A Systematic Review: The Role of Fuzzy Logic and Blockchain in Healthcare Data Analytics

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Abstract: The healthcare industry has always been under pressure to deliver high-quality services while minimizing errors and ensuring patient safety. The healthcare industry faces several challenges, including decision-making accuracy, diagnostic errors, and data security. Blockchain and fuzzy logic design are emerging technologies that may provide potential solutions in order to address these challenges. Blockchain technology offers a secure and decentralized system for storing and sharing patient healthcare data, while fuzzy logic design deals with uncertainty and imprecision, improving patient healthcare decision-making and reducing errors. In this systematic review, the combination of fuzzy logic design and blockchain technology highlights the potential benefits in patient healthcare applications while addressing significant concerns in healthcare like decision-making accuracy, diagnostic errors, and data security. The successful implementation of these technologies in inpatient healthcare may significantly contribute to handling uncertainty and imprecision in complex healthcare systems. In the future, it may be incorporated with machine learning techniques like federated learning and explainable artificial intelligence that could improve decision-making and accuracy in a better way.

Keywords: Systematic review; fuzzy logic; blockchain; healthcare; data analytics

1 Introduction

In the realm of technological advancements, the Internet of Medical Things (IoMT) emerges as a catalyst for transformative healthcare solutions. By integrating medical devices into the Internet of Things (IoT), IoMT offers promising benefits such as improved quality of life, cost reduction, and enhanced patient knowledge. Its ability to efficiently allocate resources, minimize disruptions, and provide timely data-driven insights empowers healthcare providers. However, the sensitive nature of the information collected by IoMT devices necessitates robust measures to safeguard patient privacy and confidentiality. As IoMT continues to revolutionize healthcare, it holds the potential to reshape the future of well-being with its seamless integration of technology and human care.

Ensuring the confidentiality, security, and privacy of medical information is critical in the IoMT. Security and privacy are among the major concerns in IoT, as IoMT devices have limited resources, making it challenging to support conventional security algorithms. Thus, developing IoT applications in a cloud computing environment is becoming more popular, as cloud computing can provide the necessary infrastructure and capabilities to devices with limited resources. In the realm of interconnected technologies, the cloud layer serves as a vital component that enhances IoT devices' storage and processing capabilities. Given the limited resources in terms of processing power and storage capacity, IoT devices rely on the cloud to meet their requirements. However, the inherent security vulnerabilities of IoT devices pose a significant challenge, rendering traditional security strategies inadequate. As a result, developing innovative security measures and strategies becomes imperative to safeguard the integrity and confidentiality of IoMT devices and the valuable data they gather. By addressing these security concerns head-on, the potential of IoMT can be fully harnessed, leading to a safer and more robust ecosystem of interconnected healthcare technologies.

IoMT is already transforming healthcare by using devices like cell phones to improve individuals' health, but its full potential lies in its scientific applications. In healthcare, medical gadgets present a unique opportunity for doctors and researchers to delve into uncharted territories of disease discovery and potential remedies. By harnessing the power of these devices, vast volumes of data can be gathered, unveiling intricate patterns and unlocking insights that were once beyond reach. This data's real-time collection and analysis offer unprecedented avenues for developing enhanced treatments, recognizing the emergence of novel diseases, and propelling the boundaries of medical science. With the immense potential of IoMT devices at our disposal, the healthcare industry stands poised to undergo a transformative revolution, ultimately paving the way for an improved quality of life for countless individuals across the globe. A global dataset could be created to document individuals' clinical stories, leading to groundbreaking medical insights. However, personal health data is sensitive, and protecting it is crucial in an untrusted environment. The IoMT facilitates patient-centered care by enabling patients to share their health data with doctors, receive remote medical support, manage their medications, and maintain personal health records. To address the security flaws of IoMT, Blockchain Technology (BT) utilizes the latest encryption technologies to ensure data confidentiality and integrity, providing a secure and trustworthy platform for IoMT applications.

Cloud computing is a dynamic field of research that promises a myriad of possibilities for resource sharing and enhanced user experiences. It empowers users with access to software, databases, data analytics, servers, and networking through the internet, delivering unparalleled flexibility, rapid deployment, and cost-efficiency through economies of scale. However, the trust and security of cloud storage services often hang in the balance, presenting challenges such as opacity, loss of control, and inadequate assurance measures. The consequences of these challenges are all too real, exemplified by numerous high-profile data breaches that have unfolded in recent times. Despite advancements in cloud computing, users' trust in these environments remains tenuous at best. A 2020 survey underscored the insufficiency of traditional security strategies in tackling cloud security threats, with many users perceiving public cloud platforms as more vulnerable than their traditional counterparts. It is imperative, therefore, to confront these trust issues head-on, fortifying the security and dependability of cloud computing for the benefit of both users and organizations alike.

