwidth and is better suited for IoT applications. A web architecture concept known as REST creates standards for computer system communication and streamlines system interaction [12]. Application programming interfaces, often known as "key"-based communication, allow for communication between two programs [13]. With the help of APIs, a single app can use programs created in many programming languages. Additionally, the REST API limits all communication to HTTP requests. An HTTP GET, POST, PUT, or DELETE request is sent from the client to the server in the form of a web URL. The server then replies with an array-based resource, such as JSON or HTML. REST API is therefore a versatile and simple IoT communication tool that offers a way for safely gathering data from IoT applications [10]. For the model in previous study [22], the authors employed similar structure of prototype using Arduino, Java programming language, robot as hardware and Wifi

Module. However, the outcome of the model [22] is to control the robotic arm using application on mobile phone, while the study uses the data to decision making in adjusting conveyor speed with the IoT concept.

4.3 Data Storage

The construction of a smart manufacturing system is made possible by the concepts of Industry 4.0 and the Internet of Things processing real-time monitoring systems using smart sensors. As IoT system expansion demands a big storage capacity in order to leverage the benefits of IoT technology, the use of smart sensors will rise [14]. These sensors produce anonymous data, which is initially processed into a usable data structure like tables, graphs, and logs for further study and use in modifying and enhancing the system's functionality in manufacturing production [15]. Additionally, analyzing the data is just as important as storing it [16]. In order for the significant data to move on to the data analysis stage for the system's overall improvement, the large volume of data generated from manufacturing processes must be successfully integrated, securely stored, and filtered.

Innovative storage techniques have been developed during the past 10 years as a result of the growth of IoT networks in the real world. IoT networks require huge storage capacities in addition to quick access to data. This made the traditional data storage model—where raw data was extensively recorded in written documents manually created by human operators, such as logbooks, notes, and charts—as well as the traditional data storage model, where data were kept on a distant main server, unsuitable for IoT networks [17]. Implementing Cloud services like Google Drive is a feasible strategy for data storage. IoT services are widely available, allowing customers to connect their devices and upload data to the cloud [18]. Cloud storage and cloud computing are terms used to describe the processes of dealing with data that has been transferred to the cloud and is accessible online [19]. Data storage using the cloud is incredibly adaptable, economical, and energy-efficient. In addition, cloud data is shielded from a variety of other dangers, guaranteeing that the owner will still have access to the data in the event of a loss of data or other unanticipated events, enabling highly scalable and shareable data storage [15]. The user may then access the data from any location and execute data analyses using cloud computing tools like Google Spreadsheets before having it sent to dashboards to be shown.

Smart manufacturing uses a lot of sensors, which calls for a lot of data storage. If thousands of sensors record data every millisecond, the quantity of storage required will rise. Therefore, it is crucial to think about how to decrease the data without losing critical facts. It is possible to employ data storage effectively in a number of ways. Sending data in response to events is the first technique. The crucial information is only kept once the action has been completed. The second approach is sending bigger data packages in the form of locally kept log files [16].

4.4 Data Analysis

Smart manufacturing technology makes it feasible for people, machines, and sensors to seamlessly share information. Huge volumes of data are produced by connected devices and are analyzed and understood by computation. The linked factory of Industry 4.0 makes use of operational, system, and machine data to improve production processes. Data analytics is a key part of this connected factory. Complete insight into diagnostic analyses and preventative maintenance is provided by real-time data [20]. However, collected data is worthless in the absence of analysis and visualization [21]. Data analysis can thereby improve decision-making, boost output and performance, guarantee product quality, and save expenses.

Statistics, graph analysis, artificial intelligence, and machine learning are methods for data analysis in smart manufacturing. When examining regressions, and relationships, and locating clusters in the data, statistical approaches are applied. By seeing clusters and relationships in the data, meaningful data may be able to help us comprehend how statistically determined values correlate and interact with one another. In the course of the process, smart manufacturing behaviors and links between processes and system elements can be discovered. According to the outcomes, data analysis using statistical approaches will be helpful for simulation and prediction instances to improve performance and efficiency or to make it possible to decide on system control for real-time adjustments [16].

Graph analysis is an additional strategy. In the context of smart manufacturing, a graph can be used to represent a wide range of ideas, including IoT interactions, changeable parameters, energy flows, and processes. A technique could involve identifying the procedures that employ the least/most manufacturing cases over time using the graphical depiction and then optimizing those operations accordingly. The identification and prediction of components in a production system are made possible by a graphical method; as a result, it will be a useful technique in the manufacturing process [16].

Another approach to data analysis is by using AI and machine learning. The ability of a machine or computer to learn something on its own is referred to as artificial intelligence (AI) [16]. "Machine learning" (ML), a branch of artificial intelligence (AI), trains computers to anticipate the future, solve challenging tasks, and recognize the underlying causes of probable errors on their own. Two of the main methods are C4.5 and k-means clustering, which are employed, for instance, in the construction of classification and decision trees. Since ML uses historical data, the accuracy of the data increases as it learns. The accumulated data allows for the evaluation of whether the results are better or worse than those that were previously known. It can also aid in the more effective and speedy resolution of problems, allowing for the optimization of manufacturing operations with little to less human intervention and high reliability [4].

