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Evolving Software Architecture Design in Telemedicine: A PRISMA-based Systematic Review

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Objectives: This article presents a systematic review of recent advancements in telemedicine architectures for continuous monitoring, providing a comprehensive overview of the evolving software engineering practices underpinning these systems. The review aims to illuminate the critical role of telemedicine in delivering healthcare services, especially during global health crises, and to emphasize the importance of effectiveness, security, interoperability, and scalability in these systems. **Methods:** A systematic review methodology was employed, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework. As the primary research method, the PubMed, IEEE Xplore, and Scopus databases were searched to identify articles relevant to telemedicine architectures for continuous monitoring. Seventeen articles were selected for analysis, and a methodical approach was employed to investigate and synthesize the findings. **Results:** The review identified a notable trend towards the integration of emerging technologies into telemedicine architectures. Key areas of focus include interoperability, security, and scalability. Innovations such as cognitive radio technology, behavior-based control architectures, Health Level Seven International (HL7) Fast Healthcare Interoperability Resources (FHIR) standards, cloud computing, decentralized systems, and blockchain technology are addressing challenges in remote healthcare delivery and continuous monitoring. **Conclusions:** This review highlights major advancements in telemedicine architectures, emphasizing the integration of advanced technologies to improve interoperability, security, and scalability. The findings underscore the successful application of cognitive radio technology, behavior-based control, HL7 FHIR standards, cloud computing, decentralized systems, and blockchain in advancing remote healthcare delivery.

Keywords: Digital Health, Telemedicine, Medical Informatics, Software, Technology

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I. Introduction

The digital transformation of healthcare is accelerating, with telemedicine emerging as a key tool in modern healthcare delivery. The coronavirus disease 2019 (COVID-19) pandemic has highlighted the importance of telemedicine, especially for the continuous monitoring of patients in regions with limited access to healthcare. Effective telemedicine services rely on robust architectural foundations that ensure efficiency, security, and scalability. Understanding the latest developments and challenges in telemedicine architectures, with an emphasis on continuous monitoring, is crucial. Through a synthesis of recent research, this review aims to identify key trends and innovations, offering insights guiding further optimization of telemedicine systems for improved healthcare delivery.

Figure 1 depicts a multi-layered software system architecture. The user interface (UI) layer includes components such as the device connection UI and data visualization for user interaction. The facade layer manages communication with services including protocol translation and encryption. The domain layer encompasses core functionalities such as business logic and data processing. The service layer facilitates operations with network management and application programming interface (API) gateways, while the foundation layer provides essential storage solutions, such as cloud database and cache services.

Existing telemedicine architectures exhibit a wide range of designs, each with advantages and drawbacks. Traditional systems frequently encounter issues such as limited interoperability, security vulnerabilities, and scalability challenges. The application of advanced software engineering principles, including agile methodologies, object-oriented programming, and model-driven architecture, is essential for the development of more robust systems [1]. These principles are designed to improve software quality, reduce costs, and facilitate the development of distributed applications [2-4]. Despite considerable progress, challenges remain, particularly regarding Internet of Things (IoT)-based healthcare applications. Security, privacy, latency, and reliable data provisioning are critical, especially in emergency situations [5-8]. Emerging solutions such as fog computing and software-defined networks show promise in improving communication, computing, and security within healthcare systems [9]. Additionally, regulatory requirements and data standards substantially influence the design of telemedicine architectures, necessitating compliance and interoperability [10-19]. This review, conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, explores recent advancements in telemedicine architectures for continuous monitoring. It addresses two primary research questions:

1) What roles do software engineering principles play in shaping the latest telemedicine architectures?
2) Which areas or technologies should be prioritized to optimize continuous patient monitoring?

By exploring these questions, the review seeks to provide a comprehensive understanding of the present landscape and future directions of telemedicine architectures within the broader context of healthcare information technology.