Trust management in cloud computing, but conventional trust paradigms rely on a centralized trust control center, leading to potential delays and congestion. Storing and processing medical data in the cloud using IoMT devices can raise privacy and security concerns. Researchers are increasingly focusing on security, privacy, and trust to address these issues. Data security ensures data authenticity, validity, and integrity while limiting access to authorized individuals. Privacy preservation protects sensitive information shared over insecure channels. Symmetric and asymmetric encryption methods are commonly used in IoMT-enabled healthcare systems, and contextual privacy, which safeguards communication context, is also essential. Since advanced machine learning techniques [89-93] may not be optimal for resource-constrained devices like IoMT, simple privacy-preserving methods may be more effective. Many studies have been published on cloud based IoMT security in healthcare systems.

Blockchain technology [94,95] has swiftly gained recognition for its wide-ranging applications in domains such as cryptocurrency, security mechanisms, trust management, and data immutability. Its decentralized

Architecture empowers it with resilience and durability, ensuring system robustness even in the face of node failures. This decentralization characteristic makes blockchain a potential solution for trust management, providing security, trust, and authentication services in a cloud computing environment. However, challenges associated with using blockchain-based trust-building in a cloud-based system include blockchain attacks, high overhead of consensus mechanisms, and delays in real-time transaction processing. Existing blockchain-based trust techniques for cloud computing systems have been reviewed to overcome these challenges, and prospective research directions for blockchain-based trust management in cloud-based systems are suggested. The integration of cloud computing and IoMT is also explored, and potential research areas, including integrating IoMT with blockchain and machine learning, 6G, and the impact of quantum computing on IoMT, are identified.

Fuzzy logic is a mathematical concept that recognizes uncertainty and ambiguity in decision-making. In healthcare, where multiple factors need to be considered before deciding, fuzzy logic can be particularly useful. It has been applied in various healthcare domains, including diagnosis, treatment planning, and decision support systems.

Fuzzy logic is a powerful computational technique that deals with uncertain and imprecise data, which permits degrees of truth rather than just binary (true/false) logic and has gained popularity in numerous fields, including healthcare. Fuzzy logic design's role in healthcare and its potential applications and benefits.

Fuzzy logic has been widely applied in healthcare to improve decision-making processes, diagnosis accuracy, and treatment planning. Fuzzy logic models can be used to develop decision support systems, which aid decision-making by providing recommendations or suggestions based on patient data. Fuzzy logic models have also been used in the development of medical expert systems, which use patient data to provide diagnosis and treatment suggestions. Fuzzy logic-based medical expert systems have demonstrated their ability to enhance diagnostic accuracy and treatment effectiveness, mainly when conventional methods fall short. The application of fuzzy logic extends to various healthcare domains, including medical imaging and robotics, where it contributes to improved analysis, interpretation, and control.

The integration of fuzzy logic in the healthcare sector has gained significant traction due to its aptitude for handling uncertain and imprecise data. Unlike traditional approaches, fuzzy logic can effectively process subjective patient information and qualitative assessments provided by medical professionals. By leveraging fuzzy logic, healthcare providers can mitigate the subjectivity and ambiguity inherent in data interpretation, fostering a more standardized and consistent analysis.

Using fuzzy logic empowers healthcare professionals to formulate personalized treatment plans that consider individual medical histories and characteristics, resulting in better treatment outcomes and reduced healthcare costs. This systematic review aims to delve into the impact of fuzzy logic design, exploring its potential applications, associated benefits, and inherent limitations in the healthcare landscape. Through this analysis, valuable insights can be gained to advance the integration of fuzzy logic for improved healthcare delivery.

2 Literature Review

A systematic review of existing literature offers valuable insights into the present understanding and identifies areas where further research is needed regarding the application of fuzzy logic in the healthcare sector. Blockchain technology, on the other hand, is an innovative and revolutionary approach that leverages a decentralized ledger consisting of interconnected blocks with timestamped information. Each

Block contains a specific number of validated transactions that are cryptographically linked through the previous block's hash value. This feature guarantees the integrity and immutability of the data stored within. Transactions are signed digitally with a private key and shared across the network [4]. Validation nodes, or mining nodes, collect and verify the transactions before adding them to a block and disseminating it back to the network. The consensus protocol replaces the role of a trusted third party or central authority as each node in the network validates the block. Once the validation process is completed, the block seamlessly finds its place within the chain. At the same time, the synchronized ledger undergoes a meticulous update, reaching all the permission nodes residing within the intricately woven network [1, 5, 6, 7]. Embracing blockchain technology's transformative power ushers in unparalleled security, undeniable audibility, and unprecedented transparency. Yet, amidst these remarkable features, the essence of anonymity gracefully envelopes the users and their intricate web of transactions, shrouding them in a cloak of discretion. Venturing into the realm of blockchain technology, we encounter the profound insights shared by the esteemed Melanie Swan [15], unraveling the intriguing journey of its evolution through three distinctive phases: Blockchain 1.0, 2.0, and 3.0. The inception of this groundbreaking revolution encapsulated within the very fabric of Blockchain 1.0, sought to defy the constraints of centralized monetary systems, beckoning forth a utopian vision of a peer-to-peer digital payment infrastructure and casting aside the shackles of reliance on trusted third-party intermediaries. It utilized Proof of Work as the consensus protocol to validate blocks and reward successful miners with digital currency[2]. The second phase, Blockchain 2.0, was introduced in 2014 and focused on decentralizing smart property and contracts. This allowed for the transfer of value through automated administration and supervision using smart contracts[3,7]. Examples of Blockchain 2.0 include Ethereum and Eris blockchains. The third phase, Blockchain 3.0, aims to use blockchain technology to benefit society; Blockchain 3.0 has expanded beyond financial applications and is now being used in areas such as government, health, science, literacy, and art. Examples of Blockchain 3.0 applications include healthcoin, learningcoin, and gridcoin [15]. Alternative consensus protocols and cryptocurrencies have also been introduced in this phase.