4.5 Conclusion

It is clear from the status of the industry described above that moving from traditional production to smart manufacturing is crucial. Real-time data gathering and automated data analysis are important goals of the production systems to enhance the manufacturing process in light of the smart manufacturing goal. Although putting this idea into practice will be difficult, it suggests that the system should be able to be autonomous in the sense of being able to make decisions autonomously through connectivity among machinery as opposed to being under human guidance. All equipment needs to be connected using IoT technology in order to track its condition and provide the necessary data visualization for intelligent decision-making. Node-RED has been shown to have important advantages in the area of data visualization, and MQTT is an excellent technology for creating connectivity between various pieces of equipment. Another tactic is to employ deep learning algorithms to make predictions and solve problems. Research and prototype development have already begun in these areas. Therefore, the objective of the smart manufacturing system will be one step closer to fruition by putting these technologies into practice.

5. Methodology

Introducing the conceptual design of the system, which consists of a manufacturing model and remote model flowchart, dashboard design, and a schematic diagram of the setup position, serves as the first demonstration of the system design for this project under the methodology section of the design specification. The system interface is broken down further into a physical architecture design diagram, and a wiring circuit diagram, to demonstrate the model application of smart and remote system applications.

The manufacturing model flowchart in Figure 1 shows the flow of each component taken at each phase for the conceptual design of this project. The procedure of the IoT model for real-time monitoring and controlling is similarly represented by the remote model flowchart in Figure 2 in both instances. Using wiring circuit schematics and physical architectural design diagrams, the project's system interfacing is demonstrated. Figure 3 depicts the remote model's dashboard layout. This is an early sketch of the dashboard that will be used to monitor and manage manufacturing operations using data that has been received.

