

Performance Monitoring and Analysis for Predictive Maintenance of a Circular Knitting Machine

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A Final Year Design Project (FYDP) submitted to the Department of
Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree
of Bachelor of Science in Electrical and Electronic Engineering (BSEEE).

Department of Electrical and Electronic Engineering
BRAC University
May, 2025

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Spring 2025 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering (BSEEE) on 15-05-2025.

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Ethics Statement

We certify that this Final Year Design Project document on "Performance Monitoring and Predictive Analysis for Circular Knitting Machine" satisfies all requirements established by the Department of Electrical and Electronic Engineering at BRAC University Authority. The final year design project at BRAC University serves as a partial prerequisite for the completion of the Bachelor of Science (B.Sc.) in Electrical & Electronic Engineering degree. As a result, this project report, which includes the results of our surveys and searches, our designs and specifics of our prototype's test results, was created with the help of every group member. As recommended by our ATC Panel, all sources and literature reviews include the appropriate citations. We have checked the plagiarism by Turnitin and the percentage of plagiarism is only 11%.

Abstract

The objective of this research is to implement a system that tracks and analyzes real-time events to improve the performance and reliability of circular knitting machines in shirt, legging and sportswear production. These technological advances have not replaced the need for manual inspections. This leads to problems that go unnoticed, sudden breakdowns and lost production. By using temperature, RPM, current, voltage, humidity, airflow and lubrication sensors, the proposed system utilizes predictions to identify potential problems early on. Besides, being able to observe systems remotely will make it easier to oversee everything and make quicker data-based decisions. To be one step further to predictive maintenance from conventional approach in order to enhance the machine reliability, to keep the constant fabric quality, as well as to promote more ecological manufacturing of the garment products. This is an innovation that should improve efficiency and competitiveness in the textile industry, particularly in the large market of ready-made garments such as that in Bangladesh.

Keywords: Circular Knitting Machine, Performance Monitoring, Predictive Maintenance, Real-Time Data, Sensor-Based Monitoring, Remote Monitoring, Textile Manufacturing, Machine Reliability

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Chapter 1: Introduction

1.1 Introduction

The textile industry has evolved significantly from manual production methods to highly automated manufacturing systems. Key inventions during the Industrial Revolution, such as the spinning jenny, water frame, and power loom, laid the groundwork for mechanized textile production. Similarly, the invention of the knitting frame by William Lee in 1589 and the later development of circular knitting machines revolutionized the knitting sector. Circular knitting machines enabled the efficient production of seamless tubular fabrics, which became essential in manufacturing garments like hosiery, t-shirts, leggings, and sportswear.

For seamless and stretchable garments such as t-shirts, leggings, sportswear and socks the circular knitting machine is being used vastly by the textile industry. The possibility of making tubular fabrics removes stitches, hence increasing comfort and durability for such garments. We can classify the new generation circular knitting machine in two different parts, one is a single jersey, and the other is a double jersey. Single jersey is used for light fabrics and the double jersey is used for thicker and stronger fabrics such as rib and interlock stitches [1]. In the global market, these textile machinery, value at approximately \$29.16 billion in 2021, which continues to grow, with circular knitting technologies playing a vital role. [2]

Despite advancements, circular knitting machines are still vulnerable to operational challenges. Performance is highly dependent on maintaining optimal parameters such as RPM, temperature, humidity, current, voltage, air pressure, and oil flow. Traditional maintenance approaches, based on manual inspection and fixed schedules, are often reactive and inefficient. This can result in delayed detection of faults, unexpected downtimes, higher operational costs, and decreased product quality.

As industries transition toward smart manufacturing under Industry 4.0, there is a pressing need for intelligent monitoring systems. Real-time sensor-based monitoring combined with predictive analytics can facilitate early detection of abnormalities, proactive maintenance, and optimization of machine operations. Additionally, remote monitoring capabilities allow centralized oversight and faster decision-making across multiple facilities.

The primary aim of this project is to develop a Performance Monitoring and Predictive Analysis System for circular knitting machines. Through continuous monitoring of critical parameters and predictive modeling, the system will enhance machine reliability, minimize downtimes, improve fabric quality, and promote sustainable manufacturing practices. The integration of real-time data acquisition, advanced sensors, and predictive algorithms will enable textile manufacturers to transition from reactive maintenance to a data-driven, proactive maintenance strategy.

In conclusion, improving the performance monitoring and predictive maintenance capabilities of circular knitting machines is essential for enhancing operational efficiency, sustaining high-quality production, and maintaining the global competitiveness of the textile manufacturing sector.

1.1.1 Problem Statement

In terms of efficiency, versatility and adaptability to various consumer needs the circular knitting machines are playing an important role in the textile industry. New generation machine models have been cost-effective and support sustainable manufacturing practices in order to minimize energy consumption and waste. Programmable machines allow complex designs that let manufacturers meet the ever-changing needs of the fashion industry. Their applications range from casual wear to sportswear, medical textiles, and industrial fabrics, proving their important role in textile production worldwide [2][3].

The circular knitting machines are regarded as the backbone of Bangladesh's textile and RMG sector of the country. One of the leading exporters of knitted garments, Bangladesh relies on these machines in producing quality fabrics at cheaper prices for various global markets. Garments such as T-shirts, sportswear, and underwear are major exports in the country, accounting for more than 80% of the country's total export earnings [5]. Higher production efficiency and shorter lead times from the adoption of modern and automated knitting machinery also keep Bangladesh competitive in the international market. Yet, issues like dependency on imported machinery and shortage of skilled labor for advanced technologies are the challenges which face this industry even today [4].

In all, the development in textile machinery and circular knitting machines indicates how crucial these machines have been in bringing about a complete transformation in the outlook of textile production across the world. Indeed, these machines increased productivity, consequently bringing economic growth, and have further placed countries like Bangladesh among the larger producers of textiles. With continuous innovation in knitting technology, the relevance of such machines in efficiency, sustainability, and economic progress would be indispensable.

Circular knitting machines are very crucial players in textile production. Therefore, a lot of compromise is inflicted on the machines by several operational issues that go through unharassed up to machine malfunctioning. For example, RPM operational parameters are in common use, and fluctuations normally pass undetected to cause serious damage, not excluding temperature, humidity, and power consumption. Though serving some useful purposes, manual checks in all these are sluggish and responsive. This often causes delays in response toward operational issues, thus causing needless downtime, low productivity, and higher operational costs.

Our aim is to monitor these parameters continuously using automated monitoring systems, and we also aim for predictive maintenance for the overall machine so that the machine won't have to face any delay regarding maintenance and operational issues.

1.1.2 Background Study

The history of textile machinery marks the journey of transformation which changed the way of textile production. Some old methods like spinning wheel and handloom were slow in work and labor-intensive. So the industrial revolution took place to solve the issue, in 1764 James Hargreaves introduced us to the Spinning jenny. Then in 1769 Richard Arkwright introduced his water frame and in 1785 Edmund Cartwright introduced the Power Loom. These three parts mechanized the spinning and weaving processes. Because of this textile manufacturing saw the light of fast and mass production. The knitting machinery evolved step by step with the invention of the first Knitting Frame back in 1589 by William Lee. The arrival of circular knitting machines paved the way for knitting fabrics as seamless tubes during the 19th century. Consequently it found a wide scope of application in the manufacture of hosiery, socks and other garments with elastic stretch. In the 20th century these machines became high-speed and automated under the control of computer technology [5][6].

For seamless and stretchable garments such as t-shirts, leggings, sportswear and socks the circular knitting machine is being used vastly by the textile industry. The possibility of making tubular fabrics removes stitches, hence increasing comfort and durability for such garments. We can classify the new generation circular knitting machine in two different parts, one is a single jersey and the other is a double jersey. Single jersey is used for light fabrics and the double jersey is used for thicker and stronger fabrics such as rib and interlock stitches [3].

The major parts of a circular knitting machine are needles, cams, and cylinders that work in coordination to form loops in a chosen pattern. Yarn feeders press for continuous yarn supply, and the take-down mechanism collects finished fabrics. These machines also have advanced drive systems that are normally electrically operated, to improve efficiency. Production speed varies between 0.5 to 1.5 meters per minute, while the high-speed machines run at 30 to 40 revolutions per second can produce quite a volume of fabric in a very short length of time [3].

Economic impact brought about by circular knitting machines is considerable. They have revolutionized textile manufacturing by significantly reducing labor costs, increasing productivity, and meeting the rising demand of the global market for knitted garments. The global textile machinery market was valued approximately at \$29.16 billion in 2021 and is expected to grow at a CAGR of 5.9% from 2022 to 2031, with circular knitting machines being one of the leading contributors. In Bangladesh, the textile and garment industry earned export earnings of \$41.75 billion in 2022, and a big chunk of this was made up of knitted garments made on circular knitting machines. These machines also support the global demand for casual and sportswear industries that alone generated revenues above \$350 billion globally in 2022.[4].

In terms of efficiency, versatility and adaptability to various consumer needs the circular knitting machines are playing an important role in the textile industry. New generation

machine models have been cost-effective and support sustainable manufacturing practices in order to minimize energy consumption and waste. Programmable machines allow complex designs that let manufacturers meet the ever-changing needs of the fashion industry. Their applications range from casual wear to sportswear, medical textiles, and industrial fabrics, proving their important role in textile production worldwide [5][6].

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Our aim is to monitor these parameters continuously using automated monitoring systems, and we also aim for predictive maintenance for the overall machine so that the machine won't have to face any delay regarding maintenance and operational issues.

1.1.3 Literature Gap

Despite significant advancements in circular knitting machine technology, there remains a noticeable gap in the literature regarding the integration of advanced performance monitoring and predictive maintenance systems for these machines. Existing research primarily focuses on mechanical design, operational efficiency, and machine operation within textile machinery, but does not sufficiently address the continuous, real-time monitoring of multiple machine parameters, such as temperature, RPM, current, voltage, air pressure and oil flow. These parameters are critical to maintaining optimal machine performance and ensuring high-quality production, yet studies combining these factors with predictive maintenance algorithms are sparse.

While predictive maintenance has been widely explored in other industrial sectors, such as automotive and general manufacturing, there is limited research on its application to circular knitting machines. Most studies on textile machinery monitoring focus on basic fault detection methods, such as vibration-based analysis or scheduled maintenance, which are often insufficient for early-stage failure detection. There is a clear need for research that integrates advanced data analytics, particularly machine learning algorithms, to analyze multi-parameter sensor data in real-time. Such models could predict machine failures before they occur, thereby improving the reliability and operational efficiency of circular knitting machines.

Moreover, the application of Internet of Things (IoT) in textile machinery industry is an area that remains underexplored. Although the IoT plays role in industrial automation is well-documented, the specific challenges and opportunities of adopting IoT-based solutions for monitoring circular knitting machines have not been adequately studied. The combination of IoT devices and predictive maintenance systems means there is potential to decrease downtime and boost the performance of machines. There are not enough detailed studies on how technology can benefit the textile manufacturing industry.

Though predictive maintenance systems are accepted to be beneficial, there isn't enough research available to measure their true economic impact for the textile industry. There are not many studies that focus on the benefits that come directly from using real-time control approaches and maintenance prediction for circular knitting equipment.

In conclusion, while there has been progress in both textile machinery design and predictive maintenance, the integration of real-time performance monitoring, multi-parameter data analysis, and predictive maintenance for circular knitting machines remains underexplored. This study aims to address these gaps by developing a system that incorporates sensor data, predictive modeling, and remote monitoring to optimize machine performance and maintenance strategies in textile manufacturing.

1.1.4 Relevance to current and future Industry

As the textile industry faces growing demands for faster, cost-effective, and sustainable production, the role of machines, especially circular knitting machines is more important than ever. These machines are key for making popular items like t-shirts, leggings, sportswear, and hosiery, where comfort, stretch, and seamless construction matter a lot. But to keep up with global expectations, it's crucial that these machines run smoothly and consistently. Even small issues can lead to fabric defects, wasted time, or higher costs.

Now, many factories still rely on manual checks and fixed maintenance schedules. While this has worked in the past, most of the time means that problems go unnoticed until it's too late. That can result in unexpected machine downtime, quality issues, and increased expenses. A smarter way is to use real-time monitoring and predictive maintenance. By tracking data like machine temperature, speed (RPM), electrical current and voltage, air pressure, and oil flow, factories can spot issues early and fix them before they cause trouble. This kind of system doesn't just reduce maintenance costs it also helps improve reliability and productivity overall.

All of this fits into the bigger shift toward Industry 4.0, where digital technologies are reshaping how manufacturing works. In the textile world, more and more companies are using IoT, data analytics, and remote monitoring to stay ahead. Real-time, sensor-based monitoring supports this shift perfectly. It gives manufacturers the insights they need to make smarter decisions, stay competitive, and adapt quickly in a fast-changing global market.

1.2 Objectives, Requirements, Specifications and constant

1.2.1. Objectives

The purpose of this project is to design and implement an electronic sensing and machine learning integrated system with IoT based advanced monitoring module for circular knitting machines. The scope include the identification and measurement of critical operational parameters of the machine such as temperature, RPM, current, voltage, oil flow rate, air pressure by using appropriate sensors and data store systems. The gathered data will then be then analyzed to establish performance benchmarks and prediction of the future, allowing better decision making and better operation adjustments. The project will also consider the implications of real time monitoring for its productivity, quality control and energy efficiency. Objectives of the project aim at promoting a more sustainable manufacturing approach and innovation in the textile industry of Bangladesh.

The objectives of our project is listed below:

1. The design and implementation of an integrated Real Time Performance Monitoring system for circular knitting machines based on critical parameters (temperature, RPM, voltage, current, air flow and lubrication level) has been proposed.
2. Design a machine learning (ML) based predictive analysis model that will analyze machine health, predict machine failure, and recommend an advanced maintenance schedule.
3. Create a dashboard to visualize machine health and alert, parameter's rating, and shift from reactive to prescriptive maintenance to enhance machine performance.
4. Enhanced monitoring systems improve the machine's efficiency and boost product's quality by predicting the fault conditions and optimized machine performance.

1.2.2 Functional and Nonfunctional Requirements

Functional requirements:

Functional Feature	Specification
Real-Time Data Collection	Data collection frequency must be less than 1 second for each sensor. Must be capable of collecting multiple sensor data without data loss.
Dashboard	It includes graphs, charts, and numerical values for visual representation of data.
Integration with Existing Systems	Must support standard communication protocols ensuring continuous data transfer.
Integration of Multiple Sensors	Integration of multiple sensors (temperature, RPM, current, voltage, air pressure, oil flow) for understanding machine condition and monitoring.
Automatic Maintenance Schedule	It needs to be generated based on historical data and predictive failure analysis results.
Notification System	SMS/ email should be configured based on thresholds limit for each parameter.
Data Storage	Store data in database (e.g., MySQL, MongoDB)

Table 1: Functional Requirements

Non-Functional requirements:

Feature	Specification
Design	Simple design
Display	High resolution display
Performance	Real-time monitoring of parameters like RPM, temperature, current, voltage oil flow and air pressure. Also display sensor data with minimum time delay.
Reliability	Fault tolerance for hardware and software components.
Scalability	Modular architecture for easy scalability to multiple machines.
Security	Encryption protocols for IoT communication, data transmission and storage to provide safety against unauthorized access.
Energy Efficiency	The whole system must be designed to operate in limited power consumption, to improve overall energy efficiency of the knitting machine.

Table 2: Non Functional Requirements

1.2.2 Specifications**Technical Specifications:**

Sub-System	Sub-System Specifications	Components	Component Specifications
Machine Monitoring	Monitors RPM, temperature, airflow, energy consumption, oil flow.	RPM Sensor	Range: 30–50 RPM, Accuracy: ± 1 RPM
		Temperature Sensor	Range: 20°C–55°C, Accuracy: $\pm 1^\circ\text{C}$

		Airflow Sensor	Range: 350–400 kPa, Accuracy: $\pm 1\%$
		Energy Meter	Range: 0–5 kW, Accuracy: $\pm 1\%$
		Oil Flow Sensor	Range: 0–7 cm ³ /sec, Accuracy: $\pm 1\%$
Data Acquisition	Continuous data collection every 1 minute	Microcontroller	Real-time data acquisition and processing
Wireless Communication	Communication range of 2–3 km using Wi-Fi/Bluetooth	Wi-Fi / Bluetooth Module	Long-range wireless communication (2–3 km)
Power Supply	Operates on 12V DC with a 5000 mAh battery backup for 6 hours	Power Unit	12V DC input; 5000 mAh rechargeable battery for backup
Data Storage	Stores 6 months of data locally on 1 TB SSD; supports cloud storage for long-term access	Industrial SSD	1 TB capacity, industrial-grade, high-speed storage
		Cloud Module	Secure integration for remote data access and backup

Predictive Maintenance	Analyzes historical trends in temperature, RPM, oil flow, air pressure, current, voltage energy to predict failures; alerts issued 1 week in advance	Predictive Analytics Engine	Runs ML models to predict anomalies and schedule maintenance
User Interface	Web-based interface accessible from any device; role-based access for Admin, Operator, Maintenance	Web Dashboard	Displays real-time data, visualizations, and control settings
		Access Control Module	Defines access levels: Admin, Operator, Maintenance
Alert & Notification	Real-time notifications via email, SMS, or alert sound when thresholds are exceeded	Alert System	Supports custom thresholds; generates alerts via email, SMS, sound
System Uptime & Health	Designed for 24/7 monitoring; includes self-diagnostics and fail-safe operation in case of partial system failure	Diagnostic Module	Monitors system status, triggers safe-mode functions during failures

Table 3: Technical Specifications

1.2.3 Technical and Non-technical consideration and constraint in design process

Constraints :

During the development process, several real-world limitations were encountered that influenced both the design and implementation phases of the project. These constraints are

outlined below and reflect the practical challenges faced in building a functional and reliable system within given boundaries:

- Budget limitations restricted the range of components we could afford.
- Access to reliable, high-quality sensors was limited in local markets
- The project needed to be completed within a specific time frame
- Integrating the system with existing factory infrastructure posed a challenge
- Real-time operation was essential for both the sensors and the software
- The system was expected to deliver highly accurate results, aiming for 99% precision.

In summary, these constraints not only shaped the technical direction of the project but also encouraged careful prioritization of features and smart use of available resources. Addressing these challenges helped ensure the final solution remained practical, efficient, and suited for real-world industrial use.

