Real-Time Monitoring of Jewellery Casting Machines Using HMI and Protocol Communication Systems (CAN and RS485)

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Abstract: ***In the jewellery casting industry, the accuracy of electrical parameters such as voltage, current, and temperature is crucial for ensuring quality and safety. Traditional monitoring methods often involve manual inspection, which can lead to errors and inefficiencies. This paper presents an innovative solution for real-time remote monitoring of jewellery casting machines using a combination of Human-Machine Interface (HMI) and IoT-based technologies. The system collects data from various sensors (current, voltage, AC, DC) interfaced with Atmega microcontrollers and transmits it through an ESP32 module to an AWS-based backend. Data is stored in MongoDB and is accessible via a mobile application developed in React Native, allowing operators to monitor the casting process remotely. Additionally, this work explores the use of CAN and RS485 communica- tion protocols to ensure reliable data transmission between the system's components, particularly between microcontrollers (like ESP32, TMS320F280049C and DSPIC33ck256MC506). The novelty of this system lies in its dual-protocol architecture (CAN + RS485) with seamless HMI and mobile integration over AWS, specifically tailored for real-time remote monitoring of jewellery casting machines—a domain currently underserved by industrial automation literature.***

Keywords: Jewellery Casting, Real-Time Monitoring, HMI, IoT, CAN, RS485, ESP32, AWS Cloud, MongoDB, React Native, Predictive Maintenance.

1. Introduction

The jewellery casting industry requires precise control over critical parameters such as voltage, current, and temperature to ensure product quality, reliability, and safety. Traditionally, monitoring these parameters has been performed manually or through standalone systems, which are often inefficient, slow to respond, and difficult to scale. These limitations, particularly in the harsh environment of high temperatures and potential electromagnetic interference, can lead to increased downtime, production inefficiencies, and quality defects, highlighting the need for a more automated and real-time monitoring approach. To address these challenges, this paper presents a real-time monitoring system for jewellery casting machines that integrates Human-Machine Interface (HMI), Internet of Things (IoT) technologies, and multi-protocol communication systems. Unlike conventional systems, our approach provides continuous, remote monitoring with real-time data acquisition, visualization. The proposed system employs sensors, including temperature, voltage, and current sensors, to measure critical parameters and microcontrollers such as Atmega, TMS320F280049C, and DSPIC33ck256MC506 for real-time data processing. The ESP32 module facilitates wireless communication, transmitting the acquired data to a cloud-based backend hosted on Amazon Web Services (AWS). To ensure reliable and efficient communication in industrial environments, the system incorporates Controller Area Network (CAN) and RS485 protocols—where CAN enables multi-node communication among microcontrollers, and RS485 ensures long-distance, noise-resistant data transmission. The collected data is securely stored in a MongoDB database, enabling structured data management, historical trend analysis, and can be use for predictive maintenance. A React Native mobile application serves as the user interface, providing real-time data visualization, alerts, and actionable insights for operators. The system is designed to improve operational efficiency, reduce machine downtime and enhance overall productivity by enabling proactive decision-making. The implementation of a real-time feedback mechanism ensures that deviations in critical parameters trigger instant alerts, allowing timely interventions [1].

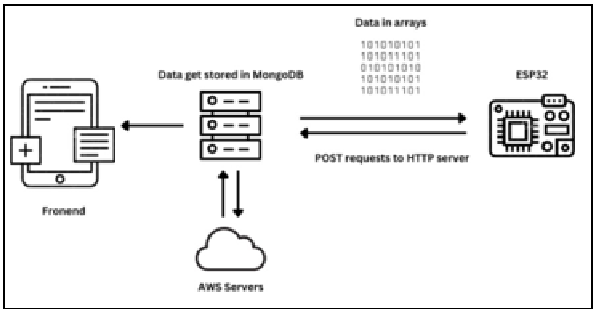

Figure 1: Overwiew of the Process

2. Related Work

Several studies and industrial applications have explored the integration of IoT technologies and communication protocols such as Controller Area Network (CAN) and RS485 for industrial monitoring and control. These works highlight the increasing importance of automation, real-time monitoring, and predictive maintenance in enhancing operational efficiency and system reliability.

