

A Comprehensive Literature Review of IoT-Based Smart Healthcare Monitoring Systems

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مراجعة شاملة للأدبيات المتعلقة بأنظمة مراقبة الرعاية الصحية الذكية القائمة على إنترنت الأشياء

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Abstract

The Internet of Things (IoT) has become an essential driver of modern medicine, facilitating automated patient tracking, remote clinical assessment, and instant diagnostic support. Innovations across wearable biosensors, wireless networking, edge-cloud architectures, and artificial intelligence have significantly propelled the evolution of intelligent health monitoring platforms.

This study offers a Systematic Literature Review (SLR) examining smart healthcare monitoring systems powered by the IoT from 2015 through 2025. Following the PRISMA 2020 guidelines, 300 records were initially identified through a systematic search. After applying the predefined inclusion and exclusion criteria, 50 studies were selected for detailed analysis. Throughout the review, attention is given to structural IoT frameworks, sensor modalities, networking protocols, medical uses, AI methodologies, and upcoming technological shifts.

This survey highlights the dominant technological solutions, outlines their practical clinical uses, and critically evaluates core obstacles such as cybersecurity, data privacy, cross-system interoperability, system scalability, power consumption, and operational reliability. Furthermore, it underscores high-potential research frontiers, encompassing localized edge intelligence, decentralized federated learning, blockchain protocols, digital twin representations, and explainable AI.

Ultimately, the synthesized insights present a holistic snapshot of today's IoT healthcare landscape while delivering actionable guidelines for building more effective, safe, and smart medical technologies.

Keywords: Internet of Things (IoT), Smart Healthcare, Internet of Medical Things (IoMT), Remote Patient Monitoring, Artificial Intelligence, Edge Computing, Systematic Literature Review.

الملخص

أصبح إنترنت الأشياء (IoT) محركاً أساسياً للطب الحديث، إذ يُسهّل تتبع المرضى آلياً، والتقييم السريري عن بُعد، والدعم التشخيصي الفوري. وقد ساهمت الابتكارات في مجالات أجهزة الاستشعار الحيوية القابلة للارتداء، والشبكات اللاسلكية، وبنى الحوسبة الطرفية والسحابية، والذكاء الاصطناعي، بشكل كبير في تطوير منصات مراقبة الصحة الذكية.

تقدم هذه الدراسة مراجعة منهجية للأدبيات (SLR) تتناول أنظمة مراقبة الرعاية الصحية الذكية المدعومة بتقنية إنترنت الأشياء خلال الفترة من 2015 إلى 2025. وفقاً لإرشادات PRISMA 2020، تم تحديد 300 سجل مبدئياً من خلال بحث منهجي. وبعد تطبيق معايير الإدراج والاستبعاد المحددة مسبقاً، تم اختيار 50 دراسة لتحليلها بالتفصيل. وتركز المراجعة على أطر عمل إنترنت الأشياء الهيكلية، وطرائق الاستشعار، وبروتوكولات الشبكات، والاستخدامات الطبية، ومنهجيات الذكاء الاصطناعي، والتحول التكنولوجية القادمة. تُسلط هذه الدراسة الضوء على الحلول التقنية السائدة، وتُبين استخداماتها السريرية العملية، وتُقيم بشكل نقدي العقبات الرئيسية مثل الأمن السيبراني، وخصوصية البيانات، وقابلية التشغيل البيئي بين الأنظمة، وقابلية توسيع النظام، واستهلاك الطاقة، والموثوقية التشغيلية. كما تُبرز الدراسة آفاقاً بحثية وأعدة، تشمل الذكاء الطرفي المحلي، والتعلم الموحد اللامركزي، وبروتوكولات سلسلة الكتل، وتمثيلات التوأم الرقمي، والذكاء الاصطناعي القابل للتفسير.

في نهاية المطاف، تُقدّم الرؤى المُجمّعة صورة شاملة لمشهد إنترنت الأشياء في مجال الرعاية الصحية اليوم، مع توفير إرشادات عملية لبناء تقنيات طبية أكثر فعالية وأماناً وذكاءً.

الكلمات المفتاحية: إنترنت الأشياء، الرعاية الصحية الذكية، إنترنت الأشياء الطبية، مراقبة المرضى عن بُعد، الذكاء الاصطناعي، الحوسبة الطرفية، مراجعة الأدبيات المنهجية.

1. Introduction.

The swift progression of Internet of Things (IoT) paradigms has fundamentally modernized healthcare delivery by introducing interconnected, data-centric, and automated clinical

services. Conventional healthcare approaches mainly depend on periodic clinical visits and manual patient monitoring, which may restrict continuous observation of patients and delay the early detection of critical health conditions. Smart healthcare systems built on the IoT circumvent these traditional barriers by combining wearable biosensors, medical equipment, wireless links, edge/cloud infrastructure, and AI algorithms to facilitate continuous remote observation and smart diagnostic decisions [1].

Systems powered by the IoT enable ongoing gathering, transfer, and smart processing of biological and context-aware metrics—such as pulse, arterial pressure, body temperature, blood oxygen, glycemic levels, and physical movement. These data are collected through sensing devices and transmitted through communication networks for processing and analysis, enabling healthcare providers to remotely monitor patients and make timely medical decisions [2]. Earlier literature confirms that leveraging IoT in clinical settings elevates care accessibility, safeguards patients, lowers overhead expenses, and streamlines preventative and therapeutic management [3].

Expanding on basic IoT, the Internet of Medical Things (IoMT) links specialized medical hardware, wearable sensors, hospital networks, and individuals via smart connectivity pipelines. IoMT-based systems have been widely applied in several healthcare domains, including remote patient monitoring, chronic disease management, elderly healthcare, emergency response, and personalized medicine [4]. Modern architectural frameworks that fuse cloud, fog, and edge nodes further boost processing performance, minimize network lag, and deliver expandable health services via distributed real-time computing [5].

Recent breakthroughs in machine learning and broader artificial intelligence have strengthened IoT monitoring by introducing predictive modeling, automated data interpretation, and clinical decision aids. Various machine learning and deep learning approaches, including support vector machines, decision trees, random forests, convolutional neural networks, and recurrent neural networks, have been applied for disease prediction, health status classification, anomaly detection, and medical data interpretation [6]. Additionally, pioneering paradigms like localized edge intelligence and privacy-preserving federated learning offer viable paths toward real-time computation, effortless system growth, and strong data privacy in decentralized setups [7].

Even with the notable strides made in medical IoT, multiple persistent bottlenecks continue to delay its universal deployment. These challenges include security and privacy threats, interoperability among heterogeneous healthcare devices, energy limitations, scalability issues, complex data management, and reliability concerns. Since healthcare applications involve sensitive patient information, ensuring secure communication, privacy preservation, data integrity, and reliable information exchange remains a critical requirement for future IoT healthcare systems [8]. Concurrently, optimizing system resources and ensuring smooth cross-platform compatibility endure as major hurdles to achieving long-term, trustworthy, and expandable IoT care ecosystems [9].

While a rich body of literature investigates IoT in medicine, most available review papers restrict their scope to isolated topics—such as individual sensor form factors, specialized security protocols, targeted AI models, or single architectural designs [10]. However, a comprehensive systematic review that simultaneously analyzes IoT architectures, sensing technologies, communication protocols, intelligent data processing approaches, healthcare applications, security challenges, and emerging research trends is still lacking. In response, this systematic literature review seeks to deliver an all-inclusive investigation of smart medical monitoring by evaluating present technological advancements, key practical barriers, and prospective research paths.

To achieve this, this work outlines a broad-scale Systematic Literature Review (SLR) focusing on healthcare IoT monitoring publications spanning 2015 through 2025. Following the PRISMA 2020 guidelines, the review systematically analyzes fifty selected studies to identify the most widely adopted healthcare applications, sensing technologies, communication

protocols, computing architectures, artificial intelligence techniques, security mechanisms, and emerging research trends. Additionally, it introduces a structured taxonomy, compares existing methods, outlines present knowledge gaps, and charts future research pathways toward scalable, smart, safe, and eco-friendly health tracking infrastructures.

The central goals of this review include the following:

- To analyze existing IoT architectures and technological frameworks used in IoT-based smart healthcare monitoring systems.
- To investigate sensing technologies, wearable devices, and communication protocols applied in IoT-enabled healthcare environments.
- To examine the applications of artificial intelligence, machine learning, and deep learning techniques for IoT-based healthcare monitoring and intelligent decision-support systems.
- To identify the major technical, security, and operational challenges affecting the adoption of IoT-based smart healthcare monitoring systems.
- To discuss emerging research directions, including edge AI, federated learning, blockchain-based healthcare security, digital twin technologies, and explainable artificial intelligence (XAI).

Key contributions made by this review are highlighted below:

- This review proposes a comprehensive multi-dimensional taxonomy of IoT-based smart healthcare monitoring systems by integrating sensing technologies, communication protocols, computing architectures, and AI-based data processing approaches.
- Unlike previous reviews that mainly focus on specific aspects of IoT healthcare systems, this study provides an integrated analysis of emerging technologies, including federated learning, blockchain, explainable artificial intelligence (XAI), and digital twin technologies.
- This study presents a structured analysis of major challenges, existing solutions, and future research opportunities in IoT-based smart healthcare monitoring systems.
- This review identifies current research gaps and future directions toward developing intelligent, secure, interoperable, and sustainable IoT healthcare systems.

The conceptual structure governing the IoT smart healthcare monitoring framework examined throughout this study is depicted in Figure 1.

