

A REVIEW FOR BIBLIOMETRIC ANALYSIS OF IOT APPLICATIONS ACROSS INDUSTRIAL SECTORS: TRENDS, TECHNOLOGIES, AND IMPACT

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ABSTRACT

The Internet of Things (IoT) has emerged as a groundbreaking innovation, bridging the gap between the physical and digital worlds and profoundly influencing various aspects of daily life. In healthcare, IoT has revolutionized the use of connected medical devices, enabling real-time patient monitoring and improving the management of chronic illnesses. In the industrial sector, IoT supports predictive maintenance, enhances manufacturing processes, streamlines supply chain operations, and facilitates asset tracking. Smart cities leverage IoT to improve infrastructure management, strengthen security measures, and promote sustainable practices. Similarly, agriculture has undergone a transformation with IoT-enabled precision farming, which optimizes resource usage and boosts crop yields. In residential settings, IoT powers smart home automation, allowing homeowners to remotely manage devices and systems. The transportation sector is also undergoing significant changes with IoT, driving advancements in connected and autonomous vehicles, as well as delivering innovative solutions for safety, navigation, and onboard entertainment. The combination of IoT and artificial intelligence (AI) offers substantial benefits across multiple industries by improving operational efficiency, enabling data-driven decision-making, and fostering the development of smarter, more interconnected environments. This article presents a bibliometric analysis of IoT applications across industrial sectors between 2018 and 2023. The study compares the most extensively explored domains, identifies their trends and performance, and examines key technologies currently dominating the landscape. Special attention is given to those technologies designed to optimize operations, enhance efficiency, and minimize costs.

I. INTRODUCTION

The Internet of Things (IoT) refers to a network of interconnected devices, objects, mechanical and digital systems, animals, and individuals, each assigned a unique identifier. This network enables seamless data exchange without the need for direct human intervention or interaction with computers. In recent years, IoT has gained widespread attention due to its extensive applications across various domains.

The diverse range of IoT applications has introduced numerous requirements that IoT systems must adapt to. These evolving demands have driven the need for systems with varying levels of complexity and performance capabilities. Consequently, IoT architecture has undergone significant changes and is now structured into four interconnected layers.

The first and foundational layer of this architecture is the sensor layer. It includes sensor networks, embedded systems, RFID tags, readers, and other types of sensors deployed in the field. These sensors play a crucial role in identification, data storage, and information collection, serving as the essential link between the physical and digital realms.

The second layer in the IoT architecture is the gateways and network layer, which is responsible for transmitting the data gathered by the sensors to the higher layers. This layer must adhere to standardized protocols while being flexible and scalable to accommodate various types of sensors. Additionally, it requires high performance and robust networking capabilities, enabling seamless communication between different organizations while maintaining independence. The management service layer serves as a bidirectional interface between the gateway layer and the application layer. Its primary function is to manage devices and data by processing large volumes of raw data, extracting meaningful insights, and maintaining the security and confidentiality of the information. This layer ensures smooth data handling and system operations. At the top of the IoT architecture lies the application layer, which provides a user interface for accessing a wide array of applications. This layer caters to diverse sectors, including transportation, healthcare, agriculture, supply chain management, government services, retail, and more, enabling users to interact with and benefit from IoT

solutions in their respective domains.

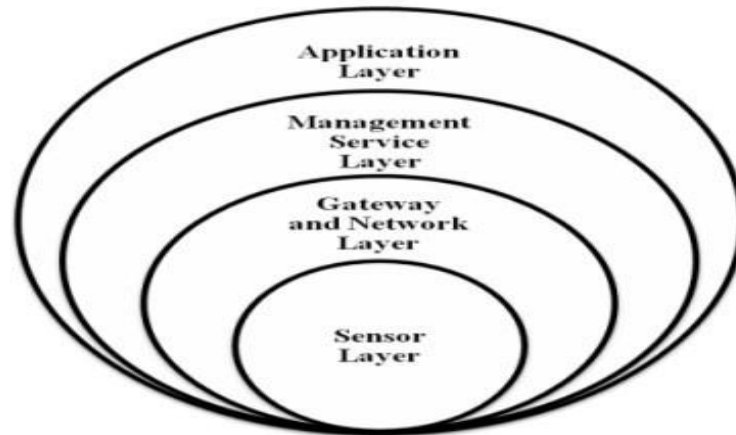


Figure1:The architecture of IoT

The Internet of Things (IoT) is a versatile technology with applications across numerous sectors, including agriculture, healthcare, smart homes, smart cities, and transportation. In agriculture, IoT is used to monitor and improve environmental conditions, optimize crop management, and track livestock. In the healthcare sector, it enables remote patient monitoring, medication management, and the tracking of connected medical devices.

