

Hybrid Lathe and Drilling Machine Integrated with IoT- Based for Smart Manufacturing

ATHARV JAVHERI¹, YADUNATH JANJALKAR², VIDHI PAWAR³, PURUSHOTTAM DESAI⁴,
S.S. SATHE⁵

1, 2, 3, 4, 5 JSPM's RSCOE Polytechnique

Abstract- The rapid advancement of manufacturing technologies has exposed the limitations of conventional machining systems such as lathe and drilling machines, which remain essential for operations including turning, facing, threading, boring, and drilling. Despite their widespread use, these machines typically operate as standalone systems with minimal automation and lack real-time monitoring capabilities. This dependence on manual supervision often results in reduced productivity, increased downtime, inconsistent product quality, and unexpected machine failures. With the emergence of Industry 4.0, the integration of the Internet of Things (IoT) has enabled the development of intelligent manufacturing systems capable of real-time data acquisition and analysis. Critical parameters such as temperature, vibration, rotational speed, and load conditions can be continuously monitored, enabling predictive maintenance and enhanced operational efficiency. In addition, small and medium-scale industries face challenges related to high capital investment and limited workspace due to the use of separate machines for different operations. To address these challenges, this paper presents the design and development of a hybrid lathe and drilling machine integrated with IoT-based sensors. The proposed system combines multiple machining operations into a single unit while enabling real-time monitoring through embedded systems and cloud-based platforms. The integration of mechanical systems with digital technologies offers a cost-effective, space-efficient, and scalable solution, contributing to the advancement of smart manufacturing practices.

I. INTRODUCTION

Machine tools play a vital role in modern manufacturing industries by enabling the shaping, cutting, drilling, and finishing of materials into precise and functional components. Among the wide range of machine tools, lathe and drilling machines are considered fundamental equipment in workshops and industrial production environments. These machines are extensively used for performing operations such as turning, facing, threading, and

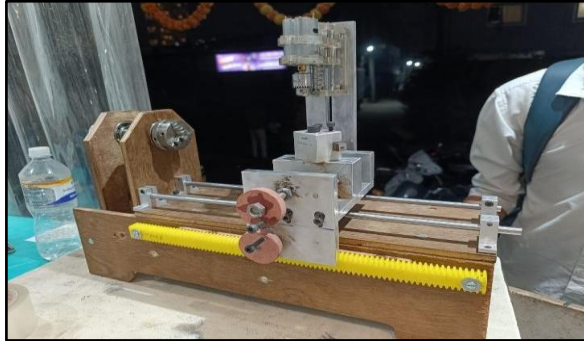
drilling, and are essential for the production of shafts, bolts, cylindrical components, holes, and threaded parts. Due to their versatility and reliability, they form the backbone of machining processes across various sectors. Over time, machine tool technology has undergone significant evolution, transitioning from manually operated systems to semi-automatic and fully automated Computer Numerical Control (CNC) machines. CNC machines offer high precision, repeatability, and automation, making them suitable for large-scale production. However, conventional manually operated machines continue to be widely used, particularly in small and medium-scale industries and educational institutions, due to their low cost, ease of operation, and flexibility in handling diverse tasks.

Despite these advantages, traditional machining systems operate as standalone units with minimal integration of digital technologies. They lack real-time monitoring capabilities and depend heavily on manual supervision for parameters such as temperature, vibration, cutting speed, and tool condition. This limitation often leads to inefficiencies, increased downtime, inconsistent product quality, and a higher probability of machine failure.

In recent years, the emergence of Industry 4.0 has emphasized the need for smart manufacturing systems that incorporate automation, data exchange, and connectivity. The integration of advanced technologies such as the Internet of Things (IoT) enables real-time data acquisition, remote monitoring, and predictive maintenance, thereby enhancing overall system performance and reliability.

The existing literature highlights a growing demand for upgrading conventional machine tools with

intelligent monitoring and control systems. In this context, the present work focuses on developing an integrated and cost-effective solution that combines traditional machining capabilities with modern digital technologies, aiming to bridge the gap between conventional systems and smart manufacturing requirements.