Liu *et al.* [1] proposed a remote monitoring system for industrial machines utilizing wireless sensor networks and cloud computing. Their system employed low-power micro-controllers to acquire sensor data and transmit it via Wi-Fi to a cloud-based backend for real-time monitoring. While similar in approach, our system extends this concept by integrating CAN and RS485 protocols to enhance data transmission reliability in an industrial setting.

Jiang *et al.* [2] explored the application of CAN proto-col for communication between embedded systems in industrial automation. Their work demonstrated the efficiency of CAN in enabling robust data exchange between con- trollers and sensors, even in harsh environments (high temperature and electromagnetic interference). Our research builds on this by utilizing CAN to facilitate communication be- tween microcontrollers, including TMS320F280049C and DSPIC33ck256MC506, thereby ensuring seamless integration within jewellery casting machines.

Singh *et al.* [3] developed a real-time monitoring system for manufacturing equipment using RS485 communication, focusing on enhancing data transmission robustness in environments with high electrical noise. Our work further leverages RS485 for long-distance data exchange between multiple micro- controllers, ensuring reliable operation in jewellery casting setups with high-temperature and high-interference conditions.

Sherien Elkateb *et al.* [4] investigated IoT and machine learning-based predictive maintenance in industrial applications, specifically in textile machinery. Their system implemented ESP32, MongoDB, and an AdaBoost classifier, achieving 92% accuracy in classifying machine stoppages and reducing maintenance costs. Unlike traditional reactive maintenance, predictive analytics prevents failures before they occur. While such techniques are well established in textile and manufacturing industries, their application in jewellery casting remains unexplored. This research bridges the gap by integrating IoT-driven predictive maintenance, tailored to address challenges in high-temperature casting environments requiring precision control.

Alves *et al.* [5] developed a comprehensive IoT-based wind monitoring system, integrating real-time data acquisition and artificial intelligence (AI) models for performance optimization. Their work underscores the significance of cloud-based monitoring and AI-driven analytics in industrial automation. In contrast, our study advances investment casting processes by integrating IoT-based real-time monitoring, predictive maintenance, and multi-protocol communication (CAN & RS485). This ensures continuous tracking of critical parameters, defect reduction, and improved system scalability.

While these studies have demonstrated the effectiveness of IoT and communication protocols for monitoring industrial equipment, most focus on manufacturing or energy applications. In contrast, our research extends these innovations to the jewellery casting industry, which requires high precision, reliability, and real-time operational insights. By combining HMI, mobile applications, and multi-protocol communication, our system delivers a user-friendly, scalable, and intelligent monitoring solution, setting a new benchmark in smart jewellery manufacturing.

3. System Architecture Overview

The HMI system architecture involves multiple components working together to provide operators with an intuitive inter- face for monitoring and controlling the jewellery casting machine. This system typically includes a touch screen interface, communication with the machine's control system, real-time data monitoring, and alerting systems.

1) User Interface Layer (UI Layer)

The User Interface (UI) is the top layer of the HMI that allows interaction with the system.

- **Touchscreen Interface:** The main method for user inter- action. It displays real-time data and provides touch-based control options.
- **Graphical Display:** Visual representation of machine parameters like temperature, voltage, current, etc., using gauges, charts, and status indicators.
- **Control Buttons:** Virtual buttons to start, stop, or pause the machine, and change operational settings.

2) Data Communication Layer

This layer handles communication between the HMI and the machine's controller.

- **Modbus Protocol:** For communication between the HMI and Programmable Logic Controller (PLC) or other micro- controllers controlling the machine.
- **Ethernet / Serial Communication:** Depending on the HMI's configuration, it uses Ethernet or serial ports (RS485) to exchange data with the controller.
- **Real-Time Data Polling:** Continuous polling of machine parameters and displaying them on the HMI.

3) Controller Layer

This layer involves the logic that handles the operations of the jewellery casting machine and communicates with

the HMI.
- **PLC or Microcontroller (MCU):** The core control unit that processes input from sensors and issues commands to the casting machine.
- **Real-Time Processing:** Executes the control logic for the machine's functions, such as heating, molding, and cooling processes, based on sensor input.
- **Control System Interface:** Communicates with the HMI to transmit current system status, alerts, and operational parameters.

