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Transforming Healthcare Through the Internet of Things (IoT): A Systematic Review on Opportunities, Challenges, and Future Prospects

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ABSTRACT

Recently, the growth and development of information and communication technologies have changed the backgrounds of various sectors, including engineering and computer science, and it has also been modernized with innovative technologies. Particularly, the growth in the stated sectors has been significantly enhanced due to the integration of Internet of Things (IoT) technologies, leading to more efficient operations and innovative solutions. The IoT is also revolutionizing healthcare by enabling innovative solutions for patient care, operational efficiency, and precision medicine. IoT helps healthcare service providers to do their work more quickly, precisely, and efficiently by streamlining the processes involved in the healthcare system. IoT technology has been increasingly important in the production of health-related technologies in recent years. IoT technology is used in applications like smart wearables, such as activity trackers, smart bands, smart watches, smart headphones, smart clothes, smart glasses, smart rings, and medical wearables. IoT facilitates real-time patient monitoring, telemedicine, predictive analytics, and resource optimization, leading to improved outcomes and reduced costs. Therefore, by knowing the objective, this systematic review examines the transformative potential of IoT in healthcare, focusing on its opportunities, challenges, and future prospects. Also, this study explores the types of IoT technologies used in healthcare and the applications of IoT in transforming healthcare.

Keywords: Internet of Things, Healthcare, Patient monitoring system, Medication management, telemedicine, and Wearable devices.

تحويل الرعاية الصحية عبر إنترنت الأشياء (IoT): مراجعة منهجية للفرص والتحديات والآفاق المستقبلية

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ملخـــــــص البحـــــــث

أحدث النمو والتطور في تقنيات المعلومات والاتصالات مؤخراً تحولاً في ملامح العديد من القطاعات، بما في ذلك الهندسة وعلوم الحاسوب، التي تشهد تحديثاً مستمراً بفضل التقنيات المبتكرة. وعلى وجه الخصوص، تسارع النمو في هذه القطاعات بشكل كبير نتيجةً لدمج تقنيات إنترنت الأشياء(IoT) ، مما أدى إلى عمليات أكثر كفاءة وحلول مبتكرة. يُحدث إنترنت الأشياء أيضاً ثورة في قطاع الرعاية الصحية من خلال تمكين حلول مبتكرة لرعاية المرضى، ورفع الكفاءة التشغيلية، وتطوير الطب

الدقيق. فهو يساعد مقدمي الخدمات الصحية على أداء عملهم بسرعة ودقة وكفاءة أكبر عبر تبسيط العمليات وتنظيمها داخل منظومة الرعاية الصحية. وقد اكتسبت تقنية إنترنت الأشياء أهمية متزايدة في السنوات الأخيرة في إنتاج التقنيات المتعلقة بالصحة، حيث تُستخدم في تطبيقات مثل الأجهزة الذكية القابلة للارتداء، كمتتبعات النشاط، والأساور والساعات الذكية، وسماعات الرأس، والملابس، والنظارات، والخواتم الذكية، بالإضافة إلى الأجهزة الطبية القابلة للارتداء.

تُسهّل تقنية إنترنت الأشياء المراقبة الآنية للمرضى، والطب عن بعد، والتحليلات التنبؤية، والاستخدام الأمثل للموارد، مما يقود إلى تحسين النتائج الصحية وخفض التكاليف. وانطلاقاً مما سبق، تدرس هذه المراجعة المنهجية الإمكانات التحويلية لإنترنت الأشياء في الرعاية الصحية، مع التركيز على الفرص المتاحة، والتحديات القائمة، والآفاق المستقبلية. كما تستكشف الدراسة أنواع تقنيات إنترنت الأشياء المستخدمة في هذا المجال وتطبيقاتها في إحداث هذا التحول.

الكلمات الدالة: إنترنت الأشياء، الرعاية الصحية، نظام مراقبة المرضى، إدارة الأدوية، الطب عن بعد، الأجهزة القابلة للارتداء.

1. Introduction

The rapid advancements in information and communication technologies have significantly transformed various sectors, with the Internet of Things (IoT) emerging as a pivotal innovation [1, 2]. IoT, defined as a network of interconnected devices facilitating communication and data exchange with the cloud, enables remote monitoring, enhanced efficiency, and insightful data analysis [3, 4]. The projected growth of IoT, with an estimated 75.44 billion devices and 79 zettabytes of data by 2025, underscores its pervasive impact across industries, including smart cities, smart transportation, and particularly healthcare [5, 6].

In healthcare, IoT is revolutionizing patient care by enabling real-time monitoring, efficient data collection, and improved patient outcomes through connected medical devices, wearables, and integrated health systems [7]. This technological integration promises personalized treatment, reduced costs, and timely interventions. However, its widespread adoption is accompanied by significant challenges, notably concerning data security, privacy, and interoperability standards [7].

This systematic review aims to comprehensively explore the transformative potential of IoT in healthcare. It critically examines the current applications and key opportunities presented by IoT while also analyzing the inherent challenges that impede its full-scale implementation. Furthermore, this study delineates the various types of IoT technologies utilized in healthcare and their specific applications in reshaping healthcare delivery. The subsequent sections detail the research methodology, including the research questions and article selection strategy, followed by a critical literature review, and concluding with an in-depth discussion of findings and future prospects.

