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ORIGINAL RESEARCH

Neuroadaptive Incentivization in Healthcare using Blockchain and IoT

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Abstract

Financially incentivizing health-related behaviors can improve health record outcomes and reduce healthcare costs. Blockchain and IoT technologies can be used to develop safe and transparent incentive schemes in healthcare. IoT devices, such as body sensor networks and wearable sensors, etc. connect the physical and digital world making it easier to collect useful health-related data for further analysis. There are, however, many security and privacy issues with the use of IoT. Some of these IoT security issues can be alleviated using Blockchain technology. Incorporating neuroadaptive technology can result in more personalized and effective therapies using machine learning algorithms and real-time feedback. The research investigates the possibilities of neuroadaptive incentivization in healthcare using Blockchain and IoT on patient health records. The core idea is to incentivize patients to keep their health parameters within standard range thereby reducing the load on healthcare system. In summary, we have presented a proof of concept for neuroadaptive incentivization in healthcare using Blockchain and IoT and discuss various applications and implementation challenges.

Keywords Blockchain · Healthcare · IoT · Neuroadaptive · Smart contracts

Introduction

The COVID-19 pandemic exposed the robustness of the global healthcare system as the patients' number grew exponentially. Being one of the worst pandemics of modern times, COVID-19 left even the countries with the best healthcare systems under stress. The sheer spread of infections flooded the hospitals with patients and there was a global shortage of both the medical staff as well as resources. The medical and scientific community played a vital role in handling the crisis with never before speed in coming up with vaccines to help bring normalcy. Learning from the catastrophe, recently, World Health Organization (WHO) issued a warning that the next pandemic could be 'even deadlier' and that we should all better be prepared [1]. Similarly, the International Federation of Red Cross and Red Crescent Societies (IFRC) has warned that the world is not ready for the next pandemic [2].

To prepare for such future exigencies, the world needs to improve the medical infrastructure as well as train more medical professionals, both of which are long-term processes. However, if the flow of patients to the hospitals and doctors can be controlled, it will help take a little load off of the medical infrastructure and improve its efficiency. As a solution to reduce the load on medical infrastructure,

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incentivizing patients to improve or maintain their health parameters could be a viable alternative. Studies such as [3] have emphasized the importance of incentives, including Bitcoin, in influencing human behavior toward information sharing. This paper proposes one such model where we propose incentivizing patients who can keep their health parameters within standard range using Blockchain and IoT technologies.

Blockchain technology can transform healthcare by enabling safe and transparent patient data storage and sharing. IoT devices can also help to motivate healthy habits by delivering real-time input on physical activity, diet, and other health parameters. Numerous research studies have looked into the possibilities of IoT and Blockchain to encourage healthy behavior.

Nevertheless, there are several obstacles to deploying these platforms, such as privacy issues, technological constraints, and the requirement for strong user engagement tactics. Overall, the literature shows that further study is required to properly look into the possibilities of IoT and Blockchain for encouraging healthy behavior and addressing these difficulties.

Blockchain technology can be used in conjunction with IoT to improve healthcare sector capabilities to improve the guarantee of confidentiality and privacy of patient records. This article examines the potential use of Blockchain and IoT in the healthcare industry and presents several healthcare applications that could be created with them. Blockchain applications, such as Smart contracts, may be used in healthcare to develop safe and effective technological infrastructure that increases care coordination and quality, hence improving the well-being of individuals and communities [4]. Agreements are Blockchain technology expansion, such as those used in the Public Blockchain [5]. That provides software to fully control the transactions or transfer payments of digital currencies (such as virtual currency or specific data) among various individuals under pre-specified standards or contracts among relevant parties [6]. One of the possible advantages of using Blockchain and IoT in the healthcare system could be the effective implementation of an award-based incentivization for patients.

A neuroadaptive technology (NAT) enhances human–computer interaction through closed-loop neurotechnology. In NAT, neurophysiology data are collected, analyzed, and adapted based on autonomous algorithms. Neuroadaptive technology allows the software to adapt in real time based on real-time measurements of neurophysiological activity.