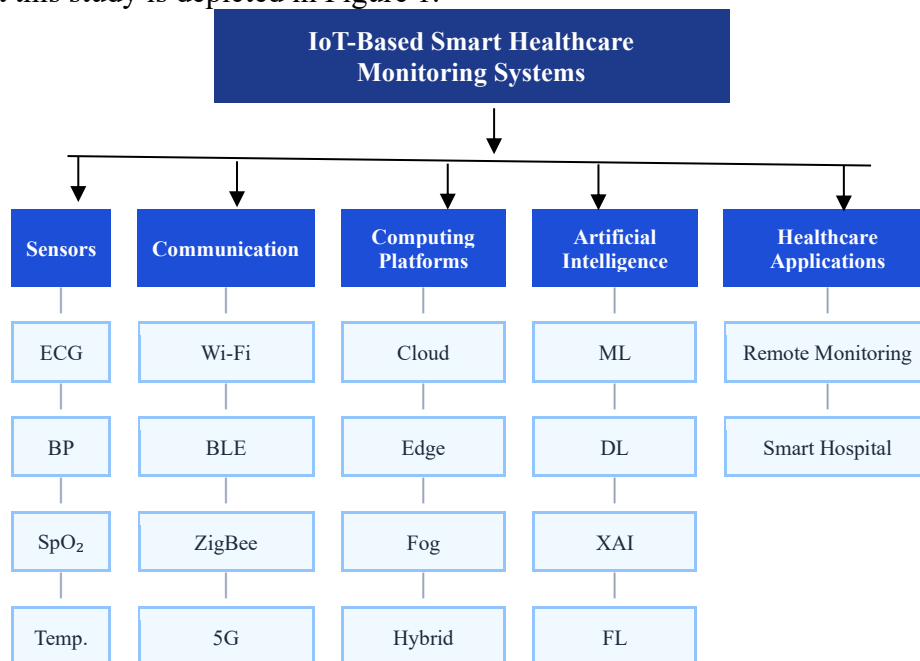


Figure 1. Conceptual Framework of IoT-Based Smart Healthcare Monitoring System.

2. Research Methodology.

To guarantee rigor, clarity, and repeatability, this systematic literature review (SLR) adhered strictly to the PRISMA 2020 statement [1]. A structured review strategy was established beforehand to systematically discover, filter, evaluate, and synthesize existing research on IoT healthcare monitoring platforms.

The methodological framework comprised five sequential phases: defining research questions, crafting search queries, executing study selection via set criteria, scoring methodological quality, and gathering/synthesizing data. Every phase was executed with precision to curb selection bias and reinforce the trustworthiness of the drawn conclusions.

Selecting relevant articles involved applying strict inclusion and exclusion guidelines established at the protocol stage. The titles and abstracts of the retrieved records were screened, followed by a full-text eligibility assessment. Studies that did not satisfy the predefined criteria were excluded. Full documentation of this filtering process was maintained via the PRISMA 2020 flow diagram to support complete analytical transparency.

The complete flow of study identification and screening aligned with PRISMA 2020 standards. After removing 80 duplicate records, 220 records remained for title and abstract screening. Subsequently, 130 records were excluded because they did not meet the predefined eligibility criteria. The full texts of the remaining 90 articles were assessed, resulting in the exclusion of 40 articles due to insufficient methodological quality or lack of relevance to the research objectives. Ultimately, 50 rigorous papers met all standards and were incorporated into the core qualitative synthesis and comparison.

The PRISMA 2020 study selection process is illustrated in Figure 2, while the details of each selection phase are summarized in Table 1.

Table 1. PRISMA 2020 Study Selection Process.

PRISMA Phase	Number of Records
Records identified from databases	300
Duplicate records removed	80
Records screened (title and abstract)	220
Records excluded after title and abstract screening	130
Full-text reports assessed for eligibility	90
Full-text reports excluded	40
Studies included in the final qualitative synthesis	50

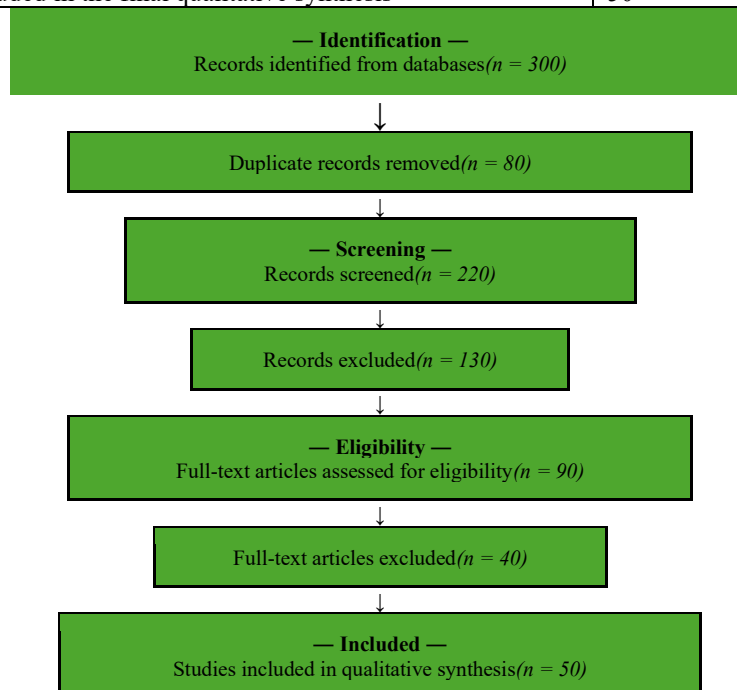


Figure 2. PRISMA 2020 Flow Diagram of the Study Selection Process

2.1 Research Questions.

This systematic literature review aims to answer the following research questions:

- **RQ1:** What IoT architectures and technological frameworks are commonly used in smart healthcare monitoring systems?
- **RQ2:** What sensing technologies, wearable devices, and communication protocols are applied in IoT-enabled healthcare environments?
- **RQ3:** How are artificial intelligence, machine learning, and deep learning techniques utilized for IoT-based healthcare monitoring and intelligent decision-support systems?
- **RQ4:** What are the major technical, security, privacy, and operational challenges affecting the adoption of IoT-based healthcare solutions?
- **RQ5:** What emerging technologies and future research directions can enhance the scalability, intelligence, security, and reliability of IoT healthcare monitoring systems?

2.2 Search Strategy.

A broad literature search was carried out across five prominent academic repositories: IEEE Xplore, ScienceDirect, SpringerLink, PubMed, and Google Scholar. Google Scholar was included to identify additional relevant studies that may not have been indexed in the major scientific databases. The query timeline was bounded between 2015 and 2025 to concentrate exclusively on modern developments in healthcare IoT tracking.

Records retrieved across all platforms were compiled into a master list, and duplicate entries were eliminated prior to title screening. Every step of this filtering workflow complied fully with PRISMA 2020 protocols.

The following Boolean search string was applied across all selected databases.

```
("Internet of Things" OR IoT OR "Internet of Medical Things" OR IoMT)
AND
("Smart Healthcare" OR "Healthcare Monitoring" OR
"Remote Patient Monitoring" OR "Digital Health")
AND
("Wearable Sensors" OR "Medical Devices" OR Sensors)
AND
("Artificial Intelligence" OR "Machine Learning" OR
"Deep Learning" OR "Federated Learning")
AND
("Edge Computing" OR "Fog Computing" OR "Cloud Computing")
```

The search process targeted studies related to IoT healthcare architectures, wearable medical devices, AI-based healthcare analytics, intelligent monitoring systems, computing frameworks, security mechanisms, and emerging healthcare technologies.

2.3 Inclusion and Exclusion Criteria.

Pre-established screening criteria were enforced to safeguard the contextual alignment, academic quality, and trustworthiness of included literature.

Table 2. Inclusion and Exclusion Criteria.

Criteria	Inclusion Criteria	Exclusion Criteria
Publication Year	Studies published between 2015–2025	Studies published before 2015
Language	Articles written in English	Articles written in other languages
Publication Type	Peer-reviewed journal articles and conference papers	Editorials, reviews without original contributions, non-peer-reviewed papers, and unrelated publications
Research Focus	Studies addressing IoT-based smart healthcare monitoring, IoMT, wearable devices, AI/ML/DL techniques, edge/cloud/fog computing, and healthcare data analysis	Studies unrelated to healthcare IoT or without IoT-based healthcare solutions
Research Contribution	Studies presenting IoT architectures, healthcare applications, intelligent approaches, security solutions, challenges, or future directions	Studies lacking sufficient methodological details or research contributions

2.4 Quality Assessment

To evaluate study validity, the methodological quality of candidates was appraised using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist [51]. The checklist was adapted to the objectives of this review to evaluate the methodological rigor of IoT-based smart healthcare monitoring studies. The assessment considered the clarity of research objectives, description of IoT architecture, datasets and experimental settings, reported evaluation metrics, and discussion of study limitations. Modifying this checklist ensured a uniform quality assessment tailored to the technical nuances of healthcare IoT research.

Individual criteria received binary grades (1 for present, 0 for absent), yielding a total possible rating of five points. Studies achieving a quality score of three or higher were considered to have sufficient methodological quality and were included in the final qualitative synthesis. Papers earning fewer than three points were deemed methodologically inadequate and discarded from the final synthesis.

All included studies achieved a quality score of at least three points; therefore, no studies were excluded on the basis of the quality threshold. The quality assessment was retained to document and transparently report the methodological rigor of the included studies.

Table 3. Adapted JBI-Based Quality Assessment Criteria.

Criterion	Assessment Question	Score
QA1	Does the study clearly define its research objectives?	Yes = 1, No = 0
QA2	Is the proposed IoT architecture clearly described?	Yes = 1, No = 0
QA3	Are datasets and experimental settings adequately explained?	Yes = 1, No = 0
QA4	Are evaluation metrics and validation methods reported?	Yes = 1, No = 0
QA5	Are study limitations and future directions discussed?	Yes = 1, No = 0

Note: The original JBI Critical Appraisal Checklist was adapted according to the characteristics and objectives of IoT-based smart healthcare monitoring studies.