II. PROBLEM STATEMENT

Conventional lathe and drilling machines are generally designed to operate as independent units, resulting in increased capital investment and inefficient utilization of workshop space. This separation limits operational flexibility, particularly in small-scale industries and educational laboratories where budget and space constraints restrict access to multiple machines and advanced equipment.

In addition, traditional machining systems lack real-time condition monitoring capabilities. Machine performance is primarily assessed through manual observation and operator experience, which may lead to delayed detection of critical issues such as overheating, excessive vibration, tool wear, and irregular speed variations. This reactive approach to maintenance often results in unexpected machine failures, increased downtime, higher repair costs, and compromised product quality.

Another significant limitation is the absence of data acquisition and storage mechanisms in conventional systems. Without continuous data logging and historical performance records, it becomes difficult to analyze machine efficiency, predict potential failures, or optimize machining parameters. This lack of data-driven decision-making restricts the implementation of predictive maintenance strategies and reduces overall productivity.

In the context of Industry 4.0 and smart manufacturing, these limitations highlight the necessity to develop a compact and cost-effective hybrid machine that combines lathe and drilling operations while incorporating IoT-based sensors for real-time monitoring, data acquisition, and smart analysis to enhance efficiency, reliability, and operational performance.

III. OBJECTIVES

The primary objective of this research is to design and develop a hybrid lathe and drilling machine integrated with IoT-based monitoring for smart manufacturing applications. The key objectives are:

- To design and fabricate a compact machine capable of performing both turning and drilling operations in a single system.
- To integrate IoT-based sensors for real-time monitoring of parameters such as temperature, vibration, spindle speed (RPM), and load.
- To develop a microcontroller-based system (e.g., ESP32/Arduino) for data acquisition and transmission.
- To enable wireless communication with a cloud platform for remote monitoring and data storage.
- To improve machine performance through predictive maintenance and reduced downtime.
- To provide a cost-effective and space-efficient solution for small-scale industries and educational use.

This project combines mechanical design, electronics, and IoT monitoring in a unified system. It includes fabrication of a rigid frame, lathe spindle setup, vertical drilling attachment, and linear motion mechanisms like lead screw or rack-and-pinion. On the electronics side, it involves sensor integration, signal conditioning, and microcontroller programming for real-time data transmission. A cloud-based dashboard is used for monitoring and alerts.

However, the project does not focus on full CNC automation or heavy industrial machining, but rather on hybrid functionality with smart monitoring.

IV. LITERATURE REVIEW

Previous studies show that lathe and drilling machines are essential in manufacturing but generally lack intelligent monitoring systems. Research on hybrid machines indicates that combining operations reduces setup time and improves productivity.

IoT-based monitoring systems are widely used for predictive maintenance and performance optimization, using sensors like temperature, vibration, and RPM to monitor machine health in real time. However, most of these systems are limited to high-cost CNC machines, with little focus on affordable hybrid solutions for small-scale industries. This gap motivates the development of the proposed system.

The primary objective of this project is to design, fabricate, and implement a hybrid lathe and drilling machine integrated with IoT-based sensing for smart manufacturing. The specific objectives are:

- To design a compact and mechanically stable hybrid structure for both turning and drilling operations.
- To integrate sensors for monitoring temperature, vibration, RPM, and load conditions.
- To develop a microcontroller-based system for real-time data acquisition.
- To establish wireless communication with a cloud platform.

V. SYSTEM ARCHITECTURE

The proposed hybrid lathe and drilling machine integrated with IoT-based monitoring is designed using a multi-layered architecture to ensure efficient coordination between mechanical operations, data acquisition, and digital communication. The system is broadly divided into three major layers: Mechanical Layer, Control Layer, and IoT Layer. Each layer performs a specific function while interacting seamlessly with the others to achieve real-time monitoring and improved machining performance.