The sensors are used to gather signals from the brain and the body. This census yields data signals, which need to be treated in some way to be filtered and cleaned for artifacts. Then, the clean signal goes over to a classification algorithm, not only some kind of machine learning approach, and this classification algorithm makes an inference about the status of the person based on those signals whether they are in a high or a low state of workload. It is that inference drives the interaction with the user. Neuroadaptive adaptation involves manipulating the user's state by controlling interactions at the interface [7].

In our study, we propose a framework for providing incentives to patients based on the observed value of the doctor-prescribed test description. We use Blockchain technology to give incentives in the form of Bitcoin/incentives to the actual recipient based on data stored at the block of the Blockchain of every patient. Every blockchain block stores and processes the data generated from each patient's used IoT devices and compares the value of a standard range of each test description. Every patient maintaining a health record within the normal range can receive the Bitcoin/incentives given by government agencies/NGOs/Societies/Employers on a monthly/Half yearly/yearly basis. For fair and timely distribution of Bitcoin/incentives, we use Blockchain technology. This helps the patients to stay motivated and maintain their health with minimum cost and using some daily exercises/Yoga.

The main contributions offered by this work can be summarized as:

- To review the research and contributions applying IoT and Blockchain Technology in incentivized health behaviors.
- To enhance health behaviors using neuroadaptive techniques.
- To incorporate neuroadaptive concepts into Blockchain and IoT-based incentive systems.
- To propose a proof-of-concept in the form of a framework for incentivization in healthcare using Blockchain and IoT incorporating the principles of neuroadaptive.

To the best of our knowledge, ours is one of the first such proposals to use Blockchain, IoT along with the concept of neuroadaptivity to incentivize the patients, thereby making this an original research idea.

This paper is organized as follows. In Sect. "Related Work", we provide little background information based on a review of literature on incentivized health behavior using Blockchain and IoT from 2016 to 2023. In Sect. "IoT in Healthcare", we present various benefits of using IoT services in healthcare. Section "Blockchain Technology in Healthcare" discusses the importance of Blockchain technologies and their use in healthcare. We emphasize demonstrating the application of neuroscience in improving health behaviors and discuss the neuroadaptive and individualized nature of reward schemes in Sect. "Neuroadaptive Techniques in Healthcare Incentivization: Utilizing IoT and Blockchain". In Sect. "Proposed Incentivization Framework

Combining Blockchain, IoT, and Neuro-Adaptivity" using a combination of Blockchain, IoT, and neuroadaptive techniques, we propose a framework for healthcare incentive programs. Finally, in Sect. "Discussion", we present some of the possible problems and their solutions followed by the conclusion and future research directions in Sect. "Conclusion and Future Research Directions".

Related Work

Various studies and their findings, in general, indicate that Blockchain and IoT can be useful tools for promoting healthy behavior as they provide an effective and visible secure mechanism for the collection and tracking of sensory data sets.

Table 1 presents a summary, based on various published works from 2016 to 2023, of various IoT, Blockchain, and related techniques used in the analysis of health behavior, etc.

Multiple research has explored the use of Blockchain, IoT, and machine learning technologies to collect, analyze, and use medical data for effective diagnosis and treatment of patients.

In 2016, Azaria et al. [8] introduced MedRec, an innovative decentralized record-keeping system that leverages Blockchain technology, smart contracts, and encryption to handle Electronic Medical Records (EMRs). In 2017, Fu et al. [9] proposed OpenCollab, a system that integrates Blockchain technology, smart contracts, cryptocurrency, and decentralized storage. This framework establishes a foundation for systems operated by networks of financially incentivized individuals who self-organize.