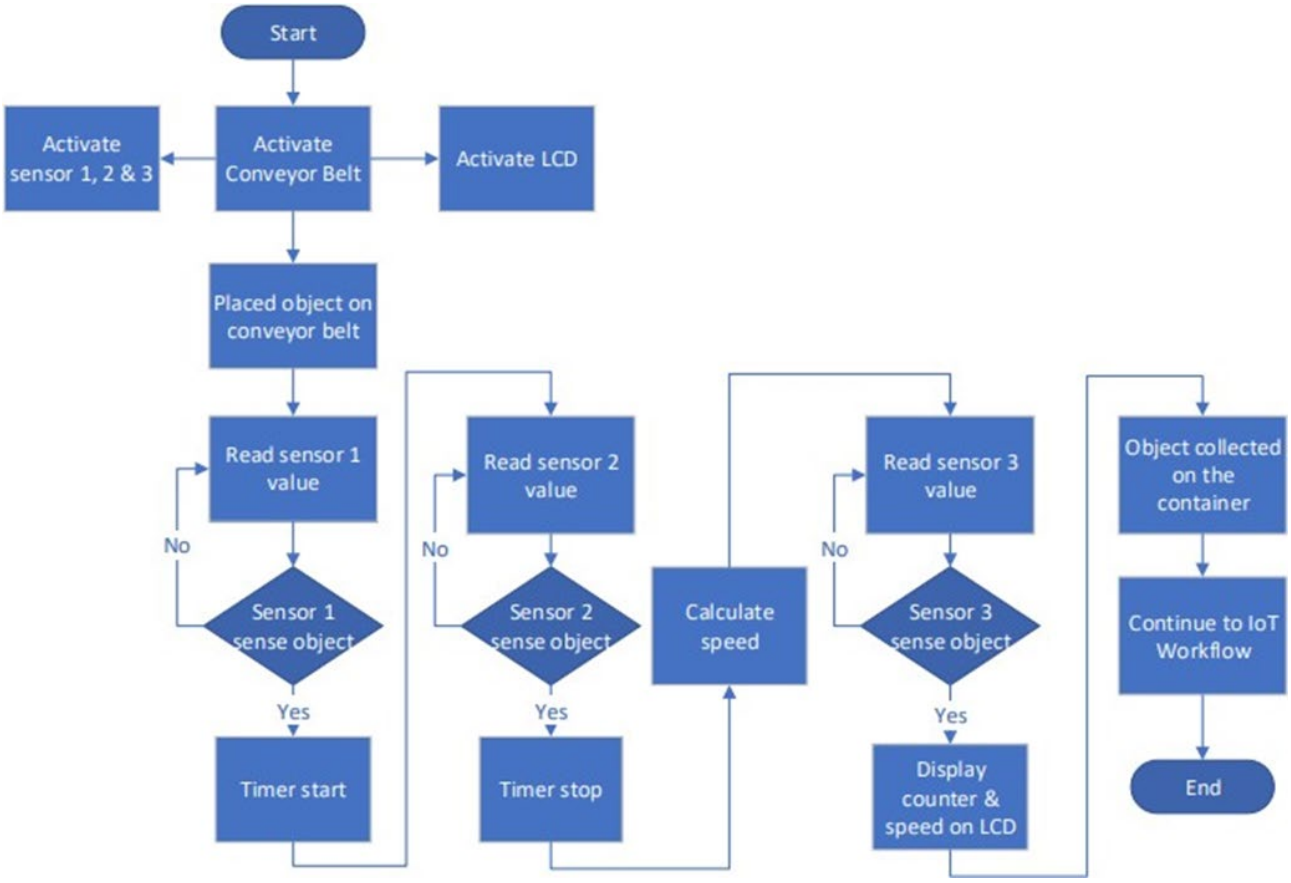


Fig. 1. Flowchart for manufacturing model

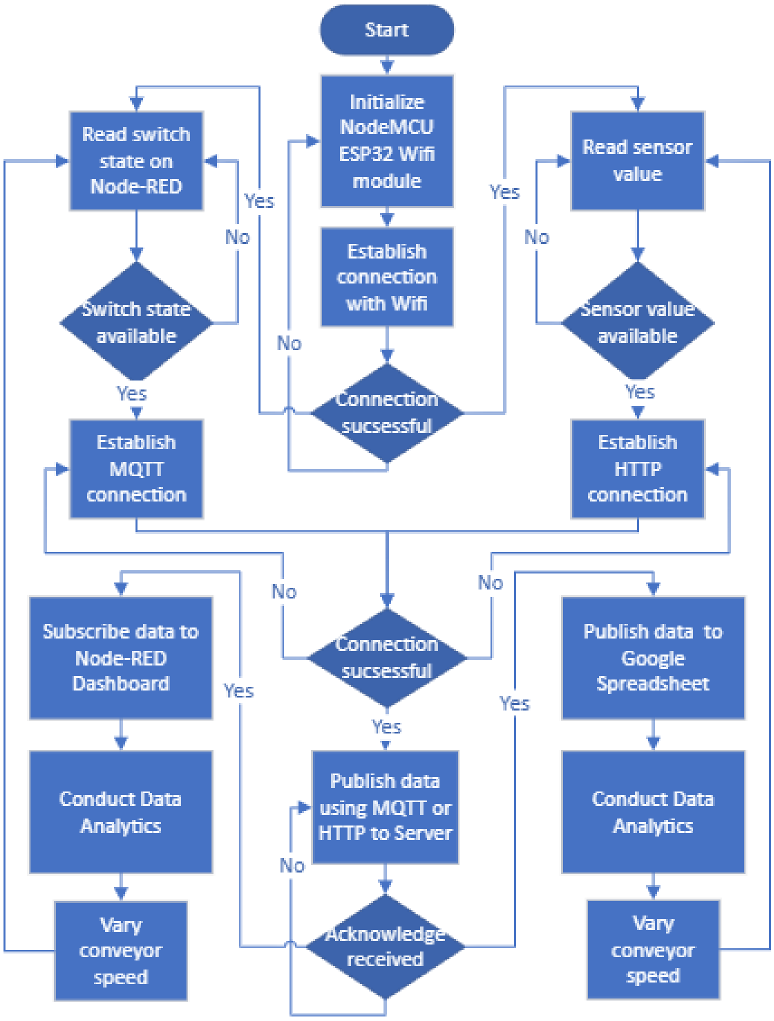


Fig. 2. Flowchart for remote model

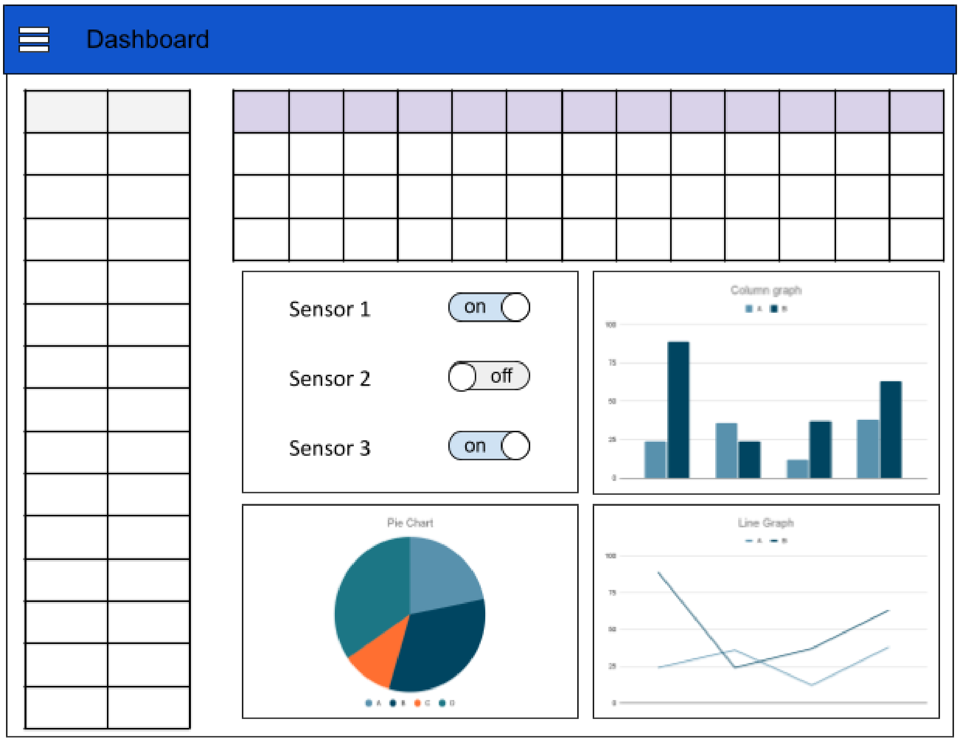


Fig. 3. Dashboard design displayed on the remote monitor

The top view of each subsystem is depicted in the schematic diagram of the system configuration in Figure 4. This depicts the system overview in its actual configuration.