VI. MECHANICAL LAYER

The mechanical layer forms the physical foundation of the system and is responsible for performing machining operations. It consists of a hybrid arrangement that integrates both lathe and drilling functionalities into a single unit.

The lathe unit is designed to perform operations such as turning, facing, threading, and boring. It includes essential components such as the headstock, spindle, chuck, carriage, and tailstock. The spindle rotates the workpiece at variable speeds, while the carriage mechanism provides controlled tool movement for material removal.

The drilling attachment is mounted vertically above or near the lathe carriage, enabling drilling operations without removing the workpiece. This arrangement improves machining efficiency by eliminating the need for repositioning and re-clamping.

A rigid base frame structure made of mild steel supports all components and ensures stability during operation. The frame is designed to withstand dynamic loads, vibrations, and cutting forces while maintaining alignment accuracy.

The power transmission system, typically consisting of a belt and pulley mechanism or direct coupling, transfers rotational motion from the motor to the spindle and drilling unit. This system allows speed variation and ensures smooth power delivery with minimal losses.

Overall, the mechanical layer enables multi-functional machining while maintaining structural rigidity and operational stability.

VII. CONTROL LAYER

The control layer acts as the intelligence unit of the system, responsible for data acquisition, processing, and basic analysis. It integrates multiple sensors and a microcontroller to monitor machine performance in real time.

Sensors are installed to measure key parameters such as temperature, vibration, RPM, and load. The temperature sensor prevents overheating, the vibration sensor detects imbalance or tool wear, the RPM sensor ensures proper spindle speed, and the current sensor monitors power consumption and load variations.

All sensors are connected to a microcontroller like ESP32 or Arduino, which collects and converts signals into readable data using built-in ADC. Signal conditioning circuits improve accuracy and reduce noise.

The microcontroller processes the data and can generate alerts when values exceed predefined limits. This layer ensures continuous monitoring and acts as a bridge between the physical machine and the digital system.

VIII. IoT LAYER

The IoT layer enables communication between the machine and external systems for remote monitoring and analysis. It transmits processed data from the microcontroller to a cloud platform. Using Wi-Fi (via ESP32), data is sent through protocols like HTTP or MQTT. Platforms such as ThingSpeak, Blynk, or Firebase store and manage this data in real time.

A user dashboard displays parameters in graphical and numerical formats, including live readings, historical trends, and alerts. It can be accessed remotely via web or mobile.

This layer supports features like data logging, trend analysis, and predictive maintenance, allowing timely action when abnormal conditions are detected.

Integrated System Functionality

The overall system operates through the interaction of all three layers. During machining operations, the mechanical layer performs cutting and drilling tasks. Simultaneously, sensors in the control layer continuously collect operational data. The microcontroller processes this data and transmits it via the IoT layer to the cloud platform. This integrated architecture ensures real-time monitoring

without interrupting machining operations. It enhances machine reliability, reduces downtime, and supports data-driven decision-making, making the system suitable for smart manufacturing applications

IX. METHODOLOGY

The development of the hybrid lathe and drilling machine integrated with IoT-based monitoring is carried out through a systematic and structured approach. The methodology includes design, fabrication, integration, programming, communication setup, and performance evaluation. Each stage is described in detail below:

Design of Mechanical Components using CAD

The initial stage involves the design of the hybrid machine using Computer-Aided Design (CAD) software such as SolidWorks or AutoCAD. The design focuses on integrating lathe and drilling mechanisms into a single compact unit while ensuring proper alignment, rigidity, and ease of operation.

Key components such as the spindle, chuck, carriage, drilling attachment, and base frame are modeled. Special attention is given to load distribution, tool positioning, and ergonomic design. The CAD model also helps in identifying potential design issues and optimizing the layout before fabrication.

Fabrication of Hybrid Machine Structure

The fabrication process involves the physical construction of the designed hybrid machine using suitable materials and manufacturing techniques.

The base frame is fabricated using mild steel sections to provide a strong and stable foundation. Cutting operations are performed using tools such as power saws or gas cutting, followed by welding processes (arc welding or MIG welding) to assemble the frame structure. Proper alignment is ensured using measuring instruments like vernier calipers, spirit levels, and dial gauges.