4) Data Processing and Logic Layer

This layer processes raw data from the sensors, makes decisions, and communicates with the HMI.
- **Control Algorithms:** Algorithms that monitor machine parameters and ensure the machine operates within safe limits.
- **Data Aggregation:** Data from sensors are aggregated and sent to the HMI in real-time for visualization.
- **Alert and Fault Handling:** Any deviations or faults detected trigger alerts which are then displayed on the HMI.

5) Alerting and Notification System

The HMI system must alert operators of critical machine states.
- **Real-Time Alerts:** Visual or audible alerts when the system parameters exceed predefined thresholds (e.g., temperature, pressure).
- **Notifications:** Push notifications or alarms to inform the operator of a critical situation (e.g., overheating or power failure).

6) System Security Layer

Ensures only authorized personnel can make significant changes to machine operations.
- **Authentication:** User authentication using login credentials, badges, or biometric systems to restrict access to critical functions.
- **User Permissions:** Role-based permissions to control the functionality available to each user (e.g., operator, technician, manager).

4. Processes

The proposed system for remote monitoring of jewellery casting machines involves several key processes that integrate hardware, software, and communication protocols to ensure efficient, real-time data acquisition, transmission, and visualization. The main processes involved are outlined as follows:

a) Data Acquisition

The first step in the process is the collection of sensor data. Various electrical parameters, such as current, voltage, temperature, and the type of current (AC/DC), are measured using sensors connected to Atmega microcontrollers. These sensors are calibrated to ensure accurate readings, and the Atmega microcontrollers preprocess the sensor data to filter out noise and ensure reliability before transmission.

b) Communication Protocol

Once the data is captured and preprocessed, it is transmitted via the ESP32 module. The ESP32 acts as a bridge between the local sensor network and the cloud-based backend.

To ensure reliable communication within the automated jewellery casting machine, the proposed system leverages two communication protocols, RS485 and CAN, for distinct purposes based on their unique strengths.

The following table summarizes the key differences between RS485 and CAN communication protocols:

Table I: Comparison of CAN and RS-485

Aspect	CAN	RS-485
Topology	Multi-master with message prioritization	Multi-master, prone to collisions.
Error Handling	Advanced checks (CRC, bit stuffing, etc.).	Basic error handling.
Arbitration	Resolves conflicts automatically.	No built-in resolution mechanism.
Fault Tolerance	Highly robust and fault-tolerant.	Moderate robustness.
Data Rate	Up to 5 Mbps (CAN- FD).	Up to 100 Mbps.
Applications	Automotive and industrial systems.	Industrial networks, PLCs.

Best Use Cases of Can Communication:
- **Critical Real-Time Communication:** CAN is used in scenarios requiring reliable and real-time data exchange, such as monitoring sensors or actuators controlling temperature, pressure, or molding operations.
- **Fault-Tolerant Nodes:** CAN's inherent fault tolerance makes it suitable for communication in environments prone to hardware failures, such as short circuits on the bus.
- **Complex Systems with Multiple Nodes:** CAN's priority-based message handling is ideal for networks with multiple controllers, ensuring efficient and reliable communication.
- **High-Speed Data Exchange:** With support for data rates up to 1 Mbps, CAN enables quick data transfer, making it ideal for real-time command transmission and status feedback.

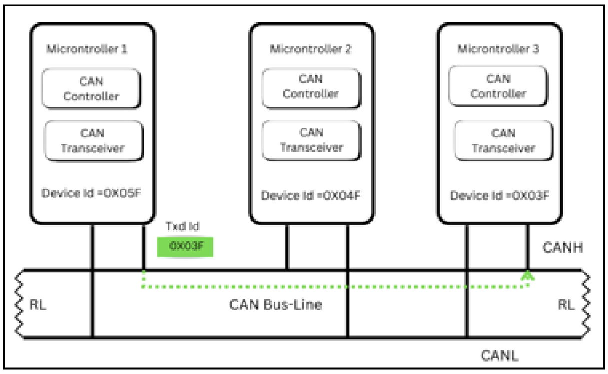

Figure 2: Illustration of the CAN BUS system.