Table 4. Summary of Quality Assessment Results of the Included Studies

Quality Score	Quality Level	Number of Studies
5	Excellent Quality	20
4	Good Quality	18
3	Acceptable Quality	12
<3	Low Quality (Excluded)	0
Total		50

2.5 Data Extraction and Synthesis.

Key attributes were systematically collected from each included study using a structured data extraction template. Extracted fields covered publication dates, structural designs, sensor models, transmission protocols, clinical domains, AI algorithms, data sources, testing metrics, security implementations, constraints, and proposed research paths.

Collected data points were grouped and analyzed to reveal overarching technological shifts, literature gaps, operational barriers, and promising directions within health IoT.

The ultimate cohort of selected studies underwent cross-comparison across system architectures, biosensors, network choices, processing setups, AI models, security tools, and medical use cases.

3. Related Work.

Over the past decade, investigations into IoT smart healthcare systems have expanded dramatically, fueled by the push for automated, continuous, and remote clinical care. Previous studies have investigated different aspects of IoT healthcare ecosystems, including wearable sensors, Internet of Medical Things (IoMT), artificial intelligence (AI), machine learning (ML), deep learning (DL), cloud and edge computing, security, and remote patient monitoring. Nevertheless, most available surveys address localized technologies or single clinical scenarios rather than offering a fully unified perspective on the complete IoT healthcare environment.

3.1 Related Work and Previous Review Studies on IoT-Based Smart Healthcare Monitoring Systems.

Foundation-level literature laid down the primary principles of IoT-driven medical tracking. Islam et al. [9] presented a comprehensive survey of IoT applications in healthcare, covering sensing technologies, communication protocols, cloud computing, big data processing, and security mechanisms. The study highlighted the potential of IoT for continuous healthcare monitoring while identifying challenges related to interoperability, privacy, and data management. Similarly, Hassanalieragh et al. [39] investigated IoT sensing technologies combined with cloud-based processing for healthcare monitoring. Their findings validated how cloud-backed IoT platforms enable remote monitoring and big data handling, while noting ongoing constraints around processing lag, data security, and hardware limits.

A broad look at healthcare IoT technologies—spanning wearables, remote tracking setups, and automated care—was provided by Baker et al. [37]. The study discussed technological opportunities and deployment challenges related to scalability, integration, and reliability. In parallel, Farahani et al. [31] analyzed fog-centered IoT networks, proving that offloading compute tasks near edge users minimizes latency and improves real-time health data handling. Marrying machine learning models with IoT health infrastructure has emerged as a major focal point in recent literature. Ahamed and Farid [18] investigated IoT and machine learning approaches for personalized healthcare and discussed challenges related to medical data processing, intelligent decision-making, and reliability. Introducing a three-tiered IoT model, Kumar and Gandhi [19] embedded ML algorithms for proactive cardiac detection, showcasing the clinical power of smart analytics in remote care.

A substantial body of work explores IoT structural designs, body-worn hardware, and health-tracking frameworks. Rahaman et al. [6] reviewed IoT-based smart health monitoring systems with emphasis on sensors, embedded devices, wearable technologies, and communication networks. Ahmadi et al. [25] presented a systematic literature review and classification of IoT applications in healthcare, identifying major healthcare domains and enabling technologies. Examining cloud-IoT synthesis in medicine, Darwish et al. [17] mapped out structural bottlenecks, prospective advantages, and unresolved technical issues.

Deploying practical, real-world remote care systems has significantly accelerated the adoption of IoT across the medical sector. Coulby et al. [5] investigated accessible IoT technologies for remote healthcare monitoring and demonstrated their potential for improving healthcare accessibility. Islam et al. [45] developed an IoT-based healthcare monitoring framework for continuous physiological monitoring and healthcare automation. Surveying next-generation medical IoT, Qadri et al. [20] highlighted the critical reliance on artificial intelligence, wearable form factors, cloud backends, and modern communication networks.

Edge intelligence and artificial intelligence have quickly solidified their positions as essential building blocks of modern health IoT. Mohammed and Askar [14] reviewed machine learning applications in IoT healthcare and highlighted their contribution to disease prediction and healthcare automation. Rathi et al. [13] proposed an edge AI-enabled IoT healthcare monitoring system for smart cities demonstrating reduced latency and improved response time. Investigating edge-AI paradigms, Hayyolalam et al. [15] showed how local processing strengthens health IoT by enabling instantaneous decision-making and cutting reliance on distant cloud servers.

Contemporary studies increasingly target IoMT deployment, cybersecurity protocols, privacy protections, and intelligent medical backbones. Hameed et al. [46] systematically reviewed security and privacy issues in IoMT and examined machine learning-based cybersecurity approaches. Al-Rawashdeh et al. [10] analyzed IoT adoption in smart healthcare and identified implementation barriers related to interoperability, security, and system integration. Categorizing health IoT deployments, Abdulmalek et al. [3] grouped core applications into

remote patient tracking, long-term disease management, emergency alert networks, and senior care.

The rise of deep learning models and sophisticated AI approaches has opened new frontiers for advanced clinical data analysis. Alshamrani [12] surveyed AI-based IoT healthcare monitoring systems and highlighted the role of ML algorithms in diagnosis, prediction, and clinical decision support. Mohammadi et al. [16] reviewed machine learning applications in healthcare and IoT environments. Assessing deep learning within medical informatics and IoT, Amiri et al. [22] demonstrated its impact on accurate disease forecasting and automated clinical choices.

Broader IoT healthcare movements and novel technological integrations have been the subject of several recent systematic reviews. Bovenizer and Chetthamrongchai [2] conducted a systematic and bibliometric review of IoT-based healthcare systems, analyzing research trends, AI integration, wearable technologies, cloud computing, and security challenges. Gaya and Danladi [1] reviewed IoT-based health monitoring systems with emphasis on sensing technologies, communication mechanisms, healthcare applications and challenges. Baiense et al. [8] investigated IoT wearable devices for healthcare monitoring and discussed future challenges related to interoperability and energy efficiency. Looking into IoMT developments, Anand et al. [23] detailed the current research direction alongside obstacles involved in constructing expandable, secure care networks.

Driven by these factors, this study delivers a broad, systematic literature review covering smart IoT health monitoring works published between 2015 and 2025. Unlike previous studies, this research provides an integrated analysis of the complete IoT healthcare ecosystem, including IoT architectures, wearable sensors, communication technologies, Internet of Medical Things (IoMT), cloud-edge-fog computing paradigms, artificial intelligence, machine learning, deep learning, federated learning, blockchain, digital twins, and security and privacy mechanisms.

The main contributions of this study are summarized as follows:

A comprehensive systematic review of IoT-based smart healthcare monitoring systems covering major technological developments and healthcare applications between 2015 and 2025.

Development of a unified taxonomy that classifies IoT healthcare systems according to sensing technologies, communication networks, computing architectures, intelligent algorithms, security mechanisms, and healthcare applications.

A comparative analysis of existing IoT healthcare approaches based on architectures, technologies, applications, datasets, evaluation metrics, contributions, and limitations.

Identification and analysis of major challenges, including security and privacy, interoperability, scalability, energy efficiency, reliability, and data management issues.

Exploration of future research directions toward intelligent, secure, and sustainable IoT healthcare systems including edge AI, federated learning, blockchain, digital twins, explainable AI, and next-generation healthcare networks.

Table 5 compares this study with previous review studies to highlight the differences in scope, methodology, taxonomy development and research coverage.

Table 5. Comparison of Previous Review Studies and the Present Systematic Literature Review on IoT-Based Smart Healthcare Monitoring Systems.

Ref.	Year	Main Contribution	Review Type	Taxonomy	Scope	Research Gap / Limitation
Islam et al. [9]	2015	Presented a comprehensive survey of IoT applications in healthcare, covering sensing technologies, communication protocols, cloud computing, big data processing, and security mechanisms.	Survey	Yes	IoT, Sensors, Cloud Computing, Security	Limited coverage of artificial intelligence, intelligent analytics, and emerging healthcare technologies.
Baker et al. [37]	2017	Reviewed IoT technologies for smart healthcare, including wearable devices, remote	Review	Yes	IoT, Wearable Devices, Smart Healthcare	Did not provide a systematic analysis of AI-based healthcare,