The lathe components, including the spindle, chuck, and carriage, are either machined or assembled from standard parts. The drilling unit is mounted vertically on the frame using a rigid support structure, ensuring perpendicular alignment with the workpiece.

The power transmission system is installed using a motor coupled with a belt and pulley arrangement. This setup allows speed variation and smooth transmission of power to both lathe and drilling units. After assembly, finishing operations such as grinding, surface cleaning, and painting are carried out to improve durability and appearance. Proper lubrication is also ensured to reduce friction and wear.

Integration of Sensors at Critical Locations

Sensors are integrated into the machine to monitor key performance parameters in real time.

- Temperature sensors are installed near the motor and spindle to monitor heat generation.
- Vibration sensors are mounted on the machine frame or near the tool post to detect abnormal vibrations.
- RPM sensors are attached to the spindle to measure rotational speed.
- Current or load sensors are connected to the power supply to monitor electrical load conditions.

Sensors are carefully positioned to ensure accurate data collection without interfering with machine operation.

Programming of Microcontroller

A microcontroller such as ESP32 or Arduino is used for data acquisition and processing. The microcontroller is programmed using Embedded C or Arduino IDE.

The program includes:

- Reading sensor data (analog and digital inputs)
- Converting signals using ADC
- Processing and filtering data
- Comparing values with predefined thresholds
- Preparing data for transmission

The program is designed to operate continuously and efficiently with minimal delay.

Establishment of IoT Communication

The IoT system is implemented to enable real-time data transmission and remote monitoring.

The ESP32 microcontroller uses built-in Wi-Fi to connect to a network. Communication protocols such as HTTP or MQTT are used to send data to cloud platforms like ThingSpeak or Blynk.

The cloud platform stores and processes the data, while a user dashboard is created to display real-time values, graphs, and alerts. This allows operators to monitor machine performance remotely using a smartphone or computer.

Testing and Validation of System Performance

After integration, the system is tested under various operating conditions to evaluate its performance.

- The machine is run at different speeds and loads
- Sensor readings are recorded and verified
- Data transmission is checked for accuracy and delay
- System response to abnormal conditions is tested

The results are analyzed to ensure proper functioning of the hybrid machine and IoT monitoring system. Any errors or inconsistencies are identified and corrected during this stage.

Overall Methodology Flow

The overall process follows a sequential approach:

Design → Fabrication → Sensor Integration → Programming → IoT Setup → Testing

This structured methodology ensures successful development of a reliable, efficient, and intelligent hybrid machining system.

X. WORKING PRINCIPLE

The proposed hybrid machine operates based on the combined principles of mechanical machining and electronic data acquisition. It integrates conventional

machining operations with real-time monitoring using embedded systems and IoT technology.

Lathe Operation (Turning Mechanism)

The lathe unit works on the principle of rotating the workpiece against a stationary cutting tool. The electric motor provides rotational motion to the spindle through a belt and pulley arrangement. The workpiece is held securely in a chuck mounted on the spindle.

As the spindle rotates, the cutting tool, mounted on the tool post, is fed linearly along the axis of the workpiece using the carriage mechanism. This relative motion between the rotating workpiece and stationary tool results in material removal in the form of chips.

Operations such as turning, facing, taper turning, and threading can be performed by controlling feed rate, depth of cut, and spindle speed. Proper alignment and rigidity ensure dimensional accuracy and surface finish.

Drilling Operation (Hole-Making Mechanism)

The drilling unit operates on the principle of rotary cutting, where a multi-point cutting tool (drill bit) rotates and advances axially into the workpiece to create holes.

In this hybrid system, the drilling attachment is mounted vertically, allowing drilling operations to be performed without removing the workpiece from the lathe setup. The drill bit is rotated by a motor-driven spindle, and axial feed is applied manually or mechanically.

The cutting edges of the drill bit remove material progressively, forming a cylindrical hole. Parameters such as feed rate, cutting speed, and drill diameter influence the quality and accuracy of the hole.

