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Telemedicine in Public Health: Analyzing Challenges and Future Directions for Sustainable Implementation

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Abstract

Background: Telemedicine has emerged as a pivotal solution in healthcare delivery, leveraging information and communication technologies to overcome geographical barriers between healthcare providers and patients. This study reviews the evolution, current applications, and future trends of telemedicine, particularly in the wake of the COVID-19 pandemic, which has intensified the demand for remote healthcare services.

Methods: Employing a systematic literature review methodology, we analyzed existing research on various telemedicine communication technologies, including wireless and internet-based systems.

Results: The findings reveal that while telemedicine significantly reduces healthcare costs and enhances accessibility, several challenges persist, including standardization of medical data exchange, data security, and patient safety associated with wearable devices. Notably, our review underscores the heterogeneity in service delivery between in-person and telemedicine consultations, indicating that telemedicine can effectively substitute traditional consultations in specific contexts, such as pediatric genetic care. Moreover, the need for robust communication infrastructure and the integration of artificial intelligence in telemedicine were identified as critical for future advancements.

Conclusions: In conclusion, this study highlights the necessity for continued research into telemedicine technologies and the development of standardized protocols to facilitate their efficient implementation in public health. Addressing these challenges will be crucial for optimizing telemedicine's role in enhancing healthcare delivery and ensuring patient safety.

Keywords: Telemedicine, Public Health, Communication Technologies, COVID-19, Healthcare Delivery

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1. Introduction

Telemedicine refers to the use of information and communications technologies to provide medical treatments regardless of the geographical distance between doctors and patients. Telemedicine has been used since the 1900s. It encompasses all types of electronic communication between healthcare professionals and patients at a distance [1,2]. Recently, researchers have increasingly concentrated on wireless communication technologies for telemedicine to provide efficient and dependable healthcare service delivery from distant locations, particularly during crises. Diverse communication technologies have been suggested and used to provide professional medical services to patients without the need of traditional face-to-face interactions. This has significantly reduced the expenses associated with medical diagnostics and the need of traveling extensive distances for expert consultations. Existing research on telemedicine installations indicates a need for ongoing investigation to tackle various concerns and obstacles [3,4]. It is essential to compare pertinent research in the area to provide a comprehensive overview of existing communication technologies appropriate for contemporary designs and to ascertain the most feasible methods of practical implementation. It is not to imply that telemedicine should entirely replace traditional physical diagnostics and other medical procedures, since certain services need in-person interaction. However, the use of telemedicine might significantly alleviate hospital overcrowding and, in turn, curtail the transmission of infectious illnesses.

The emergence of the COVID-19 pandemic has heightened the need to use the advantages of telemedicine and eHealth. Recent studies have seen a spike in telemedicine and eHealth research [5]. The authors of [6] investigated the heterogeneity in services between in-person consultations versus telemedicine. The used procedure included the investigation of 1,104 patients. Analysis of patients evaluated in-person against those assessed via telemedicine demonstrated that telemedicine serves as a viable substitute for in-person consultations in regular pediatric clinical genetics treatment. This result corroborates similar findings in [7-11]. Numerous studies have advocated for the use of telemedicine in the post-COVID-19 period; hence, a study of communications technology is necessary to provide fully operational telemedicine services [12-15].

This review delineates prior research conducted by various scholars about the many communication technologies used in telemedicine. This includes internet and wireless technologies for digital data transfer, mobile telemedicine, wireless design, WBAN, satellite communication, and cellular technologies, as well as infrared connectivity. Figure 1 provides a comprehensive overview of telemedicine systems. In telemedicine applications, communications may be categorized as follows:

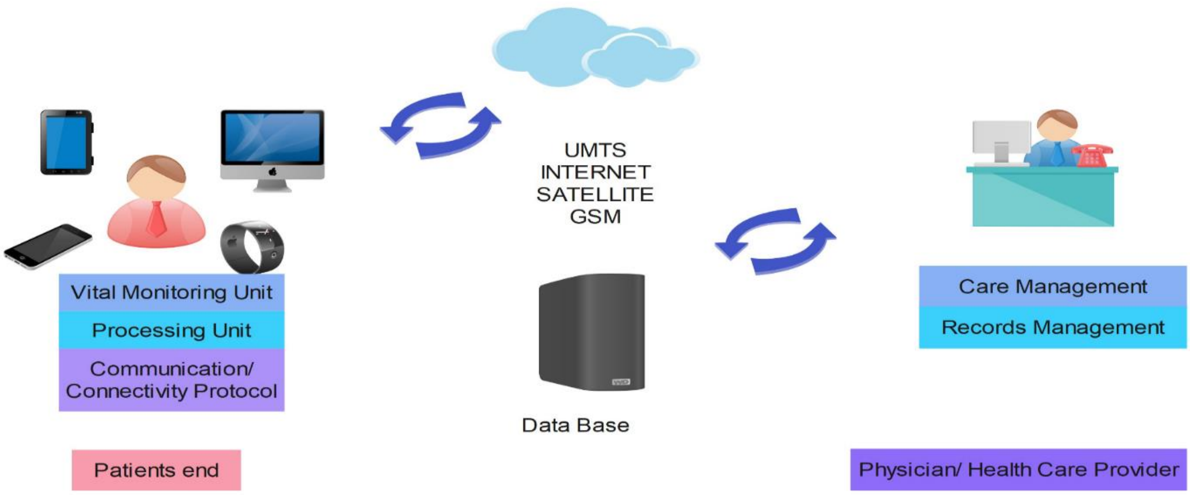

Figure 1. Telemedicine Systems.

This study primarily examines communication technologies used in telemedicine, the obstacles and concerns related to their deployment, and the standardization and future research prospects. Notwithstanding several attempts by researchers in the current literature, a standardized format for medical data exchange in telemedicine has yet to be established [16]. The challenge of standardization and incompatible equipment has significantly hindered the efficient and rapid implementation of newly developed telemedicine initiatives. Additional obstacles and research concerns include data security and privacy, patient safety regarding wearable devices, and quality of service needs. These critical areas need study focus to improve the implementation of telemedicine in response to the increasing demand and expenses associated with medicines.

2. Related Studies

A multitude of research and surveys have been undertaken about e-health and telemedicine. In a survey paper, [17], the authors examined several key issues, including future applications of internet and wireless telemedicine systems, specifically the advent of mobile IP and its potential compatibility with Wireless Application Protocol (WAP) and GPRS-based phones for internet telemedicine. A companion paper by [18] examined several uses and data transfer in e-health. The authors provided a comprehensive review and study of wireless technologies used in telemedicine, in addition to the current application of wireless telemedicine for real-time and digital data transfer. In [19], the authors examined IoT technologies and architecture, highlighting the foundation they provide for telemedicine applications. Another similar study [20] further on the growth of wireless technologies for telemedicine, informing academics about the advancements in ICT that have improved telemedicine. Alternative radio technologies, including RFID-based devices, were examined for healthcare delivery in [21].

In [22], the authors delineated the use of wireless communication technologies in telemedicine and presented a comprehensive architectural framework. Several significant challenges associated with mobile telemedicine were identified, accompanied by an overview of the prospective advantages of integrated wireless telemedicine systems. A pertinent research by [23] outlined telemedicine communication technology and the problems associated with implementing telemedicine services in Indonesia. The communication technologies examined included the utilization of wireless LAN and satellite connection in telemedicine frameworks.

The discussion in [24] focused on the use of wireless communication and designs in telemedicine, highlighting developing technology in telemedicine and e-health applications. The author predicted cost-effective wireless systems including enhanced data transmission rates and the incorporation of intelligent agents in forthcoming telemedicine system designs. An analogous summary of design analysis for mobile and wireless systems in telemedicine was provided in [25]. This article delineated three key facets of mobile and wireless telemedicine designs: mobile health systems, Wireless Body Area Network (WBAN), and intelligent wireless sensors.