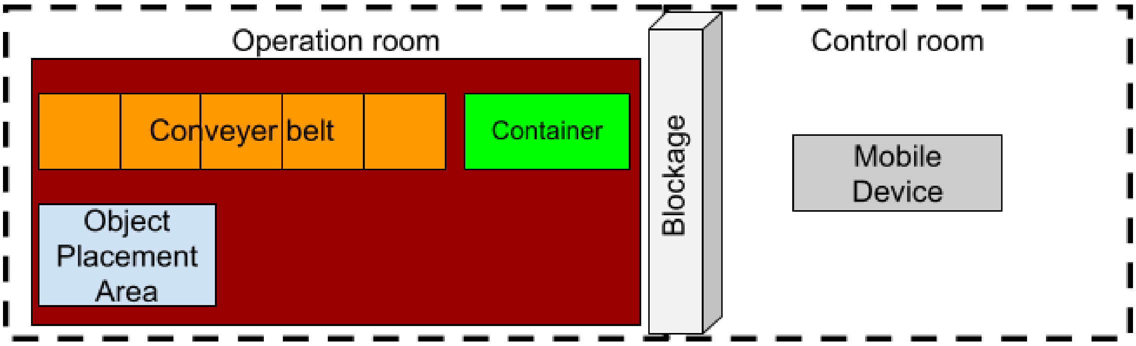


Fig. 4. Schematic diagram of setup position

An interconnected block diagram of all the parts, systems, and connections used in this project is shown as the system architecture in Figure 5. The arrows depict the power/battery lines that are used to power various system components as well as the data exchange paths between two devices.

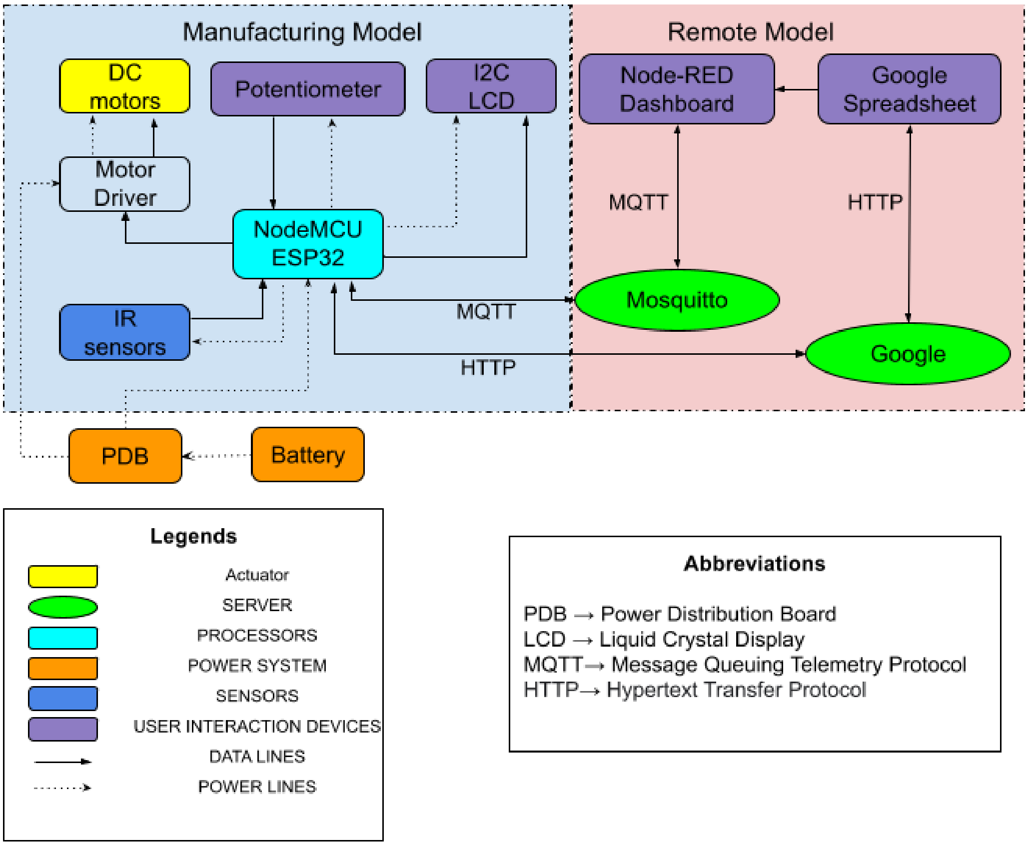


Fig. 5. System architecture

The electrical circuit arrangement of the components and the wire connections are depicted simply in the wiring circuit diagram in Figure 6. Simple rectangular shapes are used to represent the circuit's parts, and coloured blocks are used to represent the connections between the devices for power and signal. JavaScript is the programming language used in this project's software development. C++ is the programming language used in this project for hardware development.