This integrated setup reduces setup time, improves productivity, and ensures better alignment between turning and drilling operations.

Sensor-Based Monitoring

Various sensors are installed on the machine to continuously monitor operational parameters:

- Temperature sensors detect heat generation in the motor and spindle.
- Vibration sensors identify abnormal machine vibrations due to imbalance or tool wear.
- RPM sensors measure spindle speed in real time.
- Current sensors monitor electrical load and power consumption.

These sensors convert physical parameters into electrical signals, which are transmitted to the microcontroller for processing.

Microcontroller Processing

The microcontroller (ESP32/Arduino) acts as the central processing unit of the system. It receives analog and digital signals from sensors and converts them into meaningful data using Analog-to-Digital Conversion (ADC).

The microcontroller performs:

- Data filtering and noise reduction
- Comparison with predefined threshold values
- Basic decision-making (e.g., detecting abnormal conditions)

If any parameter exceeds safe limits, the system can generate alerts, improving machine safety and reliability.

IoT-Based Data Transmission

The processed data is transmitted to a cloud platform using Wi-Fi communication. The ESP32 microcontroller enables wireless connectivity and uses communication protocols such as HTTP or MQTT.

The cloud platform stores data in real time, allowing continuous monitoring and historical data analysis. This enables predictive maintenance and performance optimization.

Real-Time Monitoring and Visualization

A user interface or dashboard is developed to display machine parameters in real time. The dashboard provides:

- Live readings of temperature, vibration, RPM, and current
- Graphical representation of data trends
- Alerts for abnormal conditions
- Remote accessibility via mobile or web This allows operators to monitor machine performance from anywhere, reducing manual dependency and improving operational efficiency.

Overall System Operation

The complete system works in a synchronized manner:

Machining Operation → Sensor Data Collection → Microcontroller Processing → IoT Transmission → Cloud Storage → User Monitoring

This integration of mechanical and digital systems ensures efficient machining, real-time monitoring, reduced downtime, and improved productivity, making the system suitable for smart manufacturing environments.

XI. RESULTS AND PERFORMANCE ANALYSIS

The results and performance analysis were conducted to evaluate the effectiveness, reliability, and feasibility of the developed hybrid lathe and drilling machine integrated with IoT-based monitoring.

The system was tested under various operating conditions to assess its mechanical performance, sensor accuracy, IoT communication, and overall efficiency. The obtained results were also compared with conventional standalone machines to determine the improvements achieved.

Experimental Setup

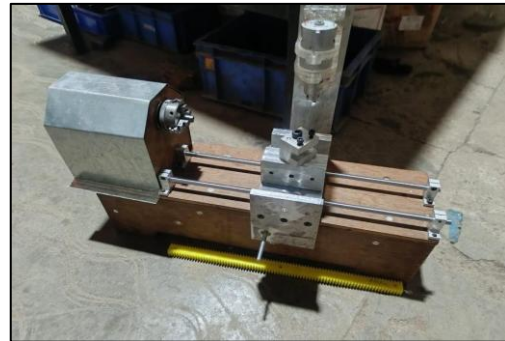
The experimental setup consisted of the fabricated hybrid machine installed in a controlled workshop environment and powered by a single-phase AC supply. The IoT module, based on an ESP32 microcontroller, was connected to a stable Wi-Fi network for continuous data transmission.

Machining tests were carried out using workpiece materials such as mild steel and aluminum under varying load conditions. Standard cutting tools and drill bits were used for turning and drilling

operations. Measurement instruments including a vernier caliper, micrometer, tachometer, and thermometer were used to validate machining accuracy and sensor readings.

The system was tested under three operating conditions:

- No-load condition
- Light-load machining
- Moderate-load machining



Mechanical Performance Evaluation

The mechanical performance was evaluated based on machining accuracy, surface finish, spindle stability, and vibration characteristics.

