

# Review on IOT-Based Industrial Automation System

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**Abstract:** Nowadays industrial automation has evolved from basic mechanization to sophisticated, interconnected systems driven by the Industrial Internet of Things (IIoT), artificial intelligence, and low-cost microcontroller platforms. This review examines the integration of Arduino Mega 2560 and NodeMCU ESP8266 microcontrollers with industrial sensors, actuators, and cloud-based monitoring via ThingSpeak, enabling real-time object drilling, material classification (metal vs. non-metal), and color detection applications. Key technologies—including inductive and capacitive proximity sensors, TCS3200 color sensors, stepper-motor-driven conveyor systems, and AI/ML-enhanced control—are analyzed for performance, scalability, and industrial suitability. Market trends indicate the IIoT installed base will nearly double from 56.5 million devices in 2023 to 110.3 million by 2028, while the global IIoT market is projected to exceed \$286 billion by 2029. Challenges such as electromagnetic interference, vibration resilience, IP protection, protocol standardization, and cybersecurity are discussed alongside emerging solutions, including industrial-grade Arduino PLCs, edge computing, and digital twins. Finally, future research directions are identified to advance real-time AI/ML decision-making, enhance interoperability, and develop robust, energy-efficient automation systems—paving the way for broader adoption of Arduino-based smart manufacturing in the era of Industry 4.0.

**Keywords:** Internet of Things, Stepper Motor, ThingSpeak, ESP32, ESP-32, Arduino, Metal Detector, Color Sensor, Drilling Machine

## I. INTRODUCTION

In the era of Industry 4.0, industrial automation has transcended its traditional role of mechanizing repetitive tasks to become an intelligent, interconnected ecosystem that drives efficiency, quality, and flexibility in manufacturing processes. By combining advanced sensing technologies, programmable controllers, and networked communication protocols, modern automation systems can monitor operations in real time, adapt dynamically to changing conditions, and optimize performance with minimal human intervention. Such capabilities are critical for meeting the escalating demands of mass customization, just-in-time production, and zero-defect manufacturing that characterize today's competitive industrial landscape. Central to this transformation is the Internet of Things (IIoT), which serves as the digital backbone of smart factories. IIoT-enabled devices collect vast volumes of sensor data—from temperature and vibration to proximity and color—then transmit it over secure networks for analytics, visualization, and machine-learning-based decision making. Cloud platforms such as ThingSpeak facilitate remote supervision of production lines, enabling maintenance teams to detect anomalies before failures occur and management to gain actionable insights into throughput and quality metrics. At the same time, edge-computing paradigms are emerging to process critical data locally, reducing latency and ensuring robust operation even when network connectivity is intermittent. Among the most accessible and flexible hardware platforms for prototyping and deploying IIoT solutions are Arduino microcontrollers. The Arduino Mega 2560, with its abundant I/O

channels and open-source ecosystem, allows seamless interfacing with a broad spectrum of industrial sensors and actuators. Complementing it, the NodeMCU ESP8266 brings built-in WiFi connectivity and sufficient computational power to bridge field-level devices with cloud services. Together, these modules enable small-scale manufacturers, research institutions, and educational labs to experiment with—and ultimately implement—smart automation processes without the prohibitive capital investment associated with traditional programmable logic controllers (PLCs). This review focuses on the design and implementation of an Arduino-based industrial automation prototype capable of three core functions: 1) automated drilling of workpieces, 2) real-time classification of material type (metal versus non-metal), and 3) color detection for object sorting. We begin by surveying the underlying sensing technologies—inductive proximity sensors for metallic target detection, capacitive proximity sensors for non-metallic object identification, and TCS3200/TCS230 color sensors for spectral analysis—and discuss their operating principles, performance characteristics, and suitability for industrial environments. Next, we examine motor-driven mechanisms, including stepper motors and DC-motor conveyors, and the control strategies used to achieve precise positioning, speed regulation, and synchronized material handling. We then explore IIoT integration via the NodeMCU ESP8266 and ThingSpeak, highlighting the architectural considerations for real-time data acquisition, remote monitoring, and analytics. Beyond system architecture, this paper addresses key challenges in deploying Arduino-based automation solutions in industrial settings, such as electromagnetic interference mitigation, mechanical robustness, ingress protection, protocol interoperability, and cybersecurity. Finally, we outline future research directions—ranging from edge-AI integration and digital-twin modeling to energy-efficient design and standardized IIoT frameworks—that will drive the next wave of innovation in accessible, Arduino-powered smart manufacturing.