1.2.4 Applicable compliance, standards, and codes

IEEE 1220 : This standard holds particular relevance in fields like textile manufacturing, where managing complex systems—such as circular knitting machines—requires a structured and well-organized approach. It outlines key requirements for system design, development, and integration, helping to ensure that the final solutions performs reliably and effectively address user needs. In relation to your project, the standard would serve as a framework for guiding the systems engineering process, supporting the development of a dependable performance monitoring and predictive maintenance system. This system can then be integrated smoothly with existing machinery, helping manufacturers maintain quality and minimize unexpected downtimes.

IEEE 1451 : This is especially important in industrial settings like textile manufacturing, where numerous sensors monitor crucial parameters such as temperature, oil flow, air pressure, voltage, current and machine speed. The standard provides guidelines on how these sensors should be integrated into existing networks, facilitating efficient data collection and communication. For your study, IEEE 1451 would help ensure smooth integration of sensors onto circular knitting machines, supplying real-time data that can enhance predictive maintenance strategies and optimize overall machine performance.

ISO 50001 : This standard is important for industries that want to save energy and protect the environment. Circular knitting machines use a lot of energy, and following ISO 50001 can help lower energy use by improving how the machines are run, monitored, and managed. Using energy-saving methods based on this standard can also help textile manufacturers meet sustainability goals and stay competitive worldwide.

IEC 61499 : This standard is especially helpful for industries like textile manufacturing, where automation helps boost productivity and cut downtime. For circular knitting machines, IEC 61499 allows building smart systems that can control different parts of the machine (like sensors, motors, and drives) on their own, while also letting you monitor and fix problems from far away. This way, your maintenance system becomes more flexible and easier to expand.

IEC 30141 : This standard helps connect IoT devices for real-time monitoring and predicting maintenance needs. By following IEC 30141, your system can link sensors, data processors, and control units to share data and make quick decisions. The standard also makes sure the IoT setup works well together, stays secure, and can grow as needed—important for successful maintenance over time.

ISO 13374 : This standard is very important for circular knitting machines because it helps keep track of things like oil flow, temperature, RPM, voltage, current to find early signs of problems. By following ISO 13374, your project can make sure the monitoring and diagnostic systems are reliable and meet standards. This way, faults can be found before they cause big breakdowns, helping machines last longer and work better.

ISO 13849-1 : This is especially important in automated settings where machines like circular knitting machines run very fast. ISO 13849-1 gives rules for designing control systems that help prevent dangerous situations or reduce risks if something goes wrong. For your project, following this standard will help create safe monitoring systems and safety measures for people working with circular knitting machines.

DIN EN 15339-2 : This standard gives rules for designing, running, and maintaining textile machines to keep operators safe and lower the chance of accidents. It covers how to use machines safely, what safety steps to follow, and the maintenance routines that should be part of the monitoring system. By following this standard, your project will not only help knitting machines work better but also make sure the system meets safety rules, protecting both workers and the machines.

Standards & Code	Details
IEEE 1220	Standard for Application and Management of Systems Engineering
IEEE 1451	Smart Sensor Interface Standards Sensor Integration
ISO 50001	Energy Management Systems
IEC 61499	Distributed Control Systems for Industrial Automation
IEC 30141	Internet of Things (IoT) Reference Architecture
ISO 13374	Condition Monitoring and Diagnostics of Machines
ISO 13849-1	Safety of Machinery: Safety-related Parts of Control Systems
DIN EN 15339-2	Safety of Machinery in the Textile Industry

Table 4: Applicable compliance, standards, and codes

1.3 Systematic Overview/summary of the proposed project

The project idea is to make and use a RTPA System for circular knitting machines, along with sensors, machine learning and a single dashboard, to increase efficiency and improve the machines' maintenance approach. The project is part of Industry 4.0 and works to transform textile machinery care by using smart, data-based methods instead of regular manual and scheduled R&M. Stretchable and seamless fabrics in t-shirts, leggings and sports clothes are made using circular knitting machines. With the progress of electrical drives and computer controls, these machines are still at risk from unknown changes in RPM, temperature, oil flow, voltage, current, and air pressure. Such problems often result in unplanned work stoppages, rising costs and worse fabric quality, mainly in Bangladesh, a country where the textile industry is so important.

The system will be equipped to gather information from sensors many times per second about the equipment's functioning. The dataset will be fed into a machine learning tool that can find out patterns and estimate likely failures. The dashboard gives easy access from web and

mobile devices, letting users see important data, get alerts and view recommendations, so maintenance can be planned ahead. The team has set up remote monitoring so that all the production units can be watched from a central place which is useful in locations where fewer technical specialists work on-site. Functional requirements for the machine involve connecting with existing machines, scheduling automatic maintenance, providing custom alerts, storing data safely and having a system that can still function in the event of an error. To support sustainable manufacturing, non-functional requirements highlight performance, flexibility, dependability and energy saving.

The completed project fills existing gaps in the literature and industry, presenting a new approach to circular knitting machine maintenance and is in line with the goals of modernizing modern textile manufacturing. In the end, it can improve the dependability of machines, help them last longer, ensure good-quality fabric, cut maintenance costs and let textile makers remain competitive worldwide.

1.4 Conclusion

Supervising how performance is achieved in circular knitting combined with making predictions helps improve textile manufacturing. Automatic monitoring of temperature, RPM, voltage, current, oil flow at set times means you can manage maintenance before a breakdown which ultimately adds to the machine's lifespan. Because of accurate sensors and early-warning tools, problems are found fast and operating within the industry ensures equipment stays safe, energy is conserved and everything in the system is coordinated. By following this process, companies can lower costs, make products more efficiently, and build a better reputation in the textile industry.

Chapter 2: Project Design Approach

2.1 Introduction

This project looks at two new ways to monitor and maintain circular knitting machines in real time for industrial use. Design Approach 1 is a hardware system using an Arduino Nano that connects several sensors to track important machine data, with local data storage and cloud-based analysis. Design Approach 2 uses simulations with MATLAB Simulink and an ESP32 IoT setup, applying machine learning to predict maintenance needs. These two methods serve different purposes—one is ready for quick setup and on-site checks, while the other focuses on testing the system, saving power, and using smart data analysis for modern manufacturing.

2.2 Identify multiple design approach

This project shows two different design approaches that improve how industrial machines are monitored and maintained. Design Approach 1 focuses on building a hardware system using an Arduino Nano as the main controller. It connects several sensors—like pressure, current, oil flow, and RPM (LM393)—to collect data in real time. The system also includes local data storage, a 2.8-inch TFT screen to display live data, and a Wi-Fi module for remote monitoring through Firebase and Adafruit IO. This setup helps detect problems quickly, allows on-site checks, and lets users access data from the cloud, making it a strong option for real-time machine monitoring.

Design Approach 2 takes a different path by using simulations to focus on saving power, testing the system, and adding smart predictive features with machine learning. Created with MATLAB Simulink, this model imitates how key hardware parts—like an ESP32 controller and virtual sensors—work under real conditions. By carefully studying signal processing and power use, the design fits well with the machine's existing electrical system. It also uses a Random Forest Regressor trained on sensor data to predict maintenance needs, making the system smarter without needing a lot of physical testing.

2.3 Describe multiple design approach

Design Approach-01 (Arduino NANO Based)

Real-time aspects of industrial applications will make monitoring and maintaining the circular knitting machine from wear-out or physical damage most of the time unpredictable machine failure or breakdown. To overcome the challenge in design Approach 1, Its configuration uses an Arduino microcontroller board handy system, which integrates a pressure sensor for airflow monitoring, required lubrication, and cooling functionalities against overheating and damage. In addition, a current sensor tracks the electrical power usage by the machine in order to detect any irregularities indicating possible fault conditions on the mechanical side to prevent future downtimes. We used an external power supply to power up the Arduino.

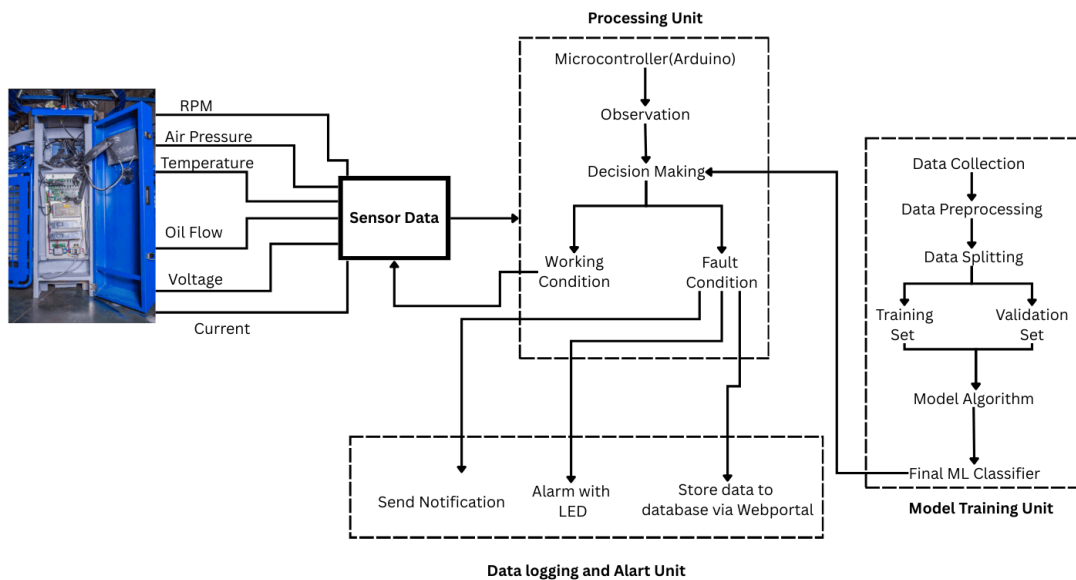


Fig 1: Arduino based fault detection and prediction design approach

This system enables operators to manage machine performance preemptively, anticipating faults that could escalate into serious disruption. The result is lower maintenance costs, longer life of machinery, and improved productivity as a result; thus, this system is useful for textile plants that are more concerned with the operational efficiency of their systems.

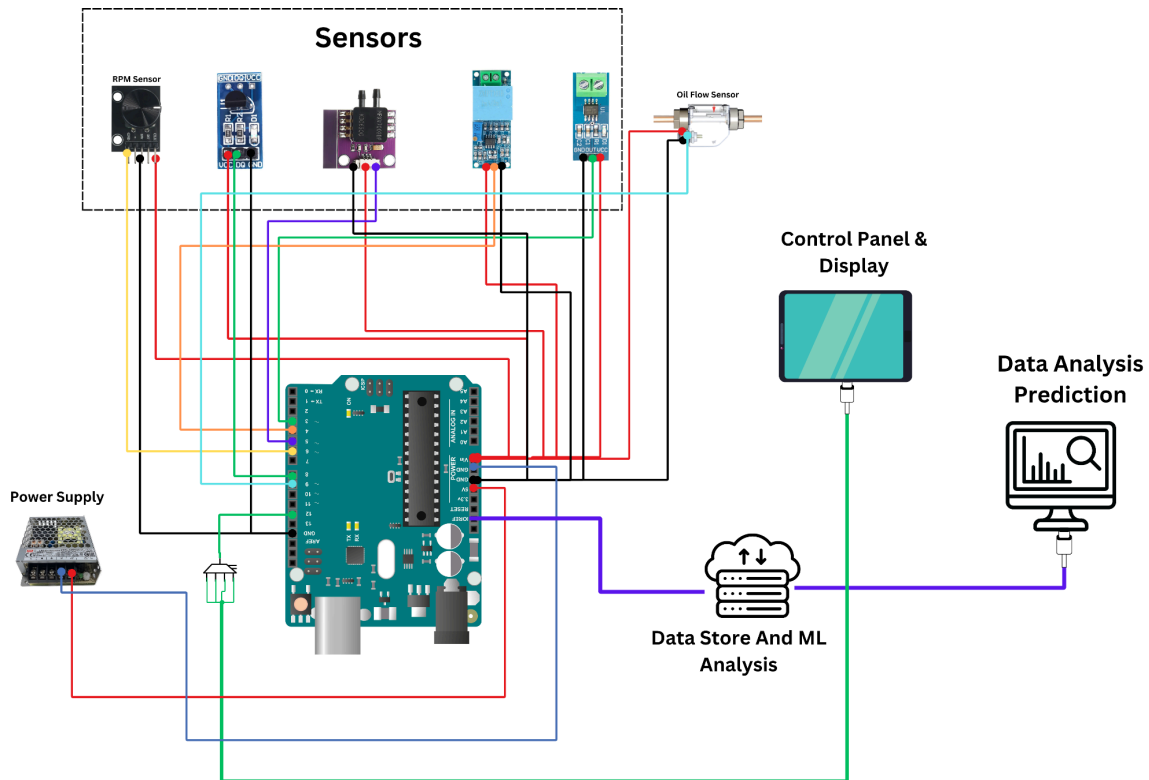


Fig 1: Arduino based fault detection and prediction design approach

This design is a real time performance monitoring system with an Arduino NANO as the central microcontroller. This system consists of several sensors and modules that monitor and log the essential parameters of a circular knitting machine. The sensors and modules of this system are used to monitor and log the critical parameters of a circular knitting machine. This machine uses the pressure sensor (HX711) to detect the oil pressure to find out oil pressure related problems in the machine. A current sensor is monitoring the machine's continuous power consumption to be acknowledged of any unusual spikes or drops in current.

The Arduino is interfaced with an LCD screen to display real time data and to give the user a quick overview of the machine to operating status. It will store all the historical machine performance data and the maintenance teams can use it to analyze long term values and patterns of faults or inefficiencies. Stored data can also be used for predictive maintenance purposes, which can warn that a machine is heading towards big damage before such incidents actually happens, and as a result, it will improve machine wear and thus its overall productivity.

Additionally, this design includes an operational amplifier circuit to improve the sensor signals to obtain accurate measurements. This circuit will also be used to stabilize the circuit and to achieve noise free operation and reliable performance. Overall, the system will be able to detect the faults and provide predictive analysis from historical performance data such as RPM, oil pressure, current, these and other vital parameters. This design can be implemented by the knitting machine so that its overall productivity, reliability and maintenance scheduling can be improved, as well as improving the downtime, and reducing the costs.

Design Approach 2 : ESP 32 based monitoring system

At modern-day industrial applications, real-time machine monitoring is essential so that production remains uninterrupted and downtime reduced to a minimum. Design Approach 2 provides for IoT predictive maintenance for the circular knitting machines; therein, a custom PCB with an ESP32 microcontroller was incorporated. The ESP32 provides Wi-Fi and Bluetooth connectivity through which remote monitoring is done and data transmitted to a cloud server. The system has other sensors like RPM sensors, oil flow sensors, temperature sensors, and current sensors for a comprehensive operational status of the machines.

An exceptional aspect includes stop detection sensors that would identify stoppages like gate stops, idle stops, feeder stops, or completed roll signals. This generates data into a scaled NoSQL database-MongoDB that manages big amounts of unstructured data, for analyses by machine learning models in the projections of failure-predictive maintenance requirements to proactively act by the operators before it escalates..

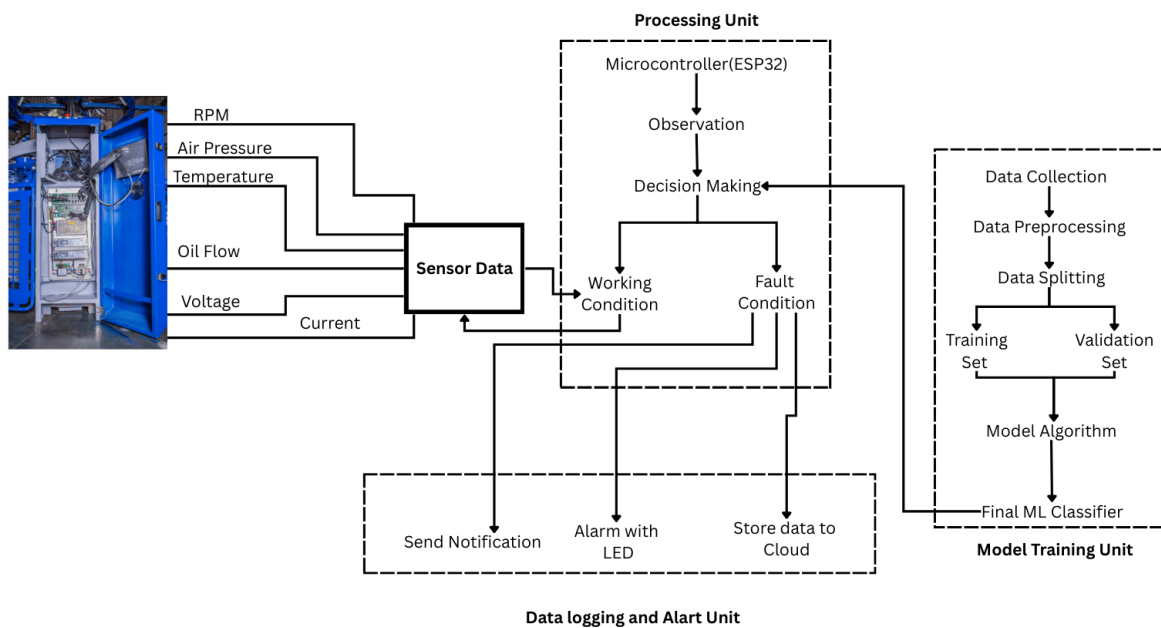


Fig 2: ESP-32 and cloud based fault detection and prediction design approach

That is practically the benefit of such a system to a manufacturer: unplanned downtime is reduced, maintenance schedules are optimized, and machine reliability is improved. Reacting to abnormalities is made easier for operators by real-time notifications, leaving no chances to huge losses. IoT enables textile factories to hence attain higher production efficiency with

lower operational cost while maintaining a sustainable manufacturing process, thus holding hope against the future as far as the industry is concerned.