		monitoring systems, and healthcare services.				advanced computing architectures, and security mechanisms.
Rahaman et al. [6]	2019	Reviewed IoT-based smart health monitoring systems focusing on sensors, embedded devices, wearable technologies, and communication networks.	Review	Yes	IoT, Sensors, Communication Networks	Limited discussion of intelligent healthcare analytics and advanced AI-driven approaches.
Darwish et al. [17]	2019	Analyzed IoT and cloud computing integration in healthcare systems and discussed opportunities, challenges, and open issues.	Review	Partial classification	IoT, Cloud Computing, Healthcare Architecture	Focused mainly on cloud-based healthcare without comprehensive analysis of AI, security, and emerging paradigms.
Ahmadi et al. [25]	2019	Presented a systematic literature review and classification of IoT applications in healthcare domains.	Systematic Literature Review	Yes	IoT Applications, Healthcare Classification	Limited coverage of deep learning, federated learning, blockchain, and digital healthcare transformation.
Qadri et al. [20]	2020	Reviewed future healthcare IoT technologies including AI, wearable devices, cloud computing, and advanced communication infrastructures.	Survey	Yes	IoT, AI, Cloud Computing, Emerging Technologies	Limited integration of security, privacy, and intelligent computing frameworks.
Al-Rawashdeh et al. [10]	2022	Reviewed IoT adoption and applications in smart healthcare and identified major implementation challenges.	Systematic Review	Yes	IoT Adoption, Healthcare Applications, Security	Focused mainly on adoption barriers rather than comprehensive technical comparison.
Abdulmalek et al. [3]	2022	Reviewed IoT healthcare monitoring systems and classified healthcare applications including remote monitoring, chronic disease management, and elderly care.	Review	Yes	IoT Healthcare Applications	Limited analysis of AI models, edge intelligence, and emerging technologies.
Mohamad Jawad et al. [4]	2022	Presented a systematic literature review of enabling IoT technologies in healthcare, including motivations, challenges, and recommendations.	Systematic Literature Review	Yes	IoT Enabling Technologies, Challenges	Limited coverage of AI, federated learning, blockchain, and intelligent healthcare frameworks.
Dwivedi et al. [34]	2022	Reviewed Internet of Medical Things (IoMT) applications and their role in smart healthcare systems.	Systematic Review	Yes	IoMT, Smart Healthcare Applications	Did not provide a complete analysis of IoT architectures, AI integration, and future intelligent healthcare trends.
Bovenizer and Chetthamrongchai [2]	2023	Conducted a systematic and bibliometric review of IoT-based healthcare systems, analyzing research trends and technological developments.	Systematic & Bibliometric Review	Yes	IoT, AI, Cloud Computing, Security	Emphasized publication trends and bibliometric analysis more than detailed technological comparison.
Ge et al. [40]	2023	Presented a systematic and comprehensive review of intelligent IoT-based healthcare systems, focusing on applications and emerging technologies.	Systematic Review	Yes	Intelligent Healthcare, IoT Applications	Limited integration of security, privacy, and advanced IoT healthcare paradigms.

Anand et al. [23]	2024	Reviewed Internet of Medical Things research trends, applications, and challenges.	Systematic Review	Yes	IoMT, Healthcare Infrastructure	Focused mainly on IoMT and did not cover the complete IoT healthcare ecosystem.
Amiri et al. [22]	2024	Investigated deep learning applications in IoT-based biomedical informatics and healthcare systems.	Systematic Literature Review	Yes	Deep Learning, AI, Biomedical Informatics	Focused mainly on deep learning techniques without covering complete IoT healthcare architectures.
Gaya and Danladi [1]	2024	Reviewed IoT-based health monitoring systems focusing on sensing technologies, communication mechanisms, applications, and challenges.	Systematic Review	Yes	IoT Monitoring Systems	Limited coverage of federated learning, blockchain, digital twins, and advanced intelligent systems.
Baiense et al. [8]	2025	Reviewed wearable IoT devices for healthcare monitoring and discussed challenges related to interoperability and energy efficiency.	Systematic Review	Yes	Wearable IoT Healthcare	Limited coverage of cloud-edge-fog architectures, AI security solutions, and integrated healthcare ecosystems.
Present Study	2025	Provides a comprehensive systematic literature review of IoT-based smart healthcare monitoring systems by integrating IoT architectures, wearable sensors, communication technologies, IoMT, AI, ML, DL, federated learning, blockchain, digital twins, edge/fog/cloud computing, security, and privacy mechanisms.	Systematic Literature Review (PRISMA 2020)	Yes	IoT, IoMT, Sensors, Communication, AI, ML, DL, FL, Edge/Fog/Cloud Computing, Blockchain, Digital Twin, Security & Privacy	Provides an integrated taxonomy, comparative analysis, critical discussion of challenges, and future research directions for next-generation IoT-based smart healthcare monitoring systems.

3.2 Research Gap and Contribution

Recent systematic survey literature has thoroughly explored smart IoT healthcare through various specialized lenses. For example, Gaya and Danladi (2024) provided a general overview of IoT-based health monitoring systems, while Bovenizer and Chetthamrongchai (2023) combined systematic and bibliometric analyses to identify research trends. Abdulmalek et al. (2022) and Mohamad Jawad et al. (2022) focused on healthcare monitoring systems, enabling technologies, challenges, and recommendations. Similarly, Baiense et al. (2025) emphasized wearable devices and healthcare monitoring, whereas Dwivedi et al. (2022) reviewed Internet of Medical Things (IoMT) applications in smart healthcare systems. Additional works targeted narrow domains like edge AI (Hayyolalam et al., 2021), cloud health backends (Darwish et al., 2019; Ullah et al., 2023), AI/ML integration (Alshamrani, 2022; Mohammadi et al., 2022), or IoMT cybersecurity and privacy (Hameed et al., 2021).

Notwithstanding these notable contributions, critical gaps persist across the literature. As summarized in Table 5, previous studies have mainly addressed specific components of IoT healthcare systems, such as wearable devices, IoMT, cloud computing, AI techniques, or security issues. However, comprehensive integration of sensing technologies, communication protocols, computing paradigms, artificial intelligence techniques, security and privacy mechanisms, implementation challenges, and emerging research directions within a unified framework remains limited. Furthermore, a large portion of existing surveys stick to narrative summaries instead of offering rigorous, cross-comparative evaluations of interconnected technologies across the medical IoT space.

To bridge these gaps, this systematic literature review synthesizes research on smart healthcare monitoring systems from 2015 to 2025. Moving beyond earlier reviews, this work unifies diverse technological facets, critically evaluates systemic bottlenecks, highlights emerging solutions, and details open research avenues—furnishing scholars and engineers with a complete, modern reference point.

Rather than isolating individual building blocks like cloud engines, edge nodes, body sensors, or specific AI algorithms, this review adopts a holistic, analytical view of the entire IoT health ecosystem.

Under a unified PRISMA 2020 structure, this paper thoroughly evaluates biosensing hardware, network protocols, compute models, AI/ML/DL pipelines, security risks, and prospective research vectors. As a result, this study resolves the disconnect among isolated, single-topic surveys by assembling an all-inclusive framework for smart healthcare monitoring.

3.3 Paper Outline

The structural flow for the rest of this paper is arranged as follows. Section 2 presents the research methodology, including the research questions, search strategy, inclusion and exclusion criteria, quality assessment, data extraction process, and PRISMA-based study selection procedure. Section 3 discusses related work and previous review studies on IoT-based smart healthcare monitoring systems and highlights the existing research gaps. Section 4 provides the background of IoT-based smart healthcare monitoring systems, including fundamental concepts, architectures, sensing technologies, communication protocols, computing paradigms, and intelligent healthcare technologies. Section 5 presents the results and discussion of reviewed studies, including research trends, IoT technologies, healthcare applications, artificial intelligence techniques, and emerging developments. Section 6 introduces the proposed taxonomy of IoT-based smart healthcare monitoring systems and presents an integrated framework for classifying the reviewed technologies and approaches. Section 7 provides a comparative analysis of existing IoT-based healthcare monitoring approaches based on architectures, technologies, applications and performance aspects. Section 8 discusses the major challenges affecting IoT-based smart healthcare monitoring systems, including security, privacy, interoperability, scalability, energy consumption, and reliability issues. Section 9 presents future research directions and emerging technologies, including edge AI, federated learning, blockchain, digital twins, explainable artificial intelligence, and next-generation healthcare networks. Ultimately, Section 10 wraps up the review by distilling core insights, primary contributions, and forward-looking viewpoints.

4. Background

4.1 Overview of IoT-Based Smart Healthcare Monitoring Systems.

The exponential expansion of the Internet of Things (IoT) has successfully reshaped legacy healthcare into connected, intelligent, and patient-focused environments. IoT-based smart healthcare monitoring systems integrate medical sensors, wearable devices, wireless communication technologies, cloud platforms, edge computing, and intelligent data analytics to enable continuous and real-time monitoring of patients. Departing from traditional models anchored to infrequent clinic checkups, IoT-centered setups enable real-time remote tracking by gathering vital signs and streaming them to clinicians for immediate assessment [12].

A standard medical IoT tracking ecosystem comprises sensor nodes, transmission networks, data processing layers, and end-user clinical software. Wearable and medical sensors collect physiological parameters such as heart rate, blood pressure, body temperature, blood oxygen saturation (SpO₂), electrocardiogram (ECG), glucose level, respiratory rate, and physical activity. Once captured, vital data move over wireless channels to edge or cloud infrastructures for aggregation and analytics before displaying diagnostic updates to medical staff [13].

Applications for IoT health monitoring span long-term condition management, geriatric care, physical rehabilitation, emergency response, and home health tracking. Deploying these

solutions promotes early anomaly detection, expands access to clinical care, lowers preventable hospital readmissions, and enables personalized patient care [14].

Nonetheless, critical issues linger around system security, patient privacy, device interoperability, power economy, system scaling, and network reliability. Resolving these roadblocks is vital for building robust, secure, and lasting medical IoT deployments [15].

4.2 Internet of Medical Things (IoMT)

Designed specifically for clinical environments, the Internet of Medical Things (IoMT) links bio-sensors, medical hardware, health apps, network nodes, and computing backends to gather and process clinical data.

IoMT targets healthcare domain demands where stringent data precision, operational uptime, confidentiality, and patient wellbeing are non-negotiable. Maintaining constant connection channels across patients, clinical teams, and hospitals, IoMT powers real-time remote surveillance, faster diagnosis, and data-driven medical decisions [16].

Contemporary research identifies IoMT as a foundational pillar of Healthcare 4.0 due to its power to broaden medical reach, lower operational overhead, and deliver smart health services. Even so, addressing cybersecurity threats, system cross-compatibility, and health data governance continues to pose significant research hurdles [17].

4.3 Wearable Medical Sensors and Monitoring Devices

Body-worn biosensors and health monitors serve as fundamental sensing elements within IoT medical platforms. Compact and non-intrusive, these portable form factors allow uninterrupted, comfortable tracking of biological indicators during routine daily living.

