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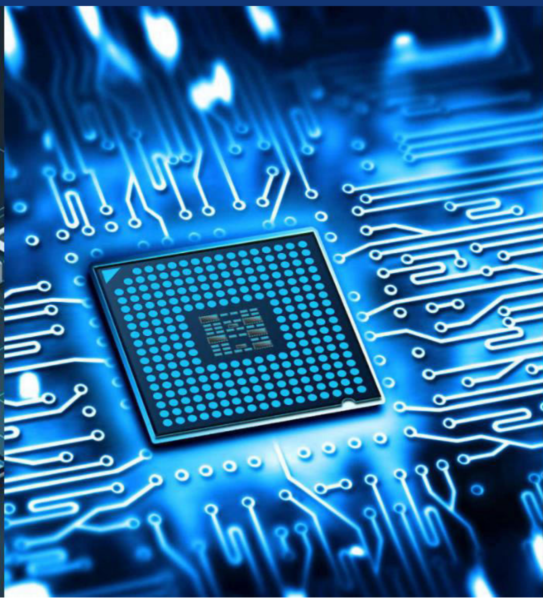


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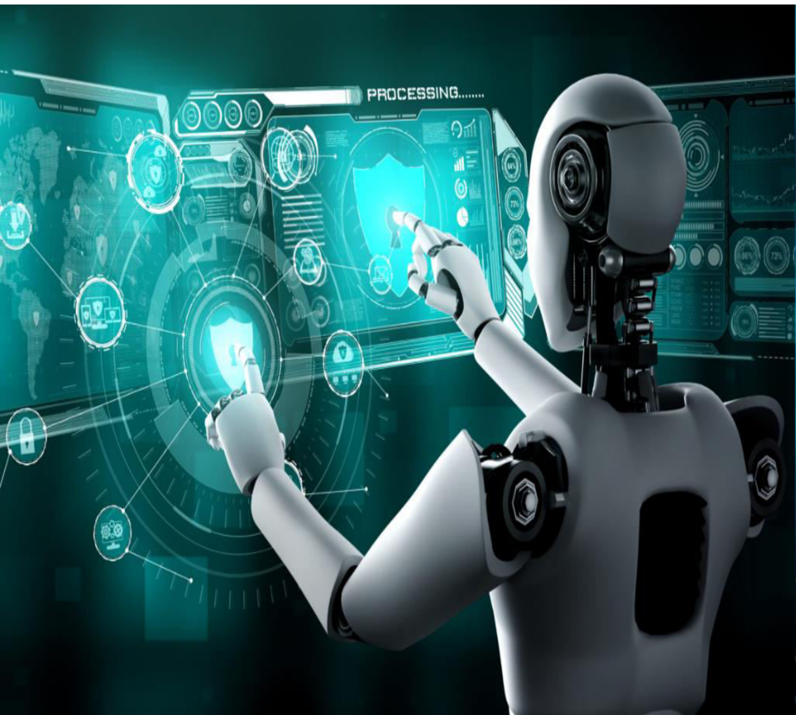