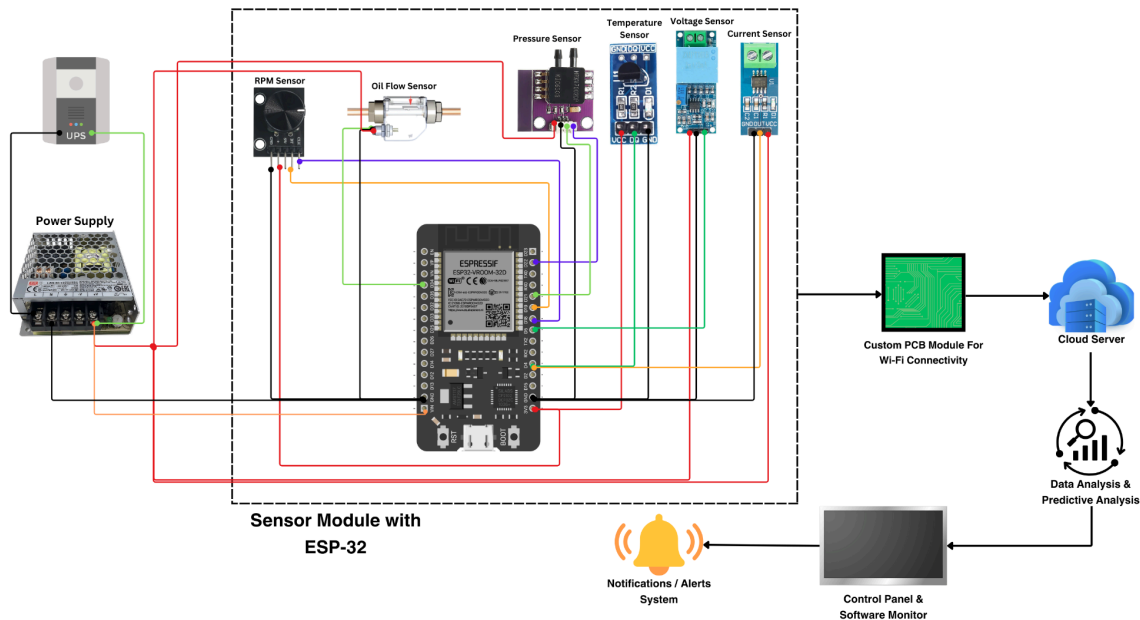


Fig 2: ESP-32 and cloud based fault detection and prediction design approach

In design approach 2, we introduce an IoT-based system for the predictive maintenance of a circular knitting machine using advanced technology for improved efficiency in operation. A custom-built Printed Circuit Board (PCB) integrated with an ESP32 microcontroller is applied-the famous small body, Wi-Fi, and Bluetooth-for easy connectivity in remote monitoring and data transmission.

This includes a set of sensors for accurate monitoring, such as speed sensors that monitor the operational speed of the machines, and machine stop detection sensors able to distinguish a variety of stops-including gate stops, idle stops caused by human intervention, feeder stops, needle stops, and completed roll signals. Thus, this wide-ranging monitoring framework provides a means to collect data on machine performance with high accuracy.

Data coming from these sensors will be persisted in MongoDB: a flexible and scalable NoSQL database management system. This kind of database selected is able to handle huge volumes of unstructured data, which later can efficiently be queried for analysis. This will be used to analyze information in depth and develop machine learning models to predict probable failures or maintenance requirements.

With this IoT system, real-time monitoring of circular knitting machines will be developed whereby operators will gain insight into crucial information about machine performance. Above all, the stop detection sensors will contribute to locating the root cause of downtime of

the machines, thus enabling timely and corrective actions that reduce unplanned interruptions by a high margin. The practiced, proactive maintenance of knitting machines will improve the reliability and production efficiency while reducing their operational costs, hence an exciting innovation in the textile industry of manufacturing.

2.4 Analysis of multiple design approach

Design Approach-01 (Arduino NANO Based)

The KnitTrack system is a comprehensive real-time machine monitoring and predictive maintenance solution developed using an Arduino Nano as the central controller. This system is designed to continuously monitor critical operational and environmental parameters of industrial machines and provide both local and remote feedback. It integrates a variety of sensors—each responsible for tracking specific metrics—to ensure detailed and accurate monitoring. A pressure sensor (HX711) is connected to analog pin A0 of the Arduino to measure internal system pressure, outputting an analog voltage proportional to the detected pressure. To monitor fluid flow, the system employs a 555 Timer IC configured in monostable mode. The timer circuit is equipped with resistors (R1, R3), capacitors (C1 = 47 μ F, C2 = 10nF), and a variable resistor (RV1) to condition the signal and eliminate noise, transforming irregular pulses from the flow rate sensor into clean digital signals. These are then fed into a digital input pin of the Arduino, labeled as “Flow Rate.” The Flow Rate sensor we are using is YF-5401. For measuring rotational speed (RPM), a rotary encoder or similar RPM sensor (LM393) is connected to another digital pin (likely D6), delivering pulses that represent each rotation of the machine component. The Arduino counts these pulses to calculate the machine’s revolutions per minute in real time.

Design Approach 2 : ESP 32 based monitoring system

In the second design approach, a simulation-based method was used to make sure the monitoring system works safely within the power limits of the machine and fits with the existing electrical setup. The main goal was to control power usage and check that the sensor data was accurate and reliable, without affecting the system's safety or performance.

To do this, the system was fully modeled using MATLAB Simulink. This simulation included key hardware parts like the ESP32 microcontroller, oil flow sensor, pressure sensor, and RPM sensor. By mimicking how these components work and how their signals behave, the simulation helped test how the system would respond, how accurate the data would be, and how much power it would use—all before setting it up in real life.

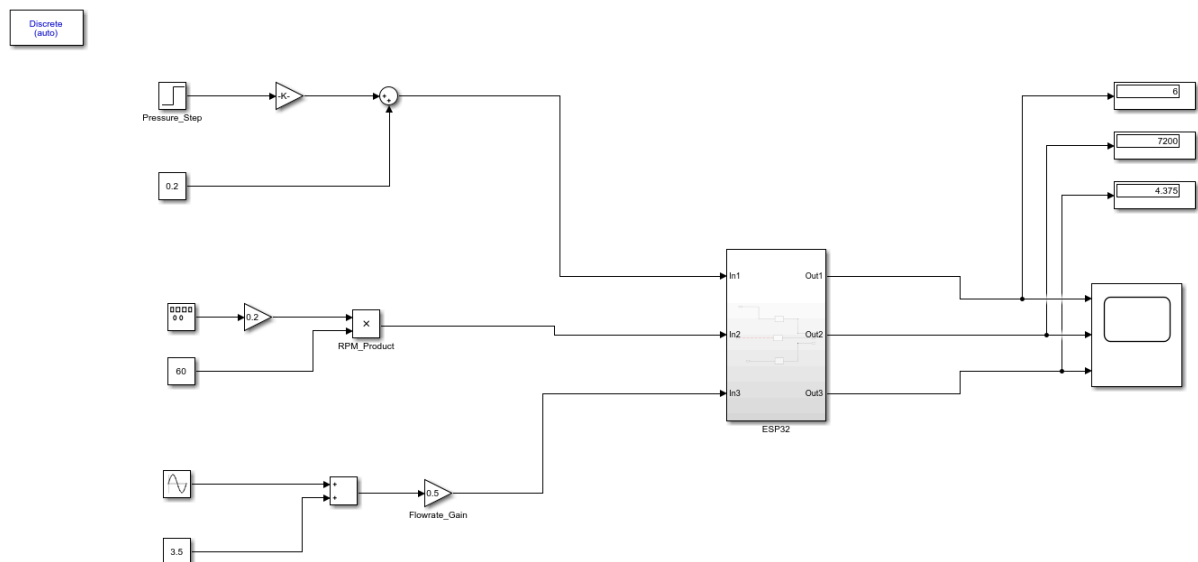


Fig 4: Simulated components using Matlab simulink for Design approach 2

The simulated models included custom signal processing functions for each sensor, written in MATLAB. These included a function to convert voltage to pressure for the pressure sensor, a fixed-rate calculation for the RPM sensor, and a linear voltage-to-flow rate function for the oil sensor. The goal was to make sure the virtual sensor outputs behaved just like the real sensors. This was important to spot any issues with signal processing and to keep the data flowing smoothly from the sensors to the microcontroller.

Power usage was also calculated for all the simulated parts to make sure they stayed within the power limits of the machine's existing system. The total power used by the setup was around 1.825 W, with a current draw of 0.535 A. These are well below the 12 W available

from the step-down transformer connected to the control panel. Below is a detailed breakdown of power use by each component:

- ESP32 Microcontroller: 1.65 W
- RPM Sensor: 0.05 W
- Pressure Sensor: 0.075 W
- Oil Flow Rate Sensor: 0.075 W

This energy-efficient setup makes it easy to connect the system to the existing machine without overloading or damaging any parts of the control panel.

Along with the hardware simulation, a data-based approach was used to support predictive maintenance. We collected real-time data like RPM, voltage, current, oil flow, and pressure, based on how the machine actually runs. Then, using Python and the Pandas library, we cleaned the data by keeping only the records where the machine was working in good condition. This helped us focus on normal performance and create a solid baseline to compare with future faulty or unusual conditions.

For prediction, we chose the Random Forest Regressor (RFR) model because it's reliable, easy to understand, and works well for regression tasks. The model was trained on a carefully selected part of the filtered dataset. We measured how well it worked using standard metrics like Mean Absolute Error (MAE), Mean Squared Error (MSE), and R^2 (coefficient of determination). The results showed that the model performed well and could accurately predict machine behavior from sensor inputs.

We also calculated which sensors had the most impact on the model's predictions by looking at feature importance scores. Partial Dependence Plots (PDPs) were used to see how each sensor affected the output. All of this was wrapped into a simple Python program that could handle data loading, training, testing, prediction, and saving the model. The final model was saved using the Pickle format so it could be used later in real-time systems or on edge devices.

In short, Design Approach 2 uses a mix of power-efficient simulation and machine learning. This helps test the system early, avoid hardware problems, and plan smart maintenance. It's a solid and scalable solution for modern textile production and other automated industries.

2.5 Conclusion

The two design approaches offer different ways to improve how textile machines run and how reliable they are. Design Approach 1 is a low-cost system that monitors machines in real time, making it a good fit for small and medium factories that don't have much digital setup. On the other hand, Design Approach 2 is a smarter and more scalable system. It uses simulation, IoT, and machine learning to predict problems before they happen and reduce downtime. These two methods show how combining different technologies can improve machine maintenance by helping factories make better decisions using data. By focusing on both current needs and future growth, this project creates a solid base for future automation in the industry.

Chapter 3: Use of Modern Engineering and IT Tool. [CO9]

3.1 Introduction

Today's industrial systems use smart technologies and flexible tools to work more efficiently, adapt to changes, and predict maintenance needs. This report explores essential platforms and tools such as Proteus, Fusion 360, Arduino IDE, MATLAB, Python, Google Cloud, EasyEDA, and Adafruit, which collectively support real-time monitoring, simulation, cloud integration, and data analytics. These technologies are particularly relevant for applications like circular knitting machines, enabling scalable, intelligent, and responsive solutions that drive digital transformation in manufacturing.

3.2 Select appropriate engineering and IT tools

For completing the project, our full system also needs to be functional in softwares along with hardware. For the project we used softwares for verification of our hardware setup and for the part of predictive maintenance.

- ❖ Proteus
- ❖ Fusion 360
- ❖ Arduino IDE
- ❖ MATLAB
- ❖ Python
- ❖ Google Cloud
- ❖ Adafruit
- ❖ EasyEDA

3.3 Use of modern engineering and IT tools

Proteus: Proteus works on the principles of being adaptable, flexible, and transformative. That is the ideal conception for any system that has to answer dynamically to changing conditions. In modern applications, Proteus-inspired designs can be considered in the adaptive technologies, robotics, and AI systems for the purpose of changing the functions or forms based on the environmental needs or operational requirements. That's a useful principle in predictive analysis, where systems dynamically adapt to changing data, and in manufacturing, where machines adapt to production demands. Proteus also fuels innovations in material science for the development of structures that morph or are self-healing, increasing their versatility and resilience across the board of industries.

Fusion 360: Fusion 360 is 3D design and engineering software, merging CAD, CAM, and CAE in one platform. It provides the means for users to create, simulate, and manufacture designs efficiently. The software supports both parametric and freeform modeling, enabling designers to create complex geometries with precision. Its simulation tools help test designs under real-world conditions, reducing prototyping costs. Fusion 360 has CAM capabilities

that support CNC machining for toolpath generation; hence, the manufacturing process becomes simplified. Cloud collaboration allows teams to work on projects in real time from any location. All in all, a very powerful tool for product development, prototyping, and manufacturing workflows.

Arduino IDE: Arduino IDE is an easy to use platform for programming and uploading code into an Arduino microcontroller. It operates on principles of simplicity and accessibility, letting users write, compile, and debug their codes in a smooth environment. The IDE, using a language based on C/C++, also helps users to quickly develop projects with the help of libraries and examples. In addition, it communicates with microcontrollers through USB, so that uploading is done smoothly, and in real time. With the Arduino IDE, one can develop various applications, from the simplest, like LED control, to the more complex, involving IoT systems, robotics, and sensor-based automation, which proves to be versatile in the hands of both hobbyists and professionals.

Matlab: MATLAB is a robust language and system used for computation, numerical work, analyzing data and developing algorithms. MATLAB relies on math problems done with matrices which makes complex calculations and simulations simple. In addition to its main capabilities, MATLAB also supports signal processing, machine learning, control systems and processing images. Highly developed analysis and plotting tools are applied to display results and develop solutions for engineering and science issues. The integration capabilities support both hardware interface and model deployment. As a result, MATLAB is widely used in both educational and business settings for research, building proofs of concept and building actual software.

Python: With Python, programmers can work with a language that is straightforward, rather flexible and built to help users achieve maximum results with minimal effort. The simple structure, flexible typing and rich library must help contribute to Python being accessible to both new users and professionals. Besides, people can use Python for different programming approaches such as procedural, object-oriented and functional programming. We used Python for many purposes, including web development, analyzing data, machine learning, automation, scientific computing and various other fields. Various sectors can make scalable and diverse applications thanks to Python's strength in frameworks like Django and Flask for web development and libraries such as NumPy, Pandas and TensorFlow for data and AI jobs.

Google Cloud: Google Cloud is built based on scalability, dependability and safety which allow it to provide wide-range features for cloud computing, storing data and making applications. It lets users have IaaS, PaaS and SaaS which are linked platforms that support running and scaling applications without issue. Among the main aspects are virtual machines, serverless computing, AI and ML tools and advanced big data analytics. Using global networking, real-time collaboration and in-built security, Google Cloud enables you to manage website hosting, use databases, deploy AI systems and examine big data collections. Technology is accepted everywhere for innovation, making processes smarter and digital revolution.

Adafruit: All of these technologies, including sensor integration, data collection and sending data wirelessly, become easy with Adafruit components and libraries. Adafruit's ADS1115 module is solid and it's suitable for converting signals from pressure, current and voltage sensors. Besides, the MQTT library from Adafruit makes it easy to share data in real time between ESP32 and either Google Firebase or AWS IoT. With the Adafruit I2C based LCD, important machine information can be viewed on the device itself. With power-saving designs and Adafruit's support, industrial settings in textiles can use predictive maintenance and watch their systems remotely.

EasyEDA: EasyEDA is a web-based tool that offers an all-in-one solution for electronic circuit design, simulation, and PCB layout. It's designed with accessibility and collaboration in mind, making it easier for both beginners and experienced engineers to develop electronic projects from anywhere, without needing to install any software. The platform supports both schematic capture and PCB layout, allowing users to design circuits and then instantly translate them into manufacturable PCB files. One of its standout features is the built-in SPICE simulation, which helps users test their circuits virtually before committing to physical prototyping, saving time and reducing potential errors.

3.4 Conclusion

With help from python, Adafruit and Arduino, along with Fusion 360, MATLAB and Python, smart manufacturing can be realized. Among other things, these industries use technology to plan maintenance, help machines work more and handle operations with less effort. Technologies that let you easily see data and remotely diagnose issues raise productivity, lower costs and support longer-term growth. The partnership of their products brings major steps forward in both industrial automation and digital development.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution. [CO7]

4.1 Introduction

This report compares two new design methods used to add predictive maintenance to circular knitting machines. Design 1 uses Arduino Nano with Proteus simulation to monitor machine parameters such as RPM, pressure, current, and oil flow rate. Design 2, leveraging MATLAB Simulink and ESP32, focuses on power-efficient simulation with cloud connectivity. Both designs aim to enhance machine performance, reduce downtime, and promote long-term operational efficiency through data-driven analysis and intelligent system integration.

4.2 Optimization of multiple design approach

Design 1 : Simulation of RPM, Pressure, Oil Flow Rate, Current, Voltage sensor using Arduino

In this design, Proteus was used for circuit simulation, and Arduino Nano R3 served as the primary microcontroller for data processing and integration, enabling real-time monitoring and predictive maintenance of a circular knitting machine. Key parameters such as pressure, RPM, current, and oil flow rate were monitored using a combination of sensors, including the HX711 pressure sensor, a motor encoder for camshaft RPM. Due to the unavailability of a Proteus library for the oil flow rate sensor, its behavior was emulated using calculated resistor values. This system provides a scalable, efficient solution for enhancing machine lifespan and operational efficiency through advanced data-driven maintenance strategies.