An analogous system using ICT applications and architectures in telemedicine was introduced in [26]. This study highlighted the advancement of ICT in telemedicine, classified wireless networks for telemedicine applications, and provided a comprehensive assessment of telemedicine designs. Although the majority of review papers so far have concentrated on close-range communication technologies, Reference [27] introduced satellite-based initiatives for telemedicine applications. Their report delineated many wireless communication methods for telemedicine and outlined particular designs for e-health systems using satellite communication technology. An overview of the fundamental components of a comprehensive wireless medical video telemedicine system was published in [28]. The authors examined an architecture for a wireless medical video telemedicine system designed for real-time applications. The paper delineated four overarching classes of research in m-health systems.

Research on internet-based telemedicine systems in China has found many obstacles that complicate their quick introduction [29]. This research analyzed several telemedicine systems used in China, including multicasting, teleconsultation, satellite communication, WLAN, SMS, Bluetooth, and wireless technologies. As shown in [3], several wireless telemedicine systems encounter significant challenges, particularly in security, patient monitoring, scheduling, video compression, and transmission medium. In a comparable study, Ref. [30] identified some significant challenges in the deployment of wireless sensor networks in telemedicine. Particularly, concerns with ZigBee and Bluetooth transmission technologies used for communication between sensors and wireless sensor networks (WSN) were highlighted.

The study paper, Ref. [31], primarily addressed mobile telemedicine systems using satellite communication and cellular technology. The study in another paper [16] concentrated on wireless technology and the obstacles to e-health. Likewise, Ref. [32] offered valuable perspectives on wireless technology and the obstacles encountered in telemedicine. Their research provided more insights on the use of wireless technology in healthcare, along with the obstacles associated with wireless telemedicine, mobile phone telemedicine, and data transfer methods. In [33], the authors published a paper on wireless telemedicine situated in Tanzania. The authors delineated several wireless technologies used in telemedicine.

Body Area Networks (BAN) for patient monitoring via telemedicine were examined in [4]. This report asserts that telemedicine may use advancements in microelectronic technology for healthcare delivery. Their article specifically addresses the incorporation of Body Area Networks (BAN) inside telemedicine systems using a Wide-Body Area Network (WBAN) architecture. A overview of equipment used in telemedicine systems was presented in [34]. The authors primarily demonstrated devices for acquiring vital signs for telemedicine applications, specifically emphasizing the integration of vital sign sensors and other wireless medical equipment into telemedicine systems. In [35], the authors demonstrated the use of an ad hoc wireless sensor network system in the telemedicine domain of catastrophe survivor identification. Relay stations were used to convey acquired data to sink nodes, which then relayed the data to either the base stations of a cellular network or to WIMAX-based antennas. In [31], the authors stated that mobile communication technologies for telemedicine must possess operational parameters that satisfy the anticipated Quality of Service standards for medical services, which may encompass clinical data measurement of images like digital X-Rays and audio signals with elevated bit error rates.

The authors of [36] conducted a comprehensive assessment of Quality of Service (QoS) and architectures in healthcare systems. Their article specifically delineated the characteristics of e-health applications and the Quality of Service (QoS) pertinent to certain healthcare services inside telemedicine and its architecture. In [37], the authors analyzed both Quality of Service (QoS) and Quality of Experience (QoE) in telemedicine systems. Wireless methodologies in telemedicine were discussed in [38], emphasizing the Vertical Handoff (VHO) methodology. Several survey studies addressing various aspects of telemedicine have been referenced above. This article focuses on the communication technologies used in wearable sensor devices for vital sign monitoring in telemedicine applications [39,40].

3. Summary of Telemedicine

Telemedicine is a method of delivering biological data between patients and caregivers at disparate sites without direct personal interaction [41]. It reduces expenses and time in healthcare services by offering remote medicine, hence obviating the need to go for medical consultations [42]. In [18], the authors characterized telemedicine as the provision of health care and the dissemination of medical information across distances using telecommunication. Telemedicine delivers skilled medical treatment to any location requiring healthcare without the need of personal interaction. It utilizes existing wired and wireless infrastructures for both prototype and real-time designs [33]. Telemedicine has been deployed utilizing plain old telephone systems (POTS) and integrated services digital networks (ISDN) using wired communication technologies. In modern telemedicine, several wireless communication technologies have been implemented for diverse systems and designs [43]. These include ZigBee, Bluetooth, VSAT, WLAN, WiMAX, GPRS, and UMTS (3G and 4G). Telemedicine is an emerging technology that integrates telecommunication and information technologies to enhance the medical profession. This is an innovative method of providing healthcare services to patients, even those in very remote regions [33].