II. Methods

This systematic review was conducted in accordance with the PRISMA framework to ensure rigor and transparency [20]. The PRISMA framework informed the processes of identification, screening, assessment of eligibility, and inclusion of studies, as depicted in Figure 2.

1. Research Design

A comprehensive literature review was conducted to understand recent advancements in telemedicine architectures designed for continuous monitoring. Relevant articles were identified, evaluated, and selected to address the research questions posed. The methodology of the review is outlined in the following steps.

1) Identification of sources

- Database search: The PubMed, IEEE Xplore, and Scopus databases were extensively searched to uncover articles relevant to telemedicine architectures designed for continuous monitoring. Six articles were identified from PubMed, two from IEEE Xplore, and nine from Scopus.

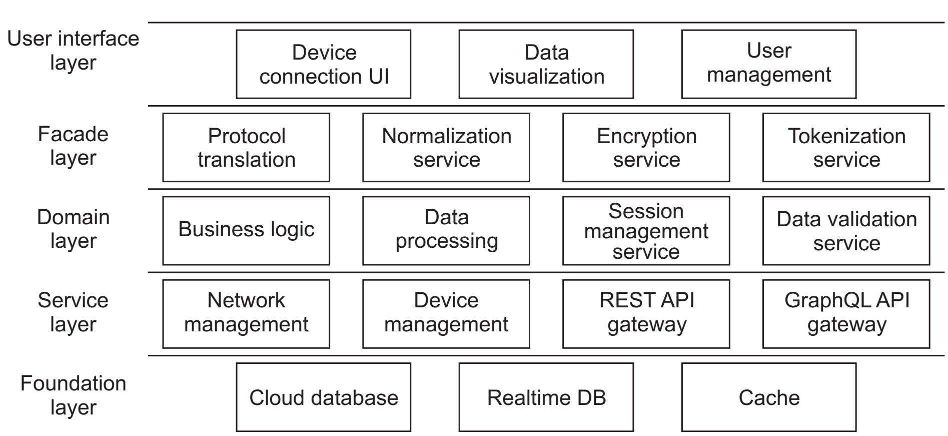

Figure 1. Telemedicine service-oriented architecture. UI: user interface, REST: Representational State Transfer, API: application programming interface.

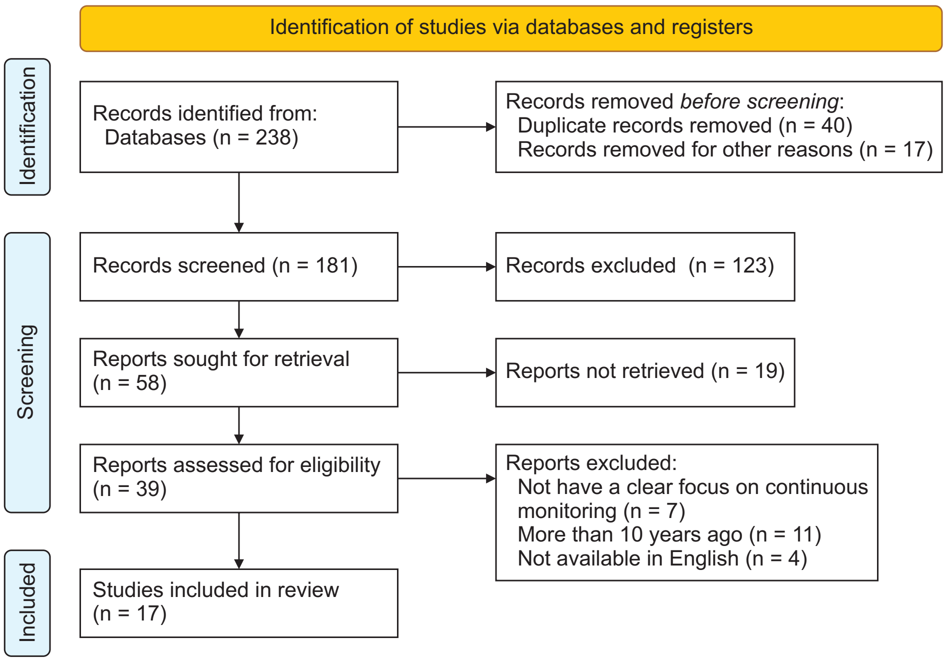

Figure 2. Preferred Reporting Items for Systematic reviews and Meta-Analyses diagram.