These programming languages are employed to enable the Google Apps Script to work between Google Spreadsheet and the hardware interface in the IoT application.

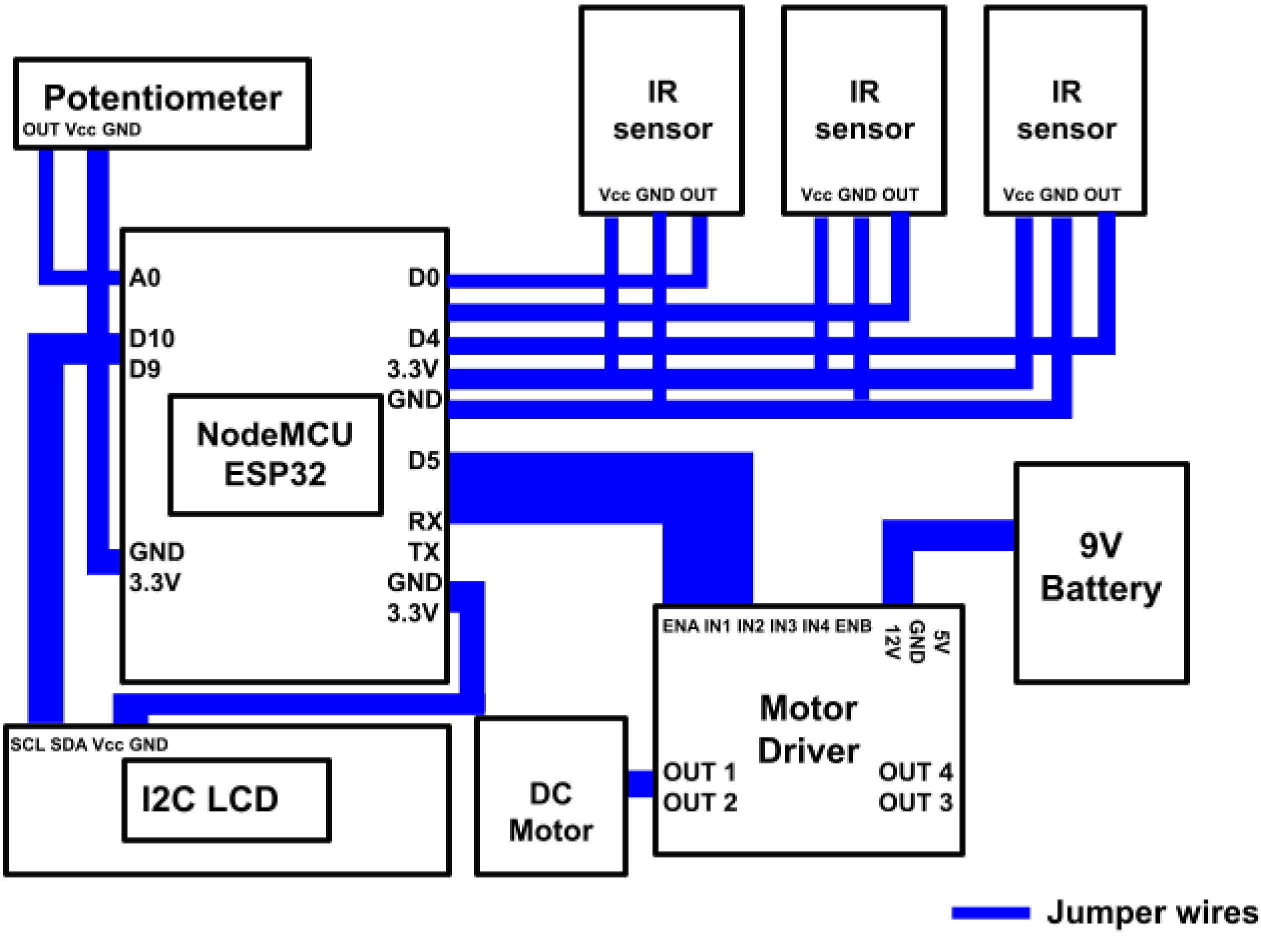
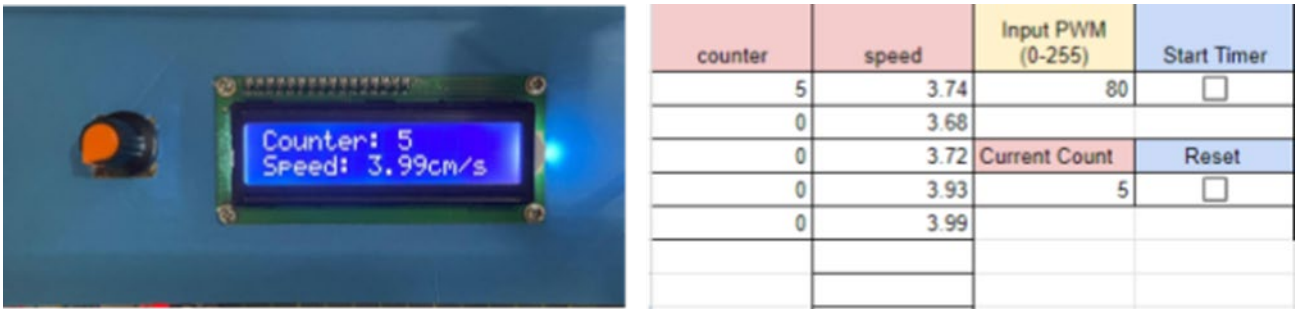