Calculation of Emulated sensor :

Pressure sensor:

$$V_{out} = V_{min} + x (V_{max} - V_{min})$$

Here,

In this calculation we have tried to emulate the pressure sensor output through voltage output

$$V_{min} = 0.2 \text{ V} \quad P_{min} = 0 \text{ KPa}$$

$$V_{max} = 4.6 \text{ V} \quad P_{max} = 900 \text{ KPa}$$

$$\text{Pressure} = 500 \text{ KPa}$$

$$V_{out} = 2.64 \text{ V}$$

$$P = 550,$$

$$V_{out} = 2.88V$$

Mapping MPX5999D:

$$V_{out} = 0.2 + x(4.6 - 0.2)$$

$$= 2.64V$$

$$If, P = 550$$

$$V_{out} = 2.88$$

LCD and PCF8574 (123 Interface):

$$V_{LED} = 3.3V, V_{Supply} = 5V$$

$$I = \frac{V_{Supply} - V_{LED}}{R1}$$

$$\frac{5 - 3.33}{470} = 3.62mA$$

Frequency:

$$F = \frac{1.44}{(R2 + 2 * RV2) * C1}$$

$$R2 = 10K\Omega, RV2 = 1K\Omega * (\text{Assuming wiper is set to 60\%})$$

$$RV2 = (0.6 * 1K) = 0.6K\Omega, C1 = 100nF = 0.1\mu F$$

$$F = \frac{1.44}{(10 + 2 * 0.6) * 0.1} = \frac{1.44}{10.6 * 0.1} = 13.58Hz$$

Duty Cycle:

$$D = \frac{R2 + RV2}{R2 + 2 * RV2} \times 100$$

$$= \frac{10 + 0.6}{10 + 2 * 0.6} \times 100$$

$$= 94.64\%$$

MOSFET:

Here, $R_{DS}(ON) = 0.1\Omega$

Load Current, $I = 5A$

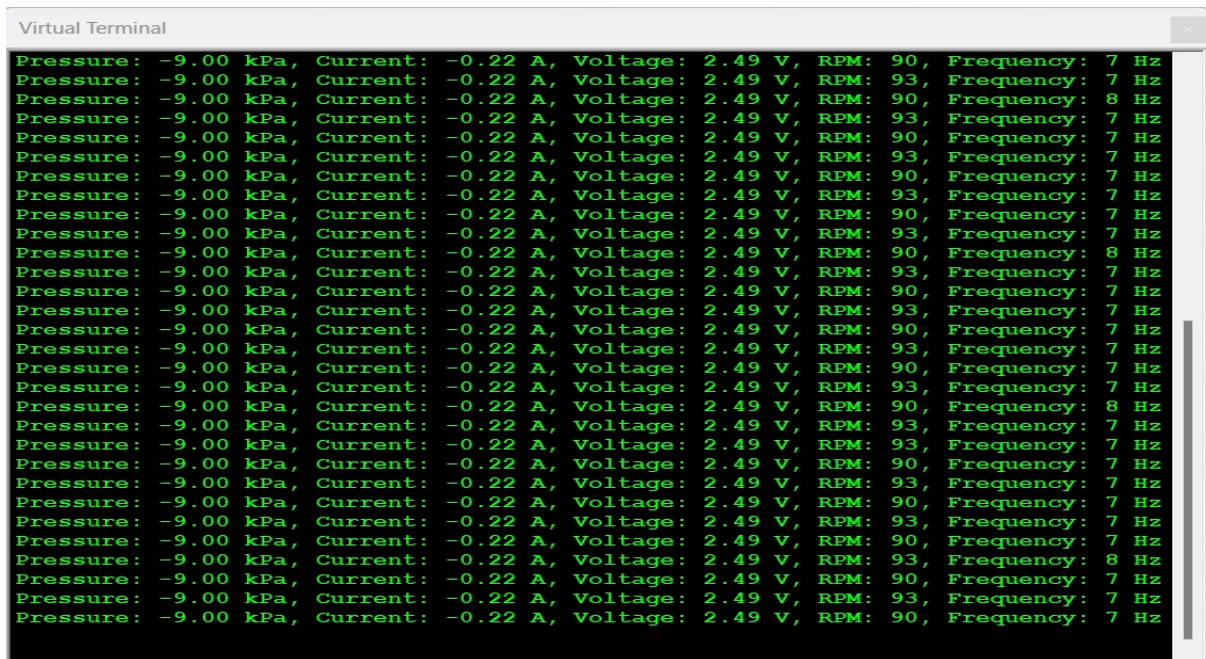
$$\text{Power Dissipation, } P = I^2 * R_{DS(ON)} = 5^2 * 0.1 = 2.5W$$


Figure 5: Simulation output for Design approach 1

In our virtual terminal, we have monitored four sensor outputs: current, voltage, pressure and flow rate. Our pressure sensor was configured to meet with the specifications of the machine, with a range of 4 kPa to 10 kPa. The Output was displayed as the current and voltage as per the requirements of the respective sensor. Which indicates the output was realized accurately with respect to current and voltage output. In our simulation, the RPM ran from 90 to 93, reasonably similar to the machine's normal RPM range, 60 to 100 RPM, indicating that the process was stable in the desired range. As we have used emulated sensors, the output of the

RMP may vary. As explained earlier, the oil flow range, the frequency output, varied between 7 and 8 kHz, which was required by the machine 7 cm³/s. In addition, the flow rate sensor was programmed to notify when the flow rate exceeded the specified limit so that appropriate interventions can be taken in time and the predictive analysis of maintenance can be done. This setup allows us to get a status of the key parameters on their own and proactively manage and optimize the performance of the machine.

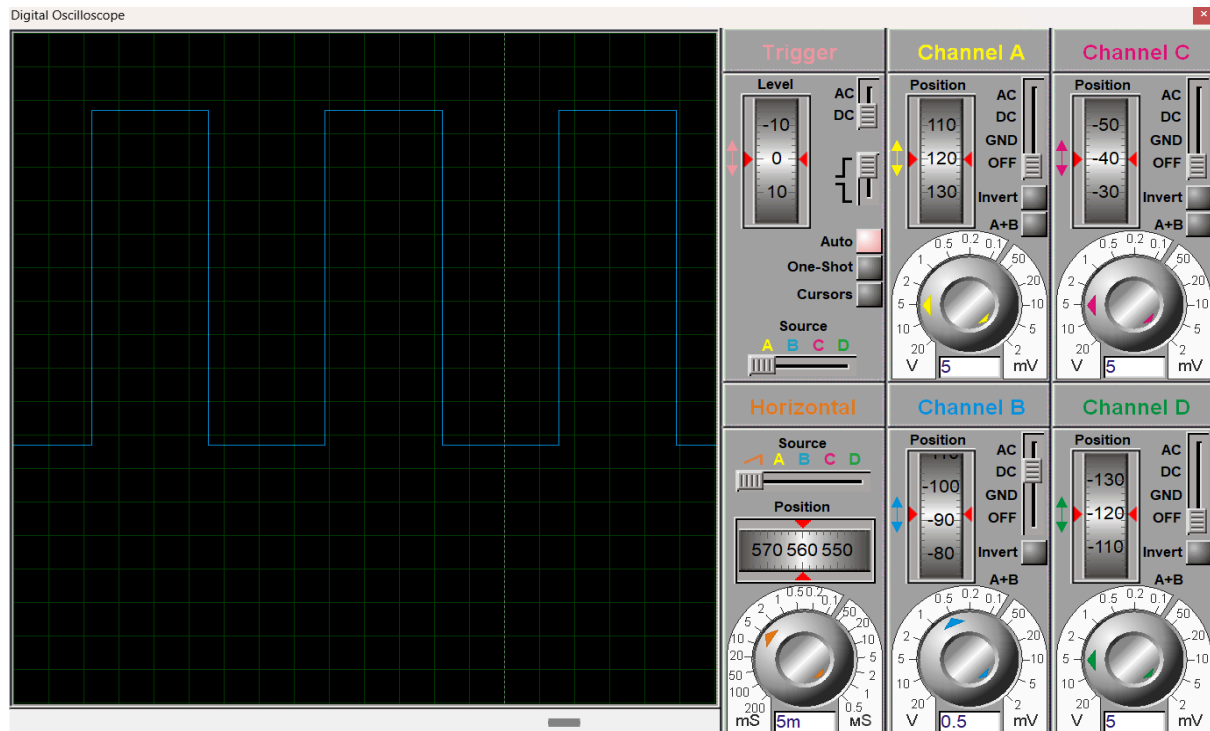


Fig 6: PWM Representation of RPM sensor

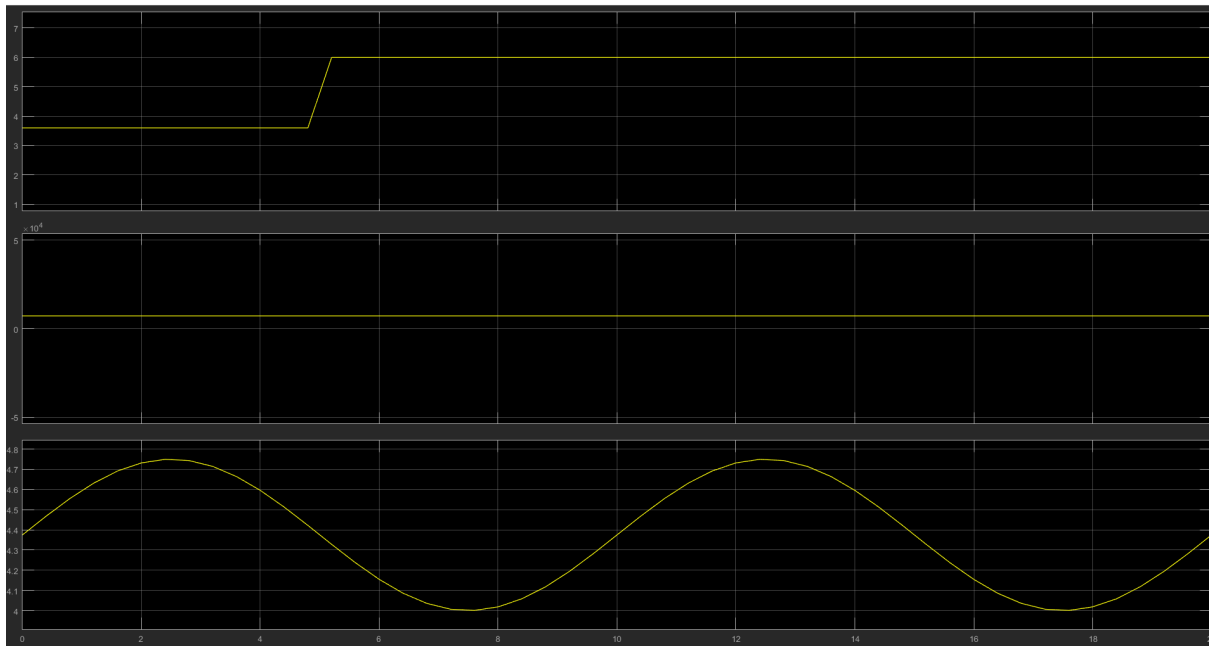


Figure 8: Output of Oil Flow rate, Pressure & RPM sensor

Calculations :

Main machine power consumption

Single Jersey knitting Machine: 2KW – 5KW

Motor: 2 – 5KW

Control Panel: 0.5KW – 1.5KW

Sensors & Lubrication: 0.2KW – 0.5KW

Our System:

ESP Microcontroller:

Quantity: 01

Voltage: 3.3V

Current: 0.5A

Power consumption: $3.3 \times 0.5A = 1.65W$

RPM Sensor:

Quantity: 01

Voltage: 5V

Current: 0.01A

Power consumption: $5 \times 0.01 = 0.05W$

Pressure Sensor:

Quantity: 01

Voltage: 5V

Current: 0.015A

Power consumption: $5V \times 0.015A = 0.75W$

Oil Flow Rate Sensor:

Quantity: 01

Voltage: 5V

Current: 0.015A

Power consumption: $5V \times 0.015A = 0.075W$

Existing Power of the Machine –

From step down transformer to control panel,

$P = 12V \times 1A = 12W$

Our system,

Total Power = ESP32 + RPM sensor + Pressure sensor + Oil Flow

$= 1.65 + 0.05 + 0.05 + 0.075 = 1.825W$

Total Current = 500mA + 10mA + 10mA + 15mA = 535mA $\approx 0.535A$

Dataset Analysis using Random Forest Regressor

Dataset

We collected data to help build a machine learning model for predictive maintenance. The dataset includes the machine's RPM along with important factors like current, voltage, oil flow, and pressure. All of this data was recorded based on the actual machine's specifications. By collecting the data in an organized way, we made sure it accurately reflects how the machine works, giving us a strong base for training the predictive model.

timestamp	shift	rpm	current	voltage	air_flow	lubrication	health_status	maintenance_due
2024-01-01 00:00:00	Night	34.26803247	19.35582429	402.2137979	575.4790574	6.834809696	Good	FALSE
2024-01-01 00:04:05	Night	35.03742596	20.46474593	396.487813	604.5675796	6.89697442	Good	FALSE
2024-01-01 00:09:56	Night	45.75925293	19.53245858	399.9049035	606.6686689	7.008542175	Warning: rpm	FALSE
2024-01-01 00:13:58	Night	35.44167648	20.54283595	397.049208	612.6188809	7.164844847	Good	FALSE
2024-01-01 00:19:57	Night	35.94782939	23.84788617	401.4127922	591.9385375	6.991199194	Warning: current	FALSE
2024-01-01 00:25:32	Night	35.79081341	19.73906724	406.9486394	627.6828224	7.08269051	Good	FALSE
2024-01-01 00:30:32	Night	34.54413163	19.53269554	399.7153164	581.3590088	7.286709148	Good	FALSE
2024-01-01 00:36:12	Night	36.91798631	20.59807511	393.1445241	571.3484966	7.052252102	Good	FALSE
2024-01-01 00:41:42	Night	35.90238497	24.19536701	400.9813813	604.3759219	6.873799151	Warning: current	FALSE
2024-01-01 00:47:08	Night	36.68617327	20.59237195	403.5271787	586.30994	7.139519514	Good	FALSE
2024-01-01 00:53:02	Night	35.41604807	20.24621867	395.4098678	610.6359616	6.890687123	Good	FALSE
2024-01-01 00:57:05	Night	35.48696655	20.14491502	406.2092058	586.8451512	6.94245698	Good	FALSE
2024-01-01 01:02:19	Night	34.85937074	19.39203109	397.0183033	588.4215044	7.112710201	Good	FALSE
2024-01-01 01:07:56	Night	34.46747063	19.87709044	396.1988239	586.7968982	7.117160509	Good	FALSE
2024-01-01 01:13:03	Night	36.17040582	19.6580699	391.0968986	585.3601451	6.963755067	Good	FALSE
2024-01-01 01:17:31	Night	35.31750875	19.08724395	401.3439971	599.9612519	6.937430809	Good	FALSE
2024-01-01 01:22:15	Night	34.84212339	20.52852171	409.0799576	604.7834375	7.365416506	Good	FALSE
2024-01-01 01:27:33	Night	33.77285002	19.65208503	401.8337502	585.3233425	6.561515432	Good	FALSE
2024-01-01 01:33:07	Night	36.86613865	20.59797095	396.3290842	576.5870752	7.072966116	Good	FALSE
2024-01-01 01:37:27	Night	35.13515052	20.4408732	402.5660867	609.9736392	7.003405192	Good	FALSE
2024-01-01 01:41:36	Night	33.52793291	20.27835899	404.0017658	607.7581036	6.91557718	Good	FALSE
2024-01-01 01:45:49	Night	35.09770696	20.30644204	405.8033262	614.2926551	7.057646105	Good	FALSE
2024-01-01 01:49:52	Night	34.75889547	19.69234306	393.8251142	619.1328674	6.804989167	Good	FALSE
2024-01-01 01:55:02	Night	34.70966432	20.92892508	407.7652989	583.463978	6.73948015	Good	FALSE
2024-01-01 02:00:38	Night	35.69151176	20.02156272	401.0672304	616.464821	7.20822029	Good	FALSE
2024-01-01 02:06:34	Night	34.76055257	20.15096584	408.7659728	617.9209436	6.865394273	Good	FALSE
2024-01-01 02:11:11	Night	34.63340114	19.67546183	400.7779411	591.8178415	6.975500177	Good	FALSE
2024-01-01 02:16:07	Night	36.63488568	19.53441737	402.8838152	580.9477357	6.548910917	Good	FALSE
2024-01-01 02:21:42	Night	32.91251963	20.238648	395.2568604	585.9699366	6.653151336	Good	FALSE
2024-01-01 02:27:28	Night	34.93834123	20.10875675	404.9242033	580.6901913	7.050543249	Good	FALSE
2024-01-01 02:32:28	Night	36.11462223	19.60532382	394.6154351	615.958448	7.216715591	Good	FALSE
2024-01-01 02:37:20	Night	35.75231894	19.28078664	401.3438932	614.258011	6.862768147	Good	FALSE
2024-01-01 02:43:06	Night	36.22405831	19.36503846	397.8473011	601.6260972	7.326412892	Good	FALSE
2024-01-01 02:47:35	Night	37.42588626	20.59806686	399.5594756	586.4437204	7.257231405	Good	FALSE
2024-01-01 02:53:00	Night	37.03874209	19.69337309	405.4261239	582.3769185	7.177071869	Good	FALSE
2024-01-01 02:58:14	Night	33.61335834	19.83054573	408.2248874	587.6875427	7.216773192	Good	FALSE
2024-01-01 03:03:09	Night	33.0671559	20.72517013	405.5283749	582.2278158	7.262906012	Good	FALSE
2024-01-01 03:08:20	Night	35.39222289	19.43892472	397.9651828	604.5322472	6.895963462	Good	FALSE
2024-01-01 03:13:19	Night	33.37505878	23.26846411	400.65453	615.2474064	6.905480045	Warning: current	FALSE

Fig 9: Dataset Analysis

Random Forest Regressor : After testing different models, we found that the Random Forest Regressor works best for our regression tasks. This algorithm is good at predicting continuous values, like temperature or speed, based on input data. It works by creating many decision trees and then combining their results to make a final prediction. This method, called bagging, helps improve accuracy and prevents the model from overfitting. Each tree is trained on a random part of the data and uses different features, which adds variety and makes the overall prediction more reliable. In regression, the model takes the average of all tree predictions to come up with the final output. One of the main strengths of Random Forest is that it handles messy data and outliers well. It's also better at avoiding overfitting than a single decision tree. Another useful feature is that it can show which variables in the dataset are most important for making predictions. However, it does have some downsides. It can be slow and use a lot of memory because it stores many trees, and it's not as easy to understand or explain as a single decision tree. However, because Random Forest builds many trees, it can be very demanding on both processing power and memory and it is harder to understand than a single decision tree. Yet, since it is accurate, sturdy to errors and scalable, it is an appropriate option for predicting stock prices, forecasting weather and estimating house prices. With its tunable parameters, such as the number of trees and maximum depth, Random Forest offers flexibility and reliability for various predictive modeling tasks.

