BLOCKCHAIN-ENABLED MULTI-SENSOR DATA FUSION WITH HEALTHCARE DATA PROCESSING – A REVIEW

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Abstract

Blockchain technology and the synthesis of data from several sensors have the potential to revolutionize remote health monitoring techniques in the healthcare industry. The management of healthcare data using multi-sensor data fusion and block-chain integration was thoroughly reviewed in this research. The study examines how these technologies might improve data security, privacy, and interoperability while enabling real-time patient monitoring and analysis. This review paper discusses the advantages and disadvantages of using these cutting-edge methods while highlighting the important findings from numerous study articles. Healthcare data is guaranteed to be immutable and transparent by the proposed block-chain-based models, and multi-sensor data fusion makes it possible to combine various data sources for a comprehensive understanding of patient health. The patient-centric approach gives people the power to control their health information and actively engage in healthcare decisions. For wider use, the assessment does recognise the need to address issues with standards, scalability, and regulatory compliance.This paper emphasizes the significance of blockchain with multi-sensor data fusion in achieving secure, efficient, and patient-centric remote health monitoring, paving the way for a data-driven and personalized healthcare future.

Keywords: Blockchain, Multi-sensor data fusion, Healthcare data, Remote Health Monitoring, Data Security, Real-time monitoring

1. Introduction

Remote Health Monitoring, also known as remote patient monitoring or telehealth monitoring, has emerged as a transformative approach in modern healthcare, revolutionizing the way patients' health is managed and monitored [1]. This innovative technology provides the information about health of the patients with collection and tracking information, regardless of their geographical location, using a diverse range of wearable devices, sensors, and mobile applications. Continuous and real-time data acquisition empowers medical professionals to gain invaluable insights into patients' health conditions, enabling timely interventions and personalized care plans [2]. Moreover, Remote Health Monitoring plays a crucial role in promoting early detection of potential health issues, preventing hospital readmissions, and enhancing overall patient outcomes. With the increasing prevalence of chronic diseases and an aging population, the adoption of Remote Health Monitoring has become indispensable in achieving efficient and cost-effective healthcare delivery [3].

The field of remote health monitoring has seen the emergence of Multi-Sensor Data Fusion as a key technology, with enormous potential to transform the way healthcare data is gathered, processed, and used [4]. The integration and fusion of data from many sources is essential in the context of remote health monitoring, where patients are continually observed by a variety of wearable devices and medical sensors, in order to provide a thorough and accurate picture of a person's health status [5]. Ecombining information from various sensors, such as heart rate monitors, blood pressure cuffs, glucose meters, and activity trackers, healthcare providers can obtain a holistic understanding of a patient's physiological and behavioural patterns. This enables timely detection of subtle changes in health parameters, early identification of potential health risks, and precise tracking of treatment outcomes [6]. Remote health monitoring systems with various wearable devices and medical sensors to continuously collect diverse sets of health data. These sensors capture information about vital signs, physical activities, sleep patterns, glucose levels, and other relevant health parameters [7]. Through fusing data from multiple sources, healthcare providers gain a comprehensive and holistic view of an individual's health status. The integration of heart rate data from a fitness tracker with blood pressure readings from a smartwatch and glucose measurements from a continuous glucose monitor provides a more accurate and dynamic representation of a patient's cardiovascular and metabolic health [8]. This comprehensive monitoring approach enables healthcare professionals to identify subtle changes or trends that might not be apparent when analyzing data from a single sensor in isolation [9]. Consequently, it facilitates early detection of potential health risks and allows for timely interventions, preventing the escalation of medical conditions and reducing hospitalizations [10].

Remote health monitoring systems' diagnostic powers are improved by multi-sensor data fusion. The accumulated information from various sensors offers a wealth of knowledge that can support precise and prompt diagnoses [11]. For instance, combining information from a body temperature sensor with information on breathing rate from a spirometer can aid in the early identification of respiratory diseases or disorders. Additionally, the cross-validation of

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measurements is made possible by the integration of several data streams, which lowers the possibility of false positives or false negatives. [12]. This increased diagnostic accuracy can lead to more effective treatment plans and improved patient outcomes. The amalgamation of data from various sensors enables the delivery of personalized healthcare interventions [13]. Throughanalysing a patient's health data holistically, healthcare providers can tailor treatment plans to address individual needs and preferences [14]. For instance, data fusion can help in designing personalized exercise routines based on an individual's heart rate, activity levels, and fitness goals. Furthermore, the ongoing evaluation of numerous health indicators enables proactive therapies when abnormalities or deviations from baseline values are detected [15]. Timely alerts and notifications can prompt patients and healthcare providers to take preventive actions or adjust treatment plans, thereby promoting better disease management and reducing the risk of complications [16].

By giving a thorough picture of a patient's health status, improving diagnostic accuracy, and enabling customized and proactive healthcare interventions, multi-sensor data fusion plays a crucial role in remote health monitoring. [17]. This innovation has the potential to transform contemporary healthcare by empowering both patients and healthcare professionals with actionable insights and facilitating more effective and patient-centric healthcare delivery [18]. Blockchain technology's contribution to improved security and privacy within the context of multi-sensor data fusion for remote health monitoring is a ground-breaking advancement that holds immense promise for revolutionizing healthcare systems [19]. The seamless integration of various health data becomes essential for providing complete and individualized patient care as wearable devices and medical sensors are increasingly adopted. However, this vast and sensitive health information presents significant challenges in terms of data security, privacy, and data integrity. Enter blockchain technology, a decentralized and immutable ledger system that offers an innovative solution to these challenges [20]. Each member of the network retains a copy of the full data history in a distributed ledger called blockchain, which functions as a decentralized ledger. Unlike traditional centralized databases that are vulnerable to single points of failure and hacking, blockchain's decentralized nature ensures that health data is distributed across numerous nodes, making it extremely resilient to attacks [21]. Furthermore, because to the immutability of block chain, it is impossible to modify data that has already been recorded or erased without the support of the majority of the network. Through preventing data tampering and illegal adjustments, this function ensures the validity and integrity of health data. [22]. With sensitive health information from multiple sensors being collected and stored, ensuring robust data security and access control is paramount. Blockchain utilizes cryptographic techniques to secure data transactions, making it practically impossible for unauthorized parties to access or decipher the stored data [23]. Cryptographic keys can be used to control access to the block chain, allowing patients to completely control who has access to their medical records. This enables patients to give healthcare providers access to their data while strictly limiting who else can access it.One of the significant challenges in remote health monitoring is enabling data sharing while safeguarding patient privacy

