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Exploring the integration of internet of things and sensor technology in healthcare

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Abstract:

The Internet of Things (IoT) stands as an innovative technological paradigm, housing billions of sensors across diverse applications. At the core of IoT lie sensors, pivotal in gathering data for analysis. With its extensive reach spanning smart cities, agriculture, education, and notably healthcare, IoT and sensors play a transformative role. Particularly in healthcare, IoT has emerged as a critical tool in tackling global health crises, exemplified in the recent battle against COVID-19. The pandemic has underscored the growing necessity for remote and digital healthcare solutions, driving up demand for IoT-enabled patient monitoring systems. This paper aims to delve into various applications, technologies, and challenges within the realm of healthcare IoT. Extensive searches across databases like Google Scholar, Elsevier, PubMed, ACM, ResearchGate, Scopus, and Springer were conducted to gather insights. By highlighting key applications of IoT in healthcare, this paper endeavors to provide valuable research directions for healthcare stakeholders, academia, and researchers to address prevailing challenges. Through efficient utilization of IoT, the healthcare system can deliver enhanced treatments while optimizing resources. Moreover, by integrating IoT with smart technologies, not only does computational efficiency improve, but it also facilitates pervasive, profitable, and accessible healthcare services. Lastly, this paper addresses future avenues and hurdles, offering pragmatic suggestions to bolster the IoT healthcare system's resilience in combating COVID-19 and potential future pandemics.

Keywords:

COVID-19, healthcare system, Internet of Things, IoT application, sensors, smart technology

1. Introduction:

The Internet of Things (IoT) encapsulates the essence of this Trans formative technology quite well. Indeed, the IoT has become a cornerstone of our digital world, facilitating the interconnection of devices and enabling them to gather, analyze, and act upon data in ways that were previously unimaginable.

By linking disparate devices through the internet, the IoT enhances their functionality and enables remote access and control. This interconnectedness fosters an ecosystem where devices can communicate, collaborate, and respond to changes in their environment in real-time. From smartphones and wearables to industrial machinery and smart home appliances, the IoT spans a vast array of devices, each contributing to the collective intelligence of the network.

The applications of IoT are virtually limitless, impacting numerous sectors including healthcare, agriculture, transportation, manufacturing, and beyond. In healthcare, for example, IoT devices can monitor patient health remotely, providing timely interventions and improving the quality of care. In agriculture, IoT sensors can optimize irrigation and fertilization, leading to increased crop yields and resource efficiency.

Moreover, the rapid proliferation of IoT technology is fueling innovation and driving new business models. Companies are leveraging IoT data to gain insights into customer behavior, optimize operations, and create personalized experiences. Additionally, the emergence of edge computing, block chain, and artificial intelligence further enhances the capabilities of IoT networks, enabling faster processing, improved security, and more intelligent decision-making at the edge of the network.

As the IoT continues to evolve and expand, it presents both opportunities and challenges. Privacy and security concerns, interoperability issues, and the need for robust regulatory frameworks are among the key challenges that must be addressed to realize the full potential of IoT technology. However, with proper safeguards and responsible deployment, the Internet of Things holds the promise of revolutionizing how we interact with technology, shaping a more connected, efficient, and responsive world.

In today's digital landscape, wireless sensor networks (WSNs) play a pivotal role in monitoring applications, thanks to their numerous advantages including cost-effectiveness, minimal infrastructure requirements, flexible network topologies, and reduced maintenance needs. Wireless sensors and WSNs have become indispensable in monitoring various aspects of life, spanning climate change, weather patterns, natural disasters, traffic flow, forestry management,

healthcare services, location tracking, and more.

Within healthcare, sensors serve crucial functions, aiming to regulate, monitor, control, alert, and track patient activities. These sensors facilitate seamless analysis and diagnosis of patient activities, fostering a healthcare system that is self-sufficient and less reliant on physical intervention. Consequently, healthcare processes can operate in real-time, accelerating the pace of care delivery and driving exponential improvements in patient outcomes.