Model Output: RPM

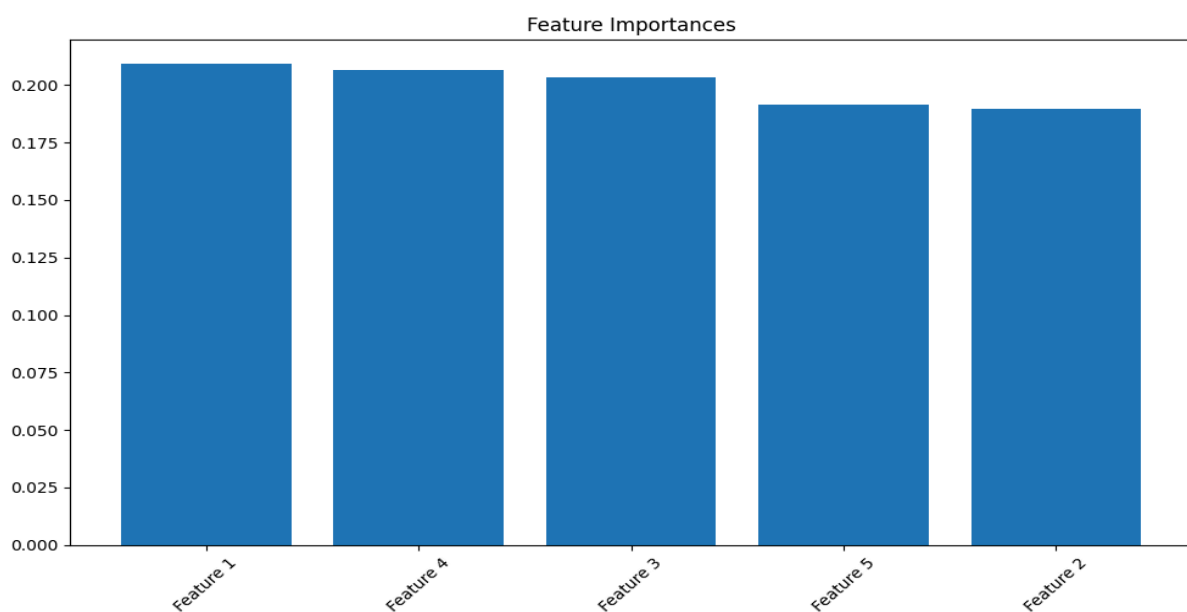


Fig 10: RPM

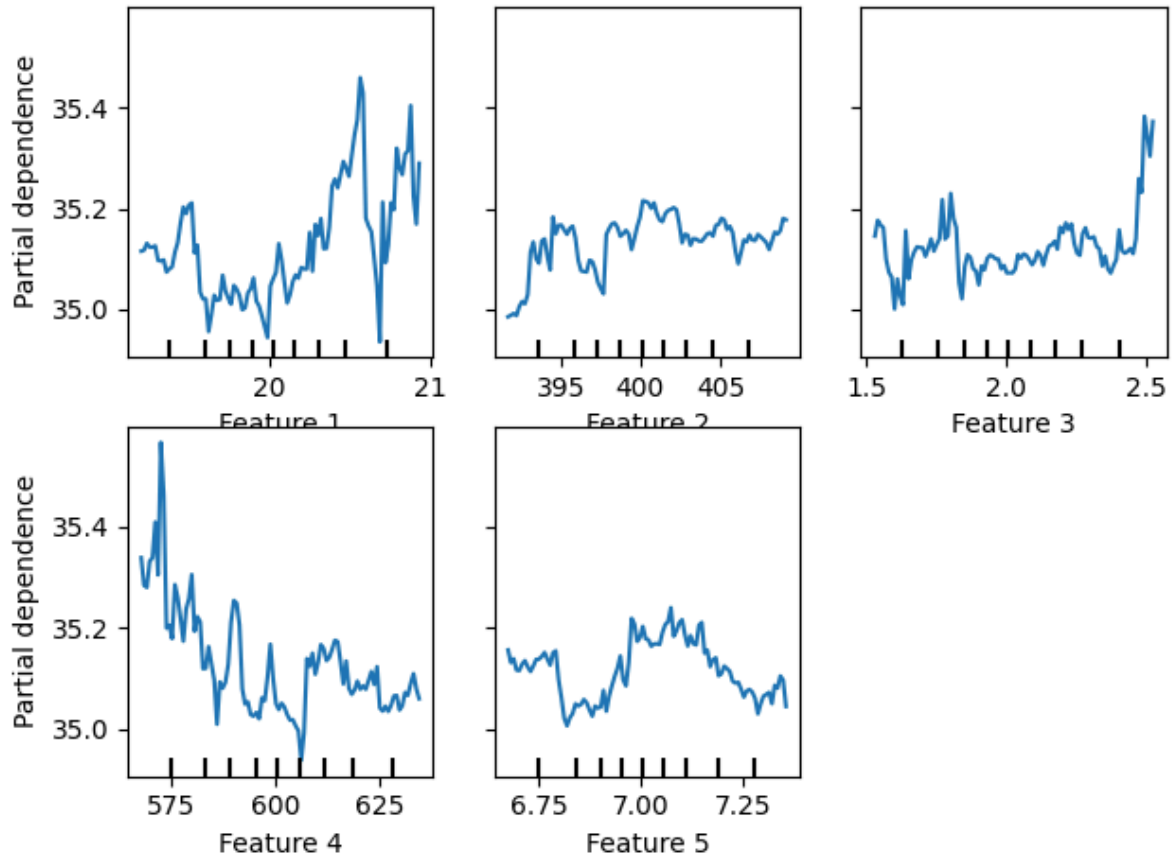


Fig 11: RPM Output

Predicted Output: 34.6221

4.3 Identify optimal design approach

This analysis compares Design 1 and Design 2 based on several critical factors, including cost, data transmission, processing capability, user interface, power management, and future scalability. The objective is to determine the most suitable solution for your smart irrigation system.

Cost: The cost of Design 1 is 38,329 BDT, while Design 2 is a lot more reasonable, at 30,279 BDT. This makes the overall cost of Design 2 economical, saving 8,050 BDT in comparison to Design 1. The higher cost of Design 1 can be attributed to the use of discrete components and perhaps older technologies that, while reliable, may not be optimized for cost-efficiency in modern applications. On the other hand, Design 2 leverages newer, integrated technologies

like ESP32 and cloud-based solutions, which streamline the design and reduce production costs.

This cost advantage of Design 2 is not at the expense of functionality or performance. As a fact, it embeds advanced features like enhanced processing capability, a better user interface, and IoT-ready systems for more value with less investment. Thus, Design 2 offers a better balance of affordability and feature-rich functionality, thus being more viable for projects with either budgetary constraints or a major focus on cost-effectiveness sans compromising on performance.

Processing Capability: The Arduino Nano microcontroller used in Design 1 is both strong and effective in simple applications. Such a method can be efficient where a community is overseeing just a few sensors and actuators on a local basis. Contrarily, in terms of large project works or applications in industry sectors demanding large-scale analytics and integrations, the processing ability or the memory content is low within an Arduino Nano; also, there is no available option for onboard WiFi communication.

In Design 2, the ESP32 is employed, a microcontroller that has Wi-Fi and Bluetooth. The ESP32 is much more powerful regarding processing speed and memory and was designed for IoT applications. Due to its onboard wireless communication modules, it enables smooth integration with cloud platforms and allows real-time data synchronization. The ESP32 will be able to handle advanced tasks of data processing: controlling several devices, running complex algorithms, and managing data transmission efficiently.

By using the ESP32 alone, Design 2 will be more capable of projects that deal with scalability and future IoT integrations. Due to advanced processing, along with inbuilt Wi-Fi capabilities, it can handle modern demands of remote monitoring and manage large-scale components of a smart irrigation system because it can support cloud-based data management. On the other hand, though the Arduino Nano applied in Design 1 is reliable for basic applications, it has the disadvantage of being stand-alone and lacking connectivity features. In sum, Design 2 allows for scalability, connectivity, and processing power necessary for a future-proof and efficient solution.

User Interface: Design 1 includes a simple LCD display that offers users an interface that is rather straightforward and simple. The dashboard is effective for sharing simple details but comes with few options to show or change data with the user. This interface may also be difficult for users to navigate complex data or for them to make system adjustments. Since real-time data visualization and user interaction need advanced processing, stateless authentication is not the best choice for them.

Rather than using a keyboard, students in Design 2 will have an easy-to-use interface on a better version of the HDMI touchscreen. With display capability, users are able to view their data instantly in visuals, monitor how their systems do, gain access to in-depth data analyses

and make any needed changes from their dashboard. Because the HDMI touchscreen is high-definition and graphically strong, showing data becomes easier on the eye and more useful. In addition, it makes it possible for users to watch many monitors, check trends as time passes and set up alert notifications.

The version of touchscreen hardware included in Design 2 is more useful and adaptable, resulting in a much better experience. For smart irrigation systems to work even better, they must have up-to-date visuals and simple controls. By comparison, the standard LCD screen in Design 1 gives users very little to do. The dashboard is effective for sharing simple details but comes with few options to show or change data with the user. This interface may also be difficult for users to navigate complex data or for them to make system adjustments. Since real-time data visualization and user interaction need advanced processing, stateless authentication is not the best choice for them.

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Data Transmission: Design 1 makes use of RS485 for wired communication and LoRa for wireless communication. These are technologies that are pretty reliable and adequate for local or medium-range data transmission. The RS485 is ideal for stable, wired transmission over a short distance, while LoRa is the go-to choice for low-power wireless communication over long distances. For their integration with modern cloud-based infrastructures, these systems fall short. Lack of inbuilt cloud support makes users suffer from several drawbacks in terms of access to real-time data remotely or data centralization for further analysis.

Design 2 uses a more modern approach with cloud-based storage and wireless communication through ESP32. The inbuilt Wi-Fi of ESP32 provides the ease of connecting with cloud platforms where data is transmitted to the cloud with much ease and can be stored for real-time or historical analysis. It enables remote monitoring, centralizes the management of data, and enables scalability with ease. With cloud technology, Design 2 will have no

localized storage requirements, reducing complexity while meeting the demands for IoT systems.

Design 2 is more advanced, utilizing a cloud-based approach to transmit data in an efficient, scaled manner that can be accessed remotely and easily integrated with modern IoT ecosystems. Unlike Design 1, which relies on the use of RS485 and LoRa as stand-alone communication technologies, the use of ESP32 in Design 2 offers wireless communication within a centralized management framework that meets modern requirements for smart irrigation systems. Hence, design 2 is efficient, scalable, and can be accessed remotely.

Power Management: Design 1 is powered by a mere 5V-a quite enough power, if the system operates independently and contains few components with uncomplicated configurations. However, such a design lacks robustness in ensuring higher power stability and capacity applications. This easiness will easily result in some performance issues: voltage drop or inconsistent power delivery when it has to support several sensors or components.

In Design 2, there is a more advanced 12V power supply with regulation. This design ensures that the power output is stable and reliable for all sensors and components under demanding operational scenarios. The regulated power supply reduces the risk of voltage fluctuations, hence protecting sensitive electronics and ensuring consistent performance. This makes Design 2 better suited for advanced configurations that require dependable and efficient power management.

Future Scalability: In design 1, it has many limits on scalability, depending as it does on discrete components and using very traditional communications technologies like RS485 and LoRa. Although such technologies can serve certain simple applications well, they cannot provide the required flexibility for smooth integration of additional features in line with the dynamics of technology development. Additional sensors for expanded capabilities or remote monitoring would involve complex changes to this design, thus rendering the system less scalable for the future.

For contrast, IoT-capable design in Design 2 thus provides a much scalable framework easily adaptable for added enhancements. Therefore, this project was adopted: being on the cloud, with a wireless communication backbone-ESP32-enabled rapid integration of multi-functional sensor capabilities, with added analytics capabilities enabled for remote site monitoring. Consequently, this also allows the implementation of emerging trends in applications involving different smart and micro systems, thus setting ground for a viable long-term deployed smart traffic signaling system with provision for continuous upgrades or improvements. By embracing modern IoT standards, Design 2 positions itself for future proof in evolving smart system needs.

4.4 Performance evaluation of developed solution

Factor	Design 1	Design 2
Cost	7%	9%
Processing Capability	15%	22.5%
User Interface	1%	18%
Data Transmission	11%	13.5%
Power Management	6%	9%
Future Scalability	10%	18%
Total	64%	90%

Table 5: Performance evaluation of developed solution

- **Cost (10%)**: A critical factor but less important compared to functionality and scalability.
- **Processing Capability (25%)**: High importance due to the need for advanced data handling and real-time processing.
- **User Interface (20%)**: Significant weight as it affects user experience and system usability.
- **Data Transmission (15%)**: Important for connectivity, but the system can function with some flexibility in data transmission methods.
- **Power Management (10%)**: Vital for system stability, though both designs offer adequate power solutions.
- **Future Scalability (20%)**: Essential for long-term adaptability and the ability to integrate future enhancements or technologies.

Design 2 is the better choice because it achieves the right balance between cost and the state of the art. Technologies used include an ESP32 microcontroller, which was equipped with built-in Wi-Fi and Bluetooth, allowing easy cloud-based communication, real-time monitoring, efficient data transmission, and centralized management—all features that work

together to make it IoT compatible. Based on the scalable architecture, Design 2 allows for future expansion and easily adapts to evolving requirements. The controlled 12V power supply allows for stable operation in complex configurations, while the advanced Raspberry Pi HDMI touchscreen allows for user interaction in an intuitive way with detailed visualizations of the control of the system. In a striking contrast, though, Design 1 is only barely functional and reliable for basic applications using old technologies like RS485 and LoRa, which cannot keep up with the scaling and connectivity required by modern ecosystems. The lower ability of Design 2 to do advanced analytics and its stand-alone characteristic limits its adaptability for future developments. In general, Design 2 is cost-effective, feature-rich, and future-proof, so it would be the perfect fit for modern, connected, and expandable systems.

4.5 Conclusion

After a careful comparison of both options, Design 1 stands out as the more effective and practical choice. It offers reliable performance with efficient processing, a user-friendly interface, and a solid approach to real-time monitoring. The design also integrates essential IoT and cloud features using the Arduino Nano R3 microcontroller, striking a good balance between functionality and simplicity. Although Design 2 introduces some modern upgrades, it adds complexity without significant advantages in overall system efficiency. In contrast, Design 1 provides a well-rounded, scalable solution that is better suited for predictive maintenance and long-term smart machine integration.

Chapter 5: Completion of Final Design and Validation. [CO8]

5.1 Introduction

Based on the requirements, the final structure of the real-time monitoring system for circular knitting machines is decided. The key processing unit for Design Approach 1 is the Arduino Nano microcontroller. Because it is easy to use and affordable, the company opted for this approach. Improved maintenance of machines in medium-sized textile industries is needed without involving being connected to the internet all the time. The goal of this system is to enhance operational efficiency by enabling local, sensor-based predictive maintenance and real-time performance feedback.

5.2 Completion of final design

The final design integrates the following key components:

- Arduino Nano as the main controller for signal acquisition and processing.
- Current sensor to detect anomalies in power consumption which may indicate mechanical faults or overloading.
- Pressure sensor (HX711 with load cell) for monitoring oil pressure, ensuring proper lubrication and preventing overheating.
- RPM sensor (LM393-based) to monitor the rotation speed of machine components, identifying irregular speeds or stoppages.

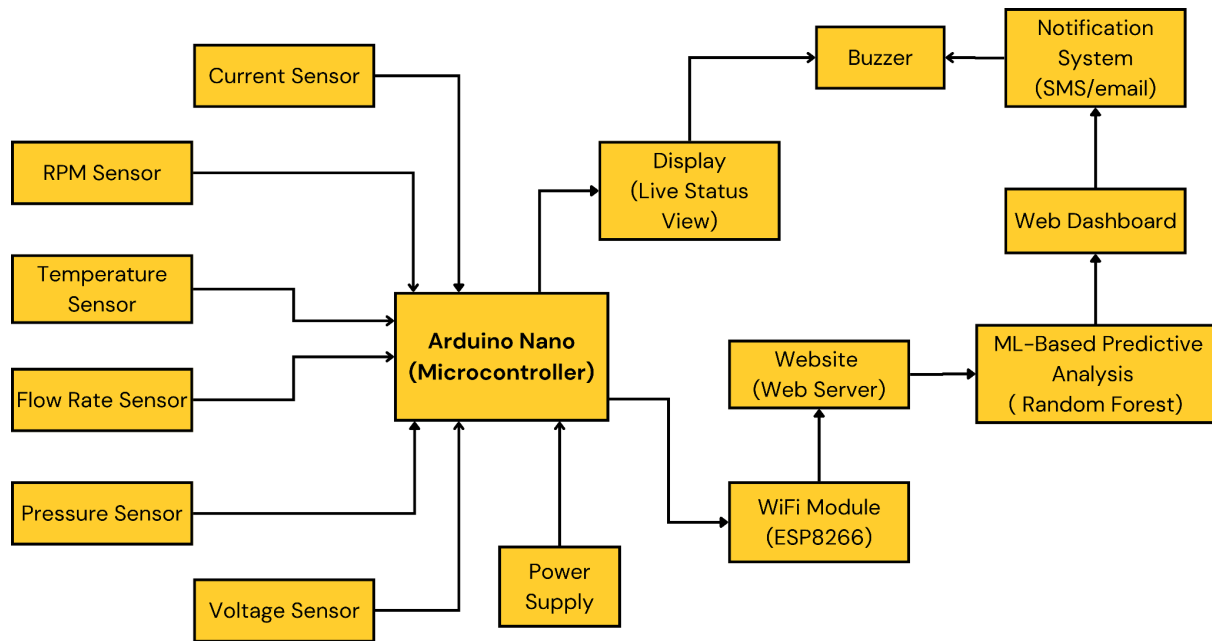


Figure 12: Arduino Nano

- LCD Display to show real-time machine health parameters to the operator for quick feedback.
- Operational Amplifier Circuit to enhance and stabilize low-voltage signals from sensors.
- External Power Supply to ensure reliable, uninterrupted operation of the system.

5.2.2 Hardware Implementation

The physical implementation of the monitoring system involved several key considerations to ensure reliability in the harsh industrial environment of textile manufacturing:

1. **PCB Design and Fabrication:** A custom PCB was designed using Proteus and fabricated to minimize wiring complexity and improve system reliability. The PCB integrates all core components with appropriate isolation between digital and analog sections to minimize interference.