Figure 1 illustrates how the dynamics of the healthcare system are altered by the implementation of IoT. These devices are easy to use, enabling remote patient monitoring and simple device administration [9]. IoT devices in healthcare enable real-time monitoring, data collection, and analysis, improving patient outcomes and operational efficiency through connected medical equipment and wearable health technology [10]. When healthcare applications in IoT systems are considered, gateways located between sensors (or PHDs) and the IoT servers usually play very important roles [11, 12]. Therefore, this systematic review aims to explore the numerous impacts of IoT on healthcare, examining its current applications, identifying the key opportunities it presents, and analyzing the challenges that stop its full-scale adoption. Further section headings are explained in Figure 2.

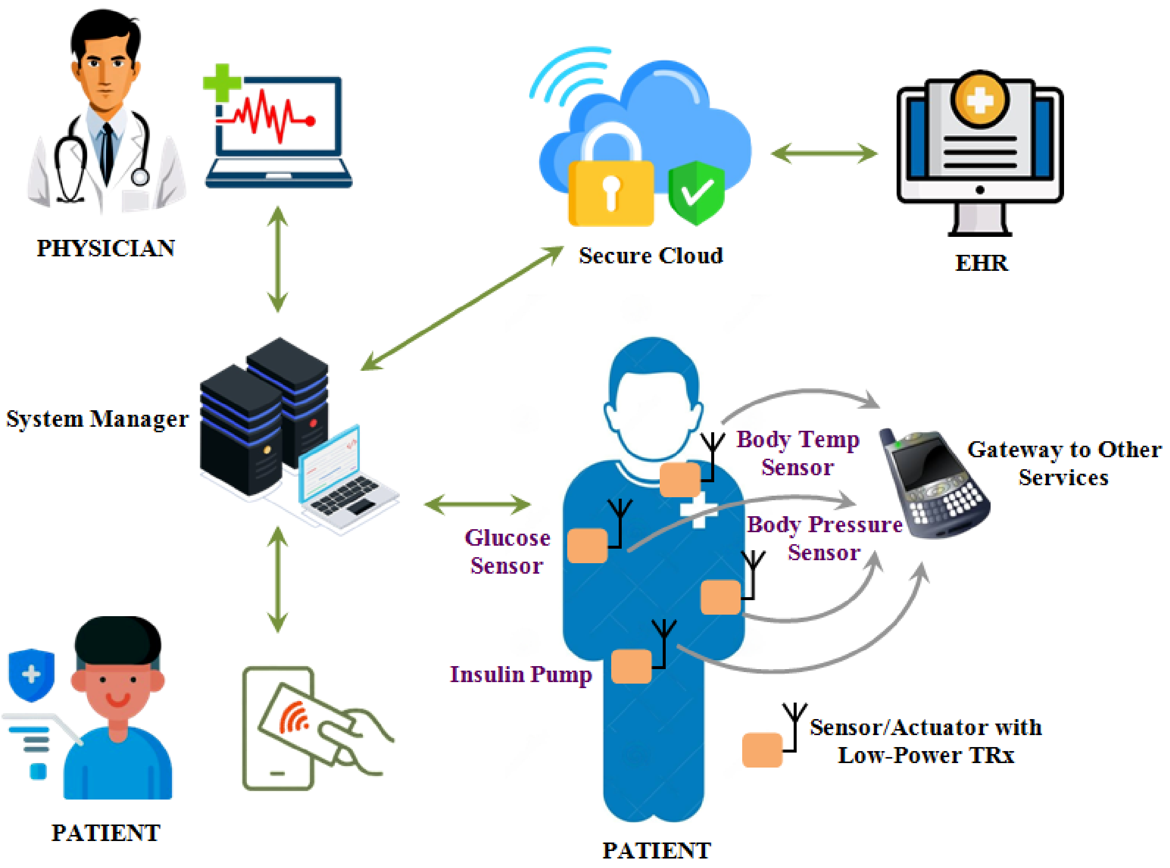


Figure 1: Use case scenario of IoT in the healthcare [8]