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[24]. Through the use of smart contracts, self-executing programs that automate transactions based on predefined circumstances, blockchain enables secure data sharing. Smart contracts can establish granular access controls, allowing patients to share specific data with designated healthcare professionals or researchers for a limited duration [25]. Consequently, patient data remains private and is only accessible for the intended purpose and timeframe, promoting patient trust and confidence in the system. Blockchain can address the interoperability challenges arising from the diversity of sensors and data formats used in remote health monitoring. By providing a standardized and secure platform for data exchange, blockchain enables seamless integration and fusion of data from various sources [26]. Furthermore, blockchain's consensus mechanisms ensure that the data stored in the network is consistent and accurate, enhancing the reliability and quality of the data used for analysis and decision-making.Strict privacy laws, such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR), apply to healthcare data. [27]. Blockchain's transparent and auditable nature facilitates compliance with these regulations by providing a complete audit trail of data transactions. Additionally, patients have better visibility into how their data is being used, promoting transparency and accountability in the healthcare ecosystem. Blockchain technology provides a reliable and creative remedy to the security and privacy challenges faced in multi-sensor data fusion for remote health monitoring [28]. With the blockchain in decentralization, immutability, and cryptographic features, healthcare systems can ensure secure, private, and reliable data sharing and management [29]. This integration of blockchain with multi-sensor data fusion has the potential to transform remote health monitoring, enabling more accurate diagnoses, personalized treatments, and ultimately improving the overall quality of healthcare services.

The goals of this review paper are to thoroughly analyse the importance, difficulties and latest advancements in the integration of multi-sensor data fusion and blockchain technology for remote health monitoring. The paper aims to elucidate how multi-sensor data fusion enables healthcare providers to obtain a holistic view of patients' health status by combining data from diverse wearable devices and medical sensors. In this paper, we explore how blockchain's inherent characteristics, such as transparency, immutability, and cryptographic encryption, can establish trust and enable secure sharing and management of health data from various sensors. By integrating blockchain with multi-sensor data fusion in remote health monitoring, we can ensure that patient information is securely stored, accessed only by authorized entities, and tamper-resistant. This technology not only empowers increased patient control with their data but also fosters collaboration between healthcare providers and researchers while adhering to stringent privacy regulations.

The evaluation will also explore how block chain technology has the potential to revolutionize security, privacy, and integrity of health data in remote monitoring scenarios. The exploration of block chain’s decentralized and immutable nature will highlight how it fosters trust, transparency, and tamper-resistant data storage, promoting secure data sharing and access control while adhering to privacy regulations. Furthermore, the review will showcase existing implementations and case

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studies of block chain-integrated remote health monitoring systems to underscore real-world applications and benefits. Ultimately, the paper seeks to offer insightful information to researchers, medical professionals and policymakers guiding them in harnessing the combined power of combination of sensor data and block chain technology to revolutionize the field of remote health monitoring and improve patient outcomes.

2. Multi-Sensor Data Fusion Techniques

Multi-sensor data fusion has emerged as a potent method to harness the quantity of information produced by different wearables and sensors in the fast changing landscape of healthcare data monitoring. This approach enables healthcare professionals to gain a comprehensive understanding of patients' health status, paving the way for personalized and proactive interventions. Multi-sensor data fusion has emerged as a potent method to harness the quantity of information generated by various sensors and wearable devices in the fast changing landscape of healthcare data monitoring. This paper delves into the key components of sensor selection and integration, data pre-processing and cleaning, feature extraction and selection, and fusion algorithms and techniques. Firstly, the process of sensor selection and integration involves identifying the most relevant and appropriate sensors for capturing the targeted health parameters. It requires considering factors such as sensor accuracy, compatibility, power consumption, and usability to ensure optimal data collection. Subsequently, data preprocessing and cleaning play a pivotal role in refining raw sensor data by removing noise, handling missing values, and standardizing formats, ultimately enhancing the quality and reliability of the fused data. Next, feature extraction and selection are essential steps to distill meaningful and informative patterns from the combined sensor data. This process involves identifying relevant features that contribute significantly to the overall health assessment while reducing dimensionality to improve computational efficiency. Finally, fusion algorithms and techniques are employed to merge the extracted features from different sensors seamlessly. These algorithms may include model-based fusion, rule-based fusion, machine learning-based fusion, or Bayesian methods, among others. By integrating the outputs from diverse sensors, these techniques enable a more comprehensive and accurate representation of patients' health status, facilitating early detection of health anomalies, and driving better healthcare outcomes. Through a thorough exploration of these key aspects, this paper seeks to clarify the crucial part of multi-sensor data fusion in healthcare data monitoring and pave the way for advancements in patient care, disease management, and healthcare system efficiency.

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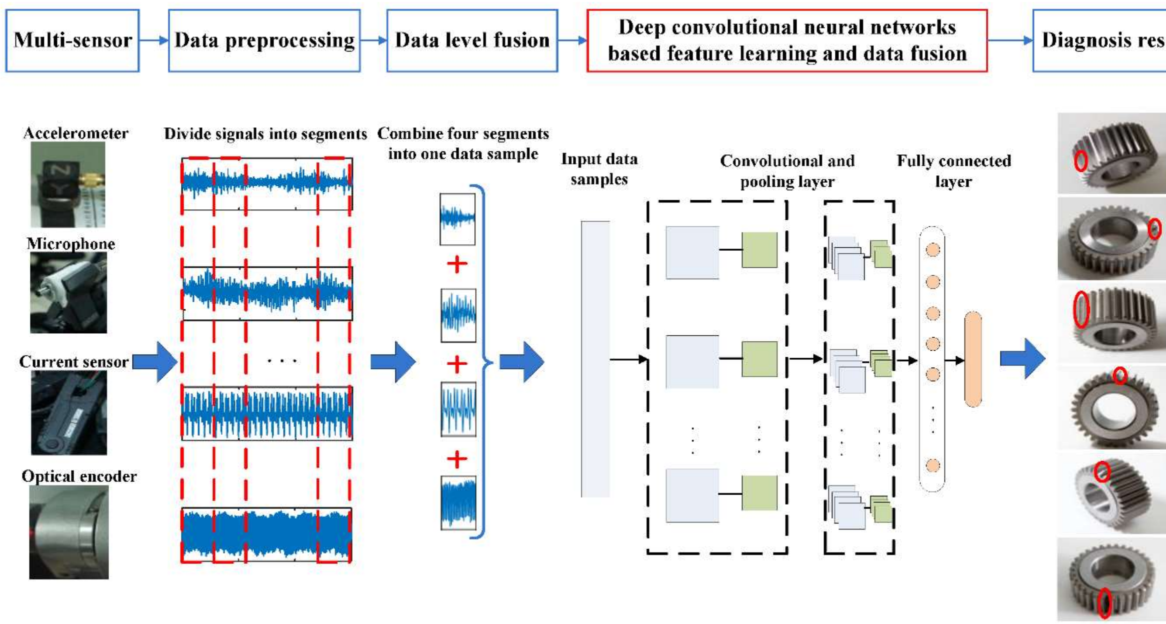