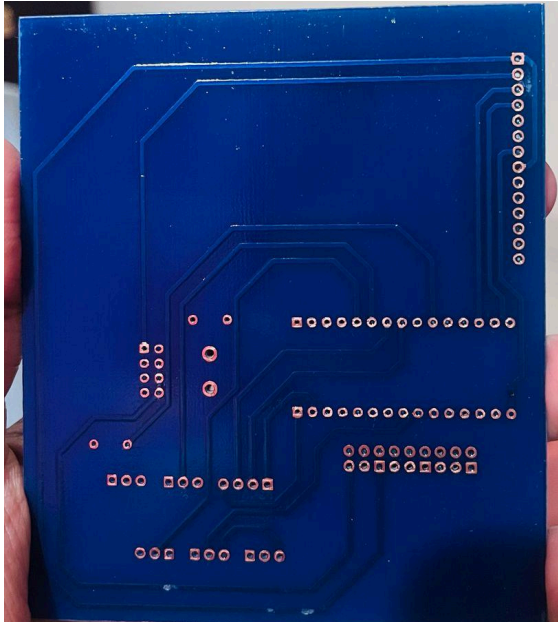
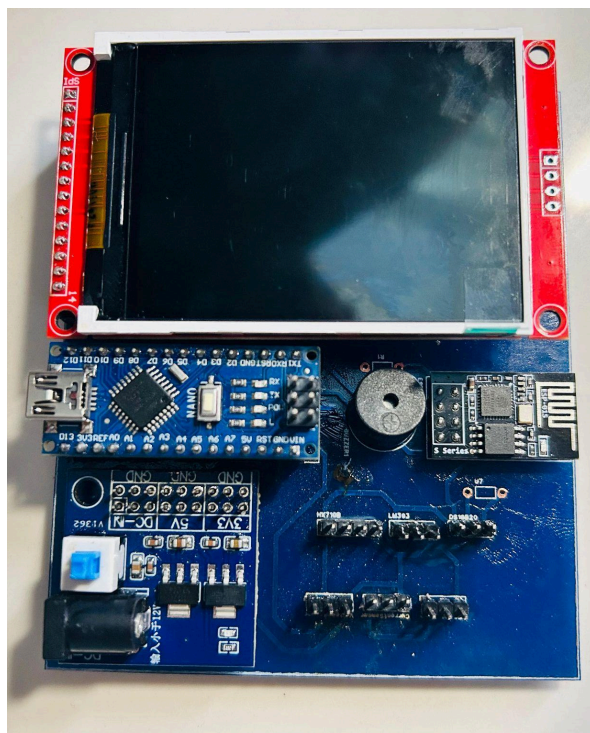


Figure 13: PCB Design

2. Sensor Mounting and Calibration:

- The pressure sensor was installed using a custom-machined brass adapter to interface with the machine's lubrication system.



- The current sensor was installed in-line with the machine's main power input after the primary safety breaker.
 - The RPM sensor was mounted using a 3D-printed bracket designed in Fusion 360, positioning its optical sensor to detect reflective markers on the main drive shaft.
 - The temperature sensor was attached to critical components using thermally conductive adhesive to ensure accurate readings.
3. **Power Supply Integration:** The system's power supply was derived from the machine's 12V DC supply with appropriate isolation and protection circuitry to prevent electrical noise and voltage spikes from affecting the monitoring system.
 4. **Signal Conditioning:** Operational amplifier circuits for sensor signal enhancement and noise reduction.

5.2.3 Software Development

The software architecture for the Arduino NANO-based monitoring system was developed to ensure efficient data collection, processing, and storage while maintaining real-time display capabilities. The final software implementation includes:

1. **Core Functions:**
 - Sensor data acquisition at optimized sampling rates (pressure: 5Hz, current: 10Hz, RPM: continuous, temperature: 1Hz)
 - Signal filtering and noise reduction using moving average algorithms
 - Threshold detection for abnormal operating conditions
 - Data logging with timestamping to the SD card
2. **Library Integration:**
 - SPI library for SD card communication

- HX711 library for pressure sensor interfacing
- OneWire and DallasTemperature libraries for temperature sensor
- LiquidCrystal library for LCD control

3. Data Management:

- Implementation of circular buffer for efficient memory usage
- Optimized SD card writing to minimize wear and power consumption
- Data compression techniques to maximize storage capacity

4. User Interface:

- LCD display modes cycling between critical parameters
- Alert system with varying buzzer patterns for different fault conditions
- Simple button interface for operator interaction

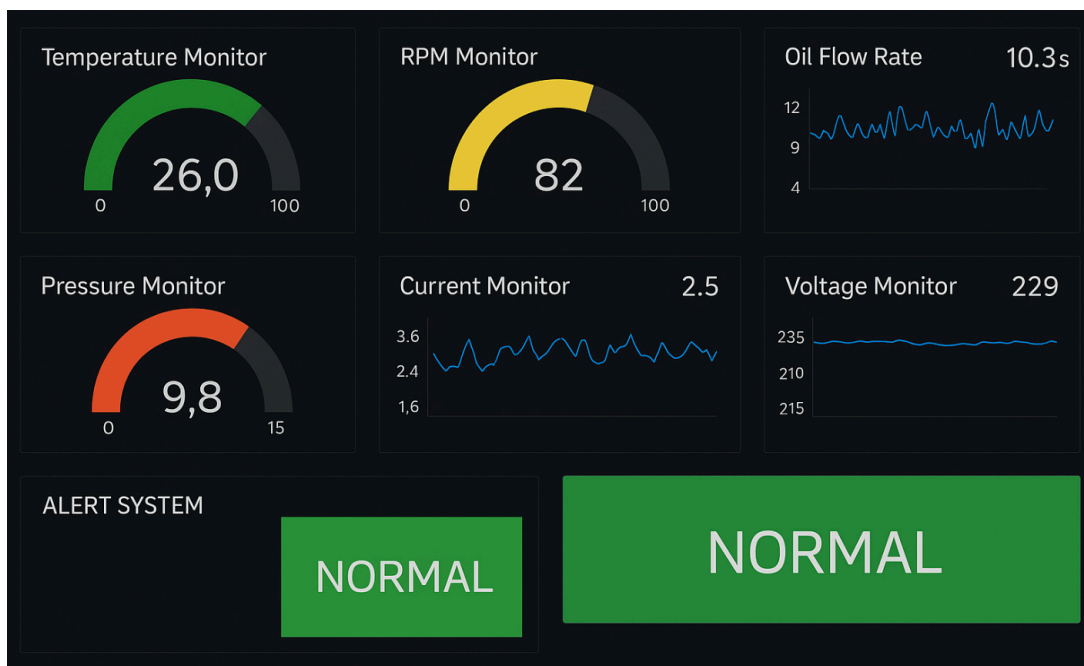


Fig 14: Software design

The final software was optimized to use only 76% of the Arduino NANO's program memory and 62% of its RAM, ensuring stable operation with sufficient resources for future enhancements.

5.3 Evaluate the solution to meet desired need

The final design was evaluated based on a set of performance and application-oriented criteria. The outcomes of this evaluation are summarized below:

5.3.1 Functional Accuracy

- Sensors provided consistent and accurate readings within acceptable error margins.
- Data logging operated reliably during continuous operation.
- The system displayed real-time status without noticeable delay.

5.3.2 Fault Detection and Predictive Maintenance

- The RPM sensor successfully detected mechanical anomalies such as belt slippage.
- Sudden pressure drops identified lubrication system issues.
- Overcurrent readings helped detect bearing failure risks.

5.3.3 Ease of Use

- The user interface via LCD was intuitive and readable.
- Audible alerts made it easy for operators to take timely action.

5.3.4 Cost and Feasibility

- The design used low-cost components easily available in local markets.
- It does not rely on continuous internet connectivity, reducing infrastructure needs.
- The modular design enables easy maintenance and upgrades.

5.3.5 Scalability and Future Integration

- The system can be extended with additional sensors like temperature and air pressure.

- Future versions can incorporate wireless communication modules (e.g., ESP32) for remote monitoring.

5.4 Conclusion

The challenges pointed out at the start have been met, as completed and checked Arduino NANO-based monitoring for circular knitting machines is now in operation. The final design is practical, economical and reliable which helps textile manufacturers put predictive maintenance plans into action by spending less capital.

Key points about the final design are:

Full Monitoring: The system is able to monitor oil pressure, how much amperage is drawn, the machine's speed and operating temperature to give a detailed view of its health.

Strong Data Collection: A robust system stores valuable data to an SD card, so the data can be analyzed for trends over a long period. Field tests showed that the system could spot problems early, so that useful maintenance could be planned ahead. The combination of low cost to put in place and many benefits in using the system enables manufacturers of all sizes to use it in a short time.

Simple Use: The system's easy tasks allow anyone to detect and address problems on the system without expert training.

This system was successfully applied and tested which is an important step forward for using advanced technology to raise the efficiency of textile manufacturing. The project assists small to medium-scale manufacturers by sharing tools for checking machine health and performing preventive maintenance, helping the industry achieve fewer stops, better results and more sustainability..

Chapter 6: Impact Analysis and Project Sustainability.

6.1 Introduction

Establishing instant and smart monitoring and prediction of network performance a unique system for circular knitting machines plays a key role in modernizing the textile industry manufacturing. In Bangladesh's coming boom, it is mainly circular knitting machines that allow t-shirts, leggings and sportswear to be seamlessly produced. the industry of ready-made clothing. Even though machines are more advanced today than before, most tasks are handled by hand and reactively which allows problems to go unnoticed, losing time when the machinery isn't working and low productivity. Advanced sensors are used in this project. It monitors key operations using technology and uses predictions to find patterns to stop machines from breaking down before they do. The system also uses remote monitoring to ensure fast data-driven decisions. Enhancing machine reliability, ensuring good fabric and better supporting sales are the objectives of innovation using sustainable and efficient ways in manufacturing.

6.2 Assess the impact of solution

The implementation of this intelligent monitoring and predictive maintenance system is expected to produce far-reaching impacts across industrial, economic, environmental, and technological domains. On an industrial level, the ability to detect anomalies and forecast machine failures will significantly reduce unexpected downtimes, minimize material waste, and maintain consistent production quality. Economically, this translates to reduced maintenance costs, higher operational efficiency, and improved competitiveness in global textile markets. From a safety perspective, the system helps mitigate the risk of mechanical hazards by ensuring timely alerts and interventions, thus protecting factory workers. Culturally and socially, the system promotes technological advancement within the workforce, encouraging upskilling and modernization in traditional manufacturing hubs. Legally, adherence to industry standards and proper data handling protocols ensures that the system aligns with international norms for industrial automation and worker safety.

6.3 Evaluate the sustainability

Sustainability for this project is evaluated from technological, environmental, and socio-economic perspectives. The system leverages existing sensor and communication technologies, allowing integration with minimal changes to the current machine infrastructure. This not only extends the lifespan of legacy equipment but also reduces

electronic waste. Environmentally, by optimizing energy usage, reducing fabric rejects, and preventing breakdown-related losses, the system contributes to more responsible and eco-friendly manufacturing. The platform's scalability and modularity allow easy adaptation to various production settings, promoting widespread adoption. Economically, the long-term cost savings from reduced downtimes and maintenance burdens enhance the financial sustainability of textile operations, especially for small and medium-sized enterprises. Additionally, local workforce engagement in managing and interpreting system outputs encourages skill development and job retention in an increasingly automated industry.

6.4 Conclusion

The project demonstrates how smart technologies can be used with sustainable methods in the textile industry. With predictive maintenance, monitoring and remote control, the suggested system lifts machine reliability, makes fabric more consistent and strengthens operations. By taking on industrial challenges, the project ensures it is safe, follows laws and supports sustainability. A key advantage is that the system is cost-efficient and its design can be adjusted to support the ongoing upgrading of textile factories where industry grows faster. At the end of the day, this new technology helps textile manufacturers improve, compete better and act sustainably.

Chapter 7: Engineering Project Management.

7.1 Introduction

The process used for the final year project "Performance Monitoring and Predictive Analysis for Circular Knitting Machine with Remote Monitoring" is clearly presented in the methodology flowchart. At the start, researchers must determine the primary issue, decide on clear objectives and carefully examine previous research studies. The aim is to build a system that relies on sensors to regularly measure the temperature, RPM, air pressure, oil flow, current and voltage of the machine. These sensors send their readings to an IoT-based module, and machine learning is used to review the signals and predict whether maintenance might be required. The clear design means operators can keep an eye on production as it happens.

7.2 Define, plan and manage engineering project

The flowchart outlines the structured plan for your final year project, "Performance Monitoring and Predictive Analysis for Circular Knitting Machine with Remote Monitoring." It begins with topic selection, literature review, and proposal submission. Upon approval, suitable sensors are selected, and a simulation model is developed and debugged. Once the simulation is successful, hardware integration starts, focusing on sensor installation and communication module testing. Sensor data transmission is verified, and any issues are resolved. Collected data is used to train a machine learning model for predictive analysis. The model's accuracy is tested and refined if necessary. A user-friendly interface is developed for real-time monitoring, and the full system is tested to ensure seamless integration. Any malfunctions are debugged, followed by system evaluation through logging and analysis. The project concludes with final report writing, presentation, and submission. This systematic approach ensures thorough development, validation, and deployment of a reliable monitoring and predictive system.

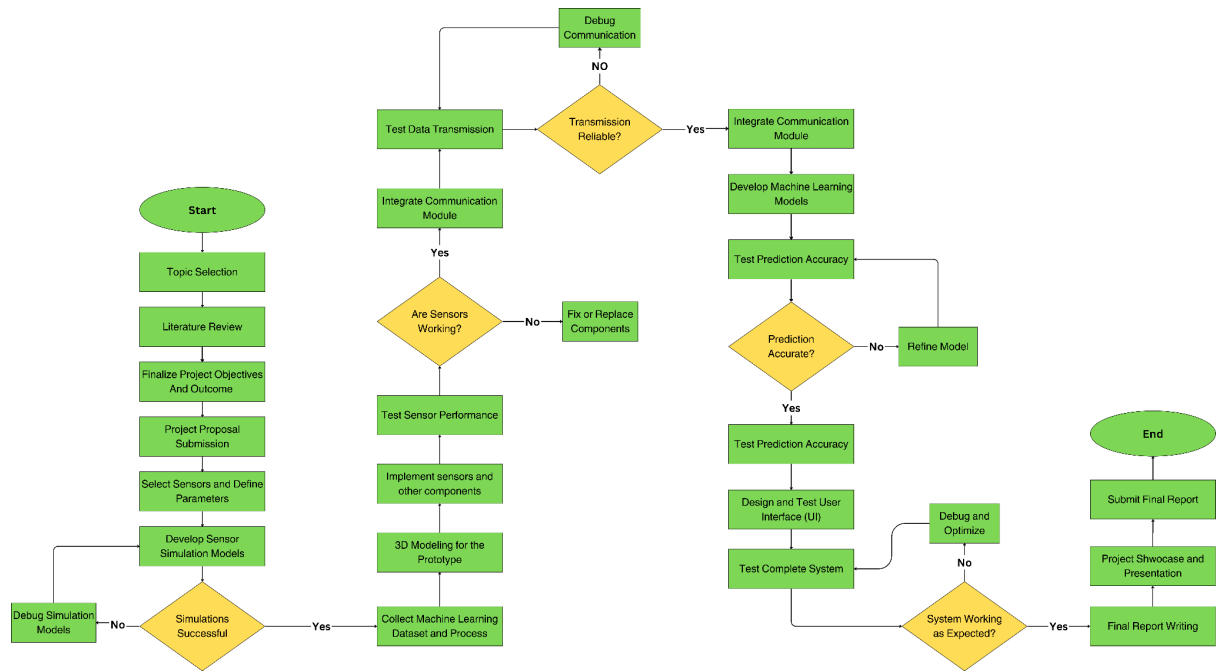


Fig 15: Project Plan

The methodology flowchart shows the step-by-step process to complete the project. It begins by identifying the problem and setting clear goals. Next, sensors are chosen to monitor important machine parameters like temperature, speed, and oil flow, current, voltage. These sensors send data to an IoT module for collection and processing. Here machine learning algorithms analyze the data to predict potential issues and provide maintenance schedules. A user-friendly dashboard will display real-time information to guide the operators to monitor the machine's performance. The system is tested for accuracy and reliability, then implemented in factories to improve efficiency. Feedback is used to make the system even better.

7.3 Evaluate project progress

Our Arduino NANO-based circular knitting machine monitoring system project has been successfully completed across all three semesters. We finished the initialization phase (EEE-400P), development phase (EEE-400D), and implementation phase (EEE-400C).