In [16], telemedicine was defined as the transfer of critical clinical information using contemporary ICT to provide healthcare services to patients situated at significant distances, categorized into live telemedicine and store-and-forward telemedicine. Live telemedicine entails audio-visual contact over high-bandwidth, low-latency connections, requiring the simultaneous presence of both patient and physician, while store-and-forward requires the collection of medical data, photographs, and video transmission by a medical professional for subsequent offline diagnosis. Telemedicine utilizes information and communication technology, particularly two-way interactive audio/video communications, computers, and telemetry, to provide healthcare services to remote patients and enable information interchange between primary care doctors and distant specialists [26]. Telemedicine may be defined as the use of modern telecommunications technology to transmit health information and provide healthcare services across geographic, temporal, social, and cultural obstacles.

The backplane serves as the primary connecting hub for other components, while the User Interface and video conferencing equipment are connected to the backplane via the control set. Information is communicated via the backplane from the patient unit to the caregiver unit via the communication channel of the communication device, and vice versa [44].

4. Advancements in Communication Technologies for Telemedicine

Telemedicine communication technologies provide the transmission of data collected from sensors affixed to the human body and may be adjusted to establish sensor network systems. The advancement of communication technology has significantly facilitated the progression of telemedicine. The advent of the electrical telegraph and Plain Old Telephone Service (POTS) is associated with the inception of contemporary telemedicine. The electrical telegraph facilitated the transmission of medical information as text more efficiently and rapidly than the previous method of mailing a letter. The military was the first to use the telegraph in a medical setting for teleconsultation, procurement of medical supplies, and transmission of health information.

Communication technology advanced beyond the capabilities of the Plain Old Telephone Service, which just offered audio services. Throughout the years, telemedicine communication has evolved from wired to wireless technologies [45]. The advent of Public Switched Telephone Network (PSTN), Integrated Services Digital Network (ISDN), and Voice over Internet Protocol (VoIP), all of which facilitate the transmission of data and voice across telephone lines, has significantly advanced telemedicine. Furthermore, these technologies provide excellent transmission data rates; for example, ISDN may deliver a data rate of 128 kbps. The emergence of the internet has resulted in a substantial augmentation in information dissemination. The abrupt increase in internet use throughout the 1990s significantly enhanced telemedicine services and applications. The advent of the internet has facilitated cloud computing, expedited and dependable transfer of medical information, and enabled videoconferencing [46].

5. Telemedicine Communication Network Connections

The development of the internet has transformed the delivery of telemedicine in several ways. Patients residing in rural or otherwise inaccessible areas may now participate in some kinds of telemedicine due to the extensive availability of inexpensive high-speed internet connections. This part examines the two communication network connections used in telemedicine: point-to-point and point-to-multipoint communication networks [47].

Utilizing point-to-point connections and high-speed internet, tiny distant health clinics may be linked to bigger healthcare facilities. This particular telemedicine connection enables the remote outsourcing of medical treatment to specialists in other areas, facilitating linked referrals to these experts. This is especially beneficial for medical institutions that are either inadequately staffed or have a limited patient demographic. Mobile patients may connect with professionals for teleconsultations using this link. Likewise, elderly individuals may choose for palliative care in the comfort of their residences while their health status is monitored remotely. In telepsychiatry, teleradiology, and other urgent care services, point-to-point connections are standard.

Point-to-multipoint connections provide connectivity for each department inside a healthcare institution to a central hub (the datacentre), ensuring smooth communication and the delivery of healthcare services. A primary care physician may use this link to order a test for a patient in the radiology department and get the results online. The same physician may authorize the pharmacy to distribute medication to a patient while concurrently the finance unit withdraws the necessary monies from the patient's account for services provided. Similarly, telesurgery may be conducted on a patient concurrently by many surgeons from various places using this connection. This link may be used inside a singular healthcare institution via an intranet connection to ensure high speed and data security. In telesurgery, which necessitates the involvement of a specialist situated in a remote healthcare facility, a high-speed internet connection facilitated by a fiber optics network is advantageous.