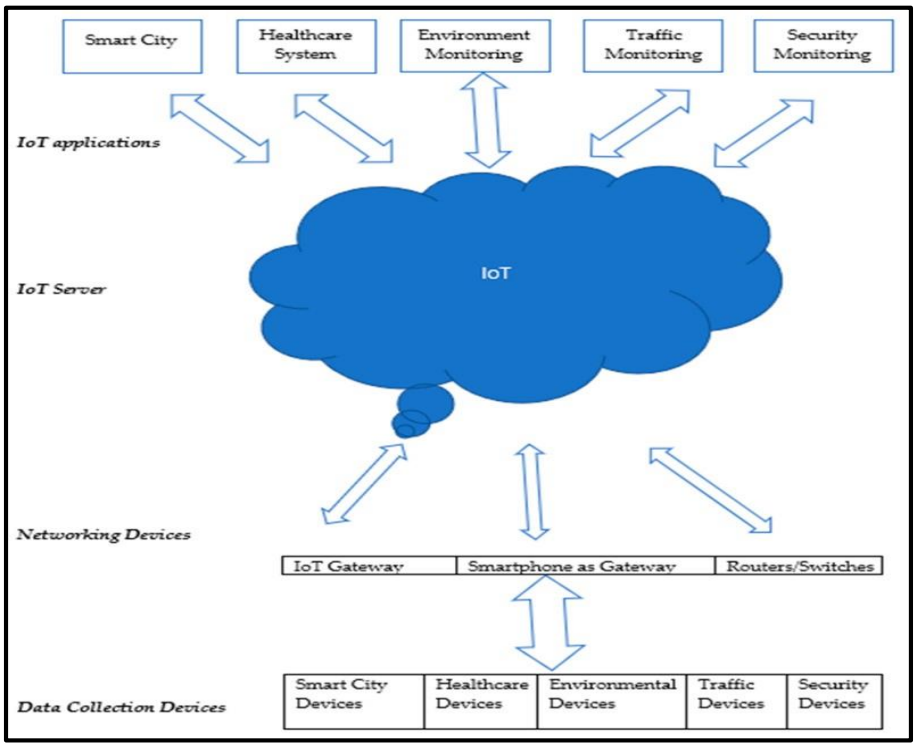

Figure. 1: IOT Network

The foundation of the Internet of Things (IoT) lies in ambient, pervasive, and ubiquitous computing. This encompasses the interconnectedness of various devices and systems, facilitated by technologies such as machine-to-machine (M2M) communication, cyber-physical systems (CPS), and wireless sensor networks (WSN).

M2M and WSN technologies are integral components of the IoT framework. M2M facilitates communication between devices, while WSN enables the collection and transmission of data from physical environments.

In the development of interactive applications within the M2M realm, CPS plays a critical role by orchestrating seamless coordination between physical objects and computational elements. This ensures robust functionality and efficiency in M2M interactions.

Furthermore, M2M, CPS, and WSN technologies collectively possess capabilities in actuation, sensing, and computation, forming the backbone of IoT functionalities.

Essentially, the IoT can be viewed as a sophisticated WSN that relies on M2M communication, while also offering the potential to generate CPS applications, thereby enhancing the integration and automation of various systems and processes.

2. Studies reviewing the utilization of IoT in healthcare:

Numerous scholarly articles have previously explored the potential of Internet of Things (IoT) applications in the healthcare sector. Researchers have employed various methodologies, including traditional literature reviews and systematic literature reviews, to synthesize the body of research on IoT in healthcare.

These studies have investigated diverse aspects of IoT adoption within healthcare, ranging from scrutinizing privacy and security concerns in IoT-enabled healthcare systems to examining its utility in elder care and even exploring its potential in combating the COVID-19 pandemic. For instance, Baker conducted a comprehensive review of IoT research in healthcare, proposing a novel framework for IoT-based healthcare systems suitable for both broad system applications and specific monitoring functions. They also assessed various non-invasive, wearable sensors, focusing on those monitoring vital signs, blood pressure, and blood oxygen levels. Communication protocols, including long-range and short-range options, were evaluated for their appropriateness in medical contexts.

In another study, Dimitrov [explored the intersection of IoT and big data applications in healthcare, highlighting the positive impact of IoT wearables in areas such as health education, fitness tracking, symptom monitoring, care coordination, and collaborative disease management. Similarly, Yin et al. provided an extensive overview of IoT-driven healthcare systems, outlining the underlying technologies and smart healthcare devices. They also discussed specific implementation strategies, including ontology-based resource management, big data handling, and knowledge management.

Furthermore, delved into the contributions of Industry 4.0 technologies, including IoT, cloud computing, fog computing, and big data analytics, to the healthcare sector. Their review shed light on how these technologies are propelling the healthcare field toward e-health, and how the advent of Healthcare 4.0 is further accelerating this transition. In this era, emerging technologies not only enhance traditional healthcare systems and processes, such as medical intake and cloud-based healthcare systems, but also inspire innovative approaches.