- Keywords used: The search strategy employed keywords and phrases such as "telemedicine architectures," "continuous monitoring," "remote patient monitoring," "telehealth systems," and "mHealth frameworks."

2) Screening

First, titles and abstracts of the identified articles were screened to assess their relevance to the research questions. Following this preliminary assessment, full-text versions were obtained of the articles deemed promising. These full-text articles were then thoroughly examined to further evaluate their relevance and quality, ensuring they met the study criteria.

3) Eligibility assessment

- Inclusion criteria: Studies were included if they explicitly illustrated or proposed new architectures within telemedicine, focusing on improving systems for continuous monitoring. The included studies needed to contribute to the field in an innovative fashion by offering new theoretical insights or practical telemedicine solutions.
- Exclusion criteria: Articles were excluded if they were unavailable in English, were published more than 10 years ago, or lacked a clear focus on telemedicine architectures for continuous monitoring.

4) Data extraction, assessment, and synthesis

Once the eligible articles were selected, data extraction was performed. Critical information was obtained from each article, including author name(s), year of publication, primary objective of the study, methodology used, key findings, and relevant implications.

Importantly, the research process involved evaluating the quality of the included studies. This assessment was based on several criteria, including the methodology of the study, the size of the sample, the depth and rigor of the statistical analysis, and the relevance of the study to the central research question.

After all required data were collected, a thematic analysis was performed to identify common themes, observe prevailing trends, and identify potential gaps in the existing literature on telemedicine architectures designed for continuous monitoring.

This systematic review, conducted in accordance with the PRISMA framework, facilitated a structured and comprehensive examination of recent advancements in telemedicine architectures designed for continuous monitoring. The methodology ensured a rigorous process for collecting, evaluating, and synthesizing the available literature, providing a robust foundation for the resulting discussion and conclusions.

III. Results

The systematic review covered a wide range of studies focused on the architecture of telemedicine applications, as detailed in Table 1 [21-37]. The primary findings of these studies underscore the importance of robust software archi-

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Table 1. Systematic review of telemedicine architectures