During turning operations, the spindle maintained stable rotational speed with minimal fluctuations. The machined components exhibited acceptable dimensional accuracy within permissible tolerances for light to medium-duty applications. Surface finish quality was satisfactory for general workshop use.

In drilling operations, the system produced accurate and concentric holes with minimal deviation. The alignment between the lathe axis and drilling spindle ensured proper hole positioning without requiring repositioning of the workpiece.

Although vibration levels increased slightly at higher speeds, they remained within safe operational limits. The rigid frame structure and proper bearing support contributed to stable machine performance.

Sensor Performance and Accuracy

The performance of integrated sensors was evaluated by comparing IoT readings with standard measuring instruments.

The temperature sensor accurately measured motor temperature variations, with readings closely matching those obtained from an external thermometer. The RPM sensor provided reliable spindle speed measurements, which were verified using a tachometer with minimal deviation.

The vibration sensor effectively detected changes in oscillation levels during increased cutting loads, indicating proper responsiveness. Similarly, the current sensor accurately reflected load variations by showing increased current consumption during machining operations compared to no-load conditions.

These results confirm that the sensor system provides accurate and reliable real-time data for monitoring machine performance.

IoT System Performance

The IoT system was analyzed in terms of data transmission, responsiveness, reliability, and data logging.

The ESP32 microcontroller successfully transmitted sensor data to the cloud platform at regular intervals. The dashboard displayed real-time updates with minimal latency under stable network conditions. Historical data logging enabled visualization of parameter trends such as temperature, vibration, and RPM.

The system also demonstrated effective alert functionality by generating warnings when predefined thresholds were exceeded. During simulated network interruptions, the system resumed normal operation upon reconnection, indicating robustness and reliability.

Comparative Analysis

A comparison between the developed hybrid system and conventional machines highlights several advantages.

The hybrid machine significantly reduces space requirements by combining lathe and drilling operations into a single unit. It also reduces capital investment compared to purchasing separate machines.

Unlike conventional systems that rely on manual observation, the proposed system provides continuous real-time monitoring, improving safety and reducing the risk of machine failure. Although CNC machines offer higher precision, the developed system provides an optimal balance between cost, functionality, and smart monitoring for small-scale applications.

Efficiency and Productivity

The hybrid configuration improves productivity by eliminating the need to transfer the workpiece between machines, thereby reducing setup time and alignment errors.

The integration of IoT monitoring enhances operational efficiency by enabling predictive maintenance. Continuous monitoring of machine parameters helps in identifying potential faults early and reduces unexpected downtime.

Energy consumption analysis indicates efficient operation under moderate loads, and real-time current monitoring allows optimization of power usage. Overall, the system improves equipment effectiveness and operational efficiency.

Limitations

Despite its advantages, certain limitations were observed. The system is primarily suitable for light to medium-duty operations and may not withstand heavy industrial loads. Increased vibration at higher speeds suggests the need for further structural improvements.

Additionally, IoT functionality depends on stable internet connectivity, which may affect real-time monitoring in low-network areas.

Discussion

The results demonstrate that the integration of IoT technology with a hybrid lathe and drilling machine significantly enhances machine intelligence, monitoring capability, and operational reliability. The

system maintains satisfactory mechanical performance while providing valuable real-time insights into machine health.

The study confirms the feasibility of implementing smart manufacturing concepts in small-scale machining systems. The developed system successfully bridges the gap between conventional machines and Industry 4.0 technologies by offering a cost-effective, space-efficient, and intelligent solution.

Advantages of the Developed System Space Optimization

The developed hybrid machine significantly improves workspace utilization by integrating lathe and drilling operations into a single compact unit. Unlike conventional setups that require separate machines, the proposed system minimizes floor space requirements, making it highly suitable for small-scale industries, technical institutions, and laboratories with limited space availability.

Cost Effectiveness

The hybrid configuration reduces overall capital investment by eliminating the need for separate lathe and drilling machines. In addition, maintenance costs are minimized through the integration of IoT-based monitoring, which enables early fault detection and reduces the likelihood of major breakdowns. The use of economical materials and components, such as mild steel structures and ESP32-based microcontrollers, further enhances affordability without compromising system performance.