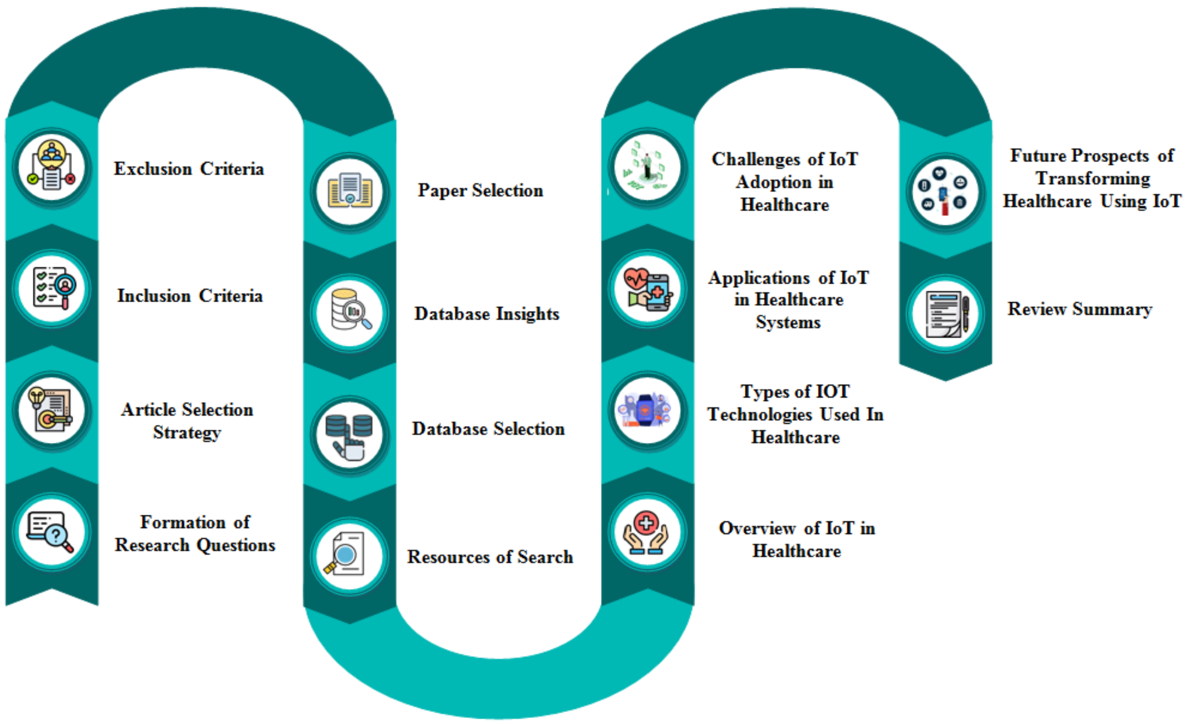


Figure 2: Further section headings

2. Research Question and Article Selection Strategy

Research questions

A Research Question (RQ) is important in a literature review because it guides the review and provides the basis for the entire research project. RQs are essential to a literature review since RQ not only direct the review but also help to define the focus and direction of the investigation. RQ also assists the review in concentrating on particular topics and confirming that the analysis remains related and associated with the objectives of the study.

Formation of RQs

The purpose is to provide clear and focused guidelines for the investigation, ensuring that the research explains specific aspects of IoT's impact on healthcare. These questions help to identify key areas, such as the applications of IoT in patient care, the benefits of real-time monitoring and data analysis, and the challenges related to data security, privacy, and interoperability. Figure 3 explains the formed RQs.

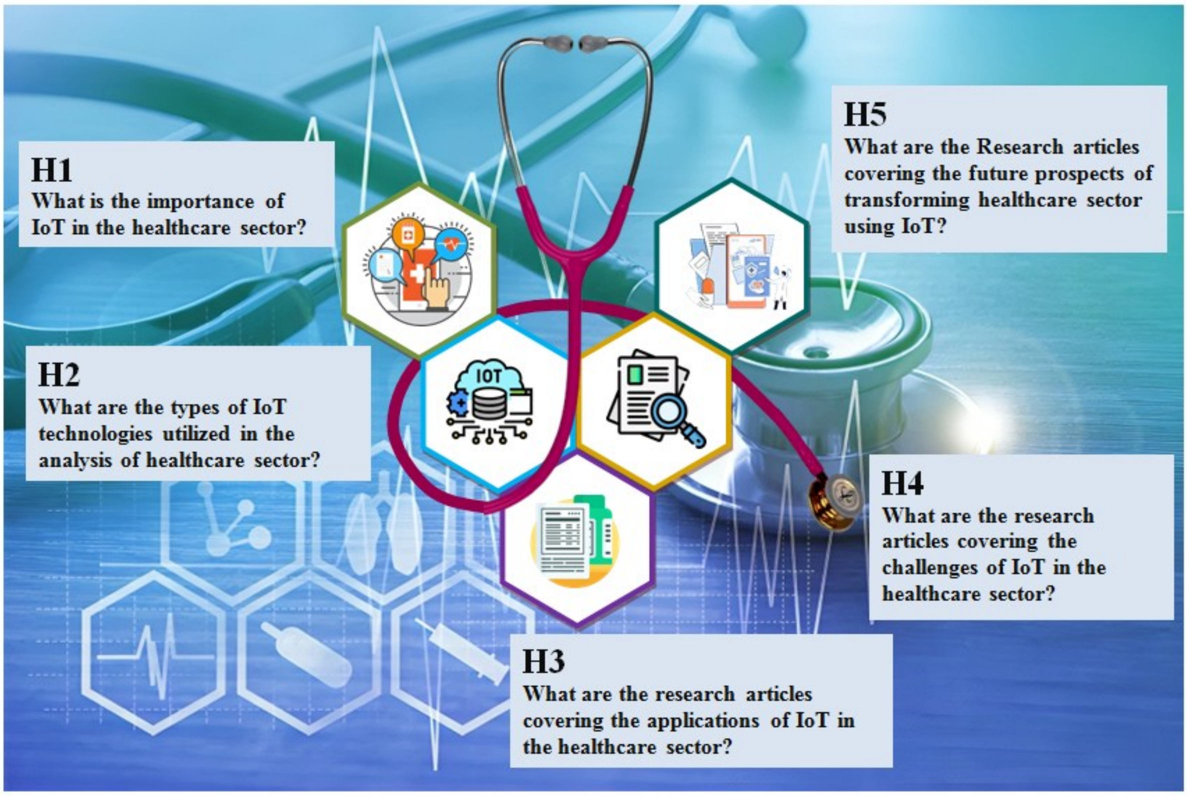


Figure 3: Developed RQs

Article selection strategy

A systematic review in research requires a strategy for choosing articles, which is known as the article selection strategy. Selecting related articles for a review-based study needs a systematic process to confirm a thorough and related examination of the subject. The article selection strategy is found to be more important for several reasons. Initially, the strategy confirms that the research is found in the most relevant and high-quality sources. By carefully selecting articles that cover various aspects of IoT, such as its technological advancements, implementation challenges, and impact on patient care, the researcher can form a comprehensive and nuanced view of the topic.