Article	Insights	Methods used
Shaikh et al. [21]	The paper proposes a Tele-COVID system architecture design for secure telemedicine treatment of COVID-19 patients.	Proposed Tele-COVID system architecture design Tested on COVID-19 patients in county hospital
Adarsh et al. [22]	The paper proposes a reliable and efficient telemedicine network architecture using cognitive radio technology for e-Health applications.	Heterogeneous wireless network architecture Cognitive radio communication
Ferdana et al. [23]	The paper proposes the design and prototype of a telemedicine robot using behavior-based control architecture.	Behavior-based control architecture Camera control behavior, robot control behavior, obstacles avoidance behavior
Albahri et al. [24]	The paper discusses a new mHealth framework for decentralized telemedicine architecture for cardiovascular disease-based integrated techniques.	Haversine-GPS for time estimation AHP-VIKOR for hospital evaluation and prioritization
Liu et al. [25]	The paper proposes an efficient architecture for optimizing medical high-resolution image transmission and rendering in mobile telemedicine systems.	Unbalance pyramid scheme based on geometric relationship Indexing scheme based on hash table and lattice partitioning
Mishra et al. [26]	The paper discusses a cloud-based multilayer telemedicine architecture that allows for remote diagnosis and consultation using a database and k-nearest neighbor algorithm.	Single layer architecture of telemedicine Multilayer telemedicine network
Ferreira et al. [27]	The paper proposes a hybrid videoconferencing architecture for telemedicine that utilizes a call routing service and a peer-to-peer contact service.	Hybrid videoconferencing Peer-to-peer contact service
Goeg et al. [28]	The paper suggests a future-proof architecture for telemedicine using small, loosely-coupled modules and HL7 FHIR for interoperability.	Core with modules for extended functionality Inversion of control mechanism for loosely coupled modules
Tiwari et al. [29]	The paper discusses the implementation of a telemedicine network architecture using existing networks such as WPAN, WLAN, and LAN.	Compressive sensing (CS) technique Fast smooth L0-norm (SL0) minimization algorithm
Dubgorn et al. [30]	The article discusses the architecture of a telemedicine system based on the Health 4.0 concept.	Service-oriented approach to simulation of social-economic systems.
Shaikh and Tamil [31]	The proposed telemedicine architecture consists of three tiers: body sensors connected to a gateway, a cognitive radio controller, and a communication link to the hospital.	UWB technology used for body sensors Cognitive radio enabled communication system for mobile vehicles
Poenaru and Poenaru [32]	The paper evaluates hospital-oriented and home-oriented architectures for telemedicine, focusing on performance aspects such as average goodput.	Simulation of home and hospital architectures, evaluation of performance metrics such as goodput, latency, and packet loss rate
Pramanik et al. [33]	The paper discusses the architecture of telemedicine and remote health monitoring using wireless body area networks (WBANs).	N/A
Luan et al. [34]	The paper proposes an E-health network design that includes telemedicine as part of its architecture.	Cognitive radio communication including idle spectrum monitoring MC-CDMA technology
Salmon et al. [35]	The paper proposes a multi-sources framework called multi sources healthcare architecture (MSHA) for remote triage prioritization in telehealth.	Multi-sources framework (MSHA) Data fusion method and prioritization technique

Continued on the next page.

Table 1. Continued

Article	Insights	Methods used
Mironov and Kountchev [36]	The paper presents a software architecture for medical image processing, analysis, and archiving, but does not specifically mention telemedicine architecture.	Adaptive algorithms for processing of medical images Task-oriented medical image processing system
Pandya et al. [37]	The paper proposes an energy-efficient wireless communication system and baseband transceiver architecture for a sensor network in telemedicine.	Multi-hop transmission Joint transmitter-receiver beamforming technique

COVID-19: coronavirus disease 2019, GPS: global positioning system, AHP: analytic hierarchy process, VIKOR: VIsekriterijumsko KOmpromisno Rangiranje, HL7: Health Level Seven International, FHIR: Fast Heathcare Interoperability Resources, WPAN: wireless personal area network, WLAN: wireless local area network, LAN: local area network, UWB: ultra-wideband, MC-CDMA: multi-carrier code-division multiple access, N/A: not applicable.

tecture in advancing the effectiveness and accessibility of telemedicine services. The analysis was segmented based on several predefined criteria: scalability, security, interoperability, and technological innovation.

The analysis highlights a trend toward the application of advanced software engineering principles in the development of telemedicine architectures. A focus on scalability, security, and interoperability is evident across the studies, reflecting the critical challenges faced in telemedicine designed for continuous monitoring. The integration of emerging technologies such as blockchain and cognitive radio technology demonstrates innovative approaches to address these challenges. Additionally, the diversity in architectural designs reveals a rich landscape of strategies designed to improve various aspects of telemedicine. This diversity also underscores the potential for further exploration and refinement of telemedicine architectures to meet the evolving needs of healthcare delivery.

Furthermore, the focus on user-centric and patient-centric models in certain architectures indicates increased personalization of healthcare delivery, aligning with the global trend towards patient-centered care.