3. Contribution and scope:

This paper elucidates the latest methodologies pertinent to IoT-based healthcare systems employing sensors. While acknowledging current research on IoT healthcare systems, the primary focus of this paper is to enhance healthcare systems through IoT integration. Additionally, it provides novel guidelines for the academic and research communities regarding user-friendly IoT applications. Understanding the architecture and components of IoT is essential to appreciate its contributions. Accordingly, a review, and only those IoT healthcare applications that have the potential to augment patient care facilities within the healthcare system are deliberated in this paper.

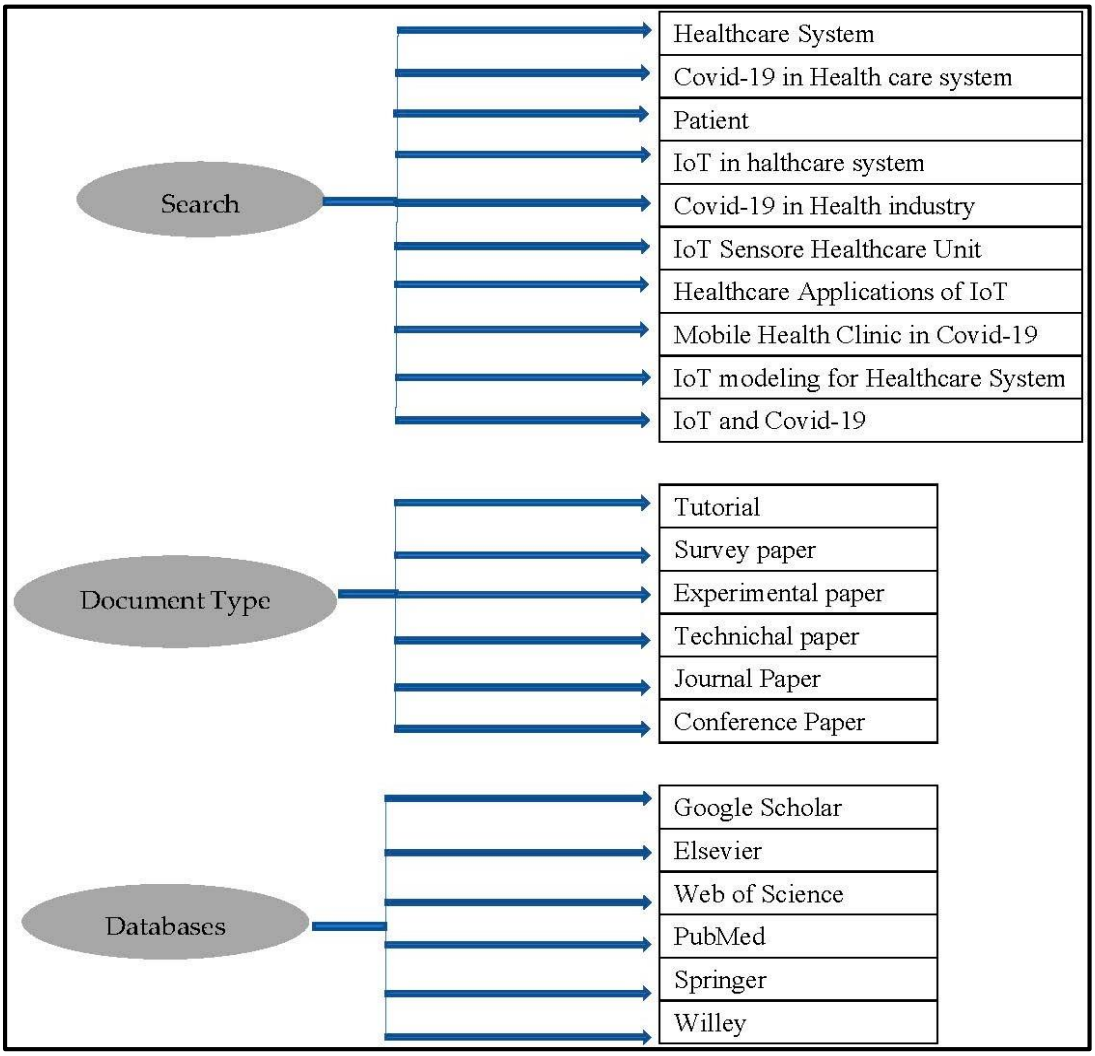

Figure. 2: Data collection criteria

4. Organization of the paper:

This manuscript is structured into seven sections. Section 1 provides an introduction, overview, and background of the IoT healthcare system, outlining its contributions with supporting