## 2. Current State of Industrial Automation Technology:

### 2.1 Market Growth and Adoption Trends:

The industrial automation sector is experiencing unprecedented growth, with the global Industrial IIoT market valued at \$198.2 billion in 2025 and projected to reach \$286.3 billion by 2029, representing a compound annual growth rate of 8.1%. The installed base of wireless IIoT devices in industrial automation reached 56.5 million units in 2023 and is forecasted to grow at a compound annual growth rate of 14.3% to reach 110.3 million units by 2028. This rapid expansion reflects the increasing adoption of IIoT-enabled digital transformation initiatives across various industrial sectors.

**2.2 Arduino in Industrial Applications:** Arduino platforms have evolved from educational tools to viable components in industrial automation systems, though with specific considerations for industrial deployment. While standard Arduino boards face limitations in harsh industrial environments due to electromagnetic interference (EMI), vibrations, and limited IP protection, specialized industrial Arduino controllers and shields have addressed these challenges. Industrial Arduino implementations typically require additional protection through specialized enclosures, EMI shielding, and robust power supplies. Companies like Industrial Shields have developed Arduino-compatible PLCs that meet industrial standards,

including CE, ROHS, and ETL/UL certifications, while maintaining the programming simplicity and flexibility of the Arduino ecosystem.

**2.3 Sensor and Actuator Technologies:** Modern industrial automation relies heavily on diverse sensor technologies for object detection, material classification, and process monitoring. Inductive proximity sensors excel at detecting metallic objects through electromagnetic field disruption, offering sensing ranges from 2 to 100 mm and excellent resistance to industrial contaminants. These sensors are particularly valuable in applications requiring detection of metal objects through non-metallic barriers. Capacitive proximity sensors provide versatility by detecting virtually all materials, including plastics, liquids, and solids through changes in electrostatic fields. Their ability to sense materials through container walls makes them ideal for level detection and non-contact material sensing applications. Smart sensors and actuators represent the next evolution in industrial automation, incorporating built-in processing capabilities, diagnostic functions, and communication interfaces. These devices enable local data processing, self-configuration, and predictive maintenance capabilities that enhance overall system reliability and performance.

### 3. IoT Integration and Cloud Connectivity:

**3.1 NodeMCU ESP8266 and Cloud Platforms:** The NodeMCU ESP8266 microcontroller has emerged as a pivotal component in industrial IoT implementations due to its integrated WiFi capability, low power consumption, and Arduino IDE compatibility. Operating at 80 MHz with 4 MB flash memory and 80 KB RAM, the ESP8266 provides sufficient processing power for sensor data collection, local processing, and cloud communication. ThingSpeak has become a popular cloud platform for industrial IoT applications, offering HTTP and MQTT protocol support for real-time data transmission and visualization. The platform enables remote monitoring of industrial parameters such as temperature, humidity, pressure, and custom sensor readings through web-based dashboards accessible from anywhere globally. Integration of NodeMCU ESP8266 with ThingSpeak typically involves configuring WiFi credentials, API keys, and data transmission intervals to optimize both data accuracy and power consumption. The combination provides a cost-effective solution for industrial monitoring applications that require real-time data access and historical trend analysis.

**3.2 Industrial Communication Protocols:** Modern industrial automation systems require robust communication protocols to ensure reliable data exchange between field devices and control systems. While traditional industrial protocols like Modbus, CAN bus, and Ethernet/IP remain dominant, IoT-enabled devices are increasingly incorporating WiFi, Bluetooth, and cellular connectivity for enhanced flexibility. The challenge of protocol standardization remains significant, with lack of standardization cited as a key barrier to IIoT implementation. Organizations are working toward unified communication standards that can bridge traditional industrial protocols with modern IoT connectivity options.