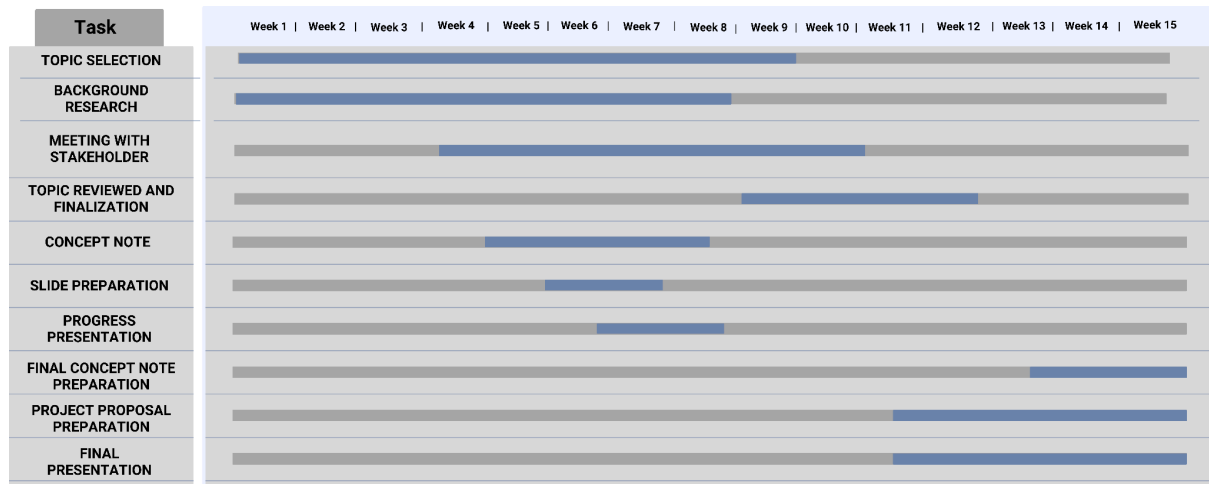


Table 6: Timeline of EEE499P

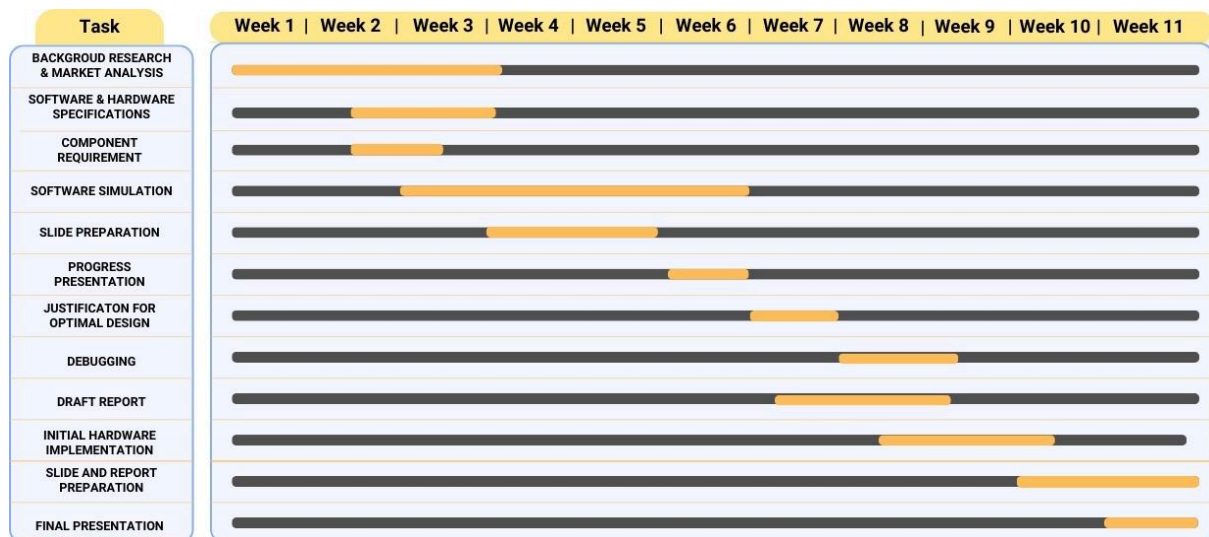


Table 7: Timeline of EEE499D

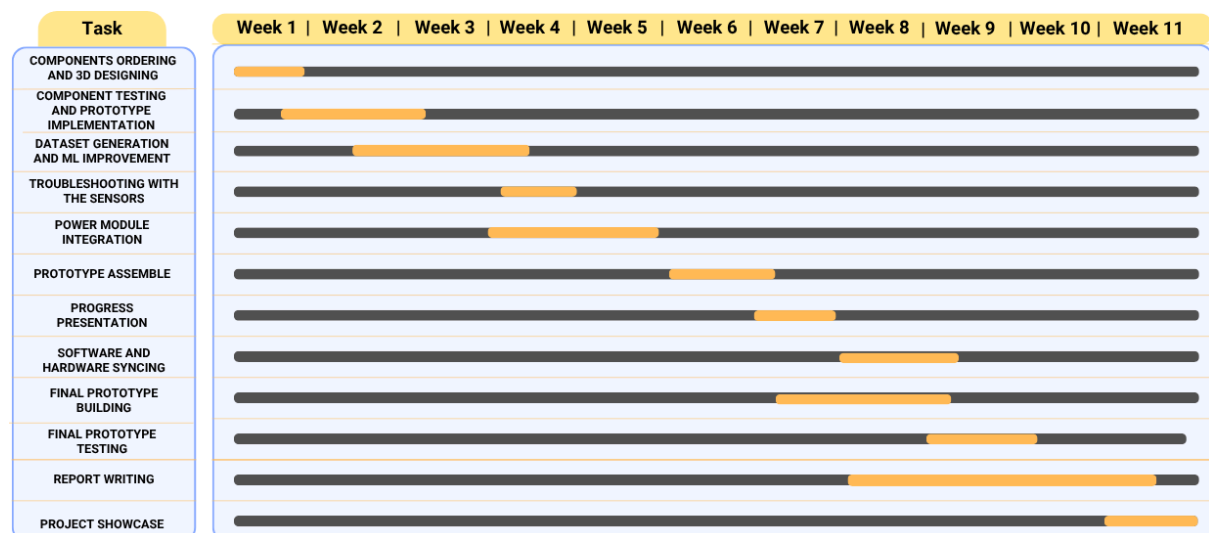


Table 8: Timeline of EEE499C

7.4 Conclusion

The project follows a clear set of steps which are outlined on the flowchart. Once the communication issues are solved and the module confirmed, data sent from the sensors is collected and analyzed in real time. The dataset is used to teach a machine learning model how to predict if a machine needs maintenance or repair. Until the performance of the model becomes acceptable, it is tested and improved using many types of data. To increase how easy the system is to use, an easy-to-use dashboard is designed for operators to quickly check and monitor machine status and performance live. The complete system is tested to confirm it runs smoothly and can be trusted. Problems found during testing are corrected and the final checks are accomplished by logging and reviewing results. You get to the final phase during this stage when you work on reporting, showing your projects and handing them over. Using this method makes the system strong technically and practical enough to function smoothly in real factories. Using predictive analytics and remote monitoring, the project provides a flexible way to reduce machine downtime and boost textile machinery productivity.

Chapter 8: Economical Analysis. [CO12]

8.1 Introduction

As the textile industry moves forward rapidly, it becomes necessary to include performance monitoring. Data processing and prediction for circular knitting adds exciting capabilities to this process. These systems give manufacturers the ability to handle work efficiently, maximize production, and maintain a low rate of downtime. Improving product quality at the same time as helping the environment and training the workforce. Still, merging these aspects can lead to ethical, professional, and technological problems that need to be managed attentively. The safety of customer information, cost-effectiveness, and involvement in the local community. Every decision made in the industry concerns itself with impact, safety, the environment, and risk control properly set up and applied to these smart technologies. Making sure to collect and use data ethically, comply with laws, and assist employees using training. There are certain duties essential to achieving lasting success in a company. This paper investigates the balance between two concepts. It gives advice on how to keep data secure, along with tips for new ways of using technology addressing risks and helping industrial growth become environmentally sustainable

8.2 Economic analysis

More than 80% of Bangladesh's clothing exports come from knitted garments, helping the textile industry make a large contribution to GDP [6]. Yet, dust-ups not scheduled ahead, inefficient upkeep routines and a lack of technology keep companies from achieving maximum productivity and waste. Built on the Arduino Nano platform, our system provides a practical and low-cost method for addressing these issues.

Component's Name	Price (BDT)
Microcontroller (Arduino Uno)	995.00
ESP8266 Wi-Fi Module	390.00
TFT Display (ST7789)	490.00
RPM Sensor (LM393)	130.00
Flow Sensor (YFS401)	530.00
Temperature Sensor (DS18B20)	210.00
Pressure Sensor (HX710B)	350.00
Buzzer	15.00
GSM Module	370.00
Power Supply & Battery	430.00
PCB	3770.00
3D Design of Prototype	5470.00
Miscellaneous	1500.00
Total	14650.00

8.3 Cost benefit analysis

A. Cost Savings from Reduced Downtime

Maintenance approaches that are manually done often result in unplanned downtimes, which may lead to production losses of up to **5–15%** in industrial environments [7]. Implementing predictive monitoring could reduce unplanned stoppages by up to **30–50%** [8].

B. Increased Machine Lifespan

Preventive alerts and real-time monitoring can increase the effective lifespan of circular knitting machines by **20–30%**, reducing the need for frequent replacements or major repairs [9].

C. ROI Estimation

Assuming a 10% downtime reduction in a factory operating 10 machines, each costing approximately 1,000 BDT/hour in downtime:

Annual Downtime Saved per Machine = 100 hours

Cost Saved per Machine = $100 \times 1,000 \text{ BDT} = 100,000 \text{ BDT}$

Annual Savings for 10 Machines = 1,000,000 BDT

Return on Investment (ROI) = $(1,000,000 - 49,300) / 49,300 \approx 1,928\%$

Here, the ROI justifies even basic installations like Design 1

8.4 Evaluate economic and financial aspects

A. Scalability

Design 1's modular architecture allows for expansion with minimal cost increases. Adding new sensors or integrating cloud services (e.g., Firebase or Adafruit IO) would require only minor adjustments to the system architecture.

B. Affordability for SMEs

This system's affordability (less than 5,000 BDT) ensures that even small textile units in semi-urban or rural areas can adopt smart monitoring systems without requiring extensive infrastructure or workforce training.

C. Long-Term Sustainability

Aligned with ISO 50001 standards, the design enhances energy efficiency and minimizes waste, which can yield long-term savings and support sustainability targets [10].

D. Local Availability of Components

Most components used in Design 1 are readily available in local electronics markets in Dhaka, which ensures maintenance and scalability without relying on expensive imports.

8.5 Conclusion

The Arduino Nano-based monitoring system presents a low-cost, high-impact solution for improving productivity, reducing machine downtime, and enabling predictive maintenance in textile factories. Because it is affordable, simple to use, and gives good returns, design 1 offers an approach that agrees with Bangladesh's textile sector's economic and operational needs. It also follows international rules for being efficient and safe, and incorporating the Internet of Things being integrated helps it succeed in supply chains and new smart manufacturing systems everywhere.

Chapter 9: Ethics and Professional Responsibilities CO13, CO2

9.1 Introduction

As textile manufacturing progresses rapidly, keeping performance under review is now essential. Using predictive analysis with circular knitting machines can trigger important changes. Because of systems, manufacturers can control processes well, cut back on stops and increase. Improving product quality works together with helping sustainability and updating the workforce. At the same time, this combination raises many ethical, professional, and technology-related problems that must be handled with care. It must be safe for our information, lower costs should be possible, and building up our neighborhood is needed.

Organizations depend on impact, safety, responsible environmental steps, and handling risk for their operations. Good use of these smart technologies. Guaranteeing proper tactics in collecting and using data. Sharing users' data, meeting regulations and helping staff with training are Duties in the workplace that are important for a manager's long-term achievements. The paper is an investigation into how California manages its economic balance.

featuring the importance of linking new developments with responsibility and describing practical ways to keep data secure, controlling threats and supporting eco-friendly growth within the industry

9.2 Identify ethical issues and professional responsibility

Data Safeguard and Security: Data gathered from circular knitting machines needs to be additionally secured for performance monitoring and predictive analytics. Data encryption in transportation and at rest should be performed; secure transportation should be granted by HTTPS and TLS. Access should be restricted by mechanisms of role-based access control and multi-factor authentication, while chances of sensitive information misuse can be reduced by anonymization and masking. This includes regular auditing, real-time monitoring, and detection of anomalies. It can detect unauthorized access and prohibit it. The secure firmware update and edge computing will reduce the vulnerable data transfer. Data governance policies, regulatory compliances, and a secure cloud/server infrastructure safeguard stored data. Security best practices training for employees and a well-defined incident response plan boost its defense-granted integrity of data for no misuse-while it supports operational efficiency and effective decision-making.

Affordability: In order to make the performance monitoring and predictive analysis systems of circular knitting machines affordable to manufacturers without compromising on safety, there has to be a strategic balance. The affordable solutions lie in using scalable sensors,

cloud-based platforms with flexible pricing, and modular system designs that allow incremental upgrades. Edge computing saves data transmission and infrastructure costs while enabling real-time analysis. Energy-efficient technologies, open-source software, and standardized components further reduce costs. Prioritizing safety, advanced cyber security, redundant systems, and secure access controls protect without using expensive proprietary tools. Benefits of predictive maintenance translate to reduced downtime and elongated machine life for manufacturers, saving them a lot in the long run. This increases operational efficiency even further with training and support services, while collaborative development fine-tunes the solution to meet both financial and functional needs, ensuring affordable and secure systems.

Impact on Local Community: The adoption of performance monitoring and predictive analysis systems on circular knitting machines may lead to a better life for the local community, with economic growth based on productivity and job creation. Moreover, such a system encourages workforce upskilling; it gives employees new technical knowledge and career opportunities. At the same time, local suppliers and service providers benefit from the increase in businesses, fostering innovation and further strengthening the regional industrial ecosystem. The environment improves because of reduced waste and energy use by predictive maintenance; this enhances the community's reputation in terms of eco-friendly practices. Moreover, increased efficiency and product quality will help local manufacturers remain competitive in global markets, thus ensuring long-term stability. The encouragement of technological adoption across industries inspires innovation, while proactive monitoring ensures the workforce enjoys safe working conditions and, therefore, promotes health and well-being for them and their families. All in all, these systems contribute to a more prosperous, sustainable, and forward-thinking community.

Professional Responsibility:

Safety Enhancement: Circular knitting machine operation can be monitored and analyzed effectively to predict the potential injuries and reduce safety risk. Speed and temperature are monitored in real time and alerts and shutdowns triggered if conditions become unsafe. Early failures are identified through predictive maintenance, decreasing risks that a system will malfunction. The interfaces also give operators real time alerts and feedback, and the historical data adjusts safety protocols to optimize them. Factory conditions such as noise and air quality are all controlled for safety, while physical safeguards, such as barriers and interlocks, are all monitored. The training programs prepare operators to manage risk. Delays in incident reporting and noncompliance with safety standards help build a continuous improvement towards a safer workplace.

Eco-Friendly and Waste Management: Promoting sustainability, the materials for performance monitoring and predictive analysis systems of circular knitting machines are eco-friendly and recyclable. Components are durable to ensure minimal waste generation and

environmental damage. Energy efficiency and optimization in machine performance reduce power consumption and increase equipment life. Predictive maintenance helps lower waste by replacing only worn-out components. It monitors energy and material usage to identify inefficiencies. Systems should also track the metrics of the environment to have improved practices and compliance with regulations in place. Responsible recycling, sustainable maintenance materials, and partnership with green suppliers further enhance eco-friendliness to support a balance between operational efficiency and environmental stewardship.

9.3 Apply ethical issues and professional responsibility

Risk Management and Contingency Plan

L I K E L I H O O D	5						A. Sensor Malfunction
	4		G	H		C	B. Communication Failure
	3		E	I	A	B	C. Overheating of the Machine components
	2	J		F	D		D.Operator error in handling remote systems
	1						E. Initial implementation costs
		1	2	3	4	5	F. Software issues in predictive analysis
		Impact					G. Environmental Impacts
							H. Lubrication System Failure
							I. Maintenance Availability
							J. Slight Delay in Real-TimeMonitoring

Table 9: Risk Management and Contingency Plan

Risk :

1. **Data Accuracy and Quality:** The accuracy and quality of the data collected from sensors or monitoring equipment can significantly impact the performance of the predictive analysis model. If the data is noisy, incomplete, or inaccurate, the predictions made about the machine's performance or potential failures will be unreliable.
2. **Sensor Malfunction or Misalignment:** Monitoring a well-defined set of parameters (like RPM, current, voltage etc.) through sensors may malfunction or misalign from

time to time. That may result in the predictive model being fed with incorrect data, which in turn would result in false alarms and missed detections of possible problems.

3. **Cybersecurity Threats** : Cyberattacks act as a threat to monitoring and control systems running over the internet or communications networks. Sensitive production data or machine operations could be accessed by hackers or interfered with.

Risk Mitigation Strategies:

Data Quality and Accuracy

- Important data processing and validation techniques will be implemented properly.
- Use data cleaning algorithms to remove the noise and outlier which can ruin the model.
- Monitor sensor data regularly to keep calibration and alignment, check the quality of the data going in on a scheduled basis.

Sensor Maintenance and Reliability

- Schedule regular maintenance and build redundancy into the system.
- Schedule a regular sensor maintenance routine, including recalibration and health checkup for all the sensors.
- Install redundant sensors for critical parameters like speed, oil flow, air pressure, voltage, current to ensure data reliability even if one sensor fails.
- Inspect for sensor data inconsistencies, which can be signaled by misalignment or malfunction, and put sensors on automatic alert if they begin to wander outside acceptable tolerances.

Cybersecurity

- Stopping unwelcome access to information with powerful and proper security protocols.
- If it's not possible to encrypt data between the machine and system, add firewalls, VPNs or end to end encryption to help keep things secure.
- Install updates, fix any flaws in your security system and perform regular network and cybersecurity checks.
- Access to the system should be allowed only for information and functions assigned to employees in their role, following RBAC.

9.4 Conclusion

Using performance tracking and predictions in circular knitting devices greatly boosts effectiveness, improves results, increases safety and benefits the environment. Even so, these benefits will only happen if ethics, duties and solid risk management are followed. Secure data procedures, keeping costs under control and benefiting surrounding communities are all elements of responsible development in industry. Managing sensors properly by cleaning them, updating your security system and verifying all data reduces the chance of trouble due to sensor breakdowns, software glitches or cyber assaults. Besides that, enhancing environmental friendliness and supporting upskilling helps the industry remain sustainable in the future. At its core, digital solutions in the textile industry make it more secure, welcoming to everyone and environmentally friendly. The industry can ensure greater results and better responsibility by using smart solutions with careful ethical consideration.

Chapter 10: Conclusion and Future Work.

10.1 Project summary/Conclusion

The proposed project is for the design of an advanced monitoring system for circular knitting machines, which will help to increase operational efficiency by providing real-time data acquisition and predictive analysis. Modern sensor-integrated IoT platforms and machine learning-enabled systems shall monitor the critical parameters: temperature, RPM, current, and voltage, crucial for early fault detection, predictive maintenance, and optimization of the performance. A centralized dashboard in itself is a powerful tool that enables decision-making capabilities, dramatically improving the capacity to carry out sustainable manufacturing practices by cutting downtime, lowering operational costs, and reducing resource wastage efficiently.

Both proposed designs have very innovative and clearly enunciated approaches and, therefore, stand remarkably differently from each other. Design 1 strongly emphasizes the utilization of proven traditional elements, specially the widely known Arduino Nano. This design is realized with a simple and basic LCD interface for user interaction, local data transmission methods using RS485, and LoRa technologies, which are in the realm of efficient communication. While this particular architecture, by all means, demonstrates a decent level of functionality and proved to be quite effective when used in standalone systems that operate independently without integration with the outside world, it has serious limitations. Those limitations begin with its relatively restricted processing power and are aggravated by its reliance on older, outdated technologies. The combination of these two factors makes it less suitable for handling or hosting more advanced applications that may arise in the future. In contrast, the ESP32 in Design 2 is vastly more modern, with a microcontroller that not only brings enhanced capabilities but has also integrated recent wireless connectivity options and compatibility with cloud-based platforms—a feature that makes it considerably more flexible in today's technical landscape—all of which lends itself to facilitating real-time monitoring, centralized management of data, and compatible IoT. Design 2 has a better and more user-friendly interface, thanks to the use of a Raspberry Pi touchscreen. This makes it easier for users to interact with the system. It also runs on a stable 12V regulated power supply, which helps it perform reliably even in tough working conditions.