In 2018, Zhang et al. [10] examined the integration of Blockchain technology, smart contracts, consensus algorithms, decentralized storage, encryption, and identity management. They highlighted that public Blockchain networks, such as the Ethereum Platform, offer software capabilities to enable interactions and transactions involving virtual goods (such as virtual currency or data) among multiple parties. These interactions adhere to initially defined norms or arrangements established by the involved participants. In 2019, Zimmerman et al. [11] explored the integration of Blockchain, cryptography, smart contracts, distributed computing, artificial intelligence, and the Internet of Things (IoT). They noted that the current US healthcare system operates on conflicting incentives.

In 2020, Akhtar et al. [12] conducted a study focusing on the integration of Blockchain technology, Internet of Things (IoT), cryptography, smart contracts, distributed computing, and sustainable computing. Their research aimed to provide valuable insights into the future of IoT, which is still in its nascent stages of development. In 2021, Jamil et al. [15] conducted a study that focused on the integration of Blockchain technology, IoT devices, machine learning algorithms, smart contracts, consensus algorithms, and encryption. They highlighted the significance of the Internet of Things (IoT) in enhancing trainee development by connecting data from various fitness devices and leveraging advanced analytics. This enables trainers to evaluate vast amounts of data in real time, facilitating more effective fitness monitoring and analysis.

In 2022, Ballandies et al. [3] conducted exploring the integration of Blockchain technology, smart contracts, cryptography, decentralized applications, and Web 3.0 technologies. Their research focused on investigating the impact of tokens on human behavior in an information-sharing environment, utilizing the theory of self-determination as a framework for analysis. In the same year, Maddikunta et al. [16] also conducted a study that focused

Table 1 Comparison of IoT/Blockchain/ML/AI technologies used in healthcare research

Year	Authors	Blockchain	IoT	Machine learning	Neuro-adaptivity	Misc. technologies used
2016	Asaph Azaria et al. [8]	✓	✗	✗	✗	Encryption
2017	Yondon Fu et al. [9]	✓	✗	✗	✗	Cryptocurrency
2018	Peng Zhang et al. [10]	✓	✗	✗	✗	Encryption, identity management
2019	Noah Zimmerman et al. [11]	✓	✓	✓	✗	Cryptography, distributed computing
2020	Mohd Majid Akhtar et al. [12]	✓	✓	✗	✗	Cryptography, distributed computing, sustainable computing
2020	Hong-Ning Dai et al. [13]	✓	✗	✗	✗	Public key infrastructure, lightweight cryptography
2020	Raifa Akkaoui et al. [14]	✓	✓	✗	✗	Edge computing,encryption, interoperability
2021	Faisal Jamil et al. [15]	✓	✓	✓	✗	Encryption
2022	Mark C. Ballandies et al. [3]	✓	✗	✗	✗	Cryptography, Web 3.0 Technologies
2022	Praveen Kumar Reddy Maddikunta et al. [16]	✓	✗	✓	✗	Cloud computing, wireless sensor networks
2023	Our work	✓	✓	✓	✓	

on the integration of Blockchain, smart contracts, cloud computing, machine learning, and wireless sensor networks in the context of the Internet of Things (IoT). Their research aimed to provide a comprehensive assessment of incentive techniques for IoT, offering general readers a comprehensive understanding of incentive-enabled IoT.

As we can see in all these works, and as evident in Table 1, most of them have used either Blockchain or IoT or a combination of these technologies. A few works have also attempted to incorporate machine learning applications in healthcare to their work.

As a unique initiative, in our work, in addition to Blockchain and IoT, we also propose using neuroadaptivity, to machine-learning-based personalization technique, for computing the reward points or any other form of incentive.

IoT in Healthcare

Remote monitoring of patient's health can be done using Internet of Things (IoT) devices in the healthcare industry. The IoT sensors installed on patients' body and their surroundings can allow doctors to monitor and analyze patients' routine medical attention remotely. Table 2 summarizes the selection of sensors used for compiling the health records and their respective applications.

Table 2 clearly outlines that IoT devices are being used and analyzed by the academic and medical community for monitoring purposes. This works as a platform for our framework with the IoT infrastructure already in place.