Today's wearable medical ecosystem includes smartwatches, activity bands, e-textiles, wireless patches, chest straps, and sub-dermal implants. Operating constantly, these hardware tools generate continuous data streams that feed diagnostic engines and clinical decision platforms.

4.4 IoT Architecture for Smart Healthcare

The architecture of IoT-based healthcare monitoring systems generally consists of four interconnected layers:

4.4.1 Perception Layer

Serving as the physical capture tier, the perception layer acquires ambient and biological signals directly from the user. Hardware deployed at this level includes wearable biosensors, sub-dermal implants, RFID tags, smart clinical gear, and environmental monitors.

The core objective of this layer centers on gathering high-fidelity data while minimizing battery draw and optimizing measurement accuracy.

4.4.2 Network Layer

The network layer routes collected health metrics from sensing nodes to processing servers using diverse wireless links. Common communication protocols include Bluetooth Low Energy (BLE), Wi-Fi, ZigBee, LoRaWAN, 4G, 5G, and Near Field Communication (NFC). Maintaining stable connectivity across this tier is necessary to safeguard uninterrupted tracking, protect data integrity, and trigger swift emergency actions.

4.4.3 Processing Layer

Operating as the system's brain, the processing layer handles data management, noise filtering, predictive analytics, and automated decision logic. Depending on the system architecture, data processing may be carried out using cloud computing, edge computing, fog computing, or hybrid cloud-edge platforms. While cloud environments offer massive storage and heavy computing power, edge nodes process data close to the source to minimize latency for urgent real-time clinical applications [18].

4.4.4 Application Layer

The application layer acts as the user interface, surfacing health services to doctors, nursing staff, family caregivers, and patients. Typical healthcare applications include remote patient monitoring, smart hospitals, elderly care, emergency alert systems, chronic disease monitoring, mobile healthcare applications, telemedicine, and home healthcare monitoring. Converting raw

readings into actionable insights, this layer directly assists clinical decision-making, elevates care standards, and improves overall patient outcomes.

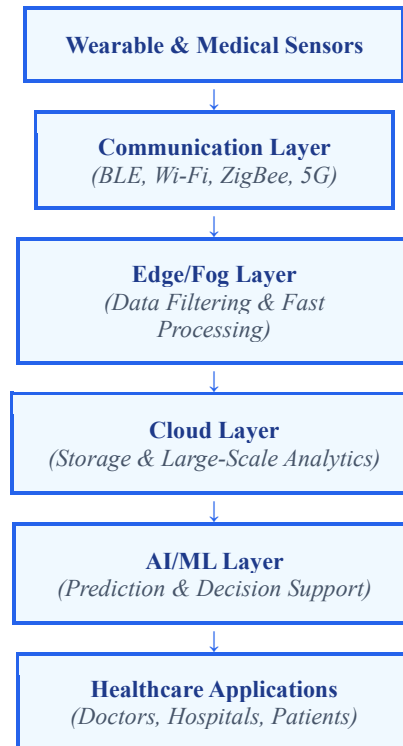


Figure 3. End-to-End Data Flow Architecture of IoT-Based Smart Healthcare Monitoring Systems.

5. Results and Discussion

5.1 Overview of Selected Studies

Following strict screening against predefined inclusion criteria, 50 studies were selected for full analysis in this systematic review. Published between 2015 and 2025, the selected works represent foundational contributions to the design and implementation of IoT healthcare monitoring.

Literature in this sample spans core domains such as system architecture, biosensors, wireless networking, edge-cloud computing, AI/ML/DL models, cybersecurity, data privacy, and novel medical technologies.

Analytical trends highlight escalating research momentum behind IoT-driven medicine, propelled by urgent demands for continuous monitoring, remote care delivery, automated diagnosis, and personalized clinical decision support [14].

Table 6 presents a summary of the selected studies including the healthcare applications, technologies, datasets, evaluation metrics, main contributions, and limitations.

Table 6. Summary of Selected IoT-Based Smart Healthcare Monitoring Systems and Applications

Ref. (Author, Year)	Healthcare Application	Technology / Model	Data Source / Input Data	Evaluation Metrics	Main Contribution	Limitations
Hassanalieragh et al. [39] (2015)	IoT Health Monitoring	IoT sensing with cloud-based processing	Sensor data	System performance analysis	Investigated cloud-assisted IoT sensing systems for continuous health monitoring and remote healthcare services	Security, privacy, and latency challenges
Zhang et al. [32] (2015)	Healthcare Cyber-	Cloud computing	Medical data	Not reported	Proposed Health-CPS	Early framework

	Physical System	and big data analytics			architecture integrating healthcare systems with cloud and big data technologies	with limited intelligent analytics
Kumar and Gandhi [19] (2018)	Early Heart Disease Detection	Three-tier IoT architecture with machine learning	Patient health datasets	Accuracy	Proposed an intelligent IoT framework using ML algorithms for early disease detection	Limited evaluation scope
Alhussein et al. [30] (2018)	Epileptic Seizure Monitoring	Cognitive IoT and cloud computing	Patient monitoring data	Detection accuracy	Developed an IoT-cloud integration framework for seizure detection and real-time monitoring	Limited to a specific healthcare application
Farahani et al. [31] (2018)	Fog-Based Healthcare	Fog computing with IoT architecture	Healthcare data	Latency and efficiency analysis	Presented a fog-driven IoT healthcare architecture to improve real-time data processing	Deployment complexity
Hossain et al. [27] (2019)	Voice Pathology Detection	IoT and artificial intelligence	Voice pathology dataset	Classification accuracy	Proposed an intelligent healthcare monitoring approach using voice pathology analysis for smart cities	Application-specific evaluation
Amin et al. [41] (2019)	Pathology Detection and Monitoring	Cognitive IoT and AI	Medical pathology data	Classification performance	Developed a cognitive healthcare approach for disease detection and monitoring	Limited healthcare applications
Coulby et al. [5] (2020)	Remote Healthcare Monitoring	Accessible IoT devices and wearable sensors	Experimental healthcare monitoring data	System performance evaluation	Investigated low-cost IoT solutions for remote patient monitoring	Limited large-scale deployment evaluation
Tuli et al. [33] (2020)	Heart Disease Diagnosis	HealthFog: Deep Learning + IoT + Fog Computing	Heart disease dataset	Accuracy, Precision, Recall	Proposed an intelligent fog-based healthcare system for automatic heart disease diagnosis	High computational requirements
Islam et al. [45] (2020)	Smart Healthcare Monitoring	IoT-based healthcare monitoring framework	Physiological patient data	System performance evaluation	Developed an IoT-based healthcare system for continuous patient observation	Limited scalability and advanced AI integration
Rathi et al. [13] (2021)	Smart City Healthcare Monitoring	Edge AI-enabled IoT	Healthcare datasets	Accuracy, latency,	Proposed an edge AI architecture to	High computational

		healthcare system		performance analysis	reduce latency and improve healthcare response time	and resource requirements
Swain et al. [50] (2021)	eHealth Monitoring	IoT and LabVIEW platform	Real-time health data	System performance evaluation	Developed an IoT-based eHealth monitoring platform for patient monitoring	Limited AI-based decision support
Albahri et al. [38] (2022)	Telemedicine and Cardiovascular Healthcare	IoT-based decision framework with AHP-VIKOR	Medical decision data	Decision performance	Developed a decentralized telemedicine support framework for cardiovascular healthcare services	Limited application scope
Nasser et al. [28] (2023)	COVID-19 Detection and Monitoring	IoT and cloud computing framework	Healthcare data	Prediction performance	Developed a smart healthcare framework for COVID-19 monitoring and detection	Limited generalization capability
Amiri et al. [22] (2024)	Biomedical Informatics and Disease Prediction	Deep Learning with IoT-based healthcare systems	Biomedical datasets	Accuracy, precision, recall, F1-score	Reviewed deep learning applications for intelligent healthcare analysis and decision support	High computational complexity and data requirements
Baiense et al. [8] (2025)	Wearable Healthcare Monitoring	IoT wearable devices and sensing technologies	Wearable sensor data	System performance analysis	Reviewed IoT wearable technologies for continuous healthcare monitoring	Energy consumption and interoperability challenges
Ravi and Dutta [49] (2025)	Remote Patient Monitoring	Internet of Medical Things (IoMT)	Remote patient health data	Monitoring performance	Analyzed IoMT-based solutions for remote patient monitoring and future healthcare services	Security, scalability, and privacy concerns

5.2 Publication Trend Analysis

Evaluating publication timelines reveals a sharp spike in research activity surrounding healthcare IoT monitoring, especially following 2020. This surge stems from concurrent leaps in wearable hardware, advanced AI techniques, decentralized edge nodes, and the general digitization of medicine.

The recent volume of published literature highlights an urgent real-world demand for remote care setups—specifically targeting long-term illness management, eldercare, and home-based health services.

Contemporary papers prioritize elevating system intelligence, minimizing transmission lag, reinforcing security/privacy protections, and processing stream data in real time [8].

Figure 4 illustrates the distribution of the selected studies according to publication year.