In the vast realm of blockchain technology, the landscape unfolds to reveal two primary forms of ownership: permissioned and permissionless, each harboring its own unique set of characteristics and implications [8][9]. Stepping into the realm of permissioned blockchains, we find their genesis in the hands of a singular authoritative entity or an exclusive consortium whose prowess reigns supreme over the creation process. Here, the validation of transactions finds solace in the comforting embrace of a central authority or a meticulously curated coterie of trusted individuals. As the boundaries of data accessibility unfurl, they are confined to a select group of users, nurturing an ecosystem where efficiency flourishes and scalability basks in the limelight of progress. However, this centralization also increases the risk of tampering, as a 51% majority can easily manipulate the consensus. Examples of permissioned blockchains include Eris, Ripple, and Hyperledger[1].

Permissionless blockchains are characterized by their fully decentralized nature, with many nodes that operate independently and make the network less efficient [1] compared to permissioned blockchains. Unlike permissioned blockchains, they don't require prior authorization for participants to mine transaction blocks, and anyone can contribute computational power for network tasks and receive monetary rewards. These blockchains provide public access to read and write transactions, making them visible to everyone and thus known as Public blockchains[8,9]. Bitcoin and Ethereum are examples of permissionless blockchains [2].

Recent studies have highlighted the need for improved security measures to address Sybil attacks in IoMT systems. For example, one study proposed a method that utilizes the physical pressure of moving automobiles to mitigate Sybil attacks [10]. Another study discussed security vulnerabilities in IoT and medical monitoring devices, including Sybil attacks [11], while a different study proposed an encrypted eHealth system for IoT devices to combat such attacks [12]. Trusted paradigms that employ time-bound group signatures [13] and trust management systems that utilize fuzzy logic [5] have also been proposed to enhance security in IoMT-based health infrastructures. Additionally, one proposed approach involves using blockchain applications to create a trustworthy IoT environment, with each zone having a master computer that uses community ID, object ID, public passwords, and a signature for its followers [14]. Smart contracts verify the master's object ID and community ID, and a confidence bubble is generated when the evidence is deemed to be true.

Several studies have proposed blockchain-based trust management frameworks to bolster the security of IoT networks. For example, Tariq et al. [15] proposed a blockchain-based multi-mobile code-driven approach to mitigate blackhole and greyhole attacks, shifting trust-related calculations to the fog layer to improve network lifetime and performance. Similarly, [16] presented a trust-based security mechanism that leverages blockchain technology to establish end-to-end trust for IoT applications and secure data storage. Another study proposed a service-oriented trust management model that uses the responsibility chain principle to create TERMS for service providers based on blockchain [17]. Users must comply with these TERMS to access the services. Access control between IoT devices is addressed in [18] through a blockchain-based reputation framework that automates the validation of attributes, calculates confidence, and validates policies for entry using three types of smart contracts. These blockchain-based trust management frameworks aim to enhance the security and reliability of IoT networks.

In their study, Liu et al. [19] proposed a semi-centralized trust management framework for IoT systems that utilizes blockchain technology. Their framework computes trust values for dynamic devices using indirect and direct trust data, a decay function, and configurable weights and credibility of recommendations. Through simulation-based experiments, they demonstrated that their framework effectively identified malicious devices and reduced malicious activities compared to traditional models. Rakesh et al. [20] presented a blockchain-based authentication and trust validation mechanism called BlockTrust-RPL for secure objective function formulation in RPL-based IoT networks. While the paper showed promising results in enabling distributed trust and authentication mechanisms, it did not comprehensively compare with other approaches and lacked empirical evaluation in real-world scenarios. Additionally, scalability was not addressed, which is a crucial factor for large-scale IoT networks. Farooq et al. [21] proposed a multi-agent system-based trust mechanism that detects and prevents attacks, such as selective forwarding, Sybil, and sinkholes, while maintaining network performance and minimizing communication latency. Their framework employed a multi-agent system to monitor node behavior and allocate trust values accordingly.

Malik et al. [22] proposed a three-tier architecture that employs blockchain to maintain integrity and control trust in IoT supply chains. Their framework includes a data, application, and blockchain layer with a trust and credibility module that evaluates consistency and trustworthiness across the supply chain. Intelligent contracts and an Access Control List (ACL) are used to automate transactions and ensure rule fulfillment during read-and-write operations on the blockchain. Alert incidents are issued based on predefined circumstances. Asif et al. [23] presented a blockchain-based security mechanism for safe and reliable access to smart city resources by authorized users. Their approach is based on the Object Security Architecture (OSCAR) for IoT object security and the Authentication and Authorization for Constrained Environments (ACE) framework-based authorization blockchain. They also developed a meteor-based application as a user-friendly interface for managing smart municipal infrastructure. However, their evaluation showed an increase in hand-shaking time with an increase in the number of clients.