1. Distribution of Focus Areas in Telemedicine Architectures

Figure 3 illustrates the distribution of focus areas within articles on telemedicine architecture, highlighting the prioritization and combination of technological aspects. Interoperability, represented by the smallest segment at 14.3%, underscores the necessity for telemedicine systems to seamlessly connect with diverse healthcare information systems, thereby improving unified patient care. Scalability is next at 17.9%, emphasizing the need for systems that can handle increasing demands without compromising performance, which is essential for the expansion of healthcare services.

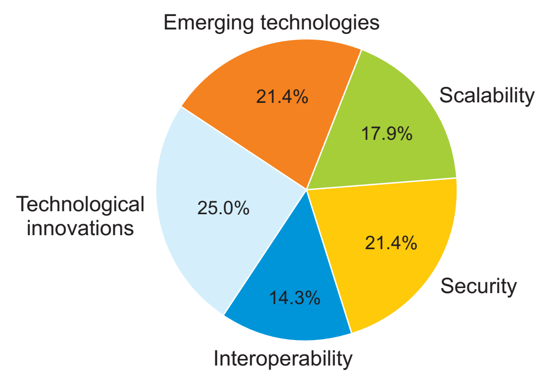

Figure 3. Focus areas in telemedicine architecture.

Both security and emerging technologies accounted for a substantial proportion at 21.4% each, stressing the vital importance of protecting patient data through robust security measures and the adoption of new technologies, like blockchain and IoT, to improve data transmission and privacy. The largest segment, technological innovations (25.0%), relates to the integration of advanced solutions like artificial intelligence and machine learning to refine diagnostic accuracy and responsiveness, illustrating a drive to improve the effectiveness and accessibility of telemedicine.

2. Intersections of Core Architectural Elements

Figure 4 illustrates both the exclusive focus on and the overlap among security, scalability, and interoperability in the context of telemedicine architecture. Security was emphasized in five articles, underscoring the importance of data protection and system integrity. Scalability was the primary focus of three papers, reflecting the need for telemedicine systems to efficiently manage growing demands. Interoperability was addressed by two papers, highlighting the role of seamless system integration among diverse healthcare

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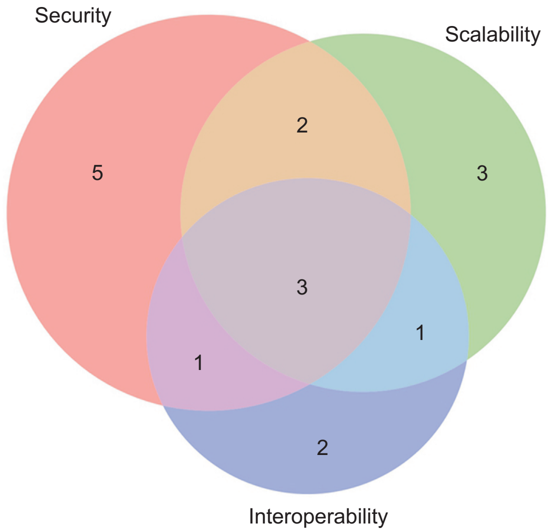

Figure 4. Venn diagram of overlap in key telemedicine architecture topics.

technologies. As indicated by the areas of overlap, two papers examined both security and scalability, ensuring robust data protection while accommodating growth. Three papers covered all three key areas, advocating for architectural designs that effectively incorporate secure, scalable, and interoperable elements. Finally, one paper at the intersections of security and interoperability and another at the junction of scalability and interoperability investigated the challenge of integrating secure protocols and scalable frameworks with other healthcare technologies to advance system functionality.

3. Overall Findings and Trends

The synthesis of the reviewed articles demonstrates a growing trend in the development of telemedicine architectures that prioritize security, interoperability, and scalability. These three pillars underpin the effectiveness and sustainability of telemedicine systems, particularly in the context of continuous patient monitoring.