Multi-Functional Capability

The system offers enhanced operational flexibility by enabling both turning and drilling operations on a single platform. This eliminates the need for workpiece transfer between machines, thereby reducing setup time and alignment errors. The ability to perform sequential machining operations improves productivity and ensures consistent machining accuracy.

Real-Time Monitoring and Data Logging

The integration of IoT technology enables continuous real-time monitoring of critical machine parameters, including temperature, vibration, spindle speed, and

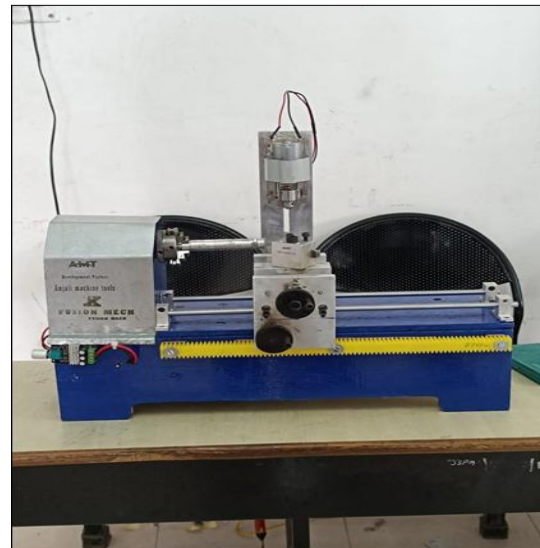
load conditions. This enhances operational awareness and machine safety. Furthermore, the system provides data logging capabilities, allowing storage and analysis of historical data, which supports performance evaluation and predictive maintenance strategies.

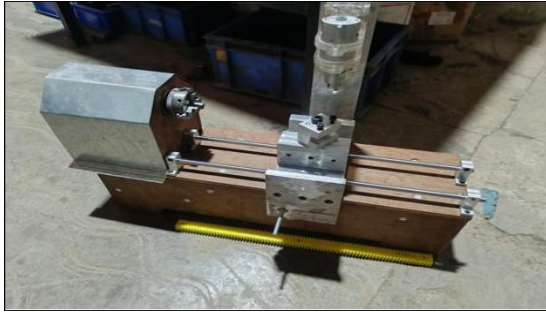
Improved Maintenance and Reliability

The proposed system supports condition-based maintenance by continuously monitoring machine health. Early detection of abnormal conditions, such as excessive vibration or overheating, helps prevent unexpected failures. This reduces downtime, enhances system reliability, and extends the operational life of the machine.

Support for Industry 4.0 Implementation

The developed system demonstrates a practical and cost-effective approach to implementing Industry 4.0 concepts in small-scale manufacturing environments. By integrating mechanical systems with IoT-based digital connectivity, the machine enables remote monitoring, data-driven decision-making, and improved process control. This aligns with modern smart manufacturing practices and provides a foundation for future technological advancement





XII. CONCLUSION



This study presents the design and development of a hybrid lathe and drilling machine integrated with IoT-based monitoring for smart manufacturing applications. The developed system successfully combines multiple machining operations into a single compact unit, thereby reducing space requirements and overall equipment cost.

The integration of IoT technology enables real-time monitoring of critical parameters such as temperature, vibration, spindle speed, and load conditions. This facilitates condition-based maintenance, improves operational reliability, and minimizes unexpected machine failures. Experimental results confirm that the system performs effectively under light to moderate machining conditions while maintaining acceptable accuracy and stability.

The hybrid configuration enhances productivity by reducing setup time and eliminating the need for workpiece transfer between machines. Additionally,

the system demonstrates the practical feasibility of implementing Industry 4.0 concepts in small-scale industries and educational environments.

Overall, the developed system provides a cost-effective, space-efficient, and intelligent solution for modern machining requirements. Future enhancements may include automation through CNC integration and the application of advanced data analytics techniques to further improve system performance and scalability.

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