Managing a Perishable Food Supply Chain (PFSC) can be demanding due to its sensitive environment and the limited shelf life of its products [24]. A crucial aspect of this supply chain is the sharing of

Information between customers and suppliers regarding product details, shipment, and monitoring of the food preservation environment to prevent the distribution of low-quality products. This approach can significantly reduce the risks associated with liability, negative publicity, and product recalls. A PFSC system's successful implementation heavily relies on a food traceability system. The industrial sector plays a significant role in most countries' economies, with Europe attributing a considerable percentage of its growth to industrial exports and innovation [25]. In the pursuit of elevating companies' operational prowess, fortifying their dependability, and amplifying productivity to satiate the ever-evolving demands of customers while embracing the irresistible allure of profitability, the advent of Industry 4.0 graciously dawned upon the horizon [26]. Like a symphony of innovation, Industry 4.0 orchestrates its harmonious melody by weaving together the threads of four quintessential technologies, each bearing its own distinctive aura: Cyber-Physical Systems (CPS), a magnificent fusion of the virtual and physical realms, seamlessly interlaced across an array of domains, summoning forth an enchanting tapestry of interconnectedness; the Internet of Things (IoT), a celestial gateway, bestowing upon us the power to foster the communion between humans and machines, fostering the ethereal dance of machine-to-machine communication, unwavering tracking capabilities, steadfast monitoring mechanisms, and the celestial art of location identification [27-28]; while the ever-pervasive allure of cloud computing, with its grandiose promise of high-performance paradigms and cost-efficient technologies, entices us with its bountiful offerings, gracefully draped in the garb of software and hardware platforms; and, last but certainly not least, the illustrious domain of big data study, a realm teeming with possibilities, where diverse datasets undergo meticulous pre-processing and meticulous analysis, birthing forth invaluable insights, wielding their might in the realm of decision-making, transcending boundaries, as efficiency blossoms and costs gracefully fade into the abyss of optimization [29].

Effective sharing of information is essential for enhancing the performance of a supply chain [30-31]. However, simply sharing information among partners may not be enough to achieve significant improvements. Instead, building trust, Enhancing supply chain performance requires fostering cooperation and integrating internal processes among partners. In the ceaseless pursuit of achieving this momentous feat, a crucial endeavor befalls upon managers, urging them to embark on a quest to unearth the most fitting pieces of information worthy of dissemination while simultaneously unraveling the enigmatic labyrinth that conceals the optimal mechanisms for its impartation. Within this intricate tapestry emerges a captivating proposition [32-37], an ethereal hypothetical model, standing resolute in its mission to appraise the lofty echelons of service quality embodied by Logistic Service Providers (LSPs). Its gaze traverses the sprawling expanse of the technological realm, transcending boundaries as it encompasses the multifaceted pillars of Information Technology (IT), the ethereal dance of Information Communication Technology (ICT), the harmonious symphony that reverberates within the Logistic Information System (LIS), and the mystical allure of Business Intelligence (BI). Together, they intertwine in a profound display, weaving the fabric of evaluation and offering a gateway to untold insights. The model assesses service quality based on service performance, market-based quality, and resource-based competitive advantages. The study reveals that many LSPs do not utilize all available techniques, which can hinder competition. The proposed model serves as a roadmap for improving LSPs' competitiveness. This decentralized database, akin to a boundless symphony, extends its gracious embrace to all entities ensconced within the vast expanse of the network's nodes, propounding an alluring fault-tolerant architecture that shatters the shackles of reliance on a solitary point of vulnerability, weaving a spellbinding tale of resilience [6][37][38][12]. Ascending beyond the realms of convention, the very fabric of the blockchain network breathes life into a peer-to-peer ecosystem, where intermediaries cease to hold sway, and a captivating dance ensues. As a digitally signed block takes shape, its fledgling existence is tenderly whisked away to the mining pool, a veritable crucible where a congregation of network nodes, known as miners, embark on an arduous journey to bestow their seal of approval. The consensus algorithm emerges as the guiding light, illuminating the path to verification and ushering forth a harmonious accord [4]. The miner who solves the algorithm broadcasts the block to all other nodes, which validate it with consensus and add it to their ledger. The miner who solves the algorithm also receives a financial reward for their work [39]. There are various consensus protocols available, including proof of stake, proof of burn, and proof of elapsed time [6][12][17], which maintain data integrity by computing consensus algorithms instead of relying on third-party trust. At its core, this transformative marvel leverages the prowess of hash functions, such as SHA-256, RSA, and RIPEMD-160, to craft a wondrous symphony of cryptographic wizardry [15] [38]. Each transaction-laden block is bestowed with a unique hash value, a digital fingerprint that encapsulates its essence, rendering it impervious to alteration without the collective consensus of the network and the formidable computational might required to surmount its defenses. As these blocks interlock harmoniously, a resilient chain unfurls, stretching across the digital realm and forging an unbreakable bond between its constituents. This sacred chain, bearing the weight of countless transactions, serves as an immutable ledger, an eternal testament to the authenticity and integrity of the recorded data. Within its sacred confines, security reigns supreme, providing a sanctuary for sensitive information and valuable assets. The distributed consensus mechanism thwarts the audacious attempts to tamper with past transactions, which demands the unwavering agreement of network participants, coupled with the formidable computational power necessary to breach the cryptographic fortifications. Beyond its impregnable fortress, blockchain technology unveils another marvel, preserving user privacy. Concealed behind a cryptographically generated hash value, individuals can partake in transactions and engage with the network while safeguarding their true identity. This veil of anonymity adds an additional layer of protection, empowering individuals to navigate the digital realm with a sense of autonomy and security 325 [17] [40].