Internet of Things (IoT) devices have gained extensive utilization within the healthcare field, encompassing various applications. We outline some of the benefits as well as possible security and privacy-related challenges while using IoT devices.

Benefits of IoT in Healthcare

- *Real-time monitoring*: IoT devices have revolutionized healthcare by providing real-time monitoring capabilities, allowing for continuous tracking of a patient's vital signs and health parameters from a remote location. These innovative devices, equipped with sensors and connectivity, enable healthcare professionals to gather crucial data, such as heart rate, blood pressure, oxygen levels, and body temperature in real time. This constant monitoring offers several benefits, including early detection of abnormalities, prompt interventions, and enhanced patient safety. By eliminating the need for frequent hospital visits, IoT devices enhance convenience for both patients and healthcare providers, enabling more efficient and personalized healthcare delivery. Ultimately, real-time monitoring through IoT devices improves patient outcomes and contributes to the advancement of telemedicine [35].
- *Remote healthcare delivery*: IoT has greatly facilitated remote healthcare delivery, particularly through telemedicine and remote patient consultations, thereby expanding access to healthcare services. With IoT devices, healthcare providers can remotely diagnose, monitor, and treat patients using video conferencing, wearable devices, and IoT-enabled medical equipment. This technology has shown promising results in improving healthcare accessibility, especially for individuals in remote areas or with limited mobility. Patients can receive timely medical advice, access specialist expertise, and manage chronic conditions from the comfort of their homes, reducing the need for in-person visits. The integration of IoT in telemedicine has led to enhanced patient outcomes, cost savings, and improved overall healthcare delivery [36].
- *Connected medical devices*: IoT has enabled connectivity and data exchange among medical devices, leading to the emergence of connected medical devices. These devices interconnected through IoT technology allow seamless

Table 2 IoT sensors used in monitoring health-related information

Sensors	Application	References
Electrocardiogram (ECG)	Monitoring heart activity, detecting arrhythmia	[17, 18]
Pulse oximeter	Measuring blood oxygen saturation (SpO2) and heart rate	[19, 20]
Blood pressure sensor	Monitoring blood pressure and detecting hypertension	[21]
Glucose sensor	Monitoring blood glucose levels in diabetics	[22, 23]
Temperature sensor	Monitoring body temperature	[24]
Respiratory rate sensor	Measuring respiratory rate and detecting abnormalities	[25, 26]
Electroencephalogram (EEG)	Recording brain activity, diagnosing epilepsy and sleep disorders	[27, 28]
Motion sensor	Monitoring patient movement and activity levels	[29, 30]
Accelerometer	Measuring gait patterns and assessing balance in elderly patients	[31, 32]
Infrared Thermometer	Non-contact temperature measurement for fever screening	[33, 34]

communication and collaboration, improving diagnostics and treatment in healthcare settings. Connected medical devices enable real-time data sharing, remote monitoring, and analysis, facilitating timely and accurate diagnoses. The integration of data from multiple devices enhances clinical decision-making, enabling healthcare professionals to provide personalized and efficient treatment plans. Additionally, the connectivity of medical devices promotes interoperability and standardization, reducing errors and improving patient safety. The use of IoT in connected medical devices has the potential to revolutionize healthcare delivery, ultimately leading to improved patient outcomes [37].

Security and Privacy Issues in IoT Devices

The IoT-based sensors collect sensitive personal data and communicate to the server and as such become a valuable target for hackers. The IoT devices and their data are vulnerable to various security risks. These include availability, confidentiality, integrity, and data privacy threats. For example, applications like remote patient monitoring run the risk of patient data leakage, data manipulation during transmission, etc., which, in the worst-case scenario, could even result in the patient's death. Most IoT resources are prone to security breaches because of their crucial utility [15].

In summary, data generation, storage, and processing using IoT devices in the healthcare industry have a heightened possibility of risks and need secure implementations especially when used to collect sensitive personal data.