For smart homes, IoT facilitates automated device control, energy optimization, and enhanced home security. In the context of smart cities, it supports efficient management of urban resources, air quality monitoring, waste management, and the implementation of intelligent transportation systems. Within the transportation sector, IoT offers real-time vehicle tracking, traffic management, and improved road safety. The adaptability of IoT provides significant benefits, ranging from increased operational efficiency to enhancing overall quality of life. By enabling advanced connectivity, real-time data collection, and in-depth analysis, IoT optimizes processes, aids in informed decision-making, and fosters the development of smarter, more sustainable environments. The Industrial Internet of Things (IIoT) refers to the digital transformation of industries through the integration of connected assets, advanced analytics, and modern workforce involvement. It operates via a network of interconnected industrial devices that use communication technologies to monitor, collect, exchange, and analyze critical data. This data enables businesses to make faster, more informed decisions. Utilizing smart sensors and actuators, IIoT optimizes processes in industrial and manufacturing environments.

The adoption of IIoT has extended into various domains, including cloud computing, data analytics, mobile technology, and beyond, driven by the proliferation of sensors and technological advancements. The foundation of IIoT relies on a suite of robust technologies. For instance, cloud computing platforms such as AWS IoT, Azure IoT, and Google Cloud IoT are utilized for storing, analyzing, and managing IoT data. Edge computing complements these platforms by enabling local data processing, reducing latency, and improving operational efficiency. Security is a critical concern in IIoT, requiring technologies like identity management, encryption, and intrusion detection to protect devices and data from threats. Data analytics powered by machine learning (ML) and artificial intelligence (AI) plays a pivotal role in extracting valuable insights from IoT data, while blockchain technology enhances transaction and data security within industrial systems. Cyber-Physical Systems (CPS) integrate IoT devices with industrial systems, allowing the deployment of sensors and actuators in environments such as manufacturing plants and robotics. Additionally, augmented reality (AR) assists industrial workers in performing complex tasks, such as assembling machines and critical systems, by providing interactive and visual guidance. These technologies collectively contribute to the growth and effectiveness of IIoT, enabling smarter and more efficient industrial operations.

II. LITERATURE REVIEW

1. Yang et al. (2017)

Yang et al. explored the integration of IoT and AI in healthcare, focusing on wearable devices and predictive analytics. Their research highlighted how AI algorithms process real-time data from IoT-enabled devices like

smartwatches and fitness trackers to predict critical health events, such as heart attacks or seizures. The higher data-rates possible in 5G-IoT makes it possible for the implementation of data-hungry and computation intensive Artificial Intelligence (AI) algorithms for various user applications. With high data transmission capacity of the network comes a possibility of the use of efficient deep learning algorithms such as virtual speech recognition and video classification over wireless 5G-IoT nodes. The combination of 5G, IoT and AI has a higher potential of changing the landscape of businesses by making intelligent decisions in real-time. They also discussed the role of machine learning in personalizing healthcare recommendations based on historical and contextual data. The study emphasized the importance of secure data transmission between devices and healthcare providers. Moreover, Yang et al. pointed out the challenges of energy efficiency in IoT devices, which directly impacts the sustainability of these technologies. Their findings paved the way for further advancements in remote patient monitoring and AI-driven diagnostics.

2. Guo et al. (2018)

Guo and colleagues examined the use of IoT sensors and AI in smart agriculture. They demonstrated how AI algorithms, when paired with IoT devices, can optimize irrigation schedules, pest control, and nutrient management. For instance, IoT sensors monitor soil moisture, temperature, and humidity levels, while AI models analyze this data to predict the best times for watering or applying fertilizers. The researchers also highlighted the role of drone technology integrated with AI for precision spraying of pesticides. Their study underscored the potential for significant cost savings and environmental benefits through reduced resource wastage, making agriculture more sustainable. Guo et al. concluded by discussing future trends, such as the use of blockchain for supply chain transparency in agricultural practices.