Fig. 6. Wiring circuit diagram

6. Results

For remote monitoring, the speed parameter is added to the Google Spreadsheet. The two IR sensors measure the object's speed each time it passes by. The ESP32 microcontroller sends the data to the appropriate cell in a Google Spreadsheet by sending HTTP requests to Google Apps Script on the server side (client side). For the Counter parameter, the same procedure is used, but the data is transferred to the Google Spreadsheet only when the predetermined time period has passed. The counter and speed settings displayed on an LCD and a Google Spreadsheet are shown in Figure 7.



```
Counter: 5
Speed: 3.99cm/s
```

counter	speed	Input PWM (0-255)	Start Timer
5	3.74	80	☐
0	3.68		
0	3.72	Current Count	Reset
0	3.93	5	☐
0	3.99		

Fig. 7. Counter and speed parameters showing on LCD and Google Spreadsheet

It is assumed that the conveyor belt will move at a constant pace throughout the procedure. The conveyor belt's condition and whether it is operating continuously at the desired speed are the key reasons for continuous monitoring of the speed parameter. If an unexpected incident occurs, the user can remotely interrupt the process to minimize downtime. Figure 8 displays a flowchart explaining the algorithms of the data analysis process. Out of the four options presented on the PWM speed option table, the algorithm selects the best decision for the Next PWM by combining if and then statements.