Although there are various risks with many possible solutions, one of our primary focuses in this work is ensuring user authentication. This is important as the medical data of patients must be stored securely and uniquely identifiable. One of the possible tools to identify the unique subject could be the use of Blockchain technology. In the next section, we will discuss the use of Blockchain technology in healthcare.

Blockchain Technology in Healthcare

A Blockchain is a platform for decentralized computation and information sharing. Our proposed healthcare solution requires multiple stakeholders, such as doctors, patients, and incentive providers, who do not trust each other, yet want to cooperate, coordinate, and collaborate. Working of Blockchain network includes a peer-to-peer consisting of multiple stakeholders [38]. The network of stakeholders validates the health-related information and participating stakeholders' status using known algorithms like cryptographic algorithms, asymmetric-key algorithms, and hash functions. Verified health-related information can involve incentives. Once verified the health-related information is combined with other health-related information to create a new block of data for the ledger. The new block is then added to the existing Blockchain in a way that is permanent and unalterable [39]. Mutual trust between patients and healthcare professionals is an absolute must to ensure transparency and guarantee the privacy of patients. To suggest therapeutic measures for medical disorders, healthcare providers rely on the quality and completeness of information provided by patients.

In the healthcare sector, Blockchain technology finds applications in various ways. These include controlling information from patient health records, addressing security issues in healthcare, managing databases and patient records, and regulating biotechnology for treatment purposes. One notable application is the use of Blockchain for illegal drug tracking, where bio-pharmaceutical companies leverage cryptocurrency techniques to combat the circulation of illicit substances. By effectively tracking these illegal medicines and aiding in detection of counterfeiters, Blockchain technology contributes to ensuring patient safety. Considering these factors, the primary objective of this research is to propose a comprehensive Blockchain technology framework supports the stakeholders as well other technologies in the healthcare sector.

Healthcare providers, as a result, end up storing huge and sensitive personal data about patients. Managing and safely retrieving the vast amounts of private medical information created by ordinary companies and service activities are a major challenge for the healthcare market [40]. Such personalized data sets can be of immense value to cybercriminals as they can be used for targeted attacks. The lack of secure links connecting all independent health systems to build an end-to-end accessible network is a significant issue in today's industrial healthcare systems [41]. Additionally, giving incentives in the form of Bitcoin to the recipient is risky. Blockchain technology has revolutionized various aspects of healthcare including;

- Blockchain guarantees the confidentiality, integrity, and availability of patient health records, ensuring secure management of patient data.
- Blockchain facilitates the seamless sharing and exchange of patient information among healthcare providers, promoting interoperability across different healthcare organizations.
- Blockchain enables transparent and auditable clinical trial processes, promoting decentralization and enhancing trust and data integrity in clinical trials.
- Blockchain enhances data security by ensuring data integrity and immutability, safeguarding patient information against unauthorized access or tampering.
- Blockchain fosters improved transparency and interoperability by enabling secure and standardized data sharing

among healthcare stakeholders, thereby reducing data silos.

IoT is a recent entrant to the healthcare industry. As IoT devices, and data collected, suffer from various security and privacy risks, Blockchain can be used to alleviate some of these concerns. Due to its special attributes, such as transparency, responsibility, integrity, and anonymity, to mention a few, Blockchain recently aroused a lot of interest. Using cryptography and game theory, Blockchain provides decentralization, immutability, and consensus. The management of health information, drug traceability, and other similar issues can be improved by augmenting features of Blockchain technology to preserve the integrity of data. Table 1 summarizes the existing studies used for incentivization in Healthcare.