2.1. Inclusion and Exclusion Criteria

Research papers that are written exclusively in English have been included in the study since it is believed that the English language is distinct and intelligible to a wide range of individuals. The research studies published between 2015 and 2023 are the focus of the investigation.

Inclusion criteria: The literature review was expanded to include articles related to the use of IoT in healthcare. The literature evaluation covered research studies that were published between 2015 and 2024.

Exclusion criteria: Articles that focused solely on the healthcare industry were omitted. Research studies that only defined the problems associated with IoT in healthcare were not included in the literature review.

2.2. Resources of search and selection strategy

This section provides an explanation of the resources used for the literature search and review process.

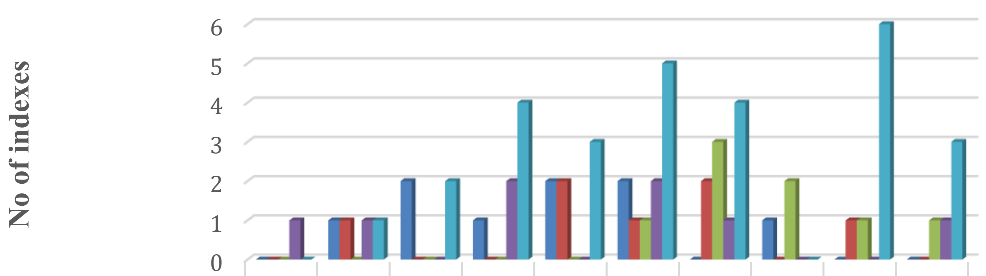
***Resources*:** Based on the initial study, several academic search engines, including Google Scholar, Springer, Elsevier, and IEEE Xplore, were found. The purpose of the aforementioned academic search engines was to save information related to the matching objective.

Database selection: Scopus, Science Citation Index Expanded (SCIE), and Web Of Science (WOS) were important databases that were used to find and choose articles for the literature review.

Database Insights: The other databases, like journals, stood out from the other databases because of the extensive abstract and citation databases of peer-reviewed material published in scientific publications. In terms of evaluation, appearance and substance, the selected databases provided significant benefits.

2.3. Paper Selection

A total of 60 papers were selected for examination after the correct count of journals relevant to the primary keywords was analyzed. The papers were chosen according to predetermined standards. Figure 4 shows a visual depiction of the search results for this review-based study and Figure 5 explains the piechart representation for the publication percentage analysis.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Science Direct	0	1	2	1	2	2	0	1	0	0
Scopus	0	1	0	0	2	1	2	0	1	0
Web of Science	0	0	0	0	0	1	3	2	1	1
IEEE	1	1	0	2	0	2	1	0	0	1
Others	0	1	2	4	3	5	4	0	6	3

Figure 4: Search results of the article

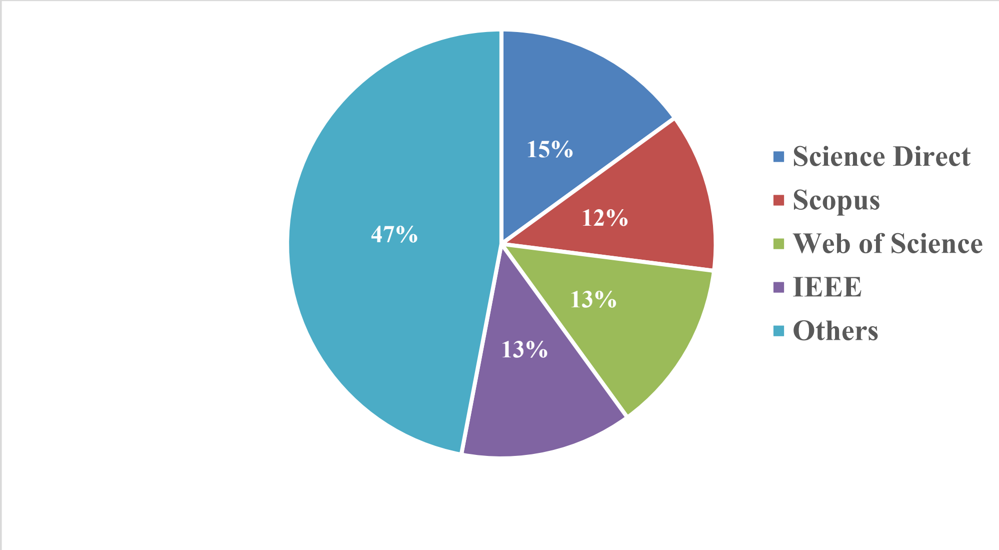


Figure 5: Percentage analysis

3. Literature review : A Critical and Comparative Analysis

The integration of the Internet of Things (IoT) into healthcare promises a paradigm shift in patient care and operational efficiency. This revised literature review moves beyond a descriptive summary to provide a systematic comparative analysis of existing research, critically examining the diversity of technological approaches, methodological rigor, and the practical outcomes achieved. This analysis serves to clearly delineate the current state of the art and to strategically identify the most critical research gaps that inform the objectives of the present study.