The symphony of hash functions and cryptographic techniques orchestrates a transformative symphony, endowing blockchain technology with unparalleled robustness and security. This feature of blockchain provides data provenance, making it an effective tool for investigating historical transactions. Smart contracts are computer programs that automatically execute the terms of an agreement between parties. They allow transactions to be triggered and executed once certain predetermined conditions are met. This functionality makes blockchain technology flexible and programmable [1][9][13], with potential applications in numerous fields, including supply chains [6], insurance claims, and clinical trials. In clinical trials, each phase can be encoded in a smart contract and executed only after achieving consensus among network nodes[40][41]. This can increase transparency and traceability while giving full control over associated processes. Below are some possible use cases of blockchain in the healthcare industry.

Several blockchain-based healthcare platforms have been developed to address the challenges of secure, interoperable, and efficient management of health records. For instance, the MedRec platform enables patients to manage and authorize data sharing while maintaining full confidentiality about storing data, logs, and permission [42][4]. Similarly, the Gem Health Network and Guardtime healthcare platform offer shared infrastructure for interoperability and transparent information sharing among stakeholders, including patients, providers, and payers[8]. Healthcare incentivizes patients to contribute their health data for research; the Blockchain-based Data Sharing (BBDS) access control system has been developed to offer a secure and scalable way to access Electronic Medical Records (EMRs) from a shared data pool [43]. This system helps to protect sensitive healthcare data while still allowing for efficient data sharing. Another solution that has been developed to improve interoperability and efficiency in the healthcare sector is the Fast Healthcare Interoperability Resources (FHIRchain) [44]. This technology is designed to facilitate clinical data exchange between different healthcare providers while ensuring data privacy and security[45].

In the realm of cutting-edge research, a compelling exploration has unfolded, captivating the minds of M. A. Khan et al. (2021) and S. K. Bhoi and S. K. Lenka (2021). Their visionary endeavors birthed forth

Ingenious smart watering systems, where the ethereal realms of fuzzy logic intertwine with the tantalizing tapestry of blockchain technology. Both studies incorporate fuzzy logic to analyze real-time crop data and optimize water usage to improve crop yield [46]. The utilization of blockchain technology in these systems provides secure and transparent transaction data and ensures the reliability and confidentiality of the data [47]. These innovative approaches offer promising solutions to deal with water and food security in the agricultural sector. In these studies, A. M. Raza and A. Qamar (2020) proposed an intelligent irrigation system that uses both fuzzy logic and blockchain technology to enhance crop yield by optimizing water usage. The proposed system employs fuzzy logic to analyze soil moisture levels and make watering decisions based on the crops' water requirements. To ensure secure and trustworthy transaction data, blockchain technology is utilized. Similarly, B. K. Gogoi et al. (2020) improved a smart irrigation system that leverages fuzzy logic and blockchain technology to analyze water consumption and get better crop yield. The system employs fuzzy logic to analyze real-time data and make informed watering decisions based on crop needs[49]. The Blockchain tools are used to assurance the protection and transparency of the transaction, enabling all stakeholders to track and verify the system's performance[50].

3 Limitations of the previous work

There are some limitations to these studies that focus on theoretical applications rather than real-world implementations, an emphasis on investigating the potential benefits of fuzzy logic and blockchain technology without thoroughly exploring their risks and limitations, the limited scope of specific contexts in which the studies were conducted, which may affect the generalizability of the findings to other healthcare settings and a lack of studies that have evaluated the long-term impacts of these technologies on healthcare outcomes.

Table 1: Previous studies Contribution using Fuzzy empowered solutions

Authors	Research context	Research content	Research Model	Main factor ofbenefits	Main factor of Risk	Research outcomes
Al Omaret al. (2021) [51]	Chronic disease management	Development of a fuzzy logic-based predictive model for monitoring and managing chronic diseases	Fuzzy logic	Improved disease management,reduced healthcare costs	Uncertainty in fuzzy logic	enhanced security, data integrity, and privacy, improved interoperability, and reduced costs.
Bandyopadhyay et al. (2019) [52]	Healthcare supply chain	Implementation of blockchain technology for secure andefficient	Blockchain	Increased supply chain efficiency, enhanced transparenc	Cybersecurity risks	Highlighted the importance of developing interoperabl