Figure 1: Architecture of Multi-Sensor Data Fusion [104]

Vidya and Sasikumar (2022) [31] presented an effective fusion of many sensors to identify human activity with the use of machine learning model. The study explores how multiple sensors on wearable devices can be combined to accurately recognize and classify human activities, providing insights for personalized health monitoring and activity tracking.Kashinath et al. (2021) [32] offer a comprehensive review based on data fusion model for the estimation and computation of multi-sensor traffic flow analysis. The paper examines various techniques to integrate traffic data from multiple sources to enhance traffic flow analysis, contributing to intelligent transportation systems and urban planning.Zeng et al. (2021) [33] proposed effective approach for the monitoring the data through fusion with fusing data from multiple sensors using imaging and an attention mechanism. This method intends to increase the tool's activity condition assessment, optimizing industrial processes and maintenance.Gawde et al. (2023) [34] conducted a review for the examination and analysis of the diagnosis of the multi-fault's estimation in the industrial application for the rotating machines with the fusion of multi-sensor. The study explores how data fusion techniques can aid in identifying and diagnosing multiple faults in rotating machinery, contributing to improved reliability and safety in industrial settings.

Li et al. (2022) [35] evaluated multi-sensor data fusion with the use of fire perception model to improve the accuracy with TCN. The study investigates how fusing data from various sensors can enhance the accuracy of indoor fire detection, facilitating early warning systems and fire safety measures.Balu (2022) [36] presents a multi-sensor fusion model with the Machine learning model for the recognition of human activity. Zhang et al. (2022) [37] propose an information fusion model with the adaptive learning in the electronic and hyperspectral features computation for the quality estimation. This research aims to improve food quality assessment and safety measures.Zhu et al. (2023) [38] explored a model for the integration of multi-sensor with the use of deep machine

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learning-based residual condition estimation. The proposed model focuses on the improvement and maintenance of the manufacturing process in industrial applications.

Saranya and Fatima (2022) [39] investigated data fusion and feature extraction models with collected data from the IoT environment. The paper likely covers how data fusion in the context of IoT enhances information status and decision-making.Chong et al. (2022) [40] presented a model to perform multi-sensor data fusion with the assessment of health risk and monitoring with the use of contrast learning. The study explores how data fusion techniques can aid in assessing health risks and monitoring health conditions for improved healthcare delivery.Zhao et al. (2021) [41] examined the contribution of the intelligent technologu for the airport application for the multi-sensor data fusion. The study focuses on how data fusion can optimize airport operation nodes, leading to enhanced safety and efficiency in aviation.Xu et al. (2022) [42] investigate multi-sensor data processing application with the data mining technique. The research explores data mining techniques to process and extract valuable insights from multi-sensor data sources. Table 1 presented the multi-sensor data-fusion model for the computation of healthcare data.

Table 1: Multi-Sensor Data Fusion

Reference	**Objective**	**Fusion Data**	**Fusion Technique**
Vidya and Sasikumar (2022) [31]	Data Fusion technique for wearable multi-sensor activity recognition of people.	Data from multiple sensors on wearable devices to recognize and classify human activities.	Machine learning algorithms.
Kashinath et al. (2021) [32]	Evaluated about real-time multi-sensor data integration for the traffic flow analysis.	Traffic data from multiple sources integrated for enhanced traffic flow analysis.	Various data fusion techniques.
Zeng et al. (2021) [33]	Tool condition monitoring through data fusion imaging and attention mechanism.	Data from multiple sensors to improve tool condition assessment in industrial processes.	Novel approach using imaging and attention mechanism.
Gawde et al. (2023) [34]	Examination of data fusion with the examination of multi-fault analysis for the industrial machine rotation.	Data fusion techniques aid in identifying and computes spinning machinery with various flaws.	Various data fusion methods for defect detection.
Li et al. (2022) [35]	Multi-sensor fusion for indoor fire perception algorithm.	Data from various sensors used to enhance the accuracy of indoor fire detection.	Improved TCN-based algorithm for fire detection.

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Balu (2022) [36]	Recognition of Human - activity with multi-sensor fusion	Data collected form the wearable devices	Machine learning algorithms.
Zhang et al. (2022) [37]	Adaptive learning method for egg quality identification by fusing electronic nose and hyperspectral data.	Fusion of information from the electronic and hyperspectralforquality identification.	Adaptive learning algorithm.
Zhu et al. (2023) [38]	With the integratesof multi-sensor and deep learning for theconditions are monitored with multi-sensor.	Data fusion from multiple sensors to enhance tool performance and maintenance in manufacturing.	Deep residual convolution network for tool condition monitoring.
Saranya and Fatima (2022) [39]	Investigate the status of information in IoT environment with fusion and feature extraction in the data.	Data fusion in IoT context for improved information status and decision-making.	Data fusion and feature extraction techniques in IoT.
Chong et al. (2022) [40]	Assessment of health risk for the system monitoring with the fusion of multi-sensor through the contrast learning process.	Data fusion techniques for assessing health risks and monitoring health conditions.	Multi-sensor information fusion and contrast learning.
Zhao et al. (2021) [41]	Examined the acquisition of intelligent technology for the operation nodes.	Data fusion for optimizing airport operation nodes to enhance safety and efficiency in aviation.	Multi-sensor data fusion for airport operation nodes.
Xu et al. (2022) [42]	Investigate multi-sensor data processing with the data mining.	Data mining techniques for processing and extracting insights from multi-sensor data sources.	Data mining technology for multi-sensor data processing.

These studies explore the utilization of data fusion techniques to address a wide range of challenges, including human activity recognition, real-time traffic flow analysis, tool condition monitoring, fault diagnosis in industrial machines, fire perception, food quality identification, IoT information status, health risk assessment, airport operation optimization, and data mining. While specific findings for each paper are not available here, these research endeavors collectively underscore the growing significance of multi-sensor data fusion in enabling sophisticated and data-

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driven applications across diverse industries and domains. The exploration of these topics highlights the transformative potential of data fusion technology in enhancing decision-making, improving safety and efficiency, and optimizing processes and systems in various contexts.