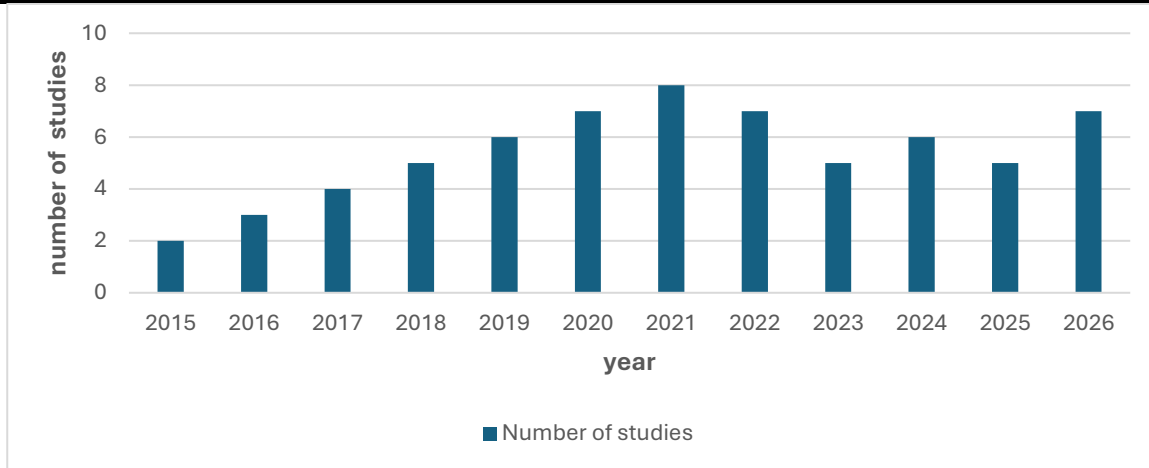


Figure 4. Distribution of Selected Studies by Publication Year.

5.3 Classification of IoT Healthcare Technologies

The selected studies were classified according to the main technological areas investigated. This classification highlights the major research trends and identifies the key technological components adopted in IoT-based smart healthcare monitoring systems.

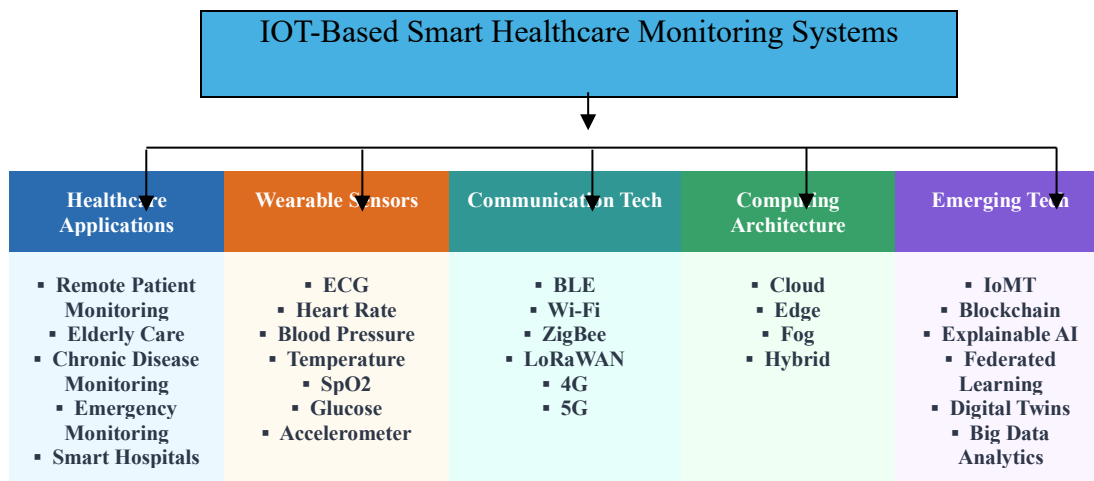


Figure 5. Proposed Taxonomy of IOT-Based Smart Healthcare Monitoring Systems

Table 7. Classification of IoT Technologies in Smart Healthcare Monitoring Systems

Technology Category	Description	Representative References
IoT Architecture	Multi-layer healthcare architectures integrating sensing devices, communication networks, processing platforms, and healthcare applications.	[9], [31], [10]
Wearable Sensors	Wearable and medical devices for continuous monitoring of physiological parameters such as ECG, heart rate, glucose level, and oxygen saturation.	[11], [8], [44]
Cloud Computing	Healthcare data storage, management, and large-scale computational processing.	[17], [5]
Edge/Fog Computing	Distributed computing approaches that enable low-latency healthcare data processing near patients.	[15], [13], [33]
Artificial Intelligence	Intelligent techniques for diagnosis, prediction, and healthcare decision support.	[12], [22]
Machine Learning	Algorithms for healthcare data classification, prediction, and condition analysis.	[14], [16]
Deep Learning	Advanced neural network models for analyzing complex physiological signals and healthcare time-series data.	[33], [22]
Security and Privacy Technologies	Authentication, encryption, privacy preservation, and secure healthcare communication mechanisms.	[46], [26]

5.4 Artificial Intelligence Techniques in IoT Healthcare

Artificial intelligence has cemented its role as a fundamental core of modern medical IoT monitoring platforms. Evidence from the literature confirms that AI algorithms actively enhance health data analytics, disease forecasting, outlier detection, and automated clinical guidance.

Conventional machine learning models—such as Support Vector Machines (SVM), Decision Trees, Random Forests, and Artificial Neural Networks (ANN)—are heavily utilized for disease classification and diagnostic support [14].

Advanced deep learning architectures—including Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Long Short-Term Memory (LSTM) models—excel at interpreting complex bio-signals and temporal health data for automated forecasting [33].

Moreover, novel strategies like localized edge intelligence and privacy-preserving federated learning gain traction for their ability to deliver instant analytics, curb communication lag, and safeguard patient data confidentiality [36].

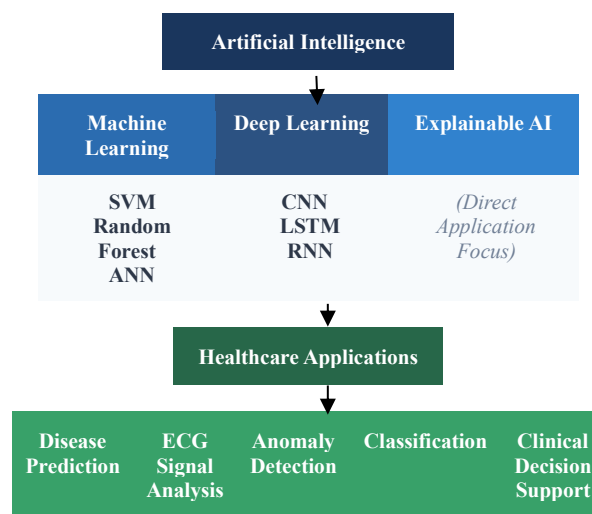


Figure 6. AI Techniques Used in IOT Healthcare Monitoring Systems.

6. Taxonomy of IoT-Based Smart Healthcare Monitoring Systems

Continuous breakthroughs in biosensors, wireless networking, distributed computing, and artificial intelligence have driven the rapid evolution of IoT healthcare monitoring. Drawing from the reviewed literature, a comprehensive taxonomy is structured around five core pillars: clinical applications, sensing modalities, communication protocols, compute architectures, and data processing methods [43].

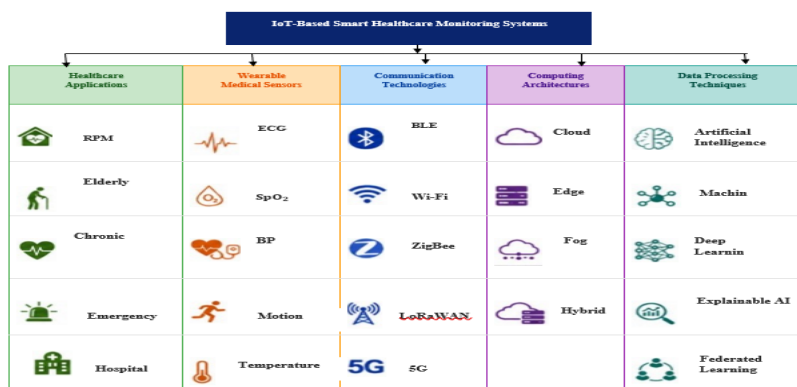


Figure 7. Taxonomy of IoT-based smart healthcare monitoring systems adopted in this review.

6.1 Healthcare Monitoring Applications

Delivering effective healthcare monitoring services stands as the ultimate objective of medical IoT platforms. Analysis confirms that IoT integrations enhance a wide array of clinical services, encompassing remote patient tracking, eldercare, long-term disease management, emergency response, and smart hospital workflows [3].

6.1.1 Remote Patient Monitoring (RPM)

Remote Patient Monitoring (RPM) has established itself as a cornerstone application within the medical IoT domain. RPM enables continuous and real-time monitoring of patients outside traditional healthcare facilities by integrating wearable sensors, medical devices, and wireless communication technologies. These systems are particularly beneficial for patients with chronic diseases such as cardiovascular diseases, diabetes, hypertension, asthma, and respiratory disorders by providing continuous observation and timely health assessment. The monitored physiological parameters commonly include heart rate, electrocardiogram (ECG), blood pressure, body temperature, blood glucose level, oxygen saturation (SpO₂), and respiratory rate. By driving early health anomaly detection, avoiding unnecessary hospital visits, and extending care coverage, RPM systems dramatically elevate patient outcomes and clinical efficiency [5].

6.1.2 Elderly Healthcare Monitoring

An expanding global elderly demographic has heightened the need for automated geriatric care platforms. IoT technologies support independent living by continuously monitoring elderly individuals through wearable devices and smart home environments. The major functions of these systems include fall detection, activity monitoring, medication reminders, sleep monitoring and emergency notifications. Coupling wearable sensors with smart IoT platforms allows remote supervision of seniors, boosting personal safety, autonomy, and overall life quality [8].