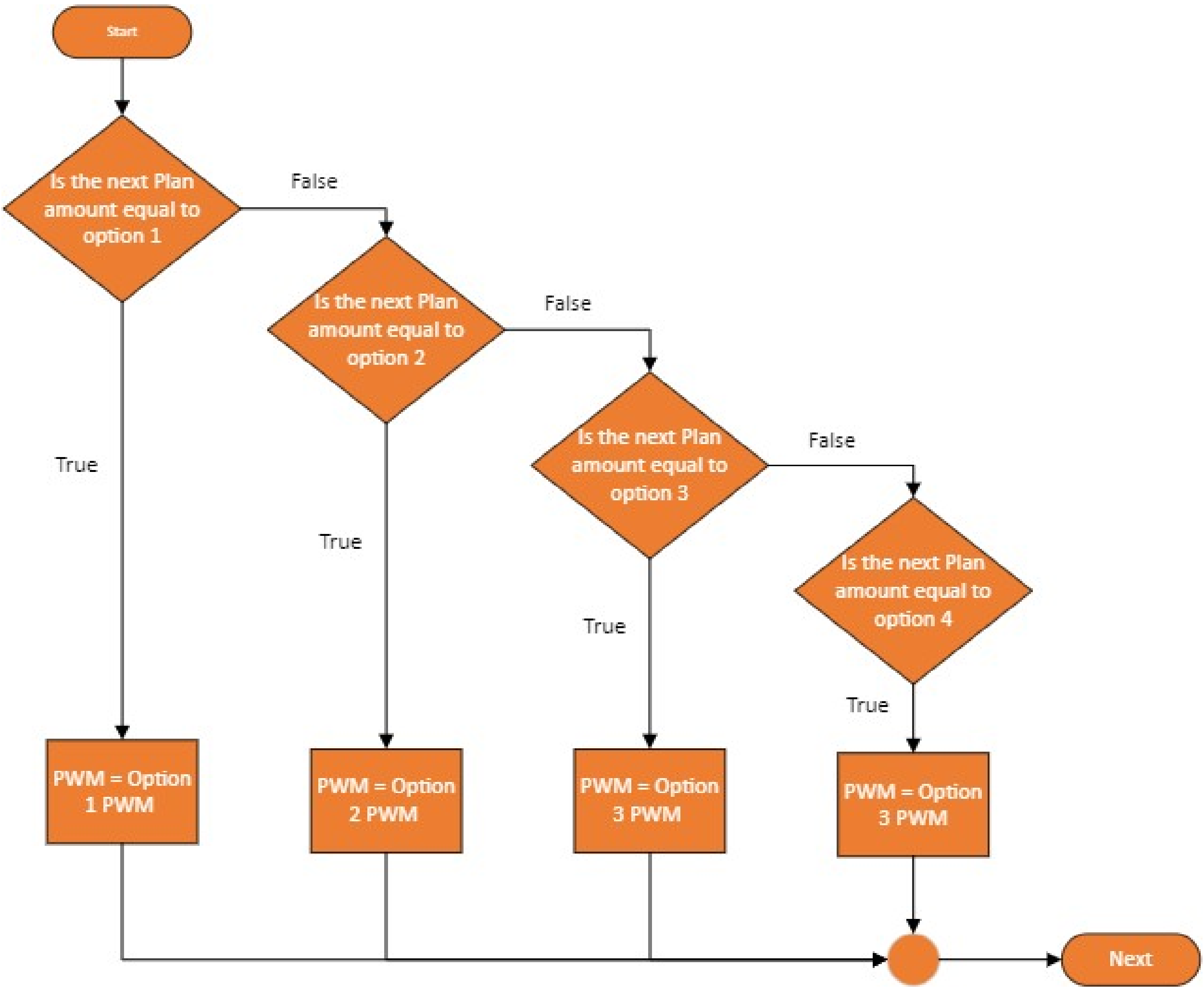


Fig. 8. Data analysis algorithm flowchart

The case study is displayed in Table 1 below. We can see that from day 1 to day 5, the production planning for this scenario is 5, 6, 8, 7, and 5, correspondingly. The real number of production results is 5,5,6,8, and 8 as indicated. On day 1, as is typically the case, there is no shortage or surplus of production, but by day 2, that may no longer be the case. It turns out that on days 2 and 3, there is less production since there is a reduction in production of 1. This was considered, which has the effect of speeding up manufacturing by raising PWM. The Next PWM value is increased from the previous value of 100 to 150, which is the highest value that can be achieved, due to the fact that the largest amount of production 8, which must be created on day 3 is also taken into account. Fortunately, it showed out to have surplus production on day 4, which reduced liability by 1. The shortfall of production on day 5 was reduced as much as possible, but there is still one more surplus production that will start the following cycle of production.

Table 1
Case study of the research

	Plan	Plan+Loss	Actual	Loss	Excess	Next PWM
1	5	5	5	0	0	100
2	6	6	5	1	-1	150
3	8	9	6	3	-3	150
4	7	10	8	2	-2	120
5	5	7	8	-1	1	80

In addition, the data analysis algorithms can be expressed in the mathematical model and expand the model for more robust algorithms. Assuming there will be 5 days in 1 cycle of production and there will be 4 options for PWM speed.

Let α = plan, β = actual, ε = lack or excess, P = Next PWM, k = PWM.

$$\forall_i \in \{1,2,3,4,5\}, P_i = \begin{cases} k_1, if\ \alpha_{i+1} + \ \varepsilon_i == k_1 \\ k_2, if\ \alpha_{i+1} + \ \varepsilon_i == k_2 \\ k_3, if\ \alpha_{i+1} + \ \varepsilon_i == k_3 \\ k_4, if\ \alpha_{i+1} + \ \varepsilon_i == k_4 \end{cases} \tag{1}$$

where $\varepsilon_i = \ \beta_i - \ \alpha_i$ and *i* = number of days.

Since similar logic applies for every four options, it can be further simplified as below for the mathematical notation above is assuming 5 days for 1 cycle production and 4 options for PWM speed.

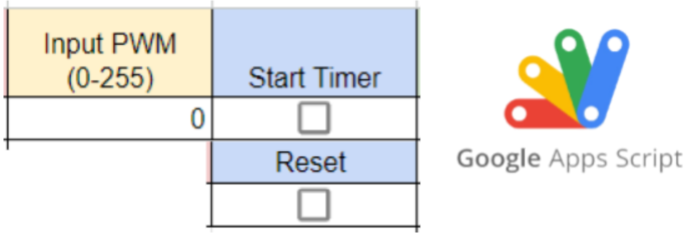
$$\forall_i \in \{1,2,3,4,5\};\ \forall_j \in \{1,2,3,4\}; P_i = k_j, if\ \alpha_{i+1} + \ \varepsilon_i == k_j \tag{2}$$

where $\varepsilon_i = \ \beta_i - \ \alpha_i$; *i* = number of days and *j* = number of options for PWM speed.

Figure 9 shows the completed system setup of the physical and remote model.

Fig. 9. Actual setup of physical and remote model

The dashboard's control section is depicted in Figure 10, where it includes the Start Timer, Reset, Input PWM, and Google Apps Script, which enables synchronous communication between the microcontroller and Google Spreadsheet. The Start Timer starts the microcontroller's internal clock to count down for a predetermined amount of time. The timer starts running as soon as the check box is toggled, and the product operation starts. Every object's speed is noted in the speed column while the timer is running. The counter column will automatically update and reflect the current day's actual column after the clock stops. The purpose of Reset is to clear the value shown on the LCD panel and reset the count and speed variables. The purpose of Input PWM is to remotely adjust the conveyor belt's speed using PWM on a scale of 0-255. For instance, 255 causes the conveyor belt to run at its highest speed while 0 causes the conveyor belt to stop. Both remotely via the Google sheet dashboard and using a potentiometer from the physical model, the motor's speed may be adjusted synchronously. By entering 0 in the cell, this part can also serve as an emergency halt for the production process.



Input PWM (0-255)	Start Timer
0	☐
	Reset
	☐

Fig. 10. Show Start Timer, Reset Count, and Input PWM using Google Apps Script

Charts and plots are displayed in real-time on a Google Sheet dashboard in Figure 11. To verify the consistency of the conveyor belt speed, the speed graph displays the speed of each object listed in the speed log column. To assess the consistency of the production outcome, the count graph compares the Plan, Plan+Loss, and Actual production outcomes for the first five days of the production cycle. The PWM Usage Chart displays the PWM speed's % distribution according to the PWM choice table. This is a summary of the PWM speed options that were most frequently utilized during the production cycle and the PWM speed options that are more demanding during the current production cycle. Not least, the PWM graph displays the PWM value that was actually applied each day.