3.1. Comparative Analysis of Key Studies

The literature on IoT in healthcare can be broadly categorized by its primary focus: System Design and Feasibility, Adoption and Socio-Technical Factors, and Security and Optimization. A comparative analysis of selected studies reveals significant variations in their scope, methodology, and the nature of their practical contributions, as summarized in Table 1.

Table 1: Comparative Analysis of Key Studies on IoT in Healthcare

Author (s)	Year	Focus/Technology	Methodology	Key Findings/Practical Results	Gaps/Limitations
Asmae, *et al.* [17]	N/A	IoT-based System (COVID-19)	Design/ Description	System designed to connect physicians and patients; emphasizes ease of use and energy efficiency.	Absence of quantitative data on actual impact (e.g., reduced hospital pressure, precision of treatment).
Adem, *et al.* [18]	N/A	IoT Adoption Factors	Empirical Study (Survey/Theoretical Models)	Perceived Advantage (PA), image, and Perceived Ease of Use (PEOU) significantly influence adoption intentions.	Reliance on self-reported intentions; lack of longitudinal data on actual adoption behavior; limited

					exploration of socio-cultural factors.
Abhisek, *et al*. [20]	N/A	Consumer Adoption in Emerging Economies	Empirical Study (Model Testing)	Model achieved 62.8% explanatory power for consumer adoption of IoT devices.	Neglects perspectives of healthcare providers; need to consider socio-economic disparities and digital literacy.
Punit, *et al*. [21]	N/A	IoT Smart Healthcare Kit (Mobile App)	System Design/Implementation	Aimed at improving health-related risks and lowering healthcare expenses through efficient data collection.	Lacks detailed empirical evidence on actual reduction in healthcare expenses or health-related risks; absence of cost-benefit analysis.
Ali, *et al*. [22]	N/A	Security Optimization (Hashing/Certificates)	Technical Optimization/Simulation	Significant improvements in energy usage, avalanche effect, and execution/encryption/decryption times.	No comprehensive analysis of real-world security threats; lack of comparison against established security protocols in a clinical setting.
Zia, *et al*. [28]	N/A	Wearable Biomedical Device (Patient Monitoring)	System Design/Demonstration	Successfully informed family/physician in an emergency; demonstrated real-time monitoring.	Vulnerability to hacking and data breaches; lack of a proposed robust security framework or comparative analysis of security methods.
Sidra, *et al*. [29]	N/A	Remote Patient Monitoring System	Technical Testing (LAN/WAN)	Implemented app showed no packet errors or data loss on LAN or WAN networks (technical reliability).	Absence of clinical context or user-based evaluation; reliability does not translate to improved patient outcomes or usability.
Suvini, *et al*. [53]	N/A	Security and Privacy Issues Overview	Systematic Review (Descriptive)	Protection of sensitive patient information is a major concern; IoT devices are vulnerable to cyber-attacks.	Offers descriptive analysis without proposing concrete, actionable

					mitigation strategies or evaluating existing countermeasures.
Omid, *et al*. [54]	N/A	Interoperability Challenges	Systematic Review (Categorization)	Categorized issues into device heterogeneity, data standardization, security, and regulatory compliance.	Provides a useful taxonomy but offers limited discussion on practical solutions or architectural models to overcome challenges.

Analysis of Methodological and Technical Divergence

The studies reviewed exhibit a clear divergence in their methodological approaches and technical focus:

1 Focus on Technical Feasibility vs. Clinical Validation: A majority of the research, such as the work by Ali, *et al*. [22] on security optimization and Sidra, *et al*. [29] on network reliability, focuses heavily on technical metrics (e.g., energy usage, packet loss, execution time). While essential for system integrity, these studies often fail to bridge the gap to clinical outcomes or patient benefit. This highlights a pervasive gap where engineering success is not translated into clinical efficacy.

2 Descriptive Design vs. Empirical Testing: Studies like Asmae, *et al*. [17] and Punit, *et al*. [21] primarily describe the design and intent of a system, offering a conceptual framework rather than empirical validation. In contrast, studies like Adem, *et al*. [18] and Abhisek, *et al*. [20] employ empirical methodologies (surveys, model testing) to explore adoption factors. However, even these empirical studies are limited, often relying on self-reported intentions rather than tracking actual, long-term adoption behavior, thereby limiting the generalizability and predictive power of their findings.

3 Narrow Focus vs. Systemic Integration: Research often concentrates on a single aspect, such as asset tracking [40]. This narrow focus overlooks the systemic challenges of integrating diverse IoT devices into the complex, existing healthcare IT infrastructure. The work by Jameel, *et al*. [35] and Saritha, *et al*. [40] explicitly identifies the lack of interoperability with Electronic Health Records (EHRs) as a critical barrier, suggesting that future research must shift from isolated device development to holistic, interoperable platform design.

This comparative analysis underscores the need for a new generation of research that employs longitudinal, quantitative methodologies to validate the clinical and economic impact of technically feasible IoT solutions, while simultaneously addressing the systemic challenges of interoperability, security, and socio-technical adoption.

3.2. Conceptual Model: Interplay of Technologies, Challenges, Applications, and Health Outcomes

To provide a clear theoretical framework for the current research and to structure the subsequent critical analysis, a Conceptual Model is proposed. This model illustrates the complex, multi-faceted relationships between the core components of IoT in healthcare: Technology Enablers, Systemic Challenges, Practical Applications, and the ultimate goal of Health Outcomes.