The integration of advanced communication technologies, such as cognitive radio technology, marks the beginning of an era characterized by dramatically improved connectivity and real-time data transmission [22]. This advancement is critical for telemedicine, which relies on uninterrupted communication between healthcare providers and patients. Real-time data transmission is particularly vital for continuous monitoring, where it can be lifesaving. Cloud computing has emerged as a viable solution for managing the vast amounts of data generated and required for effective telemedicine. This tool not only meets the storage requirements but also offers powerful computational capabilities to process and analyze data efficiently. This is especially advantageous for continuous monitoring, which produces large datasets over time [30]. The shift toward decentralized systems reflects broader goals to eliminate single points of failure, improve data integrity and security, and encourage patient-centric models in telemedicine. Decentralization also promotes a more collaborative healthcare ecosystem, enabling secure and efficient data sharing among stakeholders [24].

Overall, the results and analysis underscore the critical importance of robust software architecture in the advancement of telemedicine, particularly for continuous monitoring. These findings represent a strong foundation for future research and development in this field.

IV. Discussion

This extensive review of telemedicine architectures across various studies underscores a concerted effort to address the increasing demand for patient monitoring, particularly in remote or resource-limited settings. The analysis offers a critical evaluation of these architectures, highlighting their strengths, challenges, technological innovations, and potential to transform healthcare delivery, especially during global health emergencies such as the COVID-19 pandemic. One limitation of this review is its exclusive focus on articles written in English, which may have excluded pertinent studies in other languages that offer relevant insights. Furthermore, the review was restricted to articles published in the last decade to ensure that the findings are up-to-date and contribute to current discussions in the field. Importantly, telemedicine is rapidly advancing; thus, while this review is current as of its publication, it may not reflect the latest technological developments. Despite these constraints, the review effectively outlines the telemedicine architecture landscape. Its findings convey valuable perspectives on potential refinements to improve healthcare access and effectiveness, particularly in settings historically lacking sufficient healthcare resources.

1. Technological Innovations

The rapid evolution of telemedicine has been characterized by the integration of sophisticated communication and control technologies. Innovations such as cognitive radio technology and behavior-based control architectures have made particular contributions toward improving the scope and effectiveness of telemedicine services.

Cognitive radio technology represents a major advancement in radio and network communication, characterized by its adaptive and intelligent features. This technology can autonomously adjust its transmission or reception parameters to optimize functionality within the available spectrum. Such adaptability is valuable in telemedicine, especially in situations necessitating the transmission of high-resolution medical imagery or real-time data critical for continuous monitoring. The potential of cognitive radio technology to improve connectivity and increase the efficiency of bandwidth utilization may help ensure that telemedicine services are both reliable and efficient [22].

Conversely, behavior-based control architectures have gained prominence, particularly in the design and prototyping phases of telemedicine tools such as robots. These architectures have endowed telemedicine systems with improved automation and agility. Consequently, the systems have become more responsive and adaptive, qualities that are essential in scenarios demanding real-time interaction and control. From remote patient monitoring to tele-surgery and tele-rehabilitation, the integration of behavior-based control ensures that telemedicine services are not only interactive but also smoothly managed [23].

2. Interoperability

In telemedicine, interoperability refers to the seamless exchange and utilization of information across healthcare systems and applications. Such integration is crucial for supporting the continuum of care and improving patient outcomes. The Health Level Seven International (HL7) Fast Healthcare Interoperability Resources (FHIR) standard has contributed to the achievement of this goal by facilitating the electronic exchange of healthcare information. Adopting a future-proof architecture that incorporates HL7 FHIR specifications ensures effective communication between telemedicine systems as well as with other healthcare information systems. This connectivity is vital for real-time monitoring and informed clinical decision-making. With such an approach, healthcare providers can access comprehensive and current information about a patient's health status, regardless of the telemedicine or electronic health record system being used [28].

