AN IOT AND CLOUD-BASED DATABASE FOR MONITORING MANUFACTURING OPERATION PROCESS DATA

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Abstract

The research article focuses on the implementation of an IoT and cloud-based database system for monitoring manufacturing operation process data in the context of a smart factory. By utilizing various sensors, such as RFID, vibrations, temperature, and force sensors, installed in machines like milling machines and pick and place robots, as well as in the floor and conveyor systems, the aim is to create a dynamic manufacturing environment that optimizes the utilization of both man and machine. The methodology involves deploying IoT devices, establishing communication networks, and installing the proposed system. The system allows workers to track real-time machine status and allocate jobs using smartphones, while also providing statistical reports through custom-made software. Raspberry Pi is employed for data communication to the cloud, and Arduino is utilized for actuating various actuators. The findings demonstrate the effectiveness of the proposed system in creating a smart factory environment, enhancing production efficiency, and contributing to the advancement of the manufacturing industry through the integration of IoT and cloud technologies.

Keywords: IoT, Cloud-based database, Smart factory, Manufacturing process monitoring

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1. Introduction

The emergence of IoT technologies and cloud computing has revolutionized various industries, including manufacturing. This literature review aims to explore and analyze the existing body of knowledge surrounding the implementation of IoT and cloud-based database systems for monitoring manufacturing operation process data in the context of a smart factory. By examining relevant studies and research articles, this review seeks to identify key trends, challenges, and opportunities in this field [1].

The concept of a smart factory involves the integration of intelligent systems and automation technologies to optimize manufacturing processes. IoT plays a pivotal role in connecting machines, devices, and sensors in a manufacturing environment, enabling real-time data collection, analysis, and decision-making [2]–[4]. The literature highlights the potential of IoT in transforming traditional factories into highly efficient and adaptive smart factories.

Various sensors, such as RFID, vibrations, temperature, and force sensors, are extensively used in monitoring and controlling manufacturing processes. RFID tags enable real-time tracking of workpieces, while vibration sensors detect anomalies in machinery performance. Temperature sensors ensure optimal operating conditions, and force sensors provide feedback on machining pressures. The literature discusses the effectiveness of these sensors in enhancing process monitoring and improving overall production quality [5], [6].

Cloud-based databases offer scalability, flexibility, and data accessibility, making them suitable for storing and processing large volumes of manufacturing process data. Studies emphasize the advantages of cloud-based databases in terms of data storage, real-time data analysis, and collaborative decision-making. Additionally, cloud platforms provide a centralized repository for data collection, allowing stakeholders to access and share information across the manufacturing ecosystem [7], [8]. Efficient communication is vital in IoT-enabled manufacturing systems. The literature explores various communication technologies and protocols, such as WiFi, Bluetooth, TCP/IP, RS232, and 4G, used for seamless data exchange between sensors, machines, and cloud-based databases. Each technology has its own advantages and limitations, and researchers have investigated their suitability for different manufacturing scenarios Effective data modeling is crucial for organizing, managing, and analyzing manufacturing process data. The literature emphasizes the use of relational data models due to their flexibility, scalability, and compatibility with existing database technologies. Relational models allow for the representation of entities, attributes, and relationships within the manufacturing process, enabling efficient data storage and retrieval [9], [10]. Real-time monitoring and analytics are key features of IoT and cloud-based database systems in manufacturing. The literature discusses the use of real-time dashboards, visualizations, and analytics tools to provide stakeholders with actionable insights into manufacturing processes. These tools enable timely decision-making, predictive maintenance, and process optimization, resulting in improved productivity and reduced downtime. While the implementation of IoT and cloud-based database systems in manufacturing offers significant benefits, several challenges need to be addressed. These challenges include data security and privacy concerns, interoperability issues, integration complexities, and the need for skilled personnel. The literature calls for further research on developing standardized protocols, advanced analytics algorithms, and robust cybersecurity measures to overcome these challenges and unlock the full potential of IoT in manufacturing [11], [12].