3. Blockchain Technology in Health Data Management

Recently, the healthcare industry has been experiencing a paradigm shift in data security and management with the putting block chain technology into practice.Block chain, initially known for its association with cryptocurrencies, has now garnered attention as a transformative tool for ensuring the integrity, security, and accessibility of health data [43]. This innovative distributed ledger technology which is decentralized provides a tamper-resistant and immutable framework that allows healthcare organizations to securely store, share, and manage patient data. With implementation of cryptographic techniques and consensus algorithms, block chain enables transparent and auditable health data transactions while maintaining patient privacy and control over their sensitive information [44]. In this context, block chain technology provides a significant revolutionize health data management by addressing critical challenges such as data interoperability, data breaches, and patient consent management. The potential and advantages of block chain technology are discussed in the context of health data management system in this paper, exploring its role in fostering trust among stakeholders, improving data accuracy, enhancing data sharing among healthcare providers, and facilitating innovative applications such as medical research and telemedicine [45]. As block chain continues to gain momentum in the healthcare sector, understanding its potential implications and limitations becomes crucial for paving the way towards a more secure, transparent, and patient-centric future in health data management.

Frikha et al. (2021) [46] discusses the implementation of an IoT-based blockchain platform for data management in healthcare. The study explores how blockchain technology enhances data security and privacy, facilitating efficient data management and sharing in the healthcare and fitness domains. Yaqoob et al. (2021) [47] provide an overview of blockchain's potential in healthcare data management. It evaluates challenges, opportunities and future related to the blockchain technology recommendations for healthcare data security and interoperability.Vyas et al. (2022) [48] investigates the performance of blockchain technology integrated with artificial intelligence for the application of healthcare and agriculture. It explores the potential synergies between these technologies to improve data management and decision-making in both domains.Singh et al. (2022) [49] focuses on the efficient data management in healthcare systems with block chain technology. It highlights the opportunities and challenges of implementing block chain solutions to improve the data privacy, integrityand interoperability in healthcare settings.Lemieux et al. (2021) [50] evaluates block chain user response for the secure healthcare data management and sharing.It explores user perceptions and attitudes towards block chain-based health data systems.

Taloba et al. (2023) [51] presented a hybrid multimedia data with blockchain data processing for the IoT Healthcare applications. It investigates how blockchain technology can enhance data processing and management in IoT-enabled healthcare applications.Al Mamun et al. (2022) [52]

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offers a comprehensive review of blockchain-basedmanagement of electronic health records. It explores the various aspects of implementing blockchain solutions for electronic records security and efficiency.Zaabar et al. (2021) [53] proposed an efficient Helathcare data management system with the computation in Heathblock. It explores the design and implementation of HealthBlock, focusing on data security and privacy in healthcare.Azbeg et al. (2022) [54] presents BlockMedCare, the developed model comprises of the blockchain, IPFS, and IoT for the data security. It investigates how the integration of these technologies enhances data security and uses of access control in health care.Ramzan et al. (2022) [55] examines blockchain technology in the healthcare scenario with an evaluation of different factors and challenges associated with IoT data. It offers a significant potential benefits and obstacles in adopting blockchain solutions in healthcare.

Pustokhin et al. (2021) [56] discussmanagement of healthcare data integrated with the combination of blockchain technology. It highlights the current limitations and areas for improvement in the implementation of blockchain in healthcare.Biswas et al. (2021) [57] introduces Globechain, interoperable healthcare data for the global data sharing focus on a COVID-19 perspective. It explores how Globechain facilitates secure and transparent sharing of healthcare data during the pandemic.Abbas et al. (2021) [58] present a blockchain-assisted management framework for the security for information analysis with the use of Internet of Medical Things (IoMT). It investigates how blockchain enhances data security and analysis in IoMT applications.Ng et al. (2021) [59] conducts a systematic review of COVID-19 and beyond blockchain model in healthcare. It provides insights into the various use cases and potential benefits of blockchain in healthcare during the pandemic and beyond.

Li et al. (2022) [60] proposes an efficient management of big data with the use of encryption with keyword searchable with the HealthChain. It explores how the integration of blockchain technology with keyword-searchable encryption enhances data security and searchability in healthcare.Yu et al. (2021) [61]a multi-role health care datasharing solution built on the block chan. It investigates how this system facilitates secure and efficient data sharing among multiple stakeholders in healthcare.Garrido et al. (2021) [62] analyzesHER system integrated with the healthcare technique for the healthcare applications. The model examined the AHP approaches with analysis of the blockchain based system HER analysis. Table 2 presented the summary of the medical healthcare data,

Table 2: Summary of Medical Heathcare Data

Reference	**Healthcare Data**	**Method**	**Results**
Frikha et al. (2021) [46]	Healthcare and fitness data	IoT-based blockchain platform for data management	Increaseddata security and data privacy, efficient management of healthcare data for the computation of fitness

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Yaqoob et al. (2021) [47]	Overview of healthcare data management	Potential of blockchain in management of data	Identification of opportunities, challenges, and future recommendations for blockchain in healthcare data security and interoperability
Vyas et al. (2022) [48]	Healthcare and agriculture data	Integration of AI and blockchain in healthcare and agriculture	Exploration of potential synergies between AI and blockchain to enhance data management and decision-making in healthcare and agriculture
Singh et al. (2022) [49]	Healthcare data management	Block chain application for effective healthcare data management.	Identification of opportunities and challenges in implementing blockchain solutions for data integrity, privacy, and interoperability in healthcare settings
Lemieux et al. (2021) [50]	Private and secure health data management	User response to blockchain-based health data systems	Evaluation of user perceptions and attitudes towards management and sharing of healthcare data with the blockchain technology
Taloba et al. (2023) [51]	IoT-Healthcare multimedia data processing	Blockchain-based hybrid platform for data processing	Investigation of how blockchain enhances data processing and management in IoT-enabled healthcare applications
Al Mamun et al. (2022) [52]	Maintenance of electronic health records.	Comprehensive analysis of blockchain-based EHR management	Exploration of various aspects of implementing blockchain solutions for secure and efficient EHR management
Zaabar et al. (2021) [53]	Healthcare data management	Proposal of HealthBlock, a secure blockchain-based data management	Exploration of HealthBlock design and implementation, focusing on data security and privacy in healthcare
Azbeg et al. (2022) [54]	IoT-based healthcare data management	BlockMedCare, a healthcare system using IoT, blockchain, and IPFS	Investigation of how integration of IoT, blockchain, and IPFS enhances data security and access control in healthcare applications
Ramzan et al. (2022) [55]	Healthcare applications using blockchain	Motivations and challenges in blockchain adoption in healthcare	Identification of benefits and challenges with blockchain solutions in healthcare