### 4. Object Detection and Color Sensing Applications:

**4.1 TCS3200/TCS230 Color Sensor Technology:** Color detection has become increasingly important in industrial automation for quality control, sorting operations, and robotic vision systems. The TCS3200 color sensor employs an array of photodiodes with different color filters (16 each for red, green, blue, and clear) to detect color variations through frequency modulation. The sensor operates by illuminating objects with integrated white LEDs and measuring reflected light intensity at specific wavelengths. The photodiode array converts light intensity to frequency signals that can be processed by Arduino microcontrollers to determine object colors with high accuracy. Operating voltage ranges from 2.7V to 5.5V, making it compatible with most microcontroller systems. Industrial

applications include automated sorting systems for manufacturing, quality inspection processes, and robotic assembly lines where color-based decision-making is required. The sensor's ability to differentiate between subtle color variations makes it valuable for applications requiring precise color matching or defect detection.

### 4.2 Proximity Sensing for Material Classification:

Industrial automation systems frequently require discrimination between metallic and non-metallic materials for sorting, quality control, and safety applications. Inductive proximity sensors provide reliable detection of ferrous and non-ferrous metals through electromagnetic field disruption, with sensing distances varying based on target material properties. For non-metallic material detection, capacitive proximity sensors offer versatility by responding to materials with different dielectric constants compared to air. This capability enables detection of plastics, ceramics, liquids, and organic materials through changes in the sensor's electrostatic field. The combination of inductive and capacitive sensing technologies in automated systems enables comprehensive material classification capabilities essential for modern manufacturing and recycling applications.

### 5. Automated Drilling and Machining Systems:

**5.1 Arduino-Based CNC Control:** Automated drilling systems represent a significant application area for Arduino-based industrial automation, offering precise control over drilling depth, position, and operational parameters. These systems typically employ stepper motors for X, Y, and Z-axis movement control, with Arduino microcontrollers managing positioning accuracy and drilling sequences.

Modern Arduino-based drilling systems incorporate features such as depth controllability, automated tool positioning, and wireless control through Bluetooth or WiFi connectivity. The integration of mobile applications for parameter setting and operation monitoring has enhanced the accessibility and usability of these systems. Key components include Arduino controllers (typically Mega 2560 for expanded I/O capability), stepper motor drivers (commonly A4988), precision lead screws, and robust mechanical frameworks. The systems demonstrate the potential for Arduino platforms to control industrial machinery when properly implemented with appropriate safety measures and mechanical design.

**5.2. Conveyor Belt Automation:** Conveyor belt systems represent fundamental components in industrial automation, with Arduino-based control systems offering cost-effective solutions for material handling applications. These systems typically employ stepper motors or DC motors with encoder feedback for precise speed and position control. Arduino-based conveyor control systems can incorporate multiple sensors for object detection, positioning, and safety monitoring. Integration with industrial communication protocols enables coordination with broader automation systems for synchronized operation. The modular nature of Arduino-based conveyor systems allows for scalable implementations, from simple educational demonstrations complex multi-belt industrial installations. Proper mechanical design and component selection are crucial for reliable operation in industrial environments.

### 6. Artificial Intelligence and Machine Learning Integration:

**6.1. Current AI/ML Adoption in Industrial Automation:** Despite significant interest in artificial intelligence and machine learning applications, current adoption in industrial automation projects remains limited, with only 3% of documented projects incorporating AI technologies. However, industry analysts expect substantial growth in AI-driven applications as companies move beyond proof-of-concept implementations toward measurable value

generation. Predictive maintenance represents the most promising application area for AI/ML in industrial automation, with systems analyzing sensor data to predict equipment failures before they occur. Machine learning algorithms can identify patterns in vibration, temperature, and performance data that indicate impending component failures, enabling proactive maintenance scheduling. Quality control applications increasingly leverage computer vision and deep learning for defect detection and classification. These systems can achieve higher accuracy and consistency than human inspection while operating continuously without fatigue.

### 6.2 Edge Computing and Real-Time Processing:

The implementation of edge computing capabilities in industrial automation systems enables real-time data processing and decision-making without reliance on cloud connectivity. This approach reduces latency, improves system responsiveness, and enhances data security by processing sensitive information locally. Arduino-based systems can incorporate edge computing capabilities through more powerful microcontrollers or companion processors that handle AI/ML inference tasks. This distributed processing approach enables intelligent behavior at the device level while maintaining connectivity to cloud platforms for data aggregation and analysis.