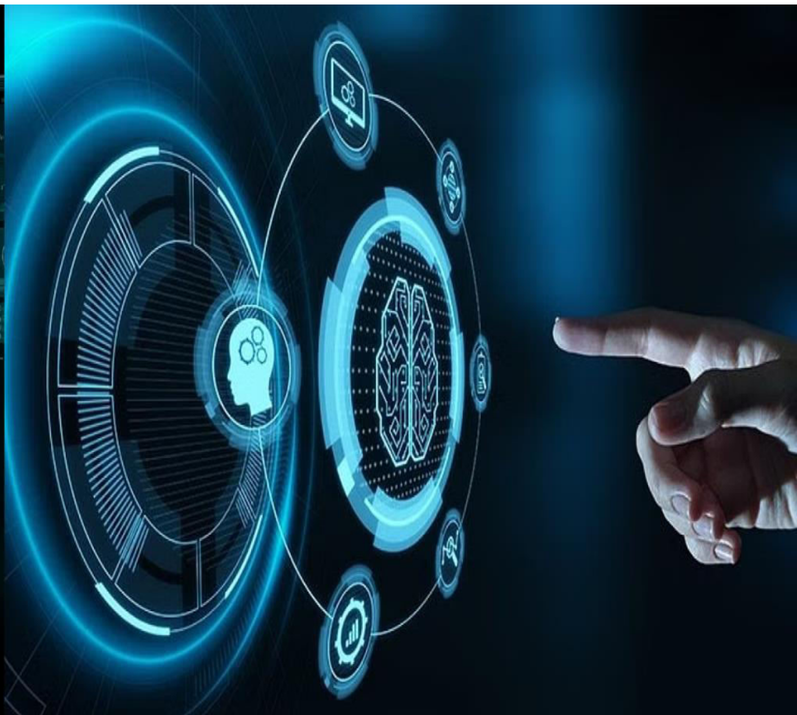

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Evolution of IoT-Enabled Logistics: A Survey on Tracking, Monitoring, and Cold Chain Management

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ABSTRACT: Traditional shipment tracking focuses primarily on location but often overlooks real- time monitoring of critical environmental factors like temperature, humidity, and shock. For delicate products like expensive electronics, perishable food, and medications, this disparity presents serious hazards. This study examines how logistics management has changed over time, moving from traditional approaches to sophisticated IoT- enabled solutions. It emphasizes significant developments in environmental sensing, data- driven decision-making, and real-time tracking. This Paper offer insights into how IoT is changing logistics for increased dependability and efficiency by examining contemporary frameworks and technologies.

KEYWORDS: IoT, GSM, Cloud Computing, AI/ML.

I. INTRODUCTION

The increasing IoT integration in logistics enhances monitoring and control through networked systems and allows for real-time tracking of cargo storage, inventory, and delivery status. By utilizing sophisticated algorithms, cargo tracking becomes more effective, guaranteeing improved shipment management and location.
A cargo-level tracking system that offers continuous monitoring and economical and energy-efficient solutions is suggested as a solution to the problems associated with cargo positioning. Temperature sensors are used to sent via WIFI to Android smartphones. By overcoming the shortcomings of previous techniques that lacked real-time transmission and security, this guarantees efficient monitoring of chilled freight. For valuable or delicate items, the method is especially helpful because real-time updates improve shipment dependability and safety. Nearly 128 million twenty-foot containers were moved globally in 2014 as a result of the quick growth of international trade. Many of these carried temperature-sensitive goods that need a regulated cold supply chain to preserve quality, like vaccinations, perishable food, and human organs. Product integrity can be greatly impacted by variables such as humidity, intense vibrations, and light exposure in addition to temperature management. By avoiding spoiling and preserving ideal conditions, real-time monitoring of these environmental factors improves cargo dependability and service quality.
Shipment delays or even the total loss of container contents present another significant logistical difficulty. By sharing information with pertinent parties, a tracking system that can follow a user's whereabouts in real time helps mitigate these hazards. Strict security precautions are also necessary for certain shipments, guaranteeing that containers stay sealed and unaltered during transportation. Enhancing overall shipment efficiency and confidence in the logistics process, a strong system with constant connectivity ensures stakeholders have access to real-time updates on cargo status, location, and security.

II. LITERATURE SURVEY

In Logistics assets are connected by IoT, allowing for smooth communication. Sensors keep an eye on cargo parameters including temperature, humidity, and vibration to protect fragile and perishable commodities. RFID tags store EPCs for real-time inventory tracking updates. In order to take preventative action, WSNs gather environmental data and wirelessly transmit it. WSNs make geofencing, route optimization, and real-time tracking possible when paired with GPS. [1] Key logistics issues are highlighted in the examined articles, such as poor tracking, cargo theft, a lack of real-time monitoring, and improper cold storage management. IoT, GPS, WSNs, and cloud platforms are combined to address these. [2]

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To create a Logistics 4.0 framework that integrates Industry 4.0 concepts to meet changing customer needs and global competition, the paper "Logistics 4.0: A Systematic Review Towards a New Logistics System" examines 114 studies.[3] Logistics 4.0 is a digital revolution that uses IoT, Big Data, cloud computing, CPS, blockchain, and AI to optimize cost, sustainability, and efficiency. While these technologies present issues like as data security, integration obstacles, and human- machine collaboration, they also improve automation, supply chain visibility, predictive analytics, and real-time decision-making. Six essential elements are identified by the study: automation, decentralized decision-making, sustainability, and real-time data integration. Although more study is required in the areas of interoperability, cybersecurity, and human factors, the authors suggest that logistics will depend on intelligent, networked systems.[3]