Pustokhin et al. (2021) [56]	Challenges in management of data	Discussion on limitations and future directions of blockchain in healthcare	Identification of current challenges and areas for improvement in implementing blockchain technology in healthcare
Biswas et al. (2021) [57]	Global sharing of healthcare data (COVID-19)	Globechain, an interoperable blockchain for healthcare data sharing	Exploration of Globechain's potential in healthcare data security during the COVID-19 pandemic
Abbas et al. (2021) [58]	Health information analysis using IoMT	Blockchain-assisted secured data management framework	Investigation of how blockchain enhances data security and analysis in IoMT applications
Ng et al. (2021) [59]	Blockchain applications in healthcare (COVID-19)	Reviewed about healthcare data with blockchain	Identification of differerent cases and potential benefits of blockchain in healthcare during the COVID-19 pandemic and beyond
Li et al. (2022) [60]	Medical big data management	Efficient data management with keyword-searchable encryption	Exploration of how blockchain with keyword-searchable encryption enhances data security and searchability in medical big data management
Yu et al. (2021) [61]	Multi-role healthcare data sharing	Blockchain-based multi-role data sharing system	Investigation of how the system facilitates data security and sharing among multiple stakeholders in healthcare
Garrido et al. (2021) [62]	Scalability of EHR systems with blockchain	Simulation-based AHP approach for blockchain-based EHR systems	Evaluation of the scalability of blockchain-based EHR systems in healthcare institutions

With improved and exploration of block chain technology in the field of healthcare data management. Block chainprovides a promising solution to address critical challenges in this domain, such as data security, privacy, interoperability, and efficient data sharing. The studies explore various applications of block chain in healthcare, such as electronic health records, healthcare data management, IoT-based healthcare systems, multimedia data processing, and medical big data management. They also shed light on the opportunities and challenges related to application of block chain technology in healthcare data. These papers demonstrate the potential of block chain to revolutionize healthcare data management by providing secure, transparent, and decentralized solutions that giving patient the power to manage their health information while

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facilitating efficient data exchange among healthcare providers. With the drastic development of healthcare sector is still embracing the block chain and digital transformation stands poised to play a pivotal role in ensuring data integrity, enhancing patient-centric care, and driving innovative healthcare applications.

3.1 Decentralized Block chain for Healthcare

In the context of healthcare, decentralization and immutability are two vital principles of block chain technology that play a crucial role in ensuring data security. Decentralization in healthcare involves distributing patient health records and sensitive medical data across a network of nodes, removing the need of the centralized organization to oversee and manage the data. This distributed approach enhances data resilience and single point of failure riskare reduced or data breach. Independently each node in the network validates and verifies transactions, ensuring that any alterations or updates to the data require consensus among the network participants.

With the inclusion of data in blocks and added to the chain, it becomes virtually impossible to modify or delete without consensus from the majority of nodes. This immutability ensures that patient health records and medical information remain secure and tamper-proof. In the healthcare sector, where data integrity and accuracy are of paramount importance, the immutability feature of block chain ensures that medical records cannot be altered maliciously or unintentionally. With combining decentralization and immutability, block chain technology offers a highly secure and transparent system for managing healthcare data. Patients can feel more confidentabout the accuracy of their medical information is protected from unauthorized access or alteration, while healthcare providers can access a trusted and unalterable record of patient history. Moreover, healthcare professionals can collaborate more effectively, exchanging sensitive data in a secure and auditable manner. Overall, decentralization and immutability provide a robust foundation for safeguarding patient data and promoting data security in the healthcare industry.

3.2 Blockchain Architectures in Healthcare

Blockchain architectures in healthcare refer to the underlying structures and configurations of blockchain networks and platforms designed specifically for healthcare applications. Blockchain, as a distributed and decentralized ledger technology, holds immense potential to revolutionize various aspects of healthcare data management, security, interoperability, and patient-centric care. Several blockchain architectures have been proposed and implemented in the healthcare domain, each offering distinct features and capabilities. Here are some commonly used blockchain architectures in healthcare:

Public Blockchain: Public blockchains are open networks without permission where anyone can participate as a node and validate transactions. In healthcare, public blockchains can be used for patient consent management, health research, and public health data sharing. However, due to their openness, privacy concerns may arise, making it challenging to share sensitive patient data.

Private Blockchain: Private blockchains are restricted networks where participation and validation of transactions are controlled by selected entities or consortiums. In healthcare, private blockchains can be utilized within a healthcare organization or among a group of trusted

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institutions to manage electronic health records, supply chain data, or clinical trial data. Private blockchains offer enhanced privacy and security features compared to public blockchains.

Consortium Blockchain: This belongs to the class of both private and public blockchain, where a group of pre-approved nodes is responsible for validating transactions. Consortium blockchains are suitable for healthcare data exchange and interoperability initiatives involving multiple organizations. They provide a balance between openness and privacy, making them ideal for collaborative healthcare networks.

Permissioned Blockchain: This blockchain explicit permission for the node and validate transactions within the network. Participants in the network are known entities, and access to data is controlled through access permissions. Permissioned blockchains offer greater control over data access and can be used for patient identity management and secure data sharing among healthcare providers.

Hybrid Blockchain: This combines the features of the both public and private blockchains to achieve specific use case requirements. In healthcare, hybrid blockchains can enable selective data sharing with patients and researchers while maintaining overall data security and integrity.

Federated Blockchain: Federated blockchains are a collection of interconnected blockchain networks, each operated independently by different organizations or entities. These interconnected networks can exchange data and share information while maintaining their autonomy and security. Federated blockchains can facilitate health data sharing among different healthcare users through the controlling strategy in data.