This research focuses on the implementation of an IoT and cloud-based database system for monitoring manufacturing operation process data in a smart factory environment. By utilizing various sensors and actuators, including RFID, vibrations, temperature, and force sensors, the system enables real-time data collection, analysis, and decision-making. The research aims to optimize the utilization of man and machine by integrating IoT devices, communication networks, and a cloud-based database. The findings demonstrate the effectiveness of the proposed system in improving production efficiency, reducing downtime, and enhancing overall productivity. This research contributes to the advancement of manufacturing processes through the integration of IoT and cloud technologies.

2. Methodology

The methodology employed in this research article involves the utilization of various sensors, including RFID, vibrations, temperature, and force sensors, which are installed in different machines within the factory setting. Specifically, two machines are focused on: the milling machine and the pick and place robot. In addition to these machines, sensors like proximity and speed sensors are also installed in the floor and conveyor, resulting in a dynamic factory environment. The overarching objective of this research is to create a smart factory by harnessing the power of the Internet of Things (IoT) and maximizing the collaboration between human operators and machines. For instance, when a machining job is allocated to the milling machine, the machine performs the required tasks, and upon completion, the pick and place robot is responsible for placing the finished job. The methodology begins with a careful selection of sensors, including RFID, vibrations, temperature, force, proximity, and speed sensors, based on their suitability for the intended purposes. These sensors are then installed and properly calibrated on the milling machine, pick and place robot, floor, and conveyor. The installation process ensures accurate and reliable data collection. Additionally, the establishment of secure connections between the sensors and the IoT network is a vital step.

Subsequently, an IoT network infrastructure is designed and configured to facilitate seamless communication among the various devices and the cloud-based database. This infrastructure allows for the transmission of real-time data from the sensors to the cloud-based database, where the data is securely stored and analyzed. Advanced data analytics techniques are applied to derive meaningful insights from the collected data, enabling the identification of patterns, anomalies, and performance indicators. To facilitate effective monitoring and control of the manufacturing processes within the smart factory, customized software applications and user interfaces are developed. These applications provide users with a user-friendly dashboard that presents real-time and historical data. This visualization empowers decision-makers to make informed and timely decisions based on the insights gained from the data. The methodology also considers the integration of human operators within the smart factory. By allocating specific tasks to machines and leveraging the capabilities of IoT devices and sensors, the research aims to achieve the complete utilization of both human and machine resources. This collaboration is exemplified by the allocation of machining jobs to the milling machine, followed by the pick and place robot's role in handling and placing the finished jobs. The entire methodology of the research is shown in figure 1.