6. Classification of Communication Technologies in Telemedicine

Telemedicine communication technologies can be categorized into short-range communications, including Bluetooth, Wireless Fidelity (Wi-Fi), Zigbee, and Ultra-wideband (UWB); long-range communications, comprising satellite-based, internet-based, and mobile cellular networks; and Wide Area Networks (WAN).

Telemedicine entails the remote acquisition of essential human data, achievable via the implementation of sensor network systems on the human body. This sensor network may be integrated with short-range communication technologies to create a Body Area Network (BAN). A Body Area Network (BAN) is a network of scattered nodes positioned on the body to collect physiological data [4].

Key considerations in the implementation of wireless Body Area Networks (WBANs) include sensor type, data management, routing methodology, quality of service expectations, communication pathways, standards/technologies, security, and simulation environments [4]. The early WBANs had minimal bandwidth demands, with data rates ranging from 10 kilobits per second (kbps) to 10 megabits per second (Mbps) [4]. The predominant short-range communication technologies used in telemedicine systems include Bluetooth, Zigbee, Wi-Fi, and UWB. The installation of a medical monitoring system using sensor communication technologies was detailed in [48]. The communication protocols used were Bluetooth and ANT/ANT+, while WebSocket technology facilitated the connection between the mobile client and the distant server. In [49], the authors introduced a telemedicine system that used an optical fiber backbone network. WBANs facilitated the collecting of vital signs via the use of sensor nodes. The network was established with nodes organized in clusters, with each microcontroller in a cluster linked to a sink capable of forecasting catastrophe characteristics for a specific person. The sensor network sent the consolidated data to physicians remotely over the internet.

Bluetooth is a widely used wireless technology that facilitates connecting with compatible devices for efficient communication. It operates at a frequency of 2.4 GHz inside the ISM frequency range. This device is cost-effective and energy-efficient, facilitating wireless voice and data transfer to various devices at varied data speeds, achieving up to 2 Mbps (BLE 5.0), contingent upon the version (fixed or mobile) within a 10 m range for Bluetooth and exceeding 240 m for Bluetooth 5.0 [50,51]. Communicating BLE devices are automatically configured in a network termed a piconet, which accommodates a maximum of eight linked devices; alternatively, a scatternet may be used for configurations beyond eight connected devices. Bluetooth 4.x and Bluetooth 5.0 use star-bus and mesh network topologies, capable of accommodating an indefinite number of nodes [52]. Various iterations of Bluetooth are now accessible for utilization according to application specifications. Bluetooth Low Energy (BLE) has been used in telemedicine and documented in several research. For example, in [53], it was used in an ECG monitoring system. Bluetooth Low Energy 4.0 was used in conjunction with Wi-Fi and an iOS mobile application to provide the findings on a mobile device inside a telemedicine framework. The biosensor's ECG signal collecting module obtained the ECG signal from the patient, the BLE 4.0 communicated the data to the mobile application, and the mobile phone's Wi-Fi relayed the data to the provider database for access by an authorized physician. The authors in [54,55] illustrated the use of BLE for data transfer inside a BAN. Research by [56] shown that BLE has superior energy efficiency for data transmission in a BAN sensor relative to ZigBee.

7. Research Obstacles and Prospective Directions

The utilization of wireless communication in telemedicine is propelled by technical breakthroughs, which are often accompanied by various concerns and obstacles. According to [16], the introduction of wireless communication technologies in telemedicine has obstacles such as interoperability and usability, coexistence and interference, and end-to-end quality of service (QoS). The need for remote diagnosis and healthcare provision is anticipated to ultimately reduce human participation in telemedicine. As a result, artificial intelligence and machine learning are rapidly advancing in telemedicine, presenting significant issues related to accuracy, interpretability, overfitting, and computing complexity.

The absence of a standardized medical data communication protocol, interference from other wireless devices, and quality of service concerning high throughput and low latency are significant challenges hindering the comprehensive implementation of telemedicine systems; many of these challenges relate to the integration of diverse wireless networks. Given the need of consistent connection in wireless sensor networks for telemedicine, handover strategies are used to provide continuous communication among the sensor nodes, gateway, and other wireless devices within the system. The connection to the optimal access network is facilitated by a Horizontal Handoff (HHO) mechanism, while Vertical Handoff (VHO) grants network access to mobile nodes across diverse access points [38].