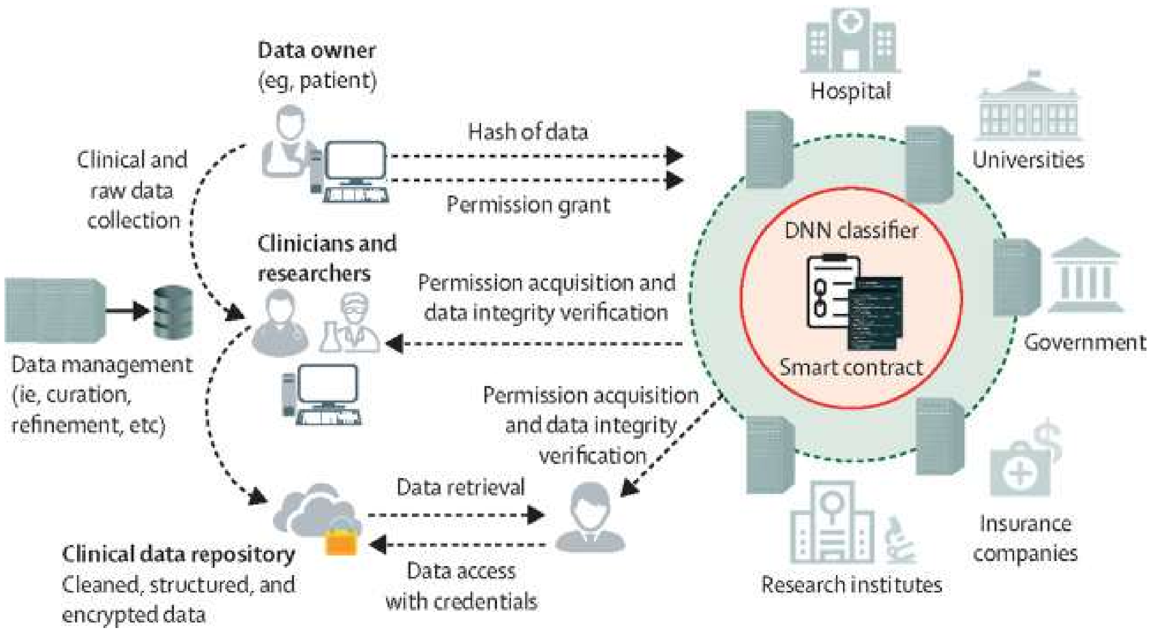

Figure 2: Blockchain Technology for the healthcare data

Figure 2 presented the healthcare data processing with the blockchain technology. Blockchain architectures in healthcare aim to address issues related to the data security, privacy, data ownership, data interoperability, and patient consent management. These architectures offer

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a distributed, tamper-resistant, and transparent framework that can enhance the efficiency, accuracy, and integrity of healthcare data management.

3.3. Smart Contracts for Secure Data Sharing and Access Control

Smart contracts exhibit the characteristics of the self-executing scenario with the pre-defined rules and condition with automated execution to perform certain actions. In the context of blockchain technology, smart contracts are coded and stored on the blockchain, allowing for decentralized, transparent, and tamper-resistant execution of contractual agreements. The use of Smart Contracts is essential for safe data transfer and access control in various industries, including healthcare. The contribution of the smart contracts on the data sharing are listed as follows:

Smart contracts enable secure data sharing among authorized parties without the need for intermediaries. In the healthcare sector, sharing of patient health information is secure between healthcare providers, researchers, and other authorized entities through smart contracts. The smart contract acts as a gatekeeper, ensuring that only authorized parties can access specific data based on predefined conditions and permissions. This eliminates the risk of unauthorized access and enhances data privacy and security.Smart contracts provide a robust access control mechanism for sensitive data. Access rights and permissions can be encoded in the smart contract, dictating who can view, modify, or interact with specific data on the block chain. The applications are healthcare, patient consent and access preferences can be recorded in a smart contract, allowing patients to control who can health care record assessment and under what conditions. This empowers data control of the patients and ensures compliance with data privacy regulations.

Smart contracts automate data governance processes by enforcing predefined rules and conditions. This reduces the need for manual intervention and minimizes the potential for human error or bias in data access and sharing. With smart contracts, access to data can be automatically granted or revoked based on real-time events or conditions, ensuring that data remains secure and up-to-date at all times.Smart contracts offer complete transparency and auditability of data access and sharing activities. On the block chain, every data transaction is immutable and retraceable to the corresponding smart contract. This level of transparency provides for increased trust and responsibility among stakeholders, as all data interactions are recorded and visible on the block chain.Smart contracts enable seamless data interoperability between different healthcare systems and organizations. Since smart contracts are coded in a standardized manner, they can be easily integrated into various block chain networks, facilitating secure data exchange and collaboration among diverse entities within the healthcare ecosystem.

Table 3: Contribution of Block chain in Healthcare

Topic	**Decentralization and Immutability for Data Security in Healthcare**	**Block chain Architectures in Healthcare**	**Smart Contracts**
Description	These principles are vital in ensuring data security in healthcare.	Refers to the underlying structures and configurations of block	Self-executing contractsaresmart contracts that facilitate

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		chain networks designed for healthcare applications.	secure data sharing and access control in healthcare.
Decentralization	Distributes a patient data throughout a node network doing away with need of central authority	Various architectures include Public, Private, Consortium, Permissioned, Hybrid, and Federated blockchains.	Enables secure data sharing among authorized parties, eliminating intermediaries.
Immutability	Once the data is stored on block chain, it cannot be altered or tampered.	Each architecture offers distinct features and capabilities to address healthcare data challenges.	Smart contracts encode access rights and permissions, providing a robust access control mechanism.
Benefits in Healthcare	Enhances data resilience, reduces single points of failure, and ensures data integrity.	Can improve data security, interoperability, data ownership, and patient consent management.	Automates data governance, ensures transparency, auditability, and enhances data interoperability.
Use Cases	Patient health records, medical data sharing, and data privacy in healthcare.	Electronic health records management, data exchange, and interoperability initiatives.	Controlling access, managing patient permission and sharing secure data are all used in health care.

The classification and contribution of block chain technology in the healthcare application is presented in table 3.

4. Multi-Sensor Data Fusion in Remote Health Monitoring

In the rapidly development of remote health monitoring, the integration of multi-sensor data fusion has emerged as a transformative approach to revolutionize healthcare practices. With the widespread adoption of wearable devices, Internet of Things (IoT) technologies, and smart sensors, there is an unprecedented abundance of health-related data generated from diverse sources. Multi-sensor data fusion involves the amalgamation and analysis of data collected from multiple sensors and devices, enabling healthcare professionals to gain comprehensive insights into patients' well-being and health conditions. This innovative technique holds immense potential to enhance the accuracy, efficiency, and personalized nature of remote health monitoring, ultimately leading to proactive interventions and improved patient outcomes. By harnessing the power of multi-sensor data fusion, healthcare systems can pave the way for seamless and remote healthcare management, bridging the gaps between patients and healthcare providers for a more connected and data-driven healthcare future.

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In [63] focuses on multi-sensor information fusion using machine learning techniques for human activity recognition. It reviews the current state-of-the-art and identifies research challenges in this area. Also, in [64] investigates multimodal medical signals fusion for smart healthcare systems, providing a comprehensive survey of different approaches to combining medical data from various sources. Similarly, [65] investigates multi-sensor information fusion-based sports health monitoring equipment interoperability technologies, highlighting its potential applications in sports-related health monitoring. In [66] proposes an AI-based body sensor network framework comprises of wearable sensors, machine learning models and real-time location monitoring for the collection of data, mining and discovery of healthcare knowledge. With [67] explains how type-2 fuzzy logic and Dempster-Shafer theory can be combined for precise inference in IoT based healthcare systems, aiming to enhance decision-making in healthcare applications. For the biomedical sensing application sensor fusion is performed to increase the medical data monitoring and detection [68]. With the healthcare 5.0 security is improved with the block chain technology through the employing federated learning in healthcare settings with a focus on data privacy and collaboration[69]. The disease of encephalitis is diagnosis with cyber-physical healthcare data for the information fusion with the use of soft computing technique [70].