3. Security

Security is paramount in telemedicine architectures, particularly when handling sensitive patient data and managing the remote treatment of infectious diseases such as COVID-19. The Tele-COVID system architecture exemplifies efforts to design secure telemedicine systems for the remote treatment of patients with COVID-19. This architecture appears to include robust encryption protocols, secure authentication mechanisms, and additional security measures to safeguard the confidentiality, integrity, and availability of patient data. Secure architectures are essential for building trust between healthcare providers and patients and for adhering to regulatory and compliance standards, such as the Health Insurance Portability and Accountability Act. Furthermore, security is vital for protecting patient privacy and ensuring the safe transmission of medical data for continuous monitoring and care delivery, particularly in the context of highly contagious diseases [21,30,34].

4. Scalability

The expanding patient base and burgeoning demand for remote healthcare services necessitate scalable telemedicine architectures. Scalability ensures that a system can handle an increasing workload by equipping it to accommodate growth in patients, healthcare providers, and data volume.

Cloud-based solutions offer virtually limitless computing resources, facilitating the management of increasing numbers of patients and healthcare providers. Multilayer architectures enable a modular approach in which various services and functionalities are managed in a layered fashion, promoting scalability and manageability. Cloud infrastructures can scale resources up or down based on demand, ensuring uninterrupted service even during times of peak usage [26].

Decentralized telemedicine architectures distribute the system's operations away from a single central location or authority. Such distribution can substantially improve the scalability of telemedicine systems, enabling them to manage more patients and data concurrently. By eliminating single points of failure and reducing bottlenecks inherent in centralized systems, decentralized architectures can be scaled to accommodate the needs of a growing patient base [24].

5. Integration of Emerging Technologies

Emerging technologies such as blockchain have the potential to address inherent challenges in telemedicine, including security, privacy, and data integrity. Blockchain technology, known for its security, transparency, and record-keeping capabilities, has been applied to decentralized telemedicine architectures, especially in the management of cardiovascular disease. Blockchain can securely manage patient records, ensuring transparency and trust in telemedicine services. The immutable nature of this technology ensures that once a record is added, it cannot be altered or deleted, thus preserving the integrity of patient data. This integration also facilitates transparent and efficient collaborations among multiple

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parties, which benefits patient management and healthcare service delivery. Furthermore, blockchain can support smart contracts to automate certain administrative processes, further increasing the efficiency of telemedicine services [24].

These advancements in scalability, efficiency, accessibility, and technology integration are instrumental in advancing telemedicine architectures. They not only address current challenges in telemedicine but also pave the way for innovative solutions that can further transform remote healthcare delivery.

6. Variations and Contradictions

The diversity of proposed architectures reflects the various technological paradigms and focus areas within the field of telemedicine. Certain architectures emphasize security to safeguard data privacy and ensure compliance with regulatory standards, while others are centered on interoperability to facilitate seamless interactions with other healthcare systems [38]. Yet others prioritize scalability to support a growing user base. These differences underscore the complex challenges inherent in designing telemedicine architectures for continuous monitoring. Technological approaches range from cloud-based solutions to decentralized, blockchain-based frameworks, each presenting advantages and challenges. These disparities underscore the emergent and swiftly advancing nature of telemedicine technology, with studies investigating different approaches to find the most effective solutions.

7. Key Findings and Implications

This systematic review of telemedicine architectures highlights key advancements and their implications for healthcare technology. Innovations such as cognitive radio technology and behavior-based control systems are essential for improving continuous monitoring capabilities, fostering a dynamic healthcare environment that is necessary for real-time data scenarios. By incorporating standards like HL7 FHIR, telemedicine architectures improve interoperability, ensuring seamless communication and access to actionable patient data. Additionally, emphases on robust security measures, scalability through cloud-based and decentralized systems, and the integration of blockchain technology not only bolster security and data integrity but also allow telemedicine to efficiently meet growing demands. These advancements are revolutionizing healthcare delivery, improving accessibility and equity—particularly important during global health crises like the COVID-19 pandemic—and laying a strong foundation for future innovations in a more integrated, responsive, and patient-centered healthcare system.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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