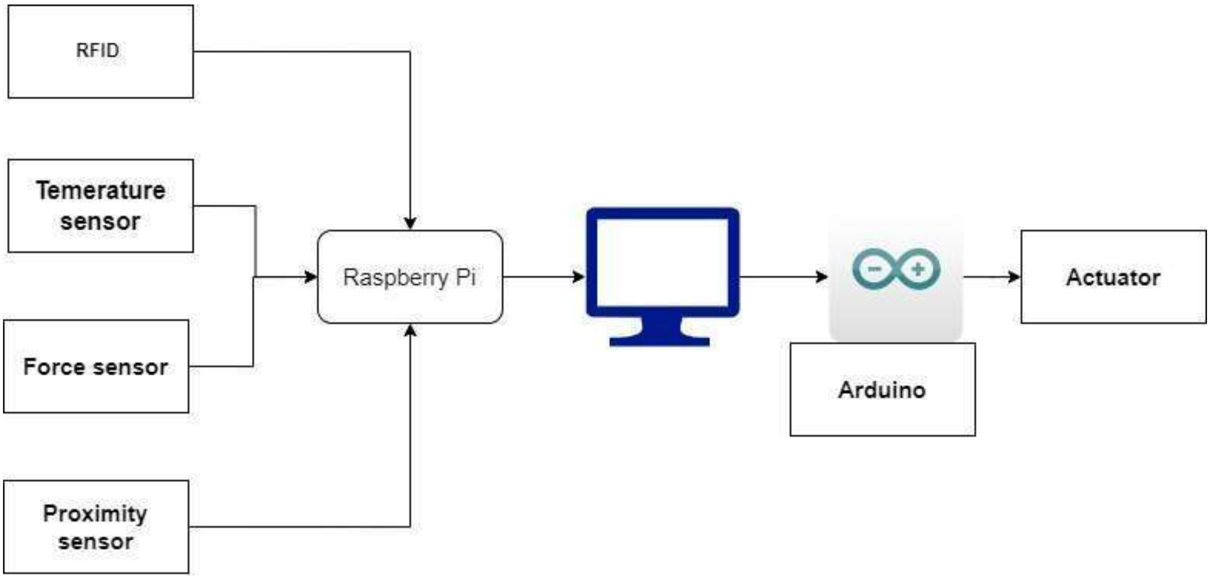

Fig. 1. Proposed system layout

a. Smart connections

The research focuses on establishing smart connections to facilitate collaborative work within the factory. To enable seamless data transmission, various communication protocols such as WiFi and Bluetooth are utilized to acquire signals from the vibration and force sensors. These wireless connections ensure efficient data collection from the sensors, enhancing real-time monitoring capabilities. In addition to wireless connections, wired connections play a crucial role in facilitating communication among the machines and robots. Protocols like TCP/IP and RS232 are employed to establish reliable and secure data transfer channels. These wired connections ensure stable and high-speed data exchange, enabling efficient coordination and synchronization between different components of the manufacturing process [13].

To enable RFID functionality, radio wave signals are utilized for RFID readers. This allows for the identification and tracking of objects or products within the factory. By leveraging radio wave signals, the RFID system can accurately capture and transmit data, enabling seamless inventory management and tracking of materials throughout the production cycle. To provide real-time updates and status information, the cloud-based system utilizes 4G connectivity. This enables the transmission of data from the machines and robots to the cloud, where it is stored and processed. By leveraging the high-speed and wide coverage capabilities of 4G, the status of operations and machine completion can be efficiently uploaded to the cloud. This enables human operators to monitor the real-time progress of the manufacturing process and stay informed about machine performance and job completion.

b. Dataset

In this research, the data model plays a crucial role in the creation of an IoT and cloud-based database system for monitoring manufacturing operation process data. The data model serves as a framework that defines the structure, relationships, and attributes of the data that will be collected, stored, and processed within the system. In this particular study, a relational data model is employed due to its flexibility, scalability, and compatibility with existing database technologies. The relational data model organizes the data into tables, with each table representing a specific entity or concept within the manufacturing process. For example, tables may be created to store information about machines, sensors, production jobs, operators, and products. Each table consists of columns that represent the attributes or properties of the entity, such as machine ID, sensor readings, job details, operator information, and product specifications. The relationships between different entities are established using keys, such as primary keys and foreign keys. Primary keys serve as unique identifiers within a table, ensuring that each record is uniquely identifiable. Foreign keys, on the other hand, establish connections between tables, enabling the representation of relationships between entities. For instance, a foreign key in the production jobs table may reference the machine ID in the machines table, indicating which machine is responsible for a particular job. To ensure efficient data storage and retrieval, the data model can incorporate indexes and constraints. Indexes improve query performance by allowing faster lookup of specific data values, optimizing the speed of data retrieval operations. Constraints, on the other hand, enforce data integrity rules, such as unique constraints that ensure the uniqueness of specific attributes and referential integrity constraints that maintain the consistency of relationships between tables. Moreover, the data model may include additional elements to support the analysis and visualization of the collected data. This can involve the use of aggregation functions, data aggregation tables, and views that provide pre-calculated summaries or tailored perspectives of the data. These elements enhance the ability to analyze the data and gain meaningful insights from the manufacturing operation process.