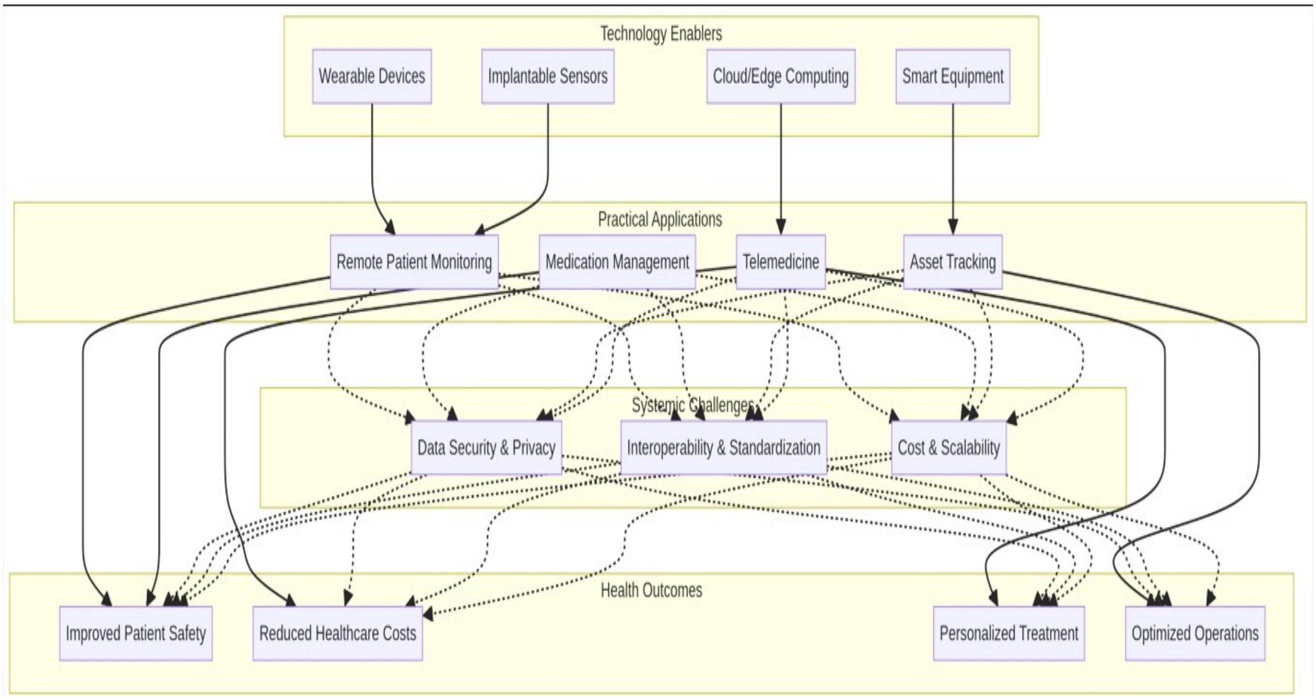


Figure 6: Conceptual Model of IoT in Healthcare Transformation

The proposed Conceptual Model of IoT in Healthcare Transformation is visually represented in Figure 6. This model establishes the systematic flow from Technology Enablers to Practical Applications, which are designed to achieve positive Health Outcomes. Crucially, the model highlights the Systemic Challenges as critical mediating factors that constrain the successful transition from application deployment to the full realization of health benefits.

- Technology Enablers: The foundation includes specific components like Wearable Devices, Implantable Sensors, Cloud/Edge Computing, and Smart Equipment.
- Practical Applications: These are the direct use cases, such as Remote Patient Monitoring, Medication Management, Telemedicine, and Asset Tracking.
- Systemic Challenges: Factors like Data Security & Privacy, Interoperability & Standardization, and Cost & Scalability act as critical constraints, influencing the success of applications and the achievement of outcomes.
- Health Outcomes: The ultimate goals, including Improved Patient Safety, Reduced Healthcare Costs, Personalized Treatment, and Optimized Operations.

The model demonstrates that the successful transition from Technology Enablers to positive Health Outcomes is contingent upon effectively mitigating the Systemic Challenges through robust Practical Applications.

3.3. Enhanced Critical Analysis and Reasons for Research Gaps

Building upon the comparative analysis, this section provides a critical analysis of the identified research gaps, explaining the potential underlying causes and reinforcing the need for the current study.

3.3.1. Lack of Quantitative Clinical and Economic Validation

A recurring and critical limitation across the literature is the absence of rigorous quantitative data to validate the clinical and economic impact of IoT solutions [21] [45]. Studies often demonstrate technical feasibility but fail to provide empirical evidence of reduced medical errors, decreased hospital readmissions, or measurable cost savings.

Potential Causes for the Gap:

- Weak Sample Size and Study Design: Many studies acknowledge that their findings are not generalizable due to a specific demographic group or small sample size. This lack of a robust, diverse cohort prevents the application of findings to a larger population and limits the ability to conduct statistically significant clinical trials.
- Nonspecific Metrics: The focus on technical metrics (e.g., energy usage [22], network reliability [29]) often overshadows the collection of patient-centric metrics (e.g., quality of life, adherence rates, morbidity/mortality). This methodological choice results in a body of literature that is strong on engineering but weak on clinical relevance.
- Absence of Cost-Benefit Analysis: The high cost of developing and maintaining IoT systems [42] is frequently noted, yet comprehensive Return on Investment (RoI) calculations or comparative cost-effectiveness analyses against traditional methods are consistently missing [21]. This lack of economic rigor is a significant barrier to large-scale institutional adoption.