		healthcare supply chain management		y and accountability		e blockchain platforms and standards to support widespread adoption in supply chain management.
Bresnick (2020) [53]	Medical record management	Blockchain technology toget better the security and interoperability of health records.	Blockchain	Improved data security, enhanced data accessibility and sharing	Lack of regulatory frameworks, integration challenges	Enable patientsto take ownership and control of their health data.
Hassan et al. (2020) [54]	Health data sharing	Advance fuzzy logic-based decision support system for sharing health data secure.	Fuzzy logic	Improved data sharing, enhanced data privacy and security	Limited interpretability of fuzzy logic	Enhances data security, facilitates decision-making, and has the potential for wider adoption in healthcare organizations and institutions.
Mohanty et al. (2020) [55]	Disease diagnosis	Development of a fuzzy logic-based diagnostic system for early detection of diseases	Fuzzy logic	Improved disease diagnosis accuracy, reduced misdiagnosis rates	Uncertainty in fuzzy logic	improve transparency, efficiency, risk management, collaboration, and potentially lead to new business

						models.
Sharma et al. (2020) [56]	Healthcare supply chain	Implementation of blockchain technology for secure and efficient healthcare supply chain management	Blockchain	Increased supply chain efficiency, enhanced transparency and accountability	Cybersecurity risks	Better inventory management, improved collaboration, and increased efficiency.
Yang et al. (2020) [57]	Clinical trial management	Blockchain technology to improve the efficiency and transparent management	Blockchain	Enhanced data integrity, increased transparency and trust in clinical trials	Regulatory and legal challenges, lack of standardization	improves data privacy, enhances resource sharing, and provides better security and trust, with potential for wider adoption.
Abbasi et al. (2021) [58]	Internet of Medical Things (IoMT)	Design and implementation of a fuzzy logic-based system for patient monitoring and diagnosis	Fuzzy logic system	Improved accuracy and reliability of diagnoses, reduced workload for healthcare professionals	Data privacy and security risks associated with the use of IoMT devices	It provides a comprehensive review of blockchain applications in healthcare and identifies future research directions.
Azad et al. (2021) [59]	Healthcare supply chain management	Development of a blockchain-based system for tracking medication	Blockchain system	Increased transparency and accountability, improved efficiency	Adoption and integration challenges, potential for errors in blockchain	Detailed provide summary of the present situation and possible future

		supply chains		of supply chain managemet	system	developments of blockchain technology in healthcare.
Bilal et al. (2020) [60]	Health data sharing	Explore the blockchain technology to help safe and efficient sharing health data	Conceptual analysis	Improved data security and privacy, enhanced data interoperability	Integration challenges, regulatory barriers	identification of future research directions.
Dagher et al. (2018) [61]	Electronic health records (EHRs)	Investigation of the potential for blockchain technology to improve EHR security and accessibility	Blockchain system	Improved data security and privacy, enhanced patient control over EHRs	Technical challenges, potential for errors in blockchain system	discusses the blockchain and smart-contract to transform accounting, finance, and corporate governance
Gope et al. (2020) [62]	Healthcare data analytics	Development of a fuzzy logic-based system for predicting patient readmission rates	Fuzzy logic system	Improved accuracy of predictions, reduced readmission rates	Technical challenges in designing and implementing the system	Emphasizing the importance of global health diplomacy in addressing global health challenges.
Zhang et al. (2020) [63]	Medical data sharing	Exploration of the Blockchain technology to help security and efficiency in sharing	Conceptual analysis	Improved data security and privacy, enhanced data interoperability	Adoption and integration challenges, regulatory barriers	identifying potential predictors for COVID-19 disease severity, such as age, comorbiditi

		medical data				es, and laboratory markers.
Dincer et al. (2020) [64]	Healthcare supply chain management	Fuzzy-based blockchain framework to improve supply chain Transparency and traceability	Fuzzy logic, Blockchain	Supply chain visibility and traceability, data security	Limited adoption, complexity of implementation	Improved supply chain transparency and traceability, Increased security of data
Li et al. (2019) [65]	Patient data management	Fuzzy logic-based blockchain framework for secure, efficiency of patient data sharing	Fuzzy logic, Blockchain	Secure and privacy of data patient, data sharing efficiency	Potential regulatory barriers, complexity of implementation	Secure and efficient sharing of patient data with improved privacy and security
Lu et al. (2021) [66]	Disease diagnosis and prediction	Fuzzy logic-based blockchain framework for improved accuracy of diagnosis and prediction	Fuzzy logic, Blockchain	Accuracy of diagnosis and prediction, data security	Limited adoption, complexity of implementation	Improved accuracy of disease diagnosis and prediction, increased security of data
Purohit et al. (2020) [67]	Medical record management	Fuzzy logic-based blockchain framework for secure, efficient management of medical records	Fuzzy logic, Blockchain	Security and privacy of medical records, data management efficiency	Potential regulatory barriers, complexity of implementation	Efficient and Secure of medical records with improved privacy and security
Rathore	Drug	Fuzzy	Fuzzy	Supply	Limited	Improved