6.1.3 Chronic Disease Monitoring

Managing long-term chronic conditions represents a critical use case for healthcare IoT. These systems continuously collect physiological information and analyze patient conditions to identify abnormal changes and support timely medical intervention. Commonly monitored diseases include diabetes, hypertension, cardiovascular diseases, asthma, Parkinson's disease, and kidney diseases. Ongoing biological tracking refines treatment management, encourages personalized therapies, and aids in lowering overall medical expenditures [10].

6.2 Wearable Medical Sensors

Body-worn biosensors form the perception layer of medical IoT networks. These devices capture non-invasive biological and kinetic data streams around the clock, generating rich datasets for downstream analysis [8].

6.2.1 Physiological Sensors

Biological sensors capture core vital signs necessary for ongoing diagnostic tracking. Common examples include ECG sensors, heart rate sensors, blood pressure sensors, temperature sensors, SpO₂ sensors, blood glucose sensors, and respiration sensors. Consequently, these hardware modules form the most prevalent sensing technology across health IoT deployments [44].

6.2.2 Motion Sensors

Movement sensors track patient kinetics, physical exercise, and daily behavioral routines. Typical examples include accelerometers, gyroscopes, and magnetometers. Such inertial hardware powers essential health uses, including fall detection algorithms, activity identification, physical therapy tracking, and geriatric monitoring.

6.2.3 Environmental Sensors

Ambient sensors enrich patient tracking by recording contextual environmental data. Common examples include humidity sensors, air quality sensors, gas sensors, temperature sensors and light sensors. Deploying ambient sensors is especially advantageous in clinical smart rooms and home health tracking setups [44].

6.3 Communication Technologies.

Robust wireless connectivity is vital for routing health data from wearable sensors to processing nodes. Several communication technologies have been adopted in medical IoT systems, including Bluetooth Low Energy (BLE), Wi-Fi, ZigBee, LoRaWAN, 4G, and 5G [9].

6.3.1 5G Networks.

Among these communication technologies, 5G has attracted particular attention for next-generation IoMT applications. Fifth-generation (5G) wireless technology offers high bandwidth, ultra-low latency, and massive device connectivity. These capabilities make 5G a major enabler of large-scale, real-time medical networks, where rapid data transmission and reliable connectivity are essential [10].

6.4 Computing Architectures.

Computing frameworks for medical IoT are selected based on specific clinical and operational requirements.

6.4.1 Cloud Computing

Cloud computing remains a dominant architecture due to its vast storage capacity, powerful processing capabilities, and centralized management. However, challenges such as round-trip network latency, privacy vulnerabilities, and dependence on Internet connectivity pose important limitations [17].

6.4.2 Edge Computing

Edge computing processes data closer to the patient or sensing device rather than transmitting all raw data to distant cloud data centers. By performing computation locally, edge computing can reduce latency, accelerate emergency alerts, and decrease network bandwidth consumption.

6.4.3 Hybrid Cloud–Edge Architecture

Contemporary healthcare IoT solutions increasingly combine edge and cloud computing to balance real-time responsiveness, persistent data storage, fault tolerance, and system scalability [10].

6.5 Healthcare Data Processing Techniques.

Data processing methodologies are crucial for transforming noisy IoT sensor streams into actionable clinical insights. The main approaches include rule-based monitoring, statistical analysis, machine learning, deep learning, artificial intelligence, explainable artificial intelligence (XAI) and federated learning. ML and DL architectures are broadly deployed to handle disease classification, risk prediction, outlier detection, and tailored care plans [22].

6.6 Summary of Taxonomy.

To summarize, literature indicates that health IoT ecosystems map neatly into five core pillars: application domains, biosensor types, networking protocols, processing architectures, and analytics methods. This structured classification offers a roadmap for assessing modern health IoT frameworks and sets up the comparative evaluations detailed in subsequent sections.

Table 8. Comparative Analysis of Selected IoT-Based Smart Healthcare Monitoring Studies

Ref.	Year	Healthcare Application	Sensors	Communication	Architecture	Strengths	Limitations
[1]	2024	IoT Health Monitoring	Wearable Sensors	BLE, Wi-Fi	Cloud	Comprehensive systematic review	Limited practical validation
[2]	2023	Smart Healthcare Systems	Multiple Sensors	BLE, Wi-Fi	Cloud	Bibliometric and systematic analysis	Limited security discussion
[3]	2022	Remote Patient Monitoring	ECG, BP, Temperature, SpO ₂	Wi-Fi	Cloud	Improves healthcare quality	Scalability challenges
[4]	2022	IoT Healthcare Systems	Various Sensors	BLE, ZigBee	Cloud/Edge	Discusses major challenges	Limited experimental evaluation
[5]	2020	Remote Healthcare Monitoring	ECG, Heart Rate	Bluetooth	Edge	Low latency processing	Limited healthcare scenarios

[6]	2019	Smart Health Monitoring	Heart Rate, Temperature	Wi-Fi	Cloud	Simple and cost-effective	Limited security mechanisms
[7]	2021	IoT-Based Smart Healthcare Monitoring Systems	Various Sensors	Wi-Fi, IoT Networks	Cloud	Comprehensive literature review of IoT-based healthcare monitoring systems	Limited discussion of emerging AI and security technologies
[8]	2025	Wearable Healthcare Monitoring	Wearable Sensors	BLE	Edge	Detailed wearable analysis	Interoperability challenges
[9]	2015	IoT Healthcare Survey	Various Sensors	Multiple	Cloud	Fundamental IoT healthcare architecture	Older technologies
[10]	2022	Smart Healthcare	Wearable Sensors	BLE, Wi-Fi	Cloud	Comprehensive systematic review	Energy efficiency issues

7.1 Comparative Discussion.

Evaluated literature reveals a distinct paradigm shift away from centralized cloud-only designs toward decentralized, edge-intelligent health frameworks. Nevertheless, rising data volumes and strict real-time requirements have driven widespread adoption of edge and fog computing architectures [15].

Body-worn hardware continues to lead as the preferred sensing modality in surveyed literature due to its affordability, mobility, and continuous tracking abilities [8]. Frequently cited form factors include smartwatches, chest-worn ECG patches, pulse oximeter clips, smart bandages, and multi-parameter vital monitors [8].

In terms of wireless protocols, Bluetooth Low Energy (BLE) dominates wearable applications thanks to its minimal power draw and seamless pairing with mobile devices. Concurrently, 5G networks are establishing themselves as vital conduits for upcoming IoMT deployments due to their rapid transmission speeds and massive device support [10].

Looking at computing setups, cloud platforms remain widespread due to their virtually unlimited storage and computation capabilities. Nevertheless, hybrid edge-cloud models gain growing favor as they accelerate response times, cut transmission delays, and optimize overall monitoring efficiency [17].

7.2 Comparative Findings.

Cross-study comparisons bring several major developments within medical IoT tracking to light. Analyzed papers clearly track a movement away from legacy cloud models toward smart, distributed ecosystems uniting IoMT hardware, edge processing, AI engines, and modern networks [43].

Biosensors retain their position as the main data capture tool due to their capacity for comfortable, continuous vital signs tracking. While the cloud handles long-term storage and heavy processing, edge and hybrid systems are deployed to deliver low-latency real-time clinical responses [15].

Additionally, advanced AI disciplines—including ML, DL, federated learning, and XAI—are proving indispensable for proactive disease forecasting, outlier detection, and clinical guidance [22].

Findings confirm that prospective medical IoT designs must prioritize smart, resilient, cross-compatible, and expandable infrastructure, as detailed in the following section.

8. Challenges of IoT-Based Smart Healthcare Monitoring Systems

Although IoT healthcare systems have advanced substantially, notable technical, security, and operational roadblocks continue to delay global adoption. Synthesizing the literature highlights core obstacles around cybersecurity, privacy, hardware interoperability, power usage, network reliability, scaling, big data management, and fault tolerance.

8.1 Security and Privacy Protection Challenges.

Data privacy and cybersecurity rank among the most formidable challenges in health IoT due to the constant transmission of confidential medical records across wireless channels to edge/cloud servers. Preserving confidentiality remains paramount given the sensitive nature of biological metrics, leading researchers to explore anonymization, differential privacy, and federated learning to prevent data exposure [36].

8.2 Interoperability Challenges.

Modern medical IoT environments rely on a disparate mix of sensors, wearable hardware, network protocols, and software solutions built by competing vendors. Therefore, implementing unified medical standards and communication protocols—such as HL7 and FHIR—is imperative for enabling smooth cross-system integration [10].

8.3 Energy Efficiency Challenges.

Power consumption persists as a bottleneck, particularly for battery-constrained wearable sensors. Applying these power-saving approaches prolongs device operating cycles while preserving uninterrupted, reliable tracking capabilities.

8.4 Communication Reliability and Latency Challenges.

Dependable, low-latency data transmission is non-negotiable for time-critical remote monitoring setups. To combat transmission issues, current studies test edge computing, 5G connectivity, and AI-driven network optimizations to guarantee swift, dependable communications [15].

8.5 Scalability Challenges.

The exponential rise of active medical IoT devices produces massive data streams, placing severe strain on processing and networking infrastructure. Fusing cloud and edge platforms offers a viable path forward by expanding capacity, decreasing bandwidth consumption, and elevating overall performance [10].

8.6 Healthcare Big Data Management Challenges.

Continuous generation of complex, multi-modal medical data demands sophisticated techniques for data ingestion, storage, integration, and real-time processing. While cloud environments supply massive storage for longitudinal analysis, edge nodes execute local data reduction to prevent network clogging and accelerate diagnostic loops [15].

8.7 Reliability and Fault Tolerance Challenges.

Constant uptime is mandatory for clinical tracking networks, as sudden system failures can stall emergency alerts and compromise patient safety. Integrating these resilient mechanisms ensures system availability and preserves uninterrupted monitoring, even during partial hardware or network outages [43].