3.3.2. The Interoperability and Standardization Deficit

The literature consistently identifies the lack of standardized protocols as a major impediment to integrating diverse IoT devices [40] [54]. This deficit is not merely a technical inconvenience but a fundamental barrier to coordinated, holistic patient care.

Potential Causes for the Gap:

- Device Heterogeneity: The rapid proliferation of proprietary IoT devices, each with its own communication protocol and data format, creates a fragmented ecosystem [54]. This device heterogeneity makes seamless data exchange with existing Electronic Health Record (EHR) systems a necessity for coordinated care nearly impossible [35].
- Lack of Semantic Data Models: Beyond simple connectivity, there is a lack of semantic standardization. Data from different devices (e.g., a wearable heart rate monitor and an implantable glucose sensor) must be interpreted and aggregated meaningfully. The absence of a unified data model hinders predictive analytics and clinical decision support.

3.4. Expanded Discussion on Cybersecurity and Practical Solutions

The security and privacy of patient data are paramount concerns in the healthcare IoT sector [53]. The current literature, while acknowledging the vulnerability of devices to cyber attacks and data breaches [28], often provides only a descriptive analysis of the problem. A deeper critical discussion is required, along with the proposal of advanced, practical solutions.

3.4.1. Critical Vulnerabilities in Current IoHT Security

The primary security challenge stems from the resource-constrained nature of many IoT devices (e.g., limited battery, processing power, and memory), which prevents the implementation of robust, traditional cryptographic protocols.

- Authentication Weaknesses: Most IoHT solutions are limited in broad dissemination due to inadequate authentication and identification methods [55]. Simple password-based or default credentials on devices create easy entry points for attackers.
- Data Integrity and Availability: The integrity of data from critical devices, such as pacemakers [30], is essential. A successful cyber-attack could not only breach patient privacy but also compromise the accuracy of data, potentially leading to incorrect diagnoses or life-threatening treatment decisions. The study by Ali, *et al*. [22] addresses optimization for security but lacks validation against real-world, sophisticated cyber threats.

3.4.2. Proposed Advanced Solutions: Blockchain and AI

To move beyond descriptive analysis, the literature must explore and validate advanced technical solutions that address the unique security requirements of IoHT.

- Blockchain Technology for Data Integrity and Access Control:
  - Solution: Implementing a private or consortium blockchain can provide an immutable, distributed ledger for storing patient data access logs and critical sensor readings. Each data transaction (e.g., a sensor reading, a physician accessing a record) is cryptographically secured and timestamped.
  - Benefit: This approach inherently solves the data integrity problem, as any tampering would be immediately detectable across the network. It also offers a highly granular and transparent mechanism for access control, ensuring that only authorized parties can view specific patient data, thereby enhancing compliance with regulations like HIPAA.
- Artificial Intelligence (AI) for Real-Time Intrusion Detection:
  - Solution: Deploying lightweight Machine Learning (ML) models at the edge (e.g., on gateway devices [11] [12] to continuously monitor network traffic and device behavior.
  - Benefit: Traditional security systems rely on known threat signatures. AI-based Intrusion Detection Systems (IDS) can detect zero-day attacks and anomalous behavior (e.g., a device suddenly transmitting an unusually large volume of data) in real-time, providing a proactive layer of defense against sophisticated cyber-attacks that target the unique communication patterns of IoHT devices.

3.5. Linking Research Gaps to Future Opportunities

The critical analysis of the literature reveals several critical research gaps that, when reframed, represent significant strategic opportunities for future research and development.

Table 2: Linking Research Gaps to Future Opportunities

Research Gap (Critical Weakness)	**Future Research Opportunity (Vision)**
Lack of Clinical and Economic Validation	Longitudinal, Randomized Clinical Trials (RCTs): Conduct large-scale, multi-site studies to empirically validate the long-term efficacy, patient outcomes, and economic impact (ROI) of deployed IoT systems.
Interoperability and Standardization Deficit	Development of Unified Data Models and Gateways: Research and develop open-source, standardized data models and middleware

	solutions to ensure seamless, secure data exchange between proprietary IoT devices and existing Electronic Health Record (EHR) systems.
Theoretical Security Validation	Real-World Security Audits and Penetration Testing: Conduct rigorous security testing of proposed solutions (e.g., Blockchain, AI-IDS) in live, simulated clinical environments against state-of-the-art cyber threats.
Focus on Consumer Adoption (Neglecting Provider/Systemic Factors)	Integrated Adoption Models: Develop and test models that incorporate the perspectives of all stakeholders (patients, providers, administrators) and include systemic variables like digital literacy, regulatory compliance, and interoperability standards.
User-Interface Challenges	Human-Centered Design and Usability Studies: Conduct extensive user experience (UX) and usability studies, particularly with vulnerable populations (e.g., the elderly), to ensure that IoT devices are intuitive, accessible, and promote high adherence rates.

3.6. Synthetic Summary and Critical Gaps

This systematic review of the literature confirms that IoT is a transformative force in healthcare, primarily through its ability to enable real-time, continuous patient monitoring and support personalized medicine. The most important scientific trends identified are the rapid development of wearable and remote monitoring technologies and the growing, albeit insufficient, focus on data security optimization.