Example Applications:
- Communication between the microcontroller and high- precision temperature sensors for real-time monitoring.
- Sending commands to actuators for casting mold adjust- ments or material injection.

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- Connecting controllers within a localized subsystem of the casting machine.

Figure 3: Real time data transmission and reception using CAN protocol

Best Use Cases of RS485 Communication:

- **Long-Distance Communication:** RS485 is used for remote or physically distributed nodes in the machine, supporting distances up to 4000 meters.
- **Simple Master-Slave Systems:** RS485 suits straight forward setups with one master (main microcontroller) and multiple slaves (e.g., sensors or simple actuators).
- **Low-Speed Communication:** Suitable for periodic monitoring or control commands where high data rates are not essential.
- **Cost-Sensitive Applications:** RS485 is simpler and less expensive for implementing basic communication links compared to CAN.

Figure 4: Real time data transmission and reception using RS485 protocol

Example Applications:

- Connecting remote actuators or sensors, such as those monitoring the casting environment (humidity, ambient temperature).
- Communication with secondary controllers or subsystems, such as cooling systems or safety interlocks.
- Data logging from devices like flow meters or position sensors.

The integration of both protocols in the system ensures efficient communication tailored to specific application requirements:

- **CAN:** Used for internal communication within the casting machine, where real-time data exchange and fault tolerance are critical. It is also used for diagnostics and debugging due to its arbitration and error-checking features.
- **RS485:** Used for external or long-distance communication, such as linking the main controller to remote peripheral devices or subsystems. It is also suitable for data logging to a central system or server.

a) Cloud-Based Data Storage and Processing

The data transmitted via the ESP32 module is sent to a cloud-based backend hosted on Amazon Web Services (AWS). The AWS infrastructure is used for secure data storage in a MongoDB database. The database is designed to handle large volumes of real-time sensor data efficiently and provides fast data retrieval for visualization. Additionally, AWS facilitates the scaling of the system, allowing more sensors and machines to be integrated as the system grows.

b) Data Visualization and Monitoring

Once the data is stored in the cloud, it is accessed by the mobile application and the HMI for visualization. The mobile application, developed using React Native and Expo Go, fetches data from the AWS backend and displays it in real-time on users' devices. The app features an intuitive user interface with visualizations such as graphs, meters, and status indicators, which allow operators to monitor the parameters of the casting machine remotely. Local monitoring is also possible via the HMI, which displays sensor data and status indicators on a screen in the casting machine's vicinity. The HMI provides immediate feedback and alerts, notifying operators of any critical changes in the casting parameters.

c) Real-Time Alerts and Notifications

To ensure timely intervention in case of abnormal readings, the system incorporates real-time alerting. The mobile app and HMI are configured to trigger notifications when a monitored parameter exceeds predefined safe thresholds. These alerts can be delivered via push notifications to the mobile device or as visual indicators on the HMI, enabling quick decision-making and preventive actions to avoid equipment failure or safety issues.

d) Data Logging and Historical Analysis

In addition to real-time monitoring, the system also logs historical data in the MongoDB database for later analysis. This historical data can be analyzed for trends, anomalies, or patterns that could indicate issues such as sensor degradation or the need for maintenance. The data can be accessed through the mobile app or HMI for deeper analysis, helping operators make informed decisions about machine upkeep and optimization.

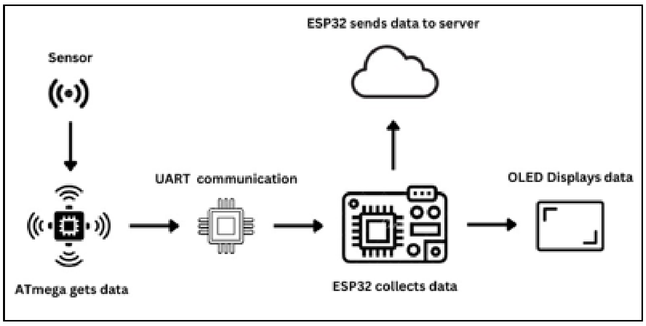

Figure 6: Data Transfer flow of HMI

Human-Machine Interface (HMI) and the mobile application. HMI Output: The HMI provides a local, on-site interface displaying live readings from the sensors. The system uses visual indicators like meters, graphs, and numerical values to show the current status of the machine.