In [71] reviewed the use of mobile and wearable sensor through the application of data-driven approach, discussing the current state-of-the-art and future prospects in this field. As in [72] evaluated the feature extraction technique with the IoT data fusion, exploring ways to extract meaningful insights from IoT-generated data.With emphasizing the importance of advanced wearable technologies for future healthcare applications [73]. In [74] proposed aIoT based scheduling and optimization technique for the healthcare data monitoring for the IoT data management and resource allocation. Also, in [75] integrated the model with sensing data for the smart home application for the prevention of diseases with exploring how wearable and IoT devices can contribute to early detection and monitoring of health conditions. Similarly, [76] discussed information fusion for edge intelligence, providing insights into how data fusion techniques can enhance processing and decision-making at the edge of IoT systems. For increases context-aware patient healthcare IoT data management data fusion is performed with improved recursive model for the feature elimination, highlighting the importance of context-awareness in healthcare data analysis [77].Using sensor data fusion, ensemble learning methods for recognizing multi-modal emotion, demonstrating the potential of combining multiple modalities for emotion detection [78].

Optimizes IoT-based artificial intelligence integrated telemedicine system for the health focusing on the application of AI and IoT in telemedicine for improved health analysis [79]. Through the context-aware passive monitoring is considered as the co-located UWB monitoring with the sensor data fusion, presenting a novel approach to unobtrusive health monitoring at home [80].Using the data monitoring techniques and Internet of Things in Smart Cities, one can follow physiological indications while they are in emotion emphasizing the role of IoT in enhancing city-wide health monitoring [81]. In [82] discusses non-invasive acquisition of data to derive the

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solution form the IoT environment for the data monitoring, exploring applications, limitations, and future prospects of wearable and IoT devices for health monitoring. Similarly, in [83] the concept of smart healthcare, summarizes recent advances, challenges, and future prospects of AI applications in healthcare. As in [84] introduces asafe and energy-efficient data fusion solution tailored for healthcare systems based on the Internet of Things (IoT). The scheme is designed to fulfil the requirements of data security and streamlined data fusion in healthcare IoT applications.Also, in [85] presented automated, monitoring multi-parameters in the biomarkers and vital signs for COVID-19 patients, demonstrating the potential of IoT devices in pandemic response and healthcare monitoring.

Multi-sensor data fusion exhibits the significant data monitoringand deep learning techniques for health monitoring using wearable sensors [86].Also in [87] discusses biocompatible data processing with the wearable, implantable and ingestible monitoring strategies and highlighting the advancements in biosensor technology for long-term health monitoring. Wearable devices in health monitoring across multiple domains, emphasizing their environmental applications and their potential impact on healthcare and well-being are reviewed in [88].A comprehensive evaluated the wearable sensor technologies for the strategy for managing chronic diseases that emphasizes the use of wearable technology for monitoring and managing chronic conditions [89].Through the implementation of the technological advancement challenges and requirement are evaluated the wireless body area networks in the healthcare data monitoring, addressing the key aspects of communication and data transmission in healthcare IoT systems investigated in [90]. In [91] introduced IoT based disease diagnosis model for the wearable body sensor with the implementation of machine learning algorithm and highlighting the potential of IoT in disease diagnosis and monitoring. Finally, in [92] constructed a lightweight IoT data privacy preserving and remote monitoring of patients to evaluate the issues related to healthcare IoT data security and privacy.

4.1 Challenges and Opportunities in Multi-Sensor Data Fusion

Through the review of existing papers and literatures associated with the multi-sensor based data fusion model for the health data management subjected to certain challenges and opportunities those are presented as follows:

1. Integrating data from diverse sensors with varying data formats, sampling rates, and measurement scales can be challenging. Ensuring compatibility and accuracy across different data sources is crucial.
2. Sensors may produce noisy or erroneous data, leading to inaccurate fusion results. Quality control mechanisms and sensor calibration are essential to ensure reliable data fusion.
3. As the number of sensors and data sources increases, managing and processing large-scale data becomes complex. Scalable algorithms and efficient data processing techniques are required.

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4. Fusion algorithms can be computationally demanding, especially when dealing with real-time applications. Developing efficient algorithms and hardware acceleration is vital for practical implementation.
5. Sensors may provide uncertain or incomplete information, requiring robust fusion techniques capable of handling uncertainty and providing reliable results.
6. Data from multiple sensors may contain sensitive information, raising privacy and security concerns during fusion. Ensuring data confidentiality and secure communication is essential.
7. The accuracy of fusion heavily relies on the quality of individual sensors and the appropriateness of fusion algorithms. Achieving high accuracy while avoiding information loss is a challenge.

4.2 Blockchain Integration for Secure Health Data Management

Blockchain integration for secure health data management is a revolutionary approach that holds capability to revolutionize the healthcare sector lies in its ability to tackle essential issues concerning data privacy, security, and interoperability. As the volume of sensitive health data continues to grow exponentially, traditional centralized systems face increasing vulnerabilities to data breaches and unauthorized access. With its decentralized and immutable characteristics, Block chain technology presents a promising resolution to these concerns..In distributed ledger technology, healthcare organizations can establish a tamper-resistant and transparent data ecosystem that ensures the confidentiality, integrity, and accessibility of patient records. This introduction explores the key aspects of block chain integration for secure health data management, highlighting its benefits in fostering patient trust, enabling seamless data sharing, and ushering in a new era of patient-centric and interoperable healthcare services.

Jayabalan and Jeyanthi (2022) [93] propose a scalable blockchain model for healthcare data security and privacy. Their approach involves using off-chain IPFS storage, ensuring efficient and secure storage of sensitive healthcare information.Mani et al. (2021) [94] introduce "Hyperledger healthchain," a patient-centric storage system for health records. This system is based on the InterPlanetary File System (IPFS), enabling decentralized and secure storage of health data.Yaqoob et al. (2021) [95] present an in-depth study on using healthcare data management. They explore various opportunities, challenges, and offer recommendations for the future implementation of blockchain technology in the healthcare domain.Merlec et al. (2021) [96] propose a management system operates in dynamic manner using smart contracts with the use ofGDPR personal data regulations. This system ensures transparent and GDPR-compliant data usage and consent management.Ismail et al. (2021) [97] integrated architecture that combines blockchain and cloud technologies (BcC) within the healthcare sector. The paper investigates potential use cases, identifies challenges, and proposes solutions to bolster healthcare data management. Miyachi and Mackey (2021) [98] introduce the hOCBS framework, a privacy-focused blockchain system for healthcare data. This framework employs a hybrid design of on-

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chain and off-chain components to safeguard sensitive patient information while ensuring data accessibility.