et al. (2020) [68]	supply chain management	logic-based blockchain framework for improved drug supply chain management	logic, Blockchain	chain visibility and traceability, data security	adoption, complexity of implementation	drug supply chain management with increased security of data
Abidi et al. (2019) [69]	Electronic health records	Fuzzy ontology-based blockchain framework for security, sharing of E-health records	Fuzzy logic, Blockchain	Efficiency, privacy and Secure of sharing health records data	Complexity of implementation, interoperability issues	Secure and efficient sharing of electronic health records with improved privacy and security
Chen et al. (2019) [70]	Medical data management	Fuzzy logic-based blockchain framework for secure and efficient Manage ent of medical data	Fuzzy logic, Blockchain	Security and privacy of medical data, data management efficiency	Potential regulatory barriers, complexity of implementation	Secure and efficient management of medical data with improved privacy and security
Gharibi et al. (2020) [71]	Medical image sharing	Fuzzy logic-based blockchain framework for secure and efficient sharing of medical images	Fuzzy logic, Blockchain	Security and privacy of medical images, data sharing efficiency	Limited adoption, complexity of implementation	Secure and efficient sharing of medical images with improved privacy and security
Han et al. (2020)	Telemedicine	Fuzzy logic-based	Fuzzy logic, Blockch	Security and privacy of telemedicin	Limited adoption, regulatory	Secure and efficient telemedicin

[72]		blockchain framework for secure and efficient telemedicine services	ain	e data, efficiency of telemedicine services	barriers	e services with improved privacy and security
Ostadabbas et al. (2020) [73]	Medical IoT	Fuzzy logic-based blockchain framework for secure and efficient management of medical IoT devices	Fuzzy logic, Blockchain	Security and privacy of medical IoT devices, data management efficiency	Complexity of implementation, interoperability issues	Secure and efficient management of medical IoT devices with improved privacy and security
Ghaznavi et al. (2021) [74]	Electronic health records	Fuzzy logic-based blockchain framework for secure sharing of electronic health records with consent management	Fuzzy logic, Blockchain	Security and privacy of health records, patient consent management	Complexity of implementation, interoperability issues	Secure sharing of electronic health records with improved privacy, security, and patient consent management
Zhang et al. (2021) [75]	Health data sharing	Fuzzy logic-based blockchain framework security and efficient health data sharing	Fuzzy logic, Blockchain	Data sharing efficiency, Privacy and Security of health data	Potential regulatory barriers, limited adoption	Secure and efficient sharing of health data with improved privacy and security
Garg et al. (2022)	Health data managem	Fuzzy logic-based	Fuzzy logic, Blockch	Security and privacy of health data,	Complexity of implementa	Secure and efficient managemen

[76]	ent	blockchain framework for secure and	ain	data management	tion, limited	t of health data with improved
		efficient management of health data		efficiency	adoption	privacy and security
Alzahrani et al. (2022) [77]	Medical IoT	Fuzzy logic-based blockchain framework for secure and efficient management of medical IoT devices with dynamic resource allocation	Fuzzy logic, Blockchain	Security and privacy of medical IoT devices, resource allocation efficiency	Complexity of implementation, interoperability issues	Secure and efficient management of medical IoT devices with improved privacy and security and dynamic resource allocation
Yousefi et al. (2023) [78]	Health information exchange	Fuzzy logic-based blockchain framework for secure and efficient health information exchange among healthcare providers	Fuzzy logic, Blockchain	Security and privacy of health information, data exchange efficiency	Limited adoption, regulatory barriers	Secure and efficient health information exchange among healthcare providers with improved privacy and security

Table 1 provides a comprehensive overview of research studies exploring the potential applications of fuzzy logic and blockchain technology in healthcare. These studies encompass various areas, including chronic disease management, healthcare supply chain, medical record management, and clinical trial management. The integration of fuzzy logic and blockchain technology offers several significant advantages, such as heightened data security, improved transparency, enhanced operational efficiency, and increased patient empowerment in managing their health data. However, the studies also shed light on

The challenges associated with implementing and adopting these technologies, including regulatory complexities, technical intricacies, and the inherent risks of cybersecurity. It is evident that while fuzzy logic and blockchain technology hold tremendous potential, careful consideration of these challenges is necessary for successful integration in the healthcare domain. Despite these challenges, the research outcomes suggest that the use of fuzzy logic and blockchain technology facilitates better collaboration and resource sharing among healthcare providers.

Table 2: Blockchain technology critical analysis in industry

Author	Limitations	Proposed Solution	Applied Algorithm	Blockchain-based contract	Platform	TransactionData
Swan, M. (2015) [79]	Limited transparency and accountability in supply chain management	Use of blockchain technology to provide a decentralized and immutable record of transactions	SHA-256	Yes	Custom-built blockchain	Transactions in the supply chain
Crosby, M. et al. (2016) [80]	Scalability issues with current blockchain technology	Use of sharding to improve scalability without compromising security and decentralization	Proof-of-work and sharding	No	Custom-built blockchain	Transactions across a decentralized network
Tapscott, D. and Tapscott, A. (2016) [81]	Lack of trust and inefficiencies in financial transactions	Use of blockchain technology to provide a transparent, secure, and efficient system for financial transactions	SHA-256	Yes	Custom-built blockchain	Financial transactions
Lian, J. et al. (2017)	Challenges in managing personal data	Use of blockchain	Proof-of-work	Yes	Custom-built blockchai	Personal health data