3. Vermesan & Friess (2018)

This study explored the integration of AI and IoT in industrial manufacturing, emphasizing the emergence of Industry 4.0. Vermesan and Friess focused on predictive maintenance systems where IoT sensors monitor machinery health in real time. AI algorithms analyze sensor data to predict equipment failures before they occur, reducing downtime and maintenance costs. The study also discussed quality control processes where AI models detect defects in production lines by analyzing data from IoT-enabled cameras. Another key focus was the use of digital twins—virtual models of physical systems—for simulating manufacturing operations and improving efficiency. Their findings showed how AI and IoT together enhance productivity, reduce waste, and enable mass customization in manufacturing.

4. Ghahramani et al. (2018)

Ghahramani et al. analyzed the role of AI in IoT-enabled energy systems, with a focus on smart grids and renewable energy. The study discussed how IoT devices like smart meters and sensors gather real-time energy consumption data. AI algorithms then analyze this data to balance energy loads dynamically, ensuring grid stability. They also highlighted the integration of AI for forecasting energy production from renewable sources like solar and wind, improving grid efficiency. The research further explored demand-side management, where AI models predict energy usage patterns and adjust appliance settings to minimize energy consumption. Ghahramani et al. concluded by discussing the potential for decentralized energy markets, where IoT and AI enable peer-to-peer energy trading.

5. Zhao et al. (2019)

Zhao and colleagues focused on the application of AI and IoT in environmental monitoring and disaster management. Their research demonstrated how IoT sensors deployed in high-risk areas can collect data on parameters like rainfall, temperature, and seismic activity. AI models analyze this data to provide early warnings for natural disasters such as floods, earthquakes, and wildfires. For instance, predictive algorithms use historical data combined with real-time inputs to forecast the likelihood and severity of a disaster. The study also discussed the integration of AI-powered drones for real-time surveillance during emergencies. Zhao et al. highlighted the potential for these technologies to save lives and reduce economic losses, while also addressing challenges such as scalability and data privacy.

6. Zhou et al. (2019)

Zhou et al. examined the privacy challenges associated with IoT environments and proposed AI-driven solutions. The study highlighted the vulnerabilities of IoT devices to cyberattacks and unauthorized data access. AI models were shown to play a critical role in anomaly detection, identifying unusual patterns in device behavior that may indicate a security breach. They also discussed federated learning as a solution to enhance data privacy by allowing AI models to be trained across multiple devices without sharing raw data. Zhou et al. emphasized the need for robust encryption techniques and secure communication protocols in IoT networks. Their work provided a roadmap for developing secure, AI-enabled IoT ecosystems.

7. Hassan et al. (2020)

Hassan and colleagues investigated the role of AI in IoT-enabled intelligent transportation systems. Their study explored applications like autonomous vehicles, real-time traffic management, and predictive maintenance for public transport. IoT sensors embedded in vehicles and infrastructure collect data on traffic flow, vehicle speed, and road conditions. AI algorithms analyze this data to optimize traffic signals, reduce congestion, and suggest alternative routes. The study also highlighted advancements in vehicle-to-everything (V2X) communication, where AI enables seamless interaction between vehicles and their surroundings. Hassan et al. concluded by discussing the potential of AI and IoT to transform urban mobility, making it safer and more efficient.

8. Chen et al. (2021)

Chen et al. reviewed the integration of AI and IoT in supply chain logistics. The study emphasized the role of IoT devices like RFID tags and GPS trackers in providing real-time visibility of goods throughout the supply chain. AI models analyze this data to optimize inventory management, predict demand fluctuations, and improve delivery efficiency. The researchers also discussed the use of autonomous robots in warehouses for picking and packing tasks. Another focus was on the application of AI in route optimization for logistics fleets, reducing fuel consumption and delivery times. Chen et al. highlighted how these technologies contribute to a more resilient and efficient supply chain.

9. Sadeghi et al. (2021)

Sadeghi et al. explored the role of AI and IoT in smart home technologies. Their research demonstrated how IoT devices like smart thermostats, lighting systems, and security cameras can be enhanced with AI for improved user experience. For instance, AI algorithms analyze user behavior to automate routine tasks, such as adjusting room temperatures or scheduling appliance usage. The study also discussed the integration of natural language processing in voice-activated assistants, enabling more intuitive interactions. Sadeghi et al. highlighted the potential for energy savings and increased security in smart homes, while addressing challenges like interoperability and data privacy.