Uddin et al. (2021) [99] suggest Hyperledger Fabric blockchain as a secure and efficient method for managing electronic health records. Their study highlights how Hyperledger Fabric can enhance both security and accessibility of healthcare data. In a similar vein, Jabarulla and Lee (2021) [100] present a patient-centric healthcare system that combines blockchain and AI to address the challenges posed by the COVID-19 pandemic. They look at the advantages and possible uses of combing block chain technology with Artificial Intelligence to control pandemics effectively.In the context of big data, Bazel et al. (2021) [101] explore the advantages, applications, and challenges associated with integrating blockchain technology into healthcare data management. Their paper provides insights into how blockchain can revolutionize the management of vast amounts of healthcare data.Haddad et al. (2022) [102] conduct review on the e-healthcare data management with the utilization of the Artificial Intelligence (AI) based blockchain for the management of records. They explore the integration of AI with blockchain to enhance the management of electronic healthcare records.Singh et al. (2022) [103] discuss the management of data effectively through blockchain for the healthcare data system.They present an overview of the opportunities and challenges involved in adopting blockchain to enhance healthcare data handling.

Table 4: Summary of Heathcare Data in Blockchain

Ref	Proposed Blockchain Technique	Healthcare Data Application	Findings
Jayabalan&Jeyanthi (2022)	Scalable IPFS storagewith blockchain technology.	Data security and privacy for the healthcare	Efficient and secure storage of healthcare information using off-chain IPFS storage.
Mani et al. (2021)	Hyperledgerhealthchain	Storage of healthcare record based on patient-centric IPFS	Decentralized and secure storage of health records based on IPFS.
Yaqoob et al. (2021)	Block chain based health care data management	Data management in healthcare	Opportunities, challenges, and recommendations for implementing blockchain in healthcare data management.
Merlec et al. (2021)	Dynamic management system with consent with smart contract	Personal data usage under GDPR	GDPR-compliant and transparent data usage

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			management using smart contracts.
Ismail et al. (2021)	Integrated blockchain-cloud (BcC) architecture	Healthcare applications	Exploration of use cases, challenges, and solutions for BcC in healthcare data management.
Miyachi& Mackey (2021)	hOCBS - privacy-preserving blockchain framework	Healthcare data privacy	Hybrid on-chain and off-chain design for enhanced patient data privacy.
Uddin et al. (2021)	Hyperledger Fabric blockchain	Electronic health records	Hyperledger fabric based secure and effective management of health records.
Jabarulla& Lee (2021)	Patient -centric healthcare integrated with AI and blockchain	COVID-19 pandemic management	Applications and opportunities of integrating blockchain and AI for pandemic management.
Bazel et al. (2021)	Management of big data related to healthcare with the use of blockchain	Big data in healthcare	Benefits, applications, and difficulties of blockchain technology in managing huge health data in healthcare.
Haddad et al. (2022)	Management of healthcare records with use of AI	Electronic healthcare records	Review about integrating AI with blockchain with management of healthcare records
Singh et al. (2022)	Efficient management of data through blockchain technology	Healthcare data handling	Overview of opportunities and challenges in adopting blockchain for healthcare data management.

Several studies proposed novel blockchain techniques, such as scalable models using off-chain IPFS storage and patient-centric IPFS-based storage for health records as presented in table 4. These approaches aimed to enhance healthcare data security and privacy while offering decentralized and transparent systems. The potential advantages of blockchain in the administration of healthcare data were thoroughly investigated with researchers highlighting opportunities for improved data security, interoperability, and efficient record management. Additionally, smart contract-based dynamic consent management systems emerged as an effective

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way to ensure patient data privacy while complying with regulations like GDPR. Block chain and Artificial Intelligence integration was invesgtigated as a patient-centric solution for combating the COVID-19 pandemic, showcasing the potential of such advanced technologies in healthcare crisis management. Despite the promise of blockchain, challenges such as scalability, regulatory compliance, and data privacy remain significant concerns in the healthcare context.

5. Conclusion

The significance of multi-sensor data fusion and blockchain technology in remote health monitoring cannot be overstated. Multi-sensor data fusion enables the integration of data from various wearable devices and sensors, providing a comprehensive and holistic view of an individual's health status. By combining data from different sources, remote health monitoring systems can deliver more accurate and real-time health insights, facilitating early detection of health issues and personalized healthcare interventions. This, in turn, empowers patients to actively manage their health and well-being. Moreover, the incorporation of blockchain technology introduces an added layer of security and trust to the remote health monitoring process. With its decentralized and tamper-resistant attributes, blockchain ensures the confidentiality and integrity of sensitive health data, while facilitating secure and transparent data sharing among healthcare providers, patients, and other stakeholders. By combining multi-sensor data fusion with blockchain technology, the landscape of remote health monitoring stands poised for transformation, ushering in a patient-centered, efficient, and dependable healthcare approach, even in distant or underserved regions. This fusion has the potential to usher in a new healthcare era, empowering individuals with more control over their health data and accessed to the individualized, data-driven healthcare services, ultimately resulting in enhanced health outcomes and an improved quality of life. The collective findings across review papers underscore the escalating significance and potential of multi-sensor data fusion and blockchain technology within healthcare and remote health monitoring. These technologies hold promise as solutions for diverse challenges in healthcare data management, privacy, security, and interoperability.

1. The review papers emphasize that multi-sensor data fusion allows the combination of aggregating data from varied sources, including wearable devices, IoT sensors, and medical instruments, contributes to a more holistic and precise comprehension the state of health of a person. It allows for a real time monitoring and analysis, making it easier to spot health risk early on personalized healthcare interventions, and data-driven decision-making.
2. Block chain technology usage in the healthcare industry is growing in popularity owing to its capacity to bolster data security, privacy, and trust. The decentralized and unalterable characteristics of blockchain guarantee that health data remains tamper-proof, protecting patient privacy and preventing unauthorized access. Blockchain also enables secure data sharing and interoperability among different healthcare providers, streamlining healthcare processes and improving patient outcomes.

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3. Several papers highlight that the proposed blockchain models and multi-sensor data fusion techniques are scalable and efficient, making them suitable for large-scale healthcare applications. This is crucial for managing the growing amount of healthcare data produced by wearables and Internet of Things sensors
4. The reviewed papers emphasize the significance of a patient-centric approach in healthcare, where individuals have more control over their health data and are actively involved in their healthcare decisions. Multi-sensor data fusion and blockchain technology enable patients to individuals can securely access their health data, share it with pertinent healthcare providers, and engage in research or clinical trials while providing informed consent.

With multi-sensor data fusion and blockchain offer promising solutions, the review papers also acknowledge various challenges, including standardization, interoperability, data quality, and regulatory compliance. Future research and developmental endeavors are essential to tackle these challenges and unleash the complete capabilities of these technologies in the realm of remote health monitoring and beyond.

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