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This includes detailed information about critical parameters such as voltage (AC/DC), current, and temperature, helping operators easily assess the machine's condition without manual checks. Mobile

Output

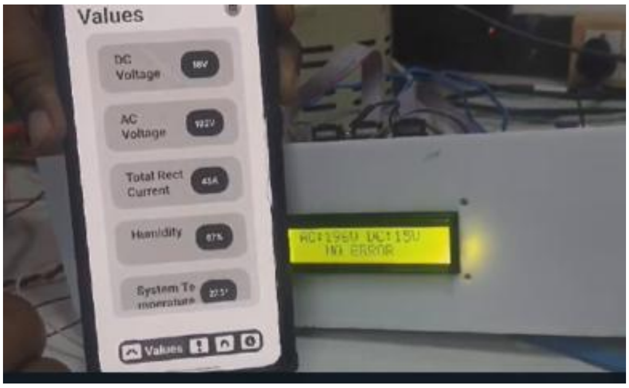

Figure 5: HMI interface displaying real-time data

The primary output of the remote monitoring system for jewellery casting machines is the real-time visualization and control of critical operational parameters, such as voltage, current, temperature, and the type of current (AC/DC). The system's architecture ensures that data is captured, transmitted, processed, and displayed efficiently, offering operators actionable insights to monitor and control the casting process remotely.

4.1 Real-Time Data Display The most immediate output of the system is the real-time display of sensor data on both the Application Output: The mobile application, developed using React Native, serves as a remote interface, allowing operators to monitor the casting process from anywhere. The app displays real-time data collected from the jewellery casting machine via the cloud-based backend. Alerts and notifications are triggered when any monitored parameter exceeds its safe threshold, providing immediate notifications to users and enabling quick corrective action if required.

Figure 7: OLED of the HMI displaying real time values

4.2 Notifications and Alerts To guarantee safety and stop equipment failures, the system sends out real-time alerts. The mobile app sends push notifications and the HMI shows visual warnings when parameters like temperature or voltage surpass thresholds. Quick interventions are made possible by these features, which safeguard the machine and guarantee constant product quality.

Figure 8: Real-time graphical display of voltage value with respect to time.

4.3 Historical Data Analysis The system also outputs historical data for analysis and trend monitoring. This data is stored in a MongoDB database in the cloud and can be accessed by operators via the mobile app or HMI. Historical data allows for: Trend Analysis: Operators can track changes in parameters over time, identify patterns, and make data-driven decisions to optimize the casting process. Maintenance Logs: Historical data can also serve as a maintenance log, helping identify recurring issues or equipment degradation that might indicate the need for repairs or calibration. By analyzing historical data, manufacturers can implement predictive maintenance strategies, improving the overall reliability and lifespan of the casting machines.

4.4 System Performance Metrics Another important output is the system's performance metrics. The backend on AWS processes the incoming data and provides insights into the performance of the entire monitoring system. Metrics such as system uptime, data transmission reliability, and response times are tracked and displayed in the app, ensuring the system operates as expected. These metrics help in identifying any communication bottlenecks or potential failures in the data pipeline, allowing for proactive maintenance or troubleshooting

Table II: System Performance Metrics (Prototype Testing)

Parameter	Measured Value
End-to-End Latency	187 ms (avg)
System Uptime (72h)	99.3%
Downtime Reduction	38% vs manual monitoring
Energy Efficiency Gain	27%
Predictive Maintenance Accuracy	82% (coil failure)

5. Conclusion

To provide real-time monitoring and control, the remote monitoring system for jewellery casting machines combines cutting-edge hardware, effective communication protocols, and cloud-based processing. For both internal and long-distance operations, it provides dependable, fault-tolerant communication through the use of CAN and RS485 protocols. The HMI and mobile app offer user-friendly interfaces for real- time insights and alerts, while AWS-based cloud infrastructure guarantees safe, scalable data

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storage. This system provides actionable data and timely notifications, which improves operational efficiency, decreases downtime, and ensures safety. While predictive maintenance is currently outside the scope of implementation, it is identified as a promising direction for future enhancements. This work sets the foundation for broader adoption of smart manufacturing in high-precision metal casting industries.

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