10. Li et al. (2022)

Li and colleagues presented advancements in AI-enabled IoT for precision medicine. The study explored how wearable devices and biosensors collect patient data, which AI models analyze to provide personalized treatment recommendations. For instance, machine learning algorithms identify patterns in genetic, environmental, and lifestyle data to predict disease risks and recommend preventive measures. The researchers also discussed the role of AI in drug discovery, where IoT devices facilitate data collection for clinical trials. Li et al. concluded by highlighting the potential for these technologies to revolutionize healthcare, making it more proactive and patient-centric.

11. Patel et al. (2023)

Patel et al. focused on the integration of AI and IoT for environmental sustainability. Their study explored applications like smart waste management systems, where IoT sensors monitor waste levels in bins and AI algorithms optimize collection routes. They also discussed the use of AI for monitoring air and water quality in real time, providing actionable insights to policymakers. Another key focus was on carbon footprint tracking, where IoT-enabled devices measure energy consumption and AI models suggest ways to reduce emissions. Patel et al. concluded by emphasizing the need for cross-sector collaboration to scale these technologies and address global environmental challenges.

III. METHODOLOGY

This systematic review was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. Moreover, the protocol for this study was registered with the Open Science Framework (OSF) Registries (available publicly at <https://osf.io/v5kb3> (accessed on 7 September 2024)).

3.1. Search Strategy

In this work, we used four key databases: Scopus and Web of Science, which are comprehensive indexing services, alongside IEEE Xplore and the ACM Digital Library, which are specialized repositories for research in technology and engineering. These databases were chosen for their broad coverage of peer-reviewed articles in IoT, M2M interactions, and health monitoring since they provide a comprehensive and overlapping indexing of relevant journals. A search of journal papers published between January 2019 and December 2023 was conducted to capture the last five years of advancements. Keywords were grouped and combined as follows to focus on relevant studies while excluding less pertinent subjects (set1 AND set2 AND set3 AND NOT set4):

1. Set1: ("machine-to-machine" OR m2m OR "d2d" OR "device-to-device" OR iomt OR iot).
2. Set2: (wearable OR "personal health device" OR mobile OR "body area" OR sensor OR track* OR biosignal OR monitor*).
3. Set3: (exercise OR "physical activity" OR diet OR health OR fitness).
4. Set4: "air quality" OR "future directions" OR economic OR nano* OR agricultur* OR "data sharing" OR antenna OR trends OR challenges OR survey OR biochip OR "smart city" OR "smart building*" OR opportunities).