Overall, Design 2 is more scalable, uses more advanced technology, and offers a better user experience compared to Design 1. This makes it a forward-thinking choice that fits well with the needs of today's textile manufacturing industry.

10.2 Future work

While the current project successfully achieved its primary objectives, there are several avenues for further enhancement and exploration that can significantly improve the system's efficiency, scalability, and user experience.

To improve the system in the future, one of the first steps is to use a larger dataset for training and testing. This will help make the system more accurate and reliable. Adding real-time data from IoT sensors or external APIs can also help the system stay updated and better handle changing conditions.

Using more advanced machine learning methods, like deep reinforcement learning or federated learning, could lead to smarter and more personalized solutions. Also, finding ways to make the models smaller and more efficient is important if the system is going to be used on low-power devices. This will make it easier to use in more places.

On the user side, future improvements could focus on making the interface easier to use. This could include adding features like voice commands, support for different languages, and layouts that work well on any device—whether it's a phone, tablet, or computer.

Security and privacy are also important. The system should use strong encryption and follow data protection rules, especially if it deals with sensitive or personal information. Adding tools to detect strange or suspicious behavior can help protect against cyber threats and make the system safer.

Another key point is making the system scalable. Future designs could use cloud or distributed systems that can handle more users and work smoothly with low delay. Exploring newer technologies like serverless computing and microservices can also help keep the system flexible and easier to manage.

Finally, collecting feedback from users and testing the system in real-world situations will be very useful. This will help identify areas for improvement and make sure the system works well outside of lab settings.

In short, future work should aim to improve the system's performance, make it easier and safer to use, and ensure it can grow and adapt to real-world needs.

Chapter 11: Identification of Complex Engineering Problems and Activities.

Attributes of Complex Engineering Problems (EP)

	Attributes	Put tick (✓) as appropriate
P1	Depth of knowledge required	✓
P2	Range of conflicting requirements	✓
P3	Depth of analysis required	✓
P4	Familiarity of issues	
P5	Extent of applicable codes	
P6	Extent of stakeholder involvement and needs	✓
P7	Interdependence	

Table 10: Attributes of Complex Engineering Problems (EP)

P1. Depth of knowledge required : This refers to the need to increase our understanding of complicated engineering states to proceed with our assessment. Comprehensive knowledge encompasses everything we have learned during our engineering education and how to apply it to tackle any challenging issues. The project must be intricate and need the use of the theoretical knowledge we have acquired in our lessons. For the problem to qualify as academic work, it must be sufficiently difficult. Absent this vital attribute, we won't be able to conduct our research.

P2. Range of conflicting requirements : This refers to the conflicting issues of the engineering, technical, technology, and other. Then the qualities of the projects tell us anything we need to trouble and what we can plan for. We never come up with a conflict in the problem we solve in a project. The other will resolve and correct the other.

P3. Depth of analysis required : We must use critical and creative thinking to come up with a feasible solution if we are trying to solve a problem but are unable to locate a suitable one. Engineering problems might occasionally be so challenging that we may need to carefully

tackle them and come up with unique innovative answers. We need in-depth investigation and critical thinking abilities to solve those issues.

Attributes of Complex Engineering Activities (EA)

	Attributes	Put tick (✓) as appropriate
A1	Range of resource	✓
A2	Level of interaction	✓
A3	Innovation	
A4	Consequences for society and the environment	
A5	Familiarity	✓

Table 11: Attributes of Complex Engineering Activities (EA)

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Appendix

Logbook

ATC panel and Members details

	Final Year Design Project (P) Summer 2024		
Student Details	NAME & ID	EMAIL ADDRESS	PHONE
Member 1	Farhan Noor Showrov	farhan.noor.showrov@g.bracu.ac.bd	01977079155
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Member 3	Khondaker Labib Al Jonayed	khondaker.labib.al.jonayed@g.bracu.ac.bd	01766912830
Member 4	Khaleed Mahmud	khaleed.mahmud@g.bracu.ac.bd	01611298654
ATC Details:			
ATC 4			
Chair	Mohammed Belal Hossain Bhuian, PhD	belal.bhuian@bracu.ac.bd	
Member 1	Sabbir Ahmed	ahmed.sabbir@bracu.ac.bd	
Member 2	Md. Mahmudul Islam	mahmudul.islam@bracu.ac.bd	

Date & Time	Attendance	Summary of the Meeting	Responsible	ATC's Comment
9.06.2024	All	1. How to define specification and features of a device 2. Actual problem according to consumer demand 3. Understanding the Problem statement	All	Home task : Study on different electronic device for every individual group member
16.06.2024	All	1. Group members studied on different device and their specifications 2. Discussion about idea	All	Find out real life problems and tentative solutions
23.06.2024	All	Preliminary Topic selection	All	Find Out and read research papers according to topic field
30.06.2024	All	1. Study on similar research papers 2. Field inspections	All	Search for new topic and related research papers
2.07.2024	All	1.Final Topic selection 2.Progress presentation preparation	All	

3.07.2024	All	Presentation review	All	1.Narrow down the topic and correction of functional and nonfunctional requirements 2.Study on specification
7.07.2024	All	Study on Research papers	1.Paper 1: Khaleed & Farhan 2.Paper 2: Labib & Asif	1.Specify the problem statement 2.Study on specification and requirements
1.09.2024	All	Detail Study on the topic and specifications of the project	All	Prepare the report and get review on the presentation
8.09.2024	All	Revise the report	All	

	Final Year Design Project (D) Fall 2024		
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Member 1	Farhan Noor Showrov	farhan.noor.showrov@g.bracu.ac.bd	01977079155
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Member 4	Khaleed Mahmud	khaleed.mahmud@g.bracu.ac.bd	01611298654
ATC Details:			
ATC 4			
Chair	Mohammed Belal Hossain Bhuian, PhD	belal.bhuian@bracu.ac.bd	
Member 1	Sabbir Ahmed	ahmed.sabbir@bracu.ac.bd	
Member 2	Md. Mahmudul Islam	mahmudul.islam@bracu.ac.bd	

Date/Time /Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
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27.10.24	1.Farhan 2.Labib 3.Asif 4.khaleed	1.Discussion about the introductory class of FYDP(D) 2.briefed us about the course outcome of FYPD(D) 3.Gave the general guidelines and tentative time schedules for the mid presentation and demonstration.		
03.11.24	1.Farhan 2.Labib 3.khaleed	1:Selecting components and methods for project implementation.	Task 1: everyone	1. To start looking for the components
12.11.24	1.Farhan 2.Labib 3.khaleed	1. Review and update the status of the project components, and mention if any issues are being faced. 2. Start preparing report writing	Task 1: Farhan & Asif Task 2: Khaleed & Labib	1. Asked to start collecting components for the implementation of the project. 2. Tasked to start writing the report.
19.11.24	1.Farhan 2.Labib 3.Asif 4.khaleed	1. Range of temperature, air flow, oil flow, vibration 2. Sensor identification and specify correct sensor	Task 1: Farhan & khaleed Task 2: Asif & Labib	1. Design according to the main machine 2. For prototype we can use as simple
05.12.24	1.Farhan 2.Labib 3.Asif	1. slides on FYDP(D) progress presentation 2.Make the block diagram of methodology slide in two rows instead of single row for better visibility.	Task 1: everyone Task 2: Khaleed & Asif Task 3:Labib & Farhan	

		3.The table of problems is truncated at the bottom. Correct it.		
15.12.24	1.Farhan 2.Asif 3.khaleed	1. Defect rate 2. Yarn consumption 3. Temperature and vibration 4. Lubrication level	Task 1: Farhan Task 2: Khaleed Task 3:Labib Task 4:Asif	
22.12.24	1.Farhan 2.Labib 3.Asif 4.khaleed	1. Design for a specific model of machine 2.Main machine sensors rating, range and calculations 3. Started working on implementing the design	Task 1: Farhan & khaleed Task 2: Asif & Labib Task 3:Farhan & khaleed	1. Do simulation and hand calculation 2. Use matlab, simulink, Proteus
29.12.24	1.Labib 2.Asif 3.khaleed	1. Method to adding your sensor with oil flow sensor 2. Adding STM 32 on design 2 as brain and ESP 32 as Wi-Fi data 3. Your pressure sensor BME21M621	Task 1: Farhan Task 2: Labib Task 3: Asif & Khaleed	1. Integrate all subsystem 2. Collect data and store or transfer 3. Do rest of the calculation and simulation 4. 3D model simulation
05.01.25	1.Farhan 2.Labib 3.Asif	1. Calculation of the sensors (Rpm, oil flow, air flow, temperature, voltage, current)	Task 1: everyone	
09.01.25	1.Farhan 2.Labib	1. slides on FYDP(D)	Task 1: everyone	

	3.Asif 4.khaleed	2.The simulink plot, try to make the traces more visible by changing the width of the trace and white background. Add legends 3. Change the technical specification as specification of your system	Task 2: Farhan & khaleed Task 3:Asif & Labib	
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	Final Year Design Project (C) Spring 2025		
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ATC Details:			
ATC 4			
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Member 1	Sabbir Ahmed	ahmed.sabbir@bracu.ac.bd	
Member 2	Md. Mahmudul Islam	mahmudul.islam@bracu.ac.bd	

Date/Time /Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
18.02.25	1.Farhan 2.Labib 3.Asif 4.khaleed	1. Briefed about introductory class of FYPD_C 2.Gave suggestions on the different modern tools to use 3. Overview of the overall guidelines for FYPD_C		
23.02.25	1.Farhan 2.Labib 3.khaleed	1. Component availability and order status. 2. Asked for permission to start doing 3d printing.	Everyone	1.make a list of all components
09.03.25	1.Farhan 2.Labib 3.Asif 4.khaleed	1. Selecting components and methods for project implementation. 2. Sensor identification and specify correct sensor	Everyone	1. Order online for the components
16.03.25	1.Farhan 2.Labib 3.Asif	1. Discussion on selecting components and methods for project implementation. 2.optimize the designs according to the components available	Everyone	
23.03.25	1.Farhan 2.Asif 3.khaleed	1. Component status. 2. Components are ordered, yet to be received.	Everyone	1. Collect all the parts as soon as possible.

13.04.25	1.Farhan 2.Labib 3.Asif 4.khaleed	1. 3D printing received. 2. Start designing PCB	Everyone	1. Start designing PCB as soon as possible.
20.04.25	1.Labib 2.Asif 3.khaleed	1. Review and update the status of the project components. 2. 3D printing received.	Everyone	
27.04.25	1.Farhan 2.Asif	1. Mid Presentation date. 2. Maintain the project timeline.	Everyone	
04.01.25	1.Farhan 2.Asif	1. Update for all the sub-systems. 2. Slide & poster update shown.	Everyone	
12.05.25	1.khaleed	1. Progress of report writing.	Everyone	
13.05.25	1.Farhan 2.Labib 3.Asif 4.khaleed	1. PCB & display received. 2. Slot for showing prototype progress.	Everyone	

Related code/theory

Code for Design Approach 1:

```
// Pin definitions

const int pressureSensorPin = A0; // MPX4115 Vout connected to A0

const int currentSensorPin = A1; // ACS712 Vout connected to A1

const int encoderPin = 3;      // Motor encoder connected to digital pin 3

const int timerPin = 2;       // 555 Timer output connected to digital pin 2


// Constants for sensors

const float VREF = 5.0;       // Reference voltage of Arduino

const int ADC_RESOLUTION = 1024; // ADC resolution (10-bit)

const float ACS712_SENSITIVITY = 0.066; // Sensitivity of ACS712 30A version (66mV/A)

const float PRESSURE_OFFSET = 0.2; // Voltage offset for MPX4115 (approx. 0.2V at 0 kPa)

const float PRESSURE_SLOPE = 45.0; // Slope for MPX4115 (kPa/V)


// Encoder and Timer variables

volatile unsigned int pulseCount = 0; // Counter for encoder pulses

volatile unsigned int timerPulseCount = 0; // Counter for 555 timer pulses

const int PPR = 20;           // Pulses per revolution for the encoder

unsigned int rpm = 0;         // Rotational speed in RPM

unsigned long lastMillis = 0;  // Timer for calculations


void setup() {

  Serial.begin(9600);         // Initialize Serial Monitor

  pinMode(pressureSensorPin, INPUT); // Set pressure sensor pin as input
```

```

pinMode(currentSensorPin, INPUT); // Set current sensor pin as input

pinMode(encoderPin, INPUT_PULLUP); // Set encoder pin as input with pull-up resistor

pinMode(timerPin, INPUT_PULLUP); // Set timer pin as input with pull-up resistor


// Attach interrupts

attachInterrupt(digitalPinToInterrupt(encoderPin), countEncoderPulses, RISING);

attachInterrupt(digitalPinToInterrupt(timerPin), countTimerPulses, RISING);
}


void loop() {

// Read and calculate pressure

float pressureVoltage = (analogRead(pressureSensorPin) * VREF) / ADC_RESOLUTION;

float pressure = (pressureVoltage - PRESSURE_OFFSET) * PRESSURE_SLOPE;


// Read and calculate current and voltage

float currentVoltage = (analogRead(currentSensorPin) * VREF) / ADC_RESOLUTION;

float current = (currentVoltage - (VREF / 2)) / ACS712_SENSITIVITY;


// Calculate RPM and frequency every second

if (millis() - lastMillis >= 1000) {

// RPM calculation

rpm = (pulseCount * 60) / PPR; // Convert pulse count to RPM

pulseCount = 0; // Reset pulse counter


// Frequency calculation

unsigned int frequency = timerPulseCount; // Frequency is pulse count per second

timerPulseCount = 0; // Reset timer pulse counter

```

```

// Display results on Serial Monitor

Serial.print("Pressure: ");

Serial.print(pressure, 2); // Display pressure with 2 decimal places

Serial.print(" kPa, ");


Serial.print("Current: ");

Serial.print(current, 2); // Display current with 2 decimal places

Serial.print(" A, ");


Serial.print("Voltage: ");

Serial.print(currentVoltage, 2); // Display voltage with 2 decimal places

Serial.print(" V, ");


Serial.print("RPM: ");

Serial.print(rpm); // Display RPM

Serial.print(", ");


Serial.print("Frequency: ");

Serial.print(frequency); // Display frequency

Serial.println(" Hz");


lastMillis = millis(); // Update timer

}

}

void countEncoderPulses() {

```

```

    pulseCount++; // Increment encoder pulse counter
}

void countTimerPulses() {
    timerPulseCount++; // Increment timer pulse counter
}

```

Machine Learning Codes:

Filter Code:

```

# Filter rows where 'health_status' is 'Good'
filtered_df = df[df['health_status'] == 'Good']

```

Function Code:

```

# Load the dataset
def load_data(file_path):
    data = pd.read_excel(file_path)
    inputs = data.iloc[:, :5].values
    outputs = data.iloc[:, 5].values
    return inputs, outputs

# Build the Random Forest model
def build_model():
    model = RandomForestRegressor(n_estimators=100, random_state=42)
    return model

```

```

# Evaluate model efficiency

def evaluate_model(model, X_test, y_test):

    predictions = model.predict(X_test)

    mae = mean_absolute_error(y_test, predictions)

    mse = mean_squared_error(y_test, predictions)

    r2 = r2_score(y_test, predictions)

    print(f"Mean Absolute Error (MAE): {mae:.4f}")

    print(f"Mean Squared Error (MSE): {mse:.4f}")

    print(f"R^2 Score: {r2:.4f}")


# Plot feature importances

def plot_feature_importances(model, feature_names):

    importances = model.feature_importances_

    indices = np.argsort(importances)[::-1]

    plt.figure(figsize=(10, 6))

    plt.title("Feature Importances")

    plt.bar(range(len(importances)), importances[indices], align="center")

    plt.xticks(range(len(importances)), [feature_names[i] for i in indices], rotation=45)

    plt.tight_layout()

    plt.show()


# Visualize the model with Partial Dependence Plots

def visualize_model(model, X_train, feature_names):

    plt.figure(figsize=(12, 8))

    PartialDependenceDisplay.from_estimator(model, X_train, range(len(feature_names)),

feature_names=feature_names)

    plt.tight_layout()

    plt.show()

```

```

# Manual prediction

def manual_prediction(model, input_data):

    input_data = np.array(input_data).reshape(1, -1)

    prediction = model.predict(input_data)

    return prediction


# Save the trained model

def save_model(model, folder_path, file_name="random_forest_model.pkl"):

    os.makedirs(folder_path, exist_ok=True)

    save_path = os.path.join(folder_path, file_name)

    joblib.dump(model, save_path)

    print(f"Model saved to {save_path}")

```

Model Code:

```

# Main script

if __name__ == "__main__":

    file_path = r"F:\ML_Model\filtered_data\RPM\rpm.xlsx" # Replace with your file path

    inputs, outputs = load_data(file_path)


    # Split data into train and test sets

    X_train, X_test, y_train, y_test = train_test_split(inputs, outputs, test_size=0.2, random_state=42)


    # Build and train the model

    model = build_model()

    model.fit(X_train, y_train)


    # Save the trained model

    save_folder = r"F:\ML_Model\filtered_data\RPM" # Replace with your desired folder path

    save_model(model, save_folder)

```

```

# Evaluate the model

evaluate_model(model, X_test, y_test)


# Plot feature importances

feature_names = [f"Feature {i+1}" for i in range(inputs.shape[1])]

plot_feature_importances(model, feature_names)


# Visualize the model

visualize_model(model, X_train, feature_names)


# Manual prediction example

manual_input = [[19.3558, 402.213, 1.3635, 575.4790, 6.83480]] # Replace with your input values

prediction = manual_prediction(model, manual_input)

print(f"Predicted Output: {prediction[0]:.4f}")

```

Test Code:

```

import numpy as np

from sklearn.ensemble import RandomForestRegressor


# Manual prediction

def manual_prediction(model, input_data):

    input_data = np.array(input_data).reshape(1, -1)

    prediction = model.predict(input_data)

    return prediction


# Example usage

if __name__ == "__main__":

```

```
# Load the pre-trained model (replace with your model loading code if necessary)

import joblib

model = joblib.load(r"F:\ML_Model\filtered_data\RPM\random_forest_model.pkl") # Replace with your
saved model file


# Input data for prediction

manual_input = [[19.9, 402., 1.3, 575, 6.8]] # Replace with your input values

prediction = manual_prediction(model, manual_input)

print(f"Predicted Output: {prediction[0]:.4f}")
```