The Architecture of IoT and Blockchain in Healthcare Data

Health data are generally considered confidential, and sharing it often raises the risk of it falling into the wrong hands. The Internet of Things (IoT) has frequently faced the challenge of prioritizing speed and energy efficiency over robust security measures. In the realm of health data sharing, conventional approaches often rely on centralized architectures, which, in turn, necessitate centralized trust and security mechanisms. To address the aforementioned challenges, we suggest leveraging Blockchain technology, which has demonstrated its effectiveness in ensuring data security and maintaining data integrity. Blockchain is renowned for its decentralized architecture, which utilizes a distributed ledger to store data in the form of transactions. The immutability of blockchain makes it a natural fit for the healthcare sector. Nonetheless, blockchain technology faces persistent challenges, including scalability concerns, delays in transaction confirmation, and high energy consumption, which have received significant attention [42].

Numerous medical IoT devices and applications are accessible in the market. These devices are accompanied by a mobile application that links with the device, acquires health data, and transmits the device data to the backend for safekeeping. In the provided Fig. 1, there is an adapter element that gathers data from the device's backend repository and transmits it to the blockchain for storage. Additionally, the adapter component manages the retrieval of data from the blockchain and forwards it to the application, which offers a user-friendly presentation of the stored information [43].

Neuroadaptive Techniques in Healthcare Incentivization: Utilizing IoT and Blockchain

In recent years, there has been a lot of interest in the implementation of rewarded healthcare behavior. The use of neuroadaptive techniques in conjunction with IoT and Blockchain technology is explored in this paper as a potential means of enhancing incentive programs in the healthcare sector. We want to explore the implications and potential of combining these cutting-edge technologies to encourage behavioral change and customized incentive schemes for patients. To do this, we will draw on insights from neuroscience.

Neuroscience and Behavioral Change

The brain's influence on health habits has been discovered through recent neuroscience studies. It has been discovered that monetary incentives and rewards activate the brain's reward system, increasing motivation and changing behavior [44]. We can create more efficient treatments that

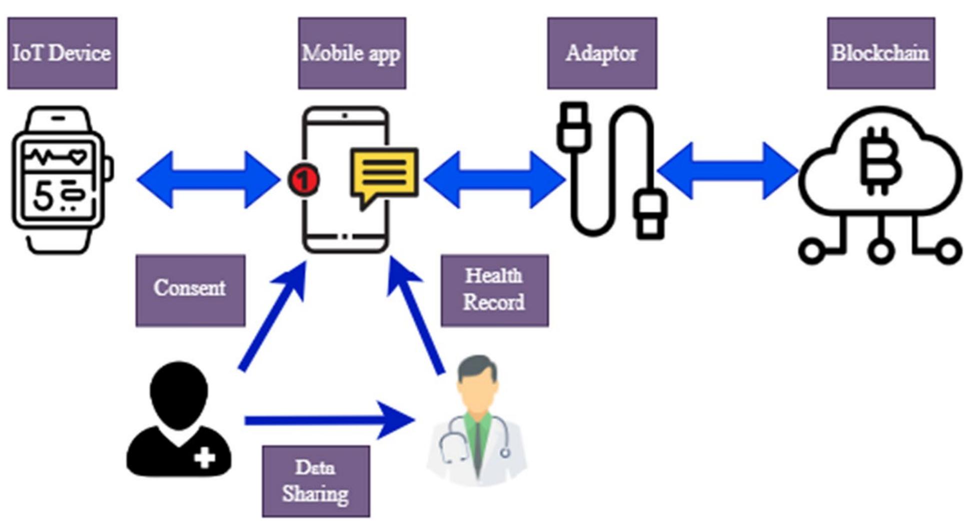

Fig. 1 The architecture of IoT and Blockchain in healthcare data

harness the power of the brain to promote healthy habits by incorporating neuroscience findings into Blockchain- and IoT-based incentive systems.

Continuous Brain Activity Monitoring

Using Brain–Computer Interfaces (BCIs) to continually track brain activity is one promising approach. It is possible to learn a lot about how each person responds to various rewards by studying how the brain reacts to various incentive systems. As an illustration, studies have demonstrated that immediate and concrete benefits are more motivating than delayed or abstract rewards [45]. Systems can be improved to give rewards that are more effective at causing behavior change using BCIs to monitor brain activity.