evidence. Section 2 delves into the related work pertaining to IoT healthcare systems. Section 3 elaborates on the IoT elements to enhance comprehension of the healthcare system. Section 4 comprehensively examines various applications pertinent to the IoT healthcare system, emphasizing their relevance during the COVID-19 pandemic and future outbreaks, aiming to support society in combating pandemics. Section 5 elucidates the technologies involved in detail. Section 6 addresses the future directions and challenges concerning the IoT healthcare system, offering more comprehensive insights than previous studies. Finally, Section 7 offers concluding remarks.

Figure.

5. Literature work:

This article conducts a parallel examination of IoT and healthcare systems. In the initial phase, relevant papers pertaining to healthcare were gathered, followed by the collection of articles concerning IoT healthcare systems and sensors. Various databases were explored using specific IoT and sensor-related keywords, as illustrated in.

With the global increase in diseases and patients, healthcare systems are becoming increasingly

complex. Therefore, it is imperative to devise a well-organized and systematic IoT methodology. The IoT is now facilitating numerous organizations and industries to achieve objectives such as the Internet of Healthcare Things (IoHT) and the Internet of Medical Things (IoMT). Leveraging the procedures and services offered by IoHT and IoMT can help manage and minimize healthcare system challenges across various diseases, including COVID-19.

In, IoT and cloud computing are integrated into healthcare systems. Proposed IoT applications aim to address multiple challenges, utilizing a cloud-based model to provide home-based patient identification services. A healthcare system implemented through Android applications connects to cloud IoT and computing resources. Similarly, present a novel healthcare system integrating IoT, responding to demand from academia, industry, and society. These articles detail systems monitoring heart rate through smart health bands, with patient information communicated to friends and family members. Additionally, introduces an early detection system called iCarMa for heart patients, enabling timely communication upon detection and diagnosis. The IoT has become a crucial component of medical aid systems, necessitating secure management of patient data against unauthorized access.

Survey specifically addresses privacy and security concerns within IoT contexts, highlighting risks introduced by cloud integration in medical care systems. The paper proposes solutions to incentivize researchers to address privacy and security issues within IoT-mediated medical care systems.

In, IoT integration with cloud computing is proposed for healthcare systems, highlighting challenges that must be addressed to enhance the system, including an audio pathology model for patient monitoring. Discusses various IoT applications, emphasizing security concerns and proposing an intelligent model to mitigate attacks and enhance IoT capabilities in medical care and e-health. Lastly, [33] discusses early symptom prediction through IoT, providing insights into review papers and challenges associated with IoT in healthcare systems, along with suggestions for improvement.

Underscores the role of communication systems in enhancing IoT practices, particularly in healthcare. It introduces a body sensor network for efficient data communication to a public IoT-based system and suggests security constraints for improved system security and future enhancements.

Overall, the papers discussed contribute to detecting patient disorders and communicating data to healthcare systems for patient assistance. This article delves into patient services facilitated by IoT and proposes recommendations for addressing risks in diabetic and heart patients within

healthcare systems. It also presents novel IoT-based technologies and healthcare applications for acute situations, emphasizing the inevitable integration of IoT in the healthcare industry due to its cost-effectiveness and practical solutions.

5.1. Sensor-based:

Sensing involves gathering information from all devices within a predefined network and transmitting it to a data warehouse or cloud for further processing. The collected data serves specific tasks and services. To maximize the benefits of IoT, smart actuators and sensing devices are essential. Various industries, such as WeMo and SmartThings, offer smart devices and applications for maintaining, updating, controlling, and monitoring numerous smart devices within a campus or building using smartphones. Microcontrollers, computers, sensors, built-in TCP/IP, and security measures are typically employed to underscore the significance of IoT products. All devices connect to a central management service to provide the necessary data to customers.

Sensors serve as the foundation of any application, calculating and managing the data generated by sensor variations in the physical world. A plethora of sensors are available in the market, ranging from simple to complex. The organization of sensors is determined by factors such as requirements, specifications, conversion methods, experimental design, material types, sensing methodologies, measurement properties, and application fields.