Real-time data from RFID, WSNs, and IoT devices is gathered and analyzed by cloud systems. They support predictive logistics by producing notifications for abnormalities such as unauthorized entry or harsh circumstances. Package-specific data is integrated via QR codes and BLE-based tracking, which notifies cloud servers and in-car devices in the event of theft or damage.[4]
Advances in UWB technology for precise location in smart logistics are reviewed in the paper "Precision Positioning for Smart Logistics Using Ultra-Wideband Technology-Based Indoor Navigation." [6] Because of its wide bandwidth, high penetration, and low transmission power, UWB is unique among indoor positioning systems (IPS) and is therefore perfect for indoor navigation. Nevertheless, issues like signal interference and non-line-of-sight (NLOS) mistakes continue to exist. To improve accuracy, the study looks at machine learning, sensor fusion, and important positioning strategies like TOA, TDOA, and AOA. Real-time tracking, supply chain automation, and increased worker safety are just a few of the logistics uses for UWB. In addition, the paper discusses licensing, system topologies, and commercial adoption while contrasting UWB with Wi-Fi, Bluetooth, and RFID. Even though UWB provides better precision, more study is required to address issues with scalability and cost in large industrial settings. [6]

This literature survey also reviewed a Blockchain and IoT-based framework for secure tracking, traceability, and real-time monitoring of agricultural food supply chains. The research addresses critical challenges such as food spoilage, supply chain inefficiencies, and security risks in transportation. The proposed system integrates Radio Frequency Identification (RFID), Wireless Sensor Networks (WSN), and Blockchain technology to ensure transparency and authenticity in tracking perishable food products. The framework utilizes real-time environmental monitoring sensors to track temperature, humidity, and other critical parameters, preventing product deterioration. Additionally, Blockchain technology ensures tamper-proof transaction records, strengthening trust among producers, suppliers, and consumers. The research also integrates Machine Learning (ML) models to predict potential supply chain disruptions and backorder risks, optimizing logistics management. The findings indicate that IoT and Blockchain significantly enhance food supply chain security, traceability, and operational efficiency. However, challenges such as integration complexities, high implementation costs, and data security concerns remain. The study concludes that adopting intelligent tracking systems can reduce food wastage, enhance regulatory compliance, and improve consumer trust in agricultural supply chains. [7]

The use of big data predictive analytics and traffic IoT to improve logistics in the logistics 4.0 era is examined in the paper "Pragmatic Real-Time Logistics Management with Traffic IoT Infrastructure." [8] Road conditions, weather, and traffic make it difficult to anticipate freight transit times with any degree of accuracy. By segmenting the regression tree to capture time-varying information, the authors' Gradient Boosting Partitioned Regression Tree (GBPRT) model enhances real-time predictions. When compared to other models, empirical testing utilizing actual traffic IoT data demonstrate greater predictive accuracy. The study emphasizes how machine learning, big data, and Internet of Things sensors optimize freight routing, lower uncertainty, and improve logistics effectiveness. These results highlight how crucial data-driven decision-making is to enhancing Logistics 4.0's responsiveness, agility, and cost-effectiveness.[8]

According to a study on IoT in smart logistics, real-time tracking, automation, and data-driven decision-making can all help to improve distribution, warehousing, and transportation. Even with increased efficiency, problems like interoperability and data security still exist. Cost- effective and environmentally friendly logistics are thought to be greatly aided by IoT.[9]

Another study highlights how tracking and tracing technology improve visibility, operational control, and customer satisfaction in contemporary supply chains. It assesses the viability and performance of Auto-ID technologies such as barcodes, RFID, QR codes, and satellite tracking. According to experimental data, RFID is the most effective technology, whereas barcodes and QR codes perform poorly in challenging environments. The study offers useful insights for logistics tracking optimization by recommending tracking solutions based on operational requirements, cost, and environmental factors. [12]

These studies demonstrate how the Internet of Things (IoT) turns conventional logistics into intelligent systems that improve supply chain transparency, lower theft or environmental damage losses, and maximize resource use. They stress the importance of traceability in fresh produce supply chains for regulatory compliance, food safety, and quality control. However, complete coverage and interoperability are frequently absent from current traceability solutions. The authors suggest AgroTRACE, an Internet of Things-based system that combines blockchain, WSNs, RFID, and QR codes for real-time data sharing and monitoring, as a solution to this problem. It improves accountability, efficiency, and transparency in a variety of supply chain phases, including waste management. AgroTRACE improves food safety and decreases waste by providing superior modularity, interoperability, and open access as compared to competing systems.[13]