Social Support and Accountability

Another way to use neuroscience is to incorporate social accountability and support into Blockchain- and IoT-based incentive schemes. According to studies [45, 46], peer support groups are particularly effective at promoting healthy habits, and social support has been shown to be a key factor in motivating behavior change. Within Blockchain and IoT-based incentive systems, social components like peer support groups and social prizes can promote a more helpful and responsible workplace.

Blockchain-Based Incentivization

A Blockchain-based incentivization strategy was used in a recent study by Wankmuller et al. [47] to encourage physical activity among college students. The program provided both monetary and interpersonal benefits, including the chance to take part in online workout sessions with pals. According to the study, participants who got both financial and social benefits were more likely to meet their physical activity goals than participants who only received monetary prizes. This emphasizes how crucial it is to incorporate social support into Blockchain- and IoT-based reward systems.

Neuro-adaptive Techniques for Personalized Incentive Programs

The way we promote healthy habits may be completely changed if neuroscience research is incorporated with Blockchain and Internet of Things-based reward programs. These methods make it possible to create more customized, effective medications that improve patient outcomes and lower healthcare expenditures. Two major strategies are as follows:

Machine Learning-Based Personalization

Personalized reward programs can be developed based on individual preferences and motivators by utilizing machine learning algorithms to examine brain and behavioral data obtained by IoT devices [48]. This neuroadaptive methodology enables the development of more potent and durable behavior change therapies. To motivate participants to meet their activity goals, Hekler et al. [49] employed machine learning to assess the physical activity data from cellphones and offer individualized coaching messages. According to the study, people who received personalized coaching had a higher likelihood of achieving their goals than people who received non-personalized messaging.

Real-Time Feedback and Reward Adjustment

Utilizing real-time input to modify incentives in response to shifting behavioral patterns is another neuroadaptive strategy [50]. For instance, an incentive program based on Blockchain was used to increase HIV-positive people's adherence to their medicine. Cash incentives were modified following real-time input on adherence provided by a smart pill container. The study showed that compared to participants who got fixed incentives, those who received real-time feedback and dynamic incentives were more likely to stick to their prescription regimens.

Healthcare could be revolutionized by the use of more individualized and efficient interventions made possible by the incorporation of neuroadaptive techniques into Blockchain and Internet of Things-based incentive programs. We can create specialized solutions that fit with unique brain and behavioral patterns by utilizing continuous brain activity monitoring, social support, machine learning algorithms, and real-time feedback. These developments may result in better patient outcomes and lower healthcare costs. The fusion of blockchain, IoT, and neuroscience technology is the key to the future of financially motivated healthcare.

Proposed Incentivization Framework Combining Blockchain, IoT, and Neuro-adaptivity

The framework proposed in Fig. 2 utilizes Blockchain technology to securely manage and evaluate large-scale healthcare data. It combines IoT technologies with security services like authentication, access control, and secure data execution, offering potential solutions for the healthcare sector. The integration of IoT and Blockchain proposes a health platform that prioritizes patient privacy. Specifically, Blockchain technology is employed to establish a security strategy for safeguarding multimedia data