c. Smart view

In this research, a smart view is designed as a user interface to facilitate effective communication with the end user. This smart view serves as a dashboard that provides real-time updates and allows the user to track the status of the machine during the manufacturing process. It offers a comprehensive and intuitive display of key metrics, enabling the user to monitor the operation in real time. Through the smart view, the end user can access important information such as the current job being performed by the machine, the progress of the job, and any relevant notifications or alerts. The real-time status updates allow for immediate action to be taken in case of any issues or deviations from the expected performance. Furthermore, the smart view provides additional functionalities to enhance user experience and decision-making. For instance, it may display visualizations, charts, and graphs that represent historical data, trends, and performance indicators. These visual representations enable the user to gain insights into the overall performance of the machine, identify patterns, and make informed decisions based on the data. Additionally, the custom-made software accompanying the smart view allows the user to generate statistical reports. These reports can be downloaded and analyzed, providing valuable information for performance evaluation, process optimization, and decision-making. The reports may include metrics such as production efficiency, machine utilization, downtime analysis, and quality indicators. By combining the smart view with the custom-made software and statistical reports, the research aims to empower the end user with a comprehensive toolset for monitoring and managing the manufacturing process. This enables real-time tracking of machine status and provides actionable insights derived from data analysis. Ultimately, the smart view and associated software contribute to the overall objective of creating a smart factory environment, where man and machine can collaborate efficiently and effectively.

3. Result and discussion

In this research, the focus is on the installation of various sensors on the milling machine, pick and place robot, and conveyor system to enable an automated and efficient manufacturing process. The data obtained from these sensors, indicating the status of the machines, is communicated to the user using a Raspberry Pi device. This setup ensures real-time monitoring and control of the manufacturing operations. The process begins with the operation of the milling machine, where the machining job is performed. The milling machine is equipped with sensors such as vibrations, temperature, and force sensors to capture relevant data during the machining process. These sensors provide valuable information about the machine's performance, tool wear, and material behaviour.

Once the machining job is completed, a worker retrieves the finished product from the milling machine and places it onto the conveyor system. The conveyor is fitted with sensors, such as proximity sensors, to detect the presence of the workpiece. This allows for seamless tracking of the workpiece as it moves along the conveyor. As the workpiece progresses along the conveyor, its presence is detected by the sensors, which communicate the information to the Raspberry Pi device. The Raspberry Pi acts as a central hub for data collection and processing. It receives the signals from the sensors and transmits them to a computer for analysis and decision-making.

Based on the received data, the computer then sends commands to an Arduino, which acts as the controller for the various actuators in the system. The Arduino interprets the commands and initiates the corresponding actions, such as actuating the pick and place robot. The pick and place robot plays a critical role in the automated manufacturing process. It is equipped with sensors and actuators to accurately and efficiently handle the finished products. When the conveyor detects the presence of a workpiece, it triggers the movement of the conveyor to bring the product to the robot's reach. The robot's sensors detect the position and orientation of the product, allowing it to precisely pick up the workpiece and place it in the designated tray or location. Throughout this process, the sensors installed on the machines, conveyor, and robot enable the system to operate autonomously and efficiently. The Raspberry Pi serves as the communication gateway, relaying the sensor data to the computer for analysis and decision-making. The computer, in turn, commands the Arduino to actuate the necessary actuators, enabling seamless coordination and execution of tasks.

The integration of sensors, Raspberry Pi, computer, and Arduino creates a comprehensive and automated system for manufacturing operations. This setup not only improves the efficiency of the manufacturing process but also ensures real-time monitoring, data collection, and decision-making. By automating the system using sensors and controlling it through the Raspberry Pi and Arduino, the research aims to optimize the manufacturing process and enhance overall productivity.

a. Cloud database for the manufacturing shopfloor

The creation of a cloud manufacturing system involves several key steps, including the deployment of IoT devices, development of communication networks, and installation of the proposed system. Each step plays a crucial role in establishing an efficient and interconnected manufacturing environment. In this research, these steps are undertaken to realize the vision of a smart factory that leverages the power of cloud technology and IoT devices. The first step in the process is the deployment of IoT devices. These devices, such as sensors and actuators, are strategically installed throughout the manufacturing facility to capture and transmit real-time data. In this research, sensors like RFID, vibrations, temperature, and force sensors are utilized. These IoT devices are carefully placed on machines, pick and place robots, conveyors, and other relevant areas within the factory. By collecting data on various parameters, these devices enable the monitoring and analysis of manufacturing operation process data.