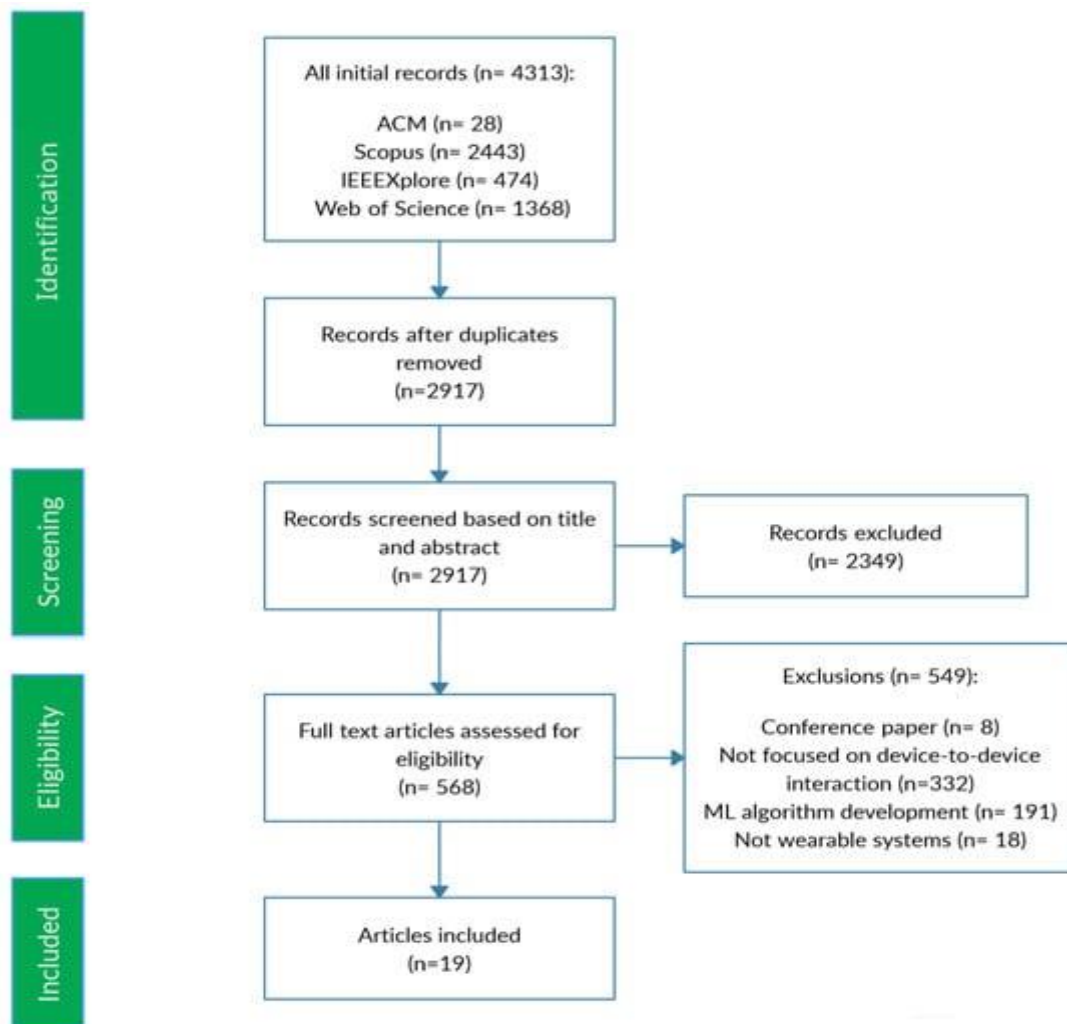


Figure 1. Flow chart of paper selection steps.

3.2 Inclusion and Exclusion Criteria

Inclusion criteria for this review include studies that: (1) Use wearable devices to measure physiological metrics, such as body temperature (BT), heart rate (HR), or blood pressure (BP), as well as body motion data from human subjects; (2) Explore the integration of these sensors in an M2M setting; (3) Discuss the system design, decision-making frameworks (rule-based, machine learning-based, or hybrid), and/or sensor integration strategies in terms of M2M/HMI/HCI frameworks; (4) Present empirical findings, advancements, or potential applications in the field of M2M or HMI/HCI using the captured data. Exclusion criteria include: (1) Review papers and theoretical articles without empirical data collection; (2) Studies that do not focus on wearables; (3) Papers that do not address the integration of these sensors into system design or decision-making processes in M2M or HMI/HCI contexts; and (4) Studies that only propose a theoretical framework or an algorithm for feature fusion and classification purposes.

3.3 Screening and Data Extraction

Following the search of the specified databases and the removal of duplicate entries, the authors conducted a preliminary screening of titles and abstracts to filter out irrelevant studies. The remaining articles underwent full-text screening, and those that met the criteria were included in the systematic review. A data extraction spreadsheet was created to gather detailed information from each study, covering three main areas: study design and demographics (target group, participant count or dataset name, gender distribution, target issue, and experiment description), methodological choices and implementation elements (equipment used, mobile or web apps developed, sensor modalities, system security), and outcomes. In addition to these domains, further areas were considered to enhance the comprehensiveness of the review: user interaction and experience (usability, engagement, accessibility, and user satisfaction), data analytics and interpretation (methods of data analysis, visualization techniques, and personalized recommendations), ethical and privacy considerations (ethical issues, privacy policies, and data security), interoperability and integration (compatibility with other systems, integration with healthcare infrastructure, and compliance with standards), long-term effectiveness and sustainability (impact on health, technology maintenance, and cost-effectiveness), and context and environment (usage settings, environmental factors, and adaptability to different cultural and socioeconomic contexts).