8. Conclusions

This review article examines the evolution of telemedicine systems, emphasizing the many communication technologies used. Communication technologies, including Body Area Networks (BAN), distant communication with telemedical servers, and telemedical application-based communication, have been systematically identified and assessed. The use of internet, satellite, WAN, and GSM communications, as referenced by many researchers for transmitting diverse data kinds from a local source (patient) to a distant server (remote physician location), has been thoroughly examined. The selection and use of any kind are contingent upon the availability of infrastructure, the nature of the application, and associated costs. The many connection protocols and standards used for communication were analyzed, with several protocols identified as more suitable for particular communication settings depending on the sort of data being transferred. The use of machine learning techniques in telemedicine was evaluated. This study aims to provide a comprehensive overview of modern wireless communication technologies used in telemedicine systems, focusing specifically on implementation concerns, obstacles, and research needs.

The analyzed studies indicate the need of implementing systems that integrate numerous wireless networks to ensure Quality of Service (QoS) and facilitate mobility for clients/patients and remote caregivers. Notwithstanding the extensive research undertaken in this domain, the transmission of medical data via a globally applicable standard format for wireless devices is still deficient. Future telemedicine frameworks must tackle challenges like scheduling, data security and privacy, and medical video streaming using contemporary compression methods. The design of wearable medical equipment must consider energy economy, the radiation absorption rate from wireless sensors, and the need for skin protection. The quality and integrity of data used by machine learning algorithms are essential for constructing dependable models in telemedicine research and development.

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الطب عن بُعد في الصحة العامة: تحليل التحديات والاتجاهات المستقبلية للتنفيذ المستدام

الملخص

الخلفية :برز الطب عن بُعد كحل محوري في تقديم الرعاية الصحية، مستفيدًا من تقنيات المعلومات والاتصالات للتغلب على الحواجز الجغرافية بين مقدمي الرعاية الصحية والمرضى. تستعرض هذه الدراسة تطور الطب عن بُعد، تطبيقاته الحالية، واتجاهاته المستقبلية، خاصةً في أعقاب جائحة كوفيد-19 التي زادت من الطلب على خدمات الرعاية الصحية عن بُعد.

الطرق :باستخدام منهجية مراجعة منهجية للأدبيات، قمنا بتحليل الأبحاث الحالية حول تقنيات الاتصال المختلفة في الطب عن بُعد، بما في ذلك الأنظمة اللاسلكية والإنترنت.

النتائج :كشفت النتائج أن الطب عن بُعد يقلل بشكل كبير من تكاليف الرعاية الصحية ويعزز إمكانية الوصول إليها، إلا أن هناك تحديات قائمة، بما في ذلك توحيد تبادل البيانات الطبية، أمان البيانات، وسلامة المرضى المرتبطة بالأجهزة القابلة للارتداء. وأظهرت المراجعة تباينًا في تقديم الخدمات بين الاستشارات التقليدية واستشارات الطب عن بُعد، مما يشير إلى أن الطب عن بُعد يمكن أن يحل محل الاستشارات التقليدية بفعالية في سياقات محددة، مثل رعاية الأمراض الوراثية للأطفال. كما تم تحديد الحاجة إلى بنية تحتية قوية للاتصالات ودمج الذكاء الاصطناعي في الطب عن بُعد كعوامل أساسية للتقدم المستقبلي.

الاستنتاج :تؤكد هذه الدراسة على ضرورة إجراء المزيد من الأبحاث حول تقنيات الطب عن بُعد وتطوير بروتوكولات موحدة لتسهيل تنفيذها بكفاءة في مجال الصحة العامة. سيكون التصدي لهذه التحديات أمرًا حيويًا لتحسين دور الطب عن بُعد في تعزيز تقديم الرعاية الصحية وضمان سلامة المرضى.

الكلمات المفتاحية :الطب عن بُعد، الصحة العامة، تقنيات الاتصال، كوفيد-19، تقديم الرعاية الصحية.