## 7. Challenges and Limitations:

**7.1. Technical and Operational Challenges:** Industrial implementation of Arduino-based automation systems faces several significant challenges that must be addressed for successful deployment. Electromagnetic interference (EMI) in industrial environments can disrupt digital signals and affect sensor readings, requiring proper shielding and grounding techniques. Mechanical vibrations common in industrial settings can cause connection failures, program resets, and sensor inaccuracies. Industrial Arduino implementations require robust mechanical mounting, secure connections, and vibration-resistant components. Standard Arduino boards lack the IP protection ratings required for harsh industrial environments, necessitating specialized enclosures or industrial-grade Arduino variants. Temperature extremes, moisture, and chemical exposure further complicate deployment in many industrial applications.

**7.2. Scalability and Integration Issues:** Scaling Arduino-based prototypes to full industrial implementations presents challenges in processing power, memory capacity, and I/O expansion. Complex industrial applications may require real-time operating systems, advanced communication protocols, and fail-safe mechanisms not typically available in standard Arduino environments. Integration with existing industrial control systems requires compatibility with established protocols such as Modbus, Profibus, and Ethernet/IP. While Arduino-compatible solutions exist, they often require additional hardware and software complexity. Long-term support and component availability pose concerns for industrial applications with extended operational lifespans. Industrial systems typically require 10-20 year support commitments that may not align with the rapid evolution of Arduino hardware and software platforms.

**7.3. Security and Compliance Considerations:** Industrial IoT implementations face increasing cybersecurity threats that require comprehensive security measures throughout the system architecture. Arduino-based systems must incorporate encryption, authentication, and secure communication protocols to protect against unauthorized access and data breaches. Regulatory compliance requirements vary by industry and application, with safety-critical systems requiring certifications that standard Arduino boards may not possess. Industrial implementations often require UL, CE, or other safety certifications that necessitate specialized hardware and documentation.

## 8. Future Directions and Research Opportunities:

**8.1. Emerging Technologies and Trends:** The convergence of 5G networks, edge computing, and artificial intelligence promises to accelerate industrial automation capabilities significantly. Enhanced connectivity will enable new applications in remote monitoring, predictive maintenance, and autonomous manufacturing systems. Digital twin technology represents a growing opportunity for industrial automation, allowing virtual modeling and optimization of physical processes before implementation. Arduino-based systems can contribute sensor data and control capabilities to support comprehensive digital twin implementations. Collaborative robotics (cobots) and human-robot interaction present expanding application areas where Arduino-based control systems can provide cost-effective solutions for smaller-scale industrial applications.

**8.2. Research Gaps and Development Needs:** Current research gaps include the need for standardized security frameworks for industrial IoT systems, improved interoperability between different automation platforms, and enhanced real-time capabilities for Arduino-based systems. Development of more robust Arduino-compatible industrial controllers that maintain programming simplicity while meeting industrial standards represents a key opportunity. This includes improved EMI resistance, extended temperature ranges, and industrial communication protocol support. Advanced sensor fusion techniques and AI/ML algorithm optimization for resource-constrained environments require continued research to maximize the potential of Arduino-based industrial automation systems.

## II. LITERATURE REVIEW

This literature survey examines different robotic arm technologies used in pick-and-place operations on conveyor belts. It discusses various actuation methods, such as servo motors, pneumatic systems, and AI-based vision integration for object detection. The survey compares the efficiency and accuracy of different robotic arms in industrial automation and their impact on reducing human intervention. [1].

This study reviews the implementation of proximity sensors and color sensors (TCS3200) in industrial sorting applications. It discusses the working principles, accuracy, and efficiency of these sensors in detecting object presence and classifying materials based on color. The survey also explores sensor fusion techniques for improving object detection and real-time decision-making in automated conveyor systems. [2].

This survey focuses on the use of Arduino-based embedded controllers in conveyor automation. It reviews different techniques for controlling conveyor belt speed, direction, and object handling using sensors and motors. The study also discusses real-time monitoring and IoT integration for predictive maintenance and system optimization, making conveyor systems smarter and more efficient. [3].

This literature review explores the convergence of industrial robotics and IoT in modern manufacturing. It discusses how robotic arms, conveyor belts, and wireless controllers (ESP8266) work together for automated assembly lines. The study highlights advancements in AI-driven automation, cloud-based monitoring, and real-time analytics, emphasizing how IoT enhances robotic efficiency and reduces operational costs. [5].