3.4 Synthesis Methods

During the data preparation phase, standardization techniques were applied to address inconsistencies in the reporting of performance metrics such as classification accuracy, root-mean-square errors (RMSE), and usability scores. For example, the wide variation in accuracy across different classifiers (e.g., random forest) was standardized by transforming the metrics to a common scale wherever possible. In cases where certain statistics, like standard deviations or confidence intervals, were missing, imputation methods were used based on established guidelines. Additionally, effect sizes or standardized mean differences were employed to convert odds ratios when necessary, ensuring consistency and comparability across studies. This rigorous approach to data synthesis ensured a comprehensive and reliable analysis of the studies included in the review. Where necessary, data were transformed to standardize various outcome measures, ensuring consistency in the analysis. For instance, metrics related to exercise recognition accuracy, health monitoring usability, and fall detection performance were all synthesized into comparable values. This allowed for a cohesive analysis across different sensor modalities, study designs, and outcome measures, facilitating a more unified comparison of results across the diverse studies included in the review.

IV. CONCLUSION

This systematic review highlights the transformative potential of multimodal IoT systems in enhancing health and wellness management through advanced machine-to-machine (M2M) interactions. IoT technologies have revolutionized the way we monitor, manage, and track users by providing real-time data, seamless system functionality, personalized user experiences, and tailored feedback. The analysis of sensors reveals considerable variation in the types and configurations used for health monitoring. For example, IMU sensors and motion detectors are highly effective for tracking physical activity and detecting postural changes, making

them essential for fitness and rehabilitation applications. ECG and EMG sensors offer accurate monitoring of cardiac and muscle activities, respectively.

The review underscores the importance of integrating multimodal sensors, as combining data from multiple biosensors provides a more comprehensive view of the user. For instance, combining heart rate monitors with motion sensors enhances the accuracy of activity recognition algorithms, which leads to better health outcomes.

However, the review also uncovers several critical limitations. Many studies have small sample sizes, which restrict the generalizability of their findings. There is also a lack of thorough data integration, which results in fragmented insights rather than offering a holistic view of an individual's health. Practical challenges with wearable sensors, such as discomfort, limited battery life, and bulky designs, hinder long-term use and user compliance. Additionally, the dependence on stable internet connectivity poses challenges in areas with weak network infrastructure, leading to data loss or processing delays. Security and privacy concerns are another issue, as many studies lack strong encryption and secure authentication protocols, leaving users vulnerable to potential data breaches.

Future research must address these limitations by focusing on larger and more diverse sample populations to improve generalizability. Studies should also prioritize comprehensive data integration and enhanced security measures to ensure the protection of user information and build trust. Developing more comfortable, user-friendly interfaces and miniaturizing wearable sensors will help improve usability and encourage long-term adoption. Additionally, long-term evaluations are crucial to assess the sustained effectiveness and user acceptance of IoT-based health monitoring systems. Future research should explore the use of advanced technologies like AI and blockchain to improve the accuracy, predictive capabilities, and security of IoT systems in health and wellness management. By focusing on these areas, future innovations can optimize IoT technology implementation, improving health outcomes and user engagement.

V. FUTURE STUDY RECOMMENDATIONS

❖ Building upon the existing research, we propose several novel directions for future studies that leverage cutting-edge technologies and concepts to address current limitations and emerging challenges in IoT-based health, wellness, and fitness tracking systems. At the heart of this evolution is the critical need for enhanced data security and privacy. Blockchain technology offers a decentralized approach to data integrity and sharing, potentially revolutionizing health data management

❖ Federated learning techniques present a promising avenue for privacy-preserving analytics, enabling machine learning models to be trained on diverse datasets without compromising individual privacy. Future research should focus on developing comprehensive security measures that protect not only the data at rest and in transit but also the ML models themselves. Exploring advanced encryption techniques for secure data transmission and investigating methods to prevent adversarial attacks on AI models are crucial areas for further study.

❖ Advanced AI techniques, including deep learning and reinforcement learning, should be explored for detecting subtle health anomalies and providing predictive analytics. Parallel research into explainable AI models is crucial to ensure transparency in health recommendations, fostering trust and user adherence. Edge computing presents an opportunity to optimize real-time processing for health and fitness applications, enabling instantaneous analysis of critical health indicators. This aligns with the rollout of 5G technologies, promising high-bandwidth, low-latency connections for seamless monitoring and telemedicine.

❖ As IoT health devices become ubiquitous, research into energy harvesting techniques and ultra-low power designs is essential to extend device longevity and reduce environmental impact. Furthermore, future studies should prioritize the development of intuitive and accessible user interfaces for both end-users and system managers. Research into adaptive UI designs that cater to diverse user needs and abilities could significantly enhance user engagement and system effectiveness.

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