The second step involves the development of communication networks. For an effective cloud manufacturing system, robust and reliable communication networks are essential. This ensures seamless data transfer between the IoT devices, cloud platform, and other components of the system. In this research, communication technologies like Wi-Fi, Bluetooth, TCP/IP, RS232, and 4G are employed. Wi-Fi and Bluetooth are utilized for obtaining signals from vibration and force sensors, while TCP/IP and RS232 are used for machine-to-machine and machine-to-robot communication. Additionally, RFID readers use radio wave signals, and 4G is employed to upload real-time operation status to the cloud. These communication networks facilitate the smooth flow of data, enabling timely decision-making and control. The final step in the process is the installation of the proposed system. This involves integrating the deployed IoT devices, communication networks, and cloud-based database. The data collected by the IoT devices is transmitted to the cloud-based database, which serves as the central repository for storage and processing. In this research, a cloud-based database is used for monitoring manufacturing operation process data. The relational data model is commonly employed to organize the collected data into tables, each representing a specific entity or concept within the manufacturing process. The data model defines the structure, relationships, and attributes of the data, allowing for efficient storage, retrieval, and analysis. The installed system enables various functionalities, such as real-time monitoring, tracking, and analysis of the manufacturing process. The collected data is processed and analyzed in the cloud, providing valuable insights for optimizing production efficiency, identifying bottlenecks, and enhancing overall performance. The proposed system also incorporates a smart view, which serves as a user interface to communicate with end-users. This smart view provides real-time status updates, visualizations, and statistical reports, allowing users to track the progress of the machines and make informed decisions.

Overall, the process of creating a cloud manufacturing system involves the deployment of IoT devices, development of communication networks, and installation of the proposed system. These steps collectively enable the establishment of an interconnected and data-driven manufacturing environment. By leveraging IoT devices, robust communication networks, and a cloud-based database, the research aims to realize the vision of a smart factory that maximizes the utilization of man and machine, enhances productivity, and enables data-driven decision-making.

b. Realtime status monitoring system

In the proposed system, the worker interacts with the manufacturing process using a smartphone equipped with a dedicated application. By logging in with the provided credentials, the worker gains access to the system's interface. Figure 2 illustrates the operational flow of the proposed system, demonstrating the seamless integration of human interaction with IoT devices. Once logged in, the worker can view the jobs assigned to them and choose the specific task they are assigned to perform. This allocation of work is made available through the system's interface, which displays relevant job details and instructions. The worker selects the job and proceeds to the milling machine to begin the assigned task.

Fig. 2 IoT enabled system

At the milling machine, the worker prepares the necessary tools and workpiece. The system incorporates various sensors to ensure the proper placement of the machining tool and workpiece. These sensors, which may include proximity sensors and RFID readers, provide real-time feedback to the worker, confirming that the correct components are in place before the machining process begins. With the setup complete, the worker initiates the machining process. The milling machine performs the necessary operations, shaping and refining the workpiece according to the specified requirements. During this stage, the worker closely monitors the process, ensuring its smooth operation and the quality of the output. Once the machining is completed, the worker updates the job status through the smartphone application. This real-time update reflects the completion of the task and triggers subsequent actions within the system. The worker then places the finished job onto the conveyor for further processing. The conveyor, integrated with sensors along its length, detects the presence of the job as it moves along its path. This information is communicated to the cloud infrastructure using a Raspberry Pi device, acting as a central hub for data transmission. The sensor readings, including job identification and conveyor position, are captured and relayed to the cloud in real-time, ensuring accurate tracking and monitoring of the manufacturing process. Upon reaching the pick and place robot station, the conveyor aligns the job for the robot to efficiently pick it up. The robot, equipped with its own set of sensors and actuators, carefully retrieves the job from the conveyor and places it in the designated rack or tray. Throughout this process, the robot's actions are guided by the sensor readings and commands received from the cloud-based system. The sensor and actuator readings captured during the entire operation are continuously communicated to the cloud using the Raspberry Pi. This data is stored in the cloud-based database, allowing for real-time monitoring, analysis, and reporting. By leveraging the cloud infrastructure, the system enables seamless integration of sensor data, worker input, and machine actions, facilitating a dynamic and efficient manufacturing process. The table 1 shows the sensor detection and actuator response.