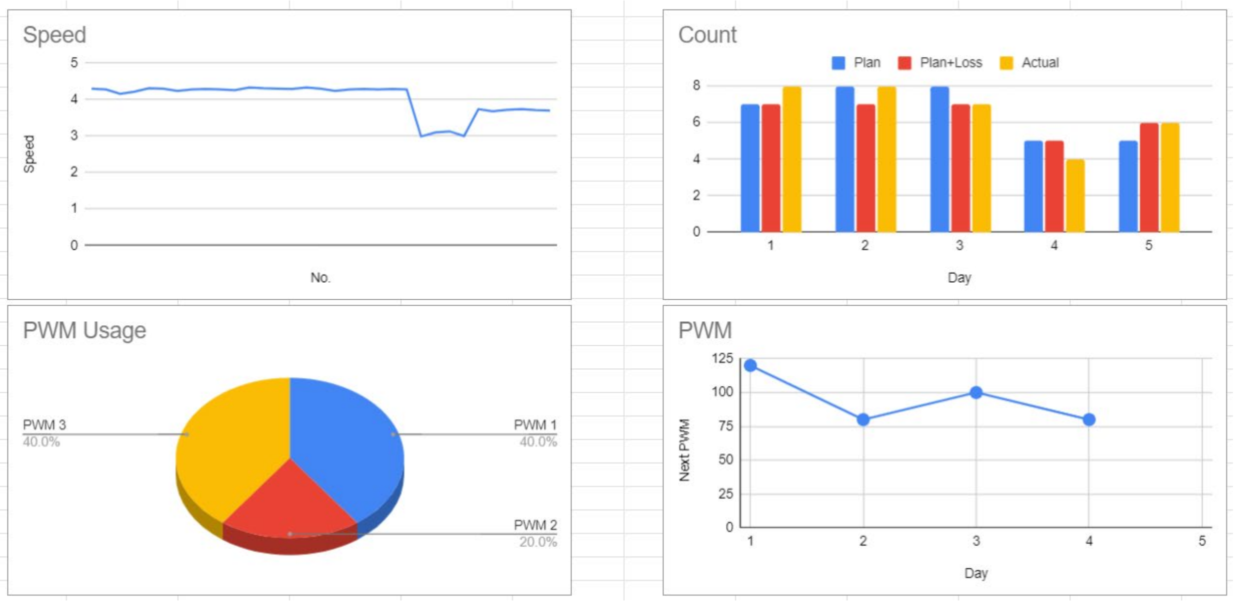


Fig. 11. Real-time visualization displayed on the dashboard

7. Findings and Discussion

A number of findings were discussed during the project. First, data from the sensor on the physical side was sent to the dashboard on the remote side to establish the wireless connection between the physical model and the remote model. time.

Second, to perform real-time monitoring and controlling, the dashboard displays data from the sensor that has been remotely acquired. The dashboard's current layout, however, only allows for the monitoring of the two metrics speed and counter.

Thirdly, remote data collection allows for data analysis and decision-making to produce the best value for the subsequent PWM. The 5 days of the production cycle and the 4 PWM speed options to regulate the manufacturing process, are the factors considered in the data analysis and decision-making process for this study.

Many sectors stand to gain from the research and use of Smart Mini Manufacturing System Models in the framework of Industry 4.0. To start, these models use data analytics, automation, and the Internet of Things to optimize production procedures. They improve overall operating efficiency by enabling real-time monitoring and control, which decreases downtime. Second, intelligent small manufacturing systems are made to be flexible and responsive to shifting market conditions. They facilitate rapid reconfiguration and modification, allowing producers to react quickly to changes in the market or specific client needs. Third, automation increases workplace safety by reducing human engagement in risky activities and increasing efficiency in production processes. Fourth, industry 4.0 technologies improve operational flexibility by enabling managers and supervisors to supervise activities and make choices remotely. This allows for a higher level of operational flexibility. In summary, Industry 4.0's produced research and real-world implementation of Smart Mini Manufacturing System Models provide a route towards more productive, adaptable, and technologically sophisticated manufacturing processes, setting up sectors for long-term growth and competitiveness in the digital era.

8. Conclusions

Automated procedures take the place of manual data gathering and analysis in the smart mini manufacturing system prototype. To connect the remote and physical models, it makes use of the NodeMCU ESP32 microcontroller for wireless communication via the HTTP and MQTT protocols. The conveyor belt's IR sensor is used by the system to detect speed and collect counter data, and a DC motor drives the belt's motion. Real-time monitoring and control are made possible by a dashboard made in Google Spreadsheet, and acquired data is kept in a cloud database. Using a PWM (Pulse Width Modulation) choice table, automated data analysis is carried out on Google Spreadsheets to compare actual and anticipated product volumes. Based on the data, this comparison aids in adjusting PWM values to either increase or decrease conveyor belt speed.

This case study represents a scaled-down form of the intelligent system. This include putting together hardware parts, integrating software, designing user interfaces, and building the logic or algorithms required to enable the capabilities. Validation is used to test the prototype's functionality using predetermined standards. The prototype complies with industry 4.0 requirements. Based on the pre-defined methodology notion as a guide, the prototype can be scaled up for full adoption across pertinent industrial processes or facilities since it has demonstrated its efficacy and efficiency.

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