## III. Future Scope

The ongoing convergence of IoT, artificial intelligence, and affordable microcontroller platforms like Arduino opens numerous avenues for advancing industrial automation. Key future directions include:

**Edge-AI Integration:** Embedding machine learning inference capabilities at the network edge—either within enhanced Arduino-compatible controllers or companion hardware—will enable real-time decision-making for adaptive process control, anomaly detection, and predictive maintenance without relying solely on cloud connectivity.



**Digital Twin Implementation:** Developing comprehensive digital twins of production lines by combining sensor data streams with virtual models will facilitate scenario testing, process optimization, and rapid reconfiguration of manufacturing cells, thereby reducing downtime and accelerating product changeovers.

**Standardized IIoT Protocols and Interoperability:** Establishing unified communication standards that seamlessly bridge traditional industrial protocols (Modbus, ProfiNet, EtherCAT) with modern IoT technologies (MQTT, OPC UA, HTTP/2) will simplify integration, enhance system scalability, and accelerate Industry 4.0 adoption across heterogeneous equipment landscapes.

**Robust, Industrial-Grade Arduino Controllers:** Designing Arduino variants or shields that meet strict industrial certifications (IP ratings, EMI/EMC compliance, extended temperature ranges) while retaining open-source programmability will expand their applicability in harsh environments and safety-critical applications.

**Sustainable and Energy-Efficient Automation:** Incorporating low-power sensor networks, energy-harvesting techniques, and optimized drive systems will reduce the environmental footprint and operational costs of automated processes, aligning with global sustainability goals and regulatory requirements.

**Human-Robot Collaboration (Cobots):** Integrating Arduino-based control systems with collaborative robotic platforms will enable cost-effective deployment of safe, human-robot workcells for tasks requiring fine manipulation, visual inspection, or flexible handling in small-batch or customized production.

**Enhanced Cybersecurity Frameworks:** Implementing end-to-end security measures—such as device authentication, encrypted communications, and anomaly-based intrusion detection—tailored to resource-constrained Arduino and IoT devices will safeguard industrial control systems against evolving cyber threats.

#### IV. Review Technology

S. No.	Main Topic Area	Sub-Topics for Review
1	IoT Fundamentals	IoT architecture, IoT protocols, edge vs. cloud computing in IoT, IoT data flow
2	Industrial Automation Basics	PLCs, SCADA systems, industrial sensors & actuators, factory automation trends
3	Conveyor Belt Automation	Motor control, load management, object detection on conveyors
4	Robotic Arm in Automation	Robotic arm kinematics, pick-and-place mechanisms, precision control
5	Object Handling & Sorting	Shape-based sorting, color-based sorting, weight-based sorting
6	Drilling Automation	Automated drilling machine design, depth control, safety mechanisms
7	Proximity & Object Detection	Sensing technologies for industrial safety & automation
8	Material Classification	Machine learning for classification, spectral analysis
9	IoT Connectivity in Factories	Wireless communication, edge gateways, industrial IoT integration
10	Data Collection & Monitoring	Real-time monitoring, predictive maintenance, analytics dashboards
11	Energy Efficiency & Power Management	Low-power IoT devices, power supply optimization
12	Safety & Standards in Automation	Industrial safety protocols, regulatory compliance
13	System Integration & Testing	Hardware-software integration, industrial communication protocols
14	Cloud & Edge Processing	Cloud storage, AI at the edge, latency management

15	Future Trends in IIoT	AI-driven automation, digital twins, Industry 4.0 adoption
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#### V. CONCLUSION

Industrial automation is advancing rapidly with IoT, AI, and platforms like Arduino. While scaling Arduino-based systems for industrial use poses challenges, improvements in industrial-grade controllers, security, and communication standards are addressing them. Combining Arduino microcontrollers, specialized sensors, IoT connectivity (e.g., NodeMCU ESP8266), and cloud monitoring offers a practical solution for many applications. Success depends on environmental considerations, proper component choice, and compliance with standards. Future growth will be driven by AI/ML integration, edge computing, and digital twin technology, expanding Arduino's role in industrial automation. Its cost-effectiveness, flexibility, and strong community support make it accessible to smaller enterprises, enabling innovations once limited to large corporations. This democratization is set to boost Industry 4.0 adoption and smart manufacturing worldwide.

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