[82]	in healthcare systems	technology to provide a secure and decentralized platform for managing personal health data			n	
Chen, J. et al. (2018) [83]	Inefficiencies and fraud in the food supply chain	Use of blockchain technology to provide a transparent and trustworthy system for tracking food supply chain data	SHA-256	Yes	Custom-built blockchain	Data on food supply chain transactions
Ge, Q. et al. (2019) [84]	Security and privacy concerns in the sharing economy	Use of blockchain technology to provide a decentralized and secure platform for sharing economy transactions	Proof-of-work and sharding	Yes	Custom-built blockchain	Transactions in the sharing economy

Table 2 highlights the promising potential of blockchain technology in addressing diverse challenges across various industries, offering a decentralized, transparent, and secure platform for managing transactions and data. Through the automation of processes via smart contracts, intermediaries can be eliminated, ensuring seamless transaction execution. While scalability, regulatory complexities, and the need for a skilled workforce present challenges, the adoption of blockchain is steadily increasing; custom-built blockchains have predominantly been utilized; one case implemented the Corda blockchain. Finance, supply chain, healthcare, and other sectors are recognizing the benefits of transparency, efficiency, and trust that blockchain brings. As organizations explore integration strategies, blockchain is poised to revolutionize industries, transforming transaction and data management systems for improved efficiency and trust. Utilizing smart contracts can automate numerous processes while constructing specialized blockchains can guarantee data integrity. Nevertheless, there exist obstacles to its adoption, and more research is necessary to confront these obstacles and investigate its potential advantages.

Table 3: Critical analysis of Fuzzy Logic in industry

Author andYear	Research Problem	Proposed Solution	Applied Algorithm
Chen, S. and Wang, C. (2016) [85]	Uncertainty in fault diagnosis of wind turbines	Use of Fuzzy Logic to identify and diagnose faultsin wind turbines	Fuzzy Logic Control
Boscariol, P. etal. (2017) [86]	Uncertainty in material classification in recyclingprocesses	Use of Fuzzy Logic to classify materials in recycling processes basedon uncertain and incomplete data	Fuzzy Logic Classification
Zhou, S. et al.(2018) [87]	Uncertainty in risk assessment of undergroundengineering projects	Use of Fuzzy Logic to assess the risk of underground engineering projects based on uncertain and incomplete data	Fuzzy Logic Risk Assessment
Kozłowski, P. etal. (2019) [88]	Uncertainty in selection ofenergy-efficient heating systems	Use of Fuzzy Logic to select energy-efficient heating systems based on uncertain and incomplete data	Fuzzy Logic Decision-Making

Table 3 it can be seen that Fuzzy Logic has been proposed as a solution to various challenges in different industries. Fuzzy Logic can deal with uncertainty and imprecision in decision-making processes and control systems. It is often applied when traditional binary logic is inadequate or impractical. Fuzzy Logic can provide more accurate and reliable results by considering multiple factors and uncertainty levels. However, further research is needed to explore its potential benefits and limitations and to develop new applications in different industries.

4 Research contribution and research gap

Fuzzy Type 1 and Fuzzy Type 2 have made significant contributions to the field of fuzzy logic, enabling the handling of uncertainty and imprecision in complex systems to provide new opportunities for applications in different fields. There has been an increasing need to include fusion-based machine learning (ML) and deep learning techniques in different applications, including those that involve handling uncertainty and imprecision. Federated learning, which allows multiple parties to train a shared model while maintaining data privacy, is one approach that has gained popularity. Incorporating fuzzy logic into federated learning could further improve the handling of uncertainty and imprecision, leading to more accurate and effective models.

Explainable Artificial Intelligence (EAI) with fuzzy fairness could bring rationality and improved decision-making to various applications, including the healthcare system. By incorporating fuzzy logic, EAI could better handle uncertainty and imprecision in data, leading to more accurate and fairer decisions. This could ultimately improve the performance of the healthcare system, as EAI could help with tasks such as diagnosis and treatment planning.

5 Conclusion and future work

This systematic review explores the potential of employing fuzzy logic design and blockchain technology in the healthcare industry, with fuzzy logic design providing trust management for reliable data identification in IoMT systems while disregarding unreliable sources. Adopting this approach can effectively address uncertainty and imprecision in decision-making, control systems, and artificial intelligence, resulting in more dependable outcomes and significant advantages across healthcare industries. Integrating fuzzy logic and blockchain technology can improve the efficiency, security, and transparency of IoT-based applications, providing valuable contributions to sustainable management systems, particularly in healthcare security and privacy, through access control, authentication, and trust validation mechanisms.

Future research can explore the integration of fuzzy logic and blockchain technology with machine learning techniques, such as federated learning and explainable artificial intelligence, to improve decision-making and accuracy while addressing challenges related to trust management, data security, and transparency in healthcare and other industries. Additionally, developing novel mechanisms such as smart contracts and evaluating the performance and scalability of these systems in real-world applications can further enhance their potential benefits.

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