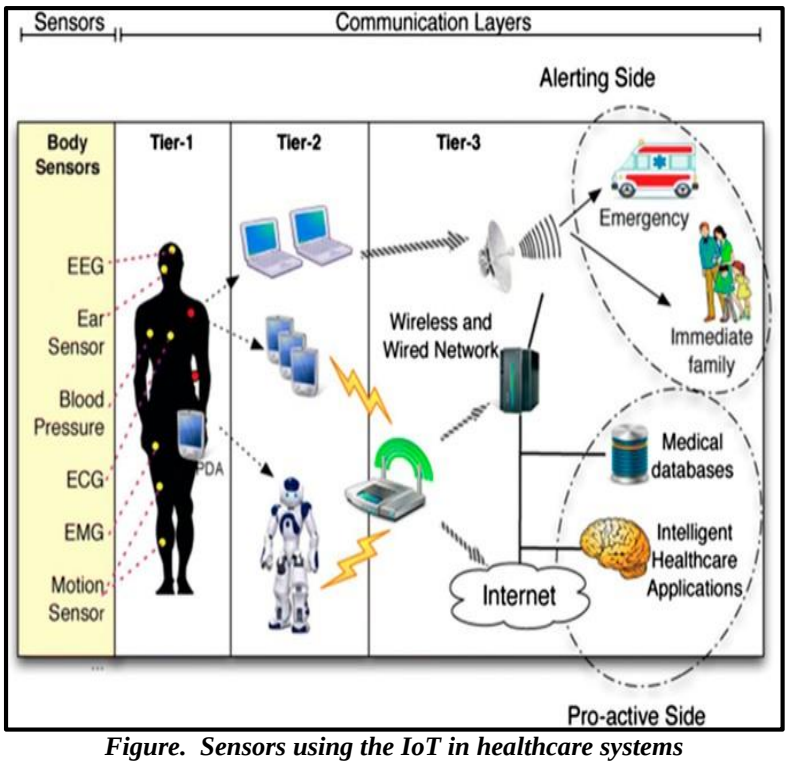

Figure. Sensors using the IoT in healthcare systems

6. Applications and Gadgets for the IoT Healthcare System:

The IoT and sensors constitute vital components from a technological standpoint as they facilitate healthcare systems, directly addressing user and patient requirements. Currently, numerous applications are user-centric, while services are primarily developer-centric, empowering the integration of technology and rendering IoT the most efficient and reliable technology for healthcare systems, including those responding to the challenges posed by COVID-19. This section explores various applications pertinent to healthcare systems.

1. IoT-Based Ambulances: Ambulance staff encounters significant stress as they handle critical patients where timely decisions are imperative for patient survival. IoT-enabled ambulances prove highly effective, allowing remote medical teams to advise necessary actions promptly, ensuring timely and effective response to patients [52]. Red Ninja pioneered the development of a Life First Emergency Traffic Control (LiFE) algorithm, which alters traffic light patterns or durations during emergencies to facilitate ambulance and emergency service.

2. Telemart: Telemart, an IoT-enabled solution, addresses challenges in maintaining social distancing, especially evident in places like supermarkets during the COVID-19 pandemic. Recently, Amazon introduced Telemart, providing users with QR codes for store entry, enabling shopping without waiting in lines. Users' Amazon accounts are debited post-shopping, eliminating the need for physical interaction at checkout counters.

3. Nexleaf Analytics: This application proves invaluable in developing countries for monitoring vaccine temperatures in refrigerators continuously. It aids in ensuring the efficacy of life-saving vaccines stored in healthcare systems and clinics in remote or rural areas. Additionally, Nexleaf Analytics contributes to improving cookstoves by providing real-time data on carbon dioxide emissions and wood fuel usage [57].

4. Barcode and Label System: This wireless cloud platform interconnects multiple therapeutic devices for chronic disease treatment and patient health monitoring. It enables mobile and web-based access for healthcare units and medical teams to respond promptly using real-time patient data [57–59]. Furthermore, it facilitates drug delivery platform development, enhancing user-system interaction for disease detection and management. The concept of virtual hospitals and wards, implemented worldwide, enables remote patient monitoring, exemplified by Sydney's virtual hospital during the COVID-19 pandemic [.

5. Quio: With an aging global population, the demand for healthcare services at home is expected to rise significantly. IoT-enabled home-based services offer a promising solution, exemplified by projects like Parkinson House, a collaborative effort by IBM and Pfizer. This initiative enhances doctor-patient relationships by monitoring medication effectiveness and patient movements through sensors, aiding real-time medication adjustments.