The analysis, however, reveals three critical gaps that currently impede the full-scale, trustworthy adoption of IoT in clinical practice:

1 The Validation Gap: A pervasive lack of rigorous, long-term clinical and economic validation of deployed systems.

2 The Interoperability Gap: The failure to establish unified data models and standards prevents the seamless integration of diverse IoT devices with critical Electronic Health Record (EHR) systems.

3 The Security Gap: A reliance on theoretical security metrics rather than practical, real-world security audits and the implementation of advanced, intelligent security frameworks (such as those leveraging Blockchain and AI).

Future research must pivot from mere demonstration of technical feasibility to empirical validation and the development of robust, intelligent, and interoperable security frameworks to bridge these critical gaps and establish a clear path for the safe and effective integration of IoT into mainstream healthcare. This synthesized conclusion serves as the foundation for the subsequent chapters of this research.

3. Summary of the Study

IoT is reshaping healthcare by introducing innovative tools and systems that enhance patient care, optimize resource management, and support precision medicine. This systematic review explores the current applications of IoT in healthcare, its challenges, and the prospects for its future integration into global health systems. IoT enables real-time monitoring and management of patient health through interconnected devices, such as wearable sensors, smart medical equipment, and mobile applications. These technologies provide continuous data streams that facilitate the early detection of health issues, personalized treatment plans, and efficient chronic disease management. Telemedicine, powered by IoT, has expanded access to healthcare, especially in remote areas, by connecting patients with providers for consultations and remote diagnostics. Predictive analytics, fueled by IoT-collected data, enhances decision-making, reduces medical errors, and improves operational efficiency in hospitals by streamlining workflows and optimizing resource allocation. The RQs are categorized as H_1, H_2, H_3, H_4, and H_5. In order to add creativity to the review article, the pertinent questions and answers are provided as follows,

- ✓ ***Importance of IoT in the Healthcare Sector* (*H_1*):** This question aimed to explain the significance of IoT in the healthcare sector and was illustrated in section 3.1.
- ✓ ***Types of IoT technologies utilized in the analysis of the healthcare sector* (*H_2*):** The mentioned question’s objective was to clearly explain the types of IoT technologies utilized in the healthcare sector, which was detailed in section 3.2.
- ✓ ***Research articles covering the applications of IoT in the healthcare sector (H_3):*** The research articles covering the applications of IoT were explained in table 2 of section 3.3.
- ✓ ***Research articles covering challenges of IoT in the healthcare sector (H_4):*** The research articles covering the challenges of IoT in the healthcare sector were described in section 3.4 from ref 53 to 57.
- ✓ ***Research articles covering the future prospects of transforming the healthcare sector using IoT (H_5):*** The research articles associated with the future prospects of transforming the healthcare sector using IoT were detailed in section 3.5.

The review highlights how IoT can revolutionize healthcare by encouraging patient-centered practices, improving diagnostic precision, and cutting expenses. But, reaching these goals necessitates removing the current problems and promising cooperation between all parties involved, including legislators, medical professionals, and IT developers. By doing this, IoT can open up the path to more effective healthcare systems around the globe.

4. Conclusion

This systematic review has thoroughly explored the transformative potential of the Internet of Things (IoT) in healthcare, examining its opportunities, challenges, and future prospects. While IoT undeniably offers significant avenues for enhancing patient care, improving operational efficiency, and reducing healthcare costs, a critical analysis of the current literature reveals a pervasive lack of rigorous quantitative assessments regarding its actual clinical and economic impacts. Many studies, though demonstrating the technical feasibility of various IoT applications, frequently fall short in providing empirical evidence of their cost-effectiveness or measurable improvements in patient outcomes.

From a clinical standpoint, IoT's potential spans real time patient monitoring, chronic disease management, and improved diagnostics. For instance, while technical advancements in security, such as those reported by Ali, *et al*. [22] (e.g., 65% energy usage reduction), are vital for system integrity, their translation into quantifiable clinical benefits like reduced medical errors or enhanced patient safety remains largely unaddressed. Similarly, proposed improvements in medication adherence via smart systems [19, 43, 46, 47] often lack data on corresponding reductions in adverse drug events or hospital readmissions.

Economically, IoT promises lower operational costs and optimized resource allocation. However, the reviewed literature offers limited quantitative data to substantiate these claims. Studies, such as that by Punit, *et al*. [21] aiming to reduce healthcare expenses, typically omit comprehensive cost-benefit analyses or Return on Investment (ROI) calculations. Given the projected scale of IoT with 75.44 billion devices generating 79 zettabytes of data by 2025 [5], robust economic models are urgently needed. These models must extend beyond direct implementation costs to encompass indirect savings from reduced hospitalizations, fewer emergency visits, and improved long-term health outcomes.

In essence, while the existing body of literature establishes a strong foundation for understanding IoT's applications in healthcare, it critically highlights significant research gaps concerning empirical validation of its clinical and economic efficacy. Future research must transcend descriptive accounts and feasibility studies. It necessitates rigorous, quantitative assessments through longitudinal studies, randomized controlled trials, and comprehensive economic analyses to generate the evidence crucial for informed policy-making, strategic investment, and effective clinical practice. Concurrently, addressing persistent challenges in interoperability, data security, and privacy remains paramount to fully realize IoT's transformative potential in fostering a more connected, efficient, and patient-centric healthcare ecosystem.

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