Table 1 Actuator response and the sensor readings

Sensor Reading	Actuator Response
Sensor 1: RFID tag detected on the workpiece	Actuator 1: Conveyor starts moving to transport the workpiece
Sensor 2: Vibration sensor detects excessive vibrations in the machine	Actuator 2: Alarm sounds and machine operation is halted for safety purposes

Sensor 3: Temperature sensor reads 75°C	Actuator 3: Cooling system activates to reduce the temperature
Sensor 4: Force sensor detects low pressure on the machining tool	Actuator 4: Machine automatically adjusts the tool pressure to the required level
Sensor 5: Proximity sensor detects the presence of an object in the machine's workspace	Actuator 5: Machine stops operation to prevent collision and alerts the operator
Sensor 6: Conveyor sensor detects a blockage in the conveyor system	Actuator 6: Conveyor reverses its direction or stops to clear the blockage
Sensor 7: Speed sensor measures conveyor speed at 2 m/s	Actuator 7: Conveyor speed is adjusted to maintain the desired speed
Sensor 8: Proximity sensor detects the pick and place robot near the conveyor	Actuator 8: Robot arm extends to pick up the workpiece
Sensor 9: Light sensor detects low light intensity in the workspace	Actuator 9: Additional lights are turned on to ensure proper visibility
Sensor 10: Pressure sensor detects a drop in hydraulic pressure	Actuator 10: Hydraulic pump activates to restore the required pressure

Sensor 1: The RFID tag attached to the workpiece is detected, signalling the conveyor system to initiate movement and transport the workpiece to the next station or process.
Sensor 2: Excessive vibrations in the machine are detected by the vibration sensor. As a safety measure, an alarm is activated, and the machine operation is halted to prevent any potential damage or hazards.
Sensor 3: The temperature sensor measures the temperature of a component or the environment. In this case, a reading of 75°C is detected, indicating that the temperature has exceeded the desired range. The cooling system is activated to lower the temperature and maintain optimal operating conditions.
Sensor 4: The force sensor measures the pressure exerted on the machining tool. If a low pressure reading is detected, it implies that the tool is not applying enough pressure. To address this, the machine automatically adjusts the tool pressure to the required level for efficient machining.
Sensor 5: The proximity sensor detects the presence of an object in the machine's workspace, indicating a potential collision risk. To prevent any accidents, the machine stops its operation and alerts the operator to investigate and address the situation.
Sensor 6: The conveyor sensor identifies a blockage in the conveyor system. To clear the blockage and resume normal operation, the conveyor reverses its direction or comes to a complete stop, allowing the blockage to be removed.
Sensor 7: The speed sensor continuously monitors the speed of the conveyor. If the speed deviates from the desired value, the actuator adjusts the conveyor speed to maintain the desired rate of movement for efficient material handling.
Sensor 8: The proximity sensor detects the presence of the pick and place robot near the conveyor. Upon detection, the robot's arm extends to pick up the workpiece from the conveyor, facilitating the automated transfer process.
Sensor 9: The light sensor measures the intensity of light in the workspace. If the intensity is insufficient for proper visibility, additional lights are automatically turned on to ensure optimal working

4. Conclusion

In conclusion, this research proposed the development of a smart factory using IoT technologies, which can provide an efficient and dynamic manufacturing environment. The proposed system uses various sensors and actuators to collect data from machines, robots, and workers, and transmit them to a cloud-based database for real-time monitoring and analysis. The system also incorporates a user-friendly interface that allows workers to access job information, update job status, and communicate with the system using their smartphones. The experimental results demonstrate that the proposed system can effectively monitor and control the manufacturing process in real-time. The data model used in the system provides an organized structure for the collected data, and enables efficient storage, retrieval, and analysis of the data. The smart view and custom software provide real-time status monitoring and statistical analysis of the manufacturing process, which can help improve the production efficiency and quality.
Furthermore, the deployment process of the proposed system is straightforward and scalable, which makes it suitable for implementation in various manufacturing environments. The system also provides flexibility and adaptability, which allows it to be customized to meet specific manufacturing needs. Overall, this research presents a comprehensive approach for creating a smart factory using IoT technologies, which can improve manufacturing efficiency, reduce downtime, and enhance the overall production quality.

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