6. Home Healthcare: Smartwatches, initially designed for entertainment, have evolved into powerful healthcare tools. Leading brands like Apple, Samsung, and Google offer features such as ECG monitoring and respiratory disease tracking. These watches also incorporate various health-related applications like activity tracking, medication reminders, and COVID-19-related alerts, promoting health monitoring and management.

7. Smart Watches: This application caters to elderly individuals living alone by providing a wearable pendant that detects falls, sudden movements, or prolonged immobility, triggering emergency services notifications with the user's location. This technology proved particularly useful during the COVID-19 pandemic, ensuring the safety of isolated elderly individuals.

8. Advanced Metering Infrastructure (AMI): During pandemics, ensuring uninterrupted power supply to healthcare infrastructure is crucial. Smart grids, equipped with sensors and transducers, monitor electricity supply and demand, facilitated by AMI. This infrastructure enables remote detection, control, and prevention of technical issues, ensuring reliable power supply to healthcare facilities during crises like COVID-19.

9. Glucose Monitoring: Devices for monitoring glucose levels, blood pressure, and temperature play essential roles in managing chronic diseases like diabetes, especially during pandemics. Real-time glucose level monitoring, coupled with IoT connectivity, facilitates seamless data transmission between patients and healthcare providers, aiding disease management and preventive measures [.

10. Smart Wheelchair: Smart electric wheelchairs, equipped with sensors and IoT connectivity, offer mobility solutions for disabled, injured, and elderly individuals. These wheelchairs gather data on user movement, environmental conditions, and location, providing valuable insights for healthcare professionals and ensuring user safety, particularly during emergencies like pandemics.

6.1. Smart Technologies of IoT Based Healthcare Systems for COVID-19:

Presently, healthcare systems extensively utilize IoT technologies, a trend accelerated by the COVID-19 pandemic. The adoption of IoT technologies is witnessing rapid growth, with new advancements continually emerging in response to user and industry demands. Below are some technologies currently in use and those with potential for future IoT healthcare systems:

7. Ambient intelligence communication technologies:

They play a vital role in enhancing the experiences of users and patients. Their application within the healthcare system is growing, aiding patients, physicians, and healthcare center staff alike. This integration involves wearable devices and integrated sensors working in tandem with healthcare settings and the IoT to gather and analyze patient data. Therefore, the embedded system of human-computer interaction, autonomous control, the IoT, and ambient intelligence can provide valuable assistance to governments, healthcare systems, and patients during the COVID-19 pandemic.

7.1. Intelligent robotics:

The pivotal role of robotics in combating COVID-19, as demonstrated by the UNDP's initiatives in Rwanda, aimed at enhancing efficiency and intelligence. Amidst the COVID-19 pandemic, the integration of IoT and robotics has proven invaluable for both industry and government. Utilizing IoT connectivity, robots are employed for tasks such as disposing of infectious materials, transporting patient belongings within hospitals, room and hospital cleaning, and disinfection. This collaborative use of robotic technology and IoT is revolutionizing work environments worldwide. Germ-zapping robots utilize ultraviolet light for automatic cleaning across hospitals, ensuring continuous proactive cleaning around the clock. This technology has expanded into various sectors including train stations, universities, grocery stores, movie theaters, shopping malls, and homes.

8. Conclusions:

The IoT stands out as a highly promising technology for seamless data transfer across interconnected networks, minimizing human intervention. It enables patients to share health-related data with specific medical professionals and healthcare systems in real-time. However, numerous challenges persist in IoT integration within the healthcare system, necessitating concerted efforts for improvement.

This paper elucidates the pivotal role of IoT in healthcare systems, particularly amidst the COVID-19 pandemic. It discusses the technological aspects, architecture, components, and applications of IoT relevant to healthcare systems, emphasizing their efficient execution and significant contributions during COVID-19 and other health crises.

Furthermore, innovative technologies are explored, laying the groundwork for further research and advancement of IoT healthcare systems. Detailed barriers are identified, and forthcoming recommendations aim to enhance healthcare systems by addressing deficiencies in IoT applications and technologies. Overcoming these barriers will pave the way for a more innovative IoT healthcare system, offering enhanced facilities at minimal cost to healthcare providers. This paper outlines potential future applications of IoT technology in healthcare alongside current barriers, particularly in the context of COVID-19 and future epidemics.

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