Existing impact monitoring solutions in shipment transport often lack accuracy and real-time responsiveness, leading to undetected mishandling and potential product damage. To address these limitations, the study introduces a smart impact detection system that utilizes advanced sensors and data processing techniques for real-time impact assessment. By continuously tracking shipment conditions, the system enhances monitoring reliability and provides actionable insights to minimize losses. The research demonstrates that integrating such technology into logistics can significantly improve efficiency and ensure better product safety during transportation.[14]

III. KEY TECHNOLOGIES OF IOT

Technology	Era	Key Features	Applications	Limitations
GSM & 2G Networks	Early 2000s	Basic tracking, SMS-based alerts	Vehicle tracking, fleet management [1 12]	Slow data speeds, unreliable for real-time monitoring
3G Networks	Mid-2000s	Faster data speeds, lower latency	Vehicle diagnostics, environmental monitoring [1 2 4]	Coverage gaps, high costs in remote areas
4G LTE & LTE- M	2010s	High-speed, reliable connectivity	Real-time tracking, urban and industrial IoT [5 6]	High power consumption, urban focus
LPWAN (LoRa, NB-IoT)	2015-Present	Long-range, low-power	Remote container tracking, cold chain monitoring [3 5 9]	Limited bandwidth, slower data rates
Satellite IoT	2010s-Present	Global coverage, continuous connectivity	Maritime logistics, remote industrial tracking [10]	Expensive, high latency
5G Networks	2020s	Ultra-low latency, high- speed	Autonomous vehicles, drone deliveries, smart warehouses [2 3]	Infrastructure not widespread yet
RFID	2000s-Present	Object identification, EPC tracking	Warehouse automation, inventory tracking [5]	Limited range, requires infrastructure (readers)
WSN (Wireless Sensor Networks)	2010s-Present	Environmental monitoring (temperature, humidity)	Cold chain logistics, perishable goods tracking [12]	Power constraints, interference issues

BLE & Zigbee	2010s-Present	Short-range, low-power tracking	Warehouse and package-level tracking [4]	Limited range, interference from other devices
Cloud Computing	2010s-Present	Centralized storage, real-time analytics	Scalable logistics management, data analysis [8]	Security and data privacy concerns
Artificial Intelligence (AI) & Machine Learning (ML)	2015-Present	Predictive analytics, optimization	Route planning, warehouse automation, predictive maintenance [8 9 12]	High computational power required
Blockchain	2020s-Present	Immutable data records, smart contracts	Secure transactions, fraud prevention, supply chain transparency [7 13]	High implementation complexity, scalability issues

Table 1: Comparison of Technologies used over the evolution of IoT-Enabled Logistics

IV. CONCLUSION

The evolution of IoT-enabled logistics has significantly transformed supply chain management by enhancing real-time tracking, automation, and data-driven decision-making. Based on the literature reviewed, the integration of advanced microcontrollers, robust sensors, and efficient communication protocols is crucial for optimizing logistics operations. Among the various microcontrollers analyzed, the ESP32 and ARM Cortex-M series stand out due to their high processing power, low energy consumption, and seamless connectivity with IoT platforms. These controllers enable real-time data acquisition and processing, making them ideal for smart logistics applications. In terms of sensors, GPS modules such as the Ublox NEO series ensure accurate location tracking, while RFID and NFC technologies improve inventory management. Environmental sensors like DHT22 for temperature and humidity and accelerometers such as MPU6050 play a vital role in monitoring cargo conditions, ensuring product quality throughout transit. For seamless communication, LPWAN technologies like LoRa and NB-IoT are highly effective for long-range, low-power applications, while 5G connectivity is emerging as a game-changer in real-time logistics management. Cloud-based analytics and AI-driven predictive models further enhance efficiency by optimizing routes, detecting anomalies, and reducing operational costs.

Future advancements in IoT-enabled logistics will likely be driven by AI, blockchain for secure data management, and edge computing to enable faster decision-making at the device level. A well-integrated system combining these technologies will pave the way for a more reliable, cost-effective, and intelligent logistics network.

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