8.8 Ethical and Regulatory Considerations.

Outside of purely technical obstacles, health IoT systems introduce complex legal, ethical, and regulatory questions that directly affect real-world clinical adoption. Because these networks continually stream sensitive personal metrics, strict adherence to privacy laws and ethical frameworks is vital to safeguard patient rights and foster user trust [46].

A primary benchmark for regulatory compliance is the Health Insurance Portability and Accountability Act (HIPAA) in the US, which mandates strict safeguards for storing, transferring, and accessing electronic medical records. Satisfying these international mandates has become an indispensable requirement for deploying clinical IoT systems across regional borders [46].

Explicit and informed patient consent stands as another mandatory consideration. Clear, user-friendly consent processes build user trust and reinforce ethical clinical standards [10].

Additionally, establishing clear legal data ownership remains an unresolved issue in literature. Establishing robust governance policies is thus necessary to regulate medical data sharing while ensuring privacy and institutional accountability [17].

Expanding reliance on artificial intelligence models introduces serious risks around algorithmic bias. Building fair, transparent, and interpretable AI pipelines is imperative to earn clinician confidence and prevent automated bias [22].

In summary, tackling legal, ethical, and privacy standards alongside technical issues is essential to creating patient-centric, trustworthy health IoT platforms.

Figure 8 summarizes the major technical and operational challenges affecting IoT-based smart healthcare monitoring systems. These challenges are interconnected and collectively influence the security, performance, scalability and reliability of healthcare monitoring applications.



Figure 8. Major Challenges in IoT-Based Smart Healthcare Monitoring Systems.

Table 9. Summary of Challenges, Solutions, and References in IoT-Based Smart Healthcare Monitoring Systems.

Challenge	Description	Possible Solutions	References
Security	Cyberattacks, unauthorized access, and security vulnerabilities affecting healthcare data.	Encryption, authentication, blockchain, and access control mechanisms.	[26], [46]
Privacy	Exposure of sensitive patient information and medical records.	Data anonymization, federated learning, privacy-preserving techniques, and secure data sharing.	[26], [46]
Interoperability	Lack of compatibility among heterogeneous IoT devices, platforms, and healthcare systems.	HL7, FHIR, standard communication protocols, and data exchange frameworks.	[10], [31]
Energy Efficiency	Limited battery lifetime of wearable healthcare devices due to continuous sensing and communication.	Low-power sensors, BLE communication, energy harvesting, and efficient resource management.	[8], [44]
Communication Reliability	Delay, interference, packet loss, and unstable wireless communication.	5G networks, edge computing, fog computing, and reliable communication protocols.	[20], [15]

Scalability	Increasing number of connected healthcare devices and growing healthcare data volume.	Cloud-Edge hybrid architectures, distributed computing, and resource management techniques.	[17], [10]
Healthcare Big Data Management	Large volume, heterogeneity, and complexity of healthcare datasets.	Cloud computing, big data analytics, AI-based processing, and data management frameworks.	[17], [32]
Reliability and Fault Tolerance	Hardware/software failures, network interruptions, and service unavailability.	Fault-tolerant architectures, redundancy mechanisms, and automatic recovery techniques.	[37], [31]

9. Future Research Directions and Emerging Technologies in IoT-Based Smart Healthcare Monitoring Systems

While smart medical IoT systems have evolved impressively, several technical limitations and research gaps remain open. Fusing these novel technologies promises to resolve modern bottlenecks and elevate continuous tracking, automated diagnostics, and patient-tailored treatments [10].

9.1 Internet of Medical Things (IoMT)

Next-generation medical platforms will increasingly hinge on integrated IoMT ecosystems linking body sensors, bio-implants, cloud backends, and smart clinical apps. Future studies must concentrate on designing safe, expandable IoMT backbones that support personalized care delivery while ensuring tight data governance and privacy protections [23].

9.2 Edge Computing and Edge Intelligence.

Edge processing is poised to become a central pillar of upcoming medical IoT architectures by executing data analytics locally near the user instead of depending on distant cloud servers [49]. Upcoming research should focus on refining lightweight edge-AI algorithms to achieve faster, more dependable clinical decisions directly at the point of care.

9.3 Blockchain Integration.

Distributed ledger technology continues to draw interest in medical domains for its capacity to enforce data integrity, transparency, and trust across healthcare networks [40]. Future efforts must explore scalable blockchain-IoT integrations to reinforce secure data exchanges and privacy, while solving computational overhead and legacy system compatibility issues.

9.4 Explainable Artificial Intelligence (XAI).

AI techniques see expanding deployment across medical IoT systems for diagnostic predictions, bio-signal interpretation, and clinical decision support. Prospective work must prioritize creating interpretable, clinician-friendly AI models that earn doctor trust and ensure safe automated diagnostic guidance [22].

9.5 Digital Twin Technology.

Digital Twin concepts present a revolutionary frontier in digital health, constructing real-time, dynamic virtual replicas of patients using continuous IoT data streams. Future inquiries must refine patient-modeling accuracy and low-latency synchronization methods to maximize the clinical utility of medical digital twins.

9.6 Next-Generation Communication Technologies (5G and 6G Networks).

Advanced 5G evolutions and upcoming 6G connectivity will drastically enhance medical IoT platforms by providing ultra-fast, near-zero latency data channels. Upcoming studies should investigate blending smart, self-optimizing network infrastructure into healthcare IoT designs to maximize operational reliability.

9.7 Green IoT and Sustainable Healthcare.

Sustainable, energy-conscious design principles are becoming critical given the explosive growth of always-on medical IoT nodes [47]. Furthermore, eco-friendly manufacturing and lifecycle strategies must be adopted to support environmentally responsible medical hardware deployments.

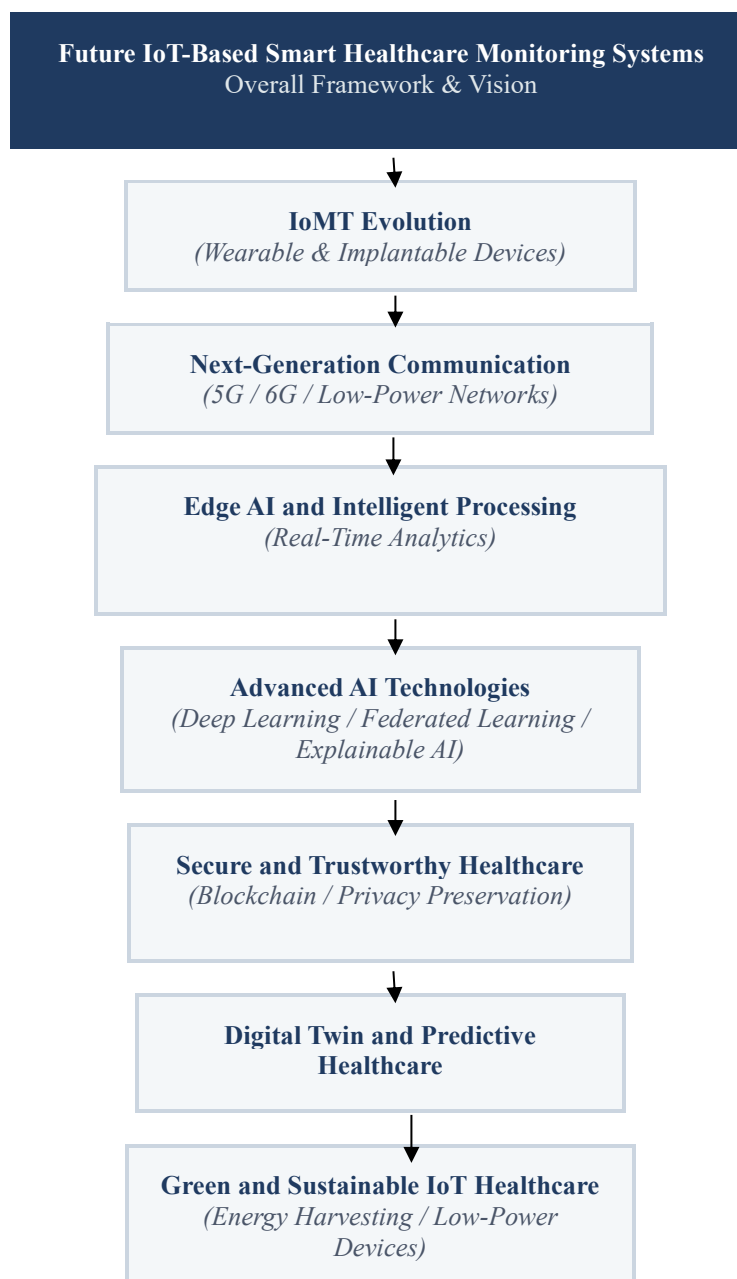


Figure 9. Future Research Roadmap and Emerging Technologies in IoT-Based Smart Healthcare Monitoring Systems.

10. Conclusion

This systematic review delivered an in-depth synthesis of IoT smart healthcare monitoring publications spanning the period from 2015 to 2025. The synthesized literature proves that combining IoT/IoMT platforms, biosensors, edge/cloud tiers, and AI algorithms has revolutionized remote patient surveillance, diagnostic accuracy, and decision support.

However, findings highlight that data privacy, cybersecurity, cross-vendor interoperability, system scaling, power limits, and big data management remain key barriers to global adoption. Looking ahead, innovations like edge intelligence, federated learning, blockchain security, patient digital twins, and explainable AI are set to shape the future of smart medical platforms. In summary, this review delivers a comprehensive reference point for clinicians and engineers by mapping recent progress, uncovering literature gaps, and charting future research directions. Subsequent research efforts should concentrate on engineering secure, power-efficient, cross-compatible, and trustworthy IoT platforms ready for large-scale clinical deployment.

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