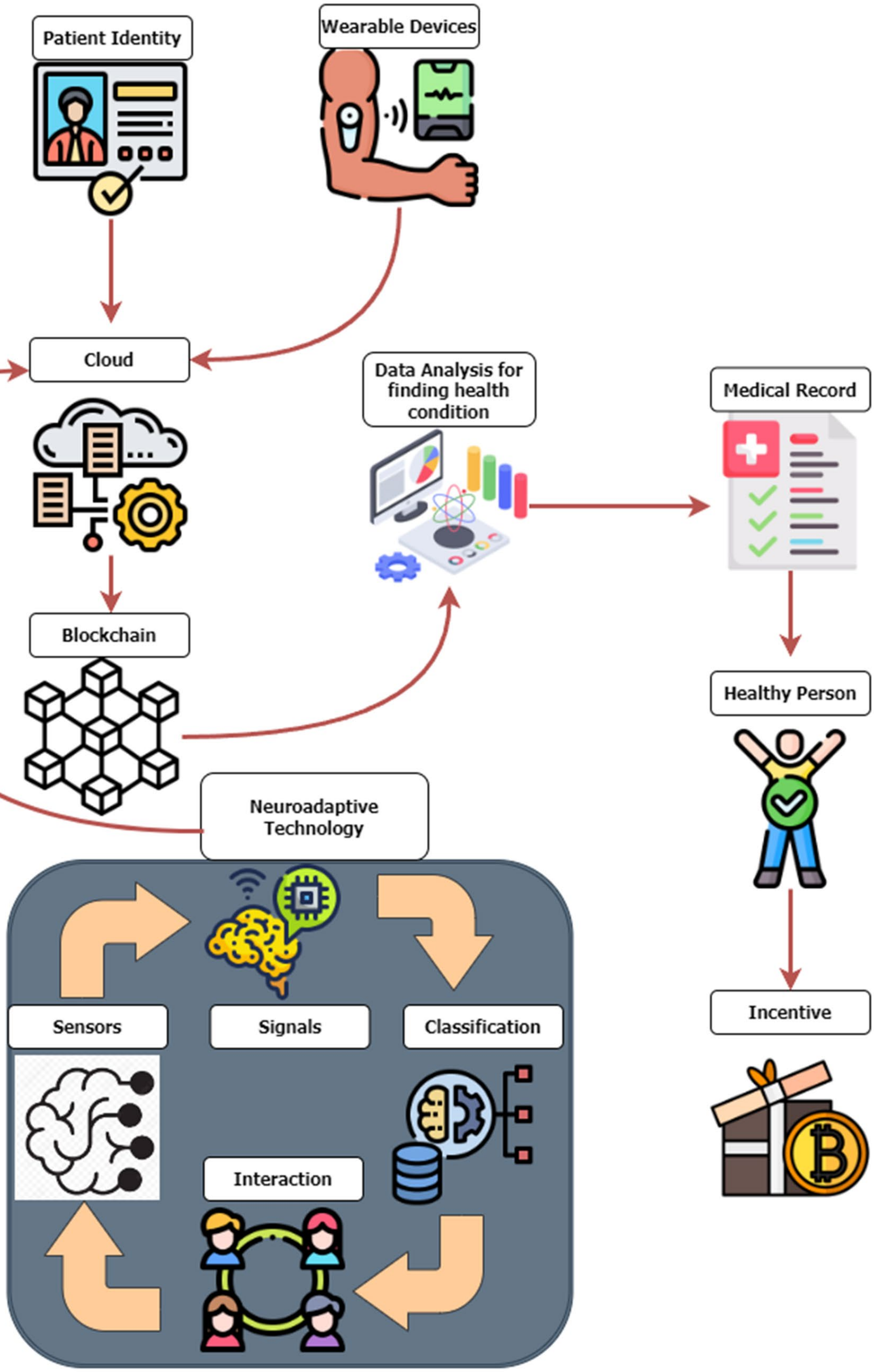

Fig. 2 Proposed framework for awarding incentive

in healthcare. This approach involves hashing each data component to prevent any unauthorized modifications or additions. This proposed framework is designed to ensure patient confidentiality and transparency.

Prior to the implementation of a Bitcoin-based system to incentivize healthy behaviors, it is crucial to define the specific behavioral patterns to be promoted, such as exercise, maintaining a healthy diet, and adherence to medication. This incentive system aims to encourage individuals to adopt and sustain these desired behaviors. Additionally, it is necessary to identify the eligible participants for the incentive program, including consumers, health experts, businesses, and funders, and establish the mechanisms for distributing and tracking incentives.

IoT devices will play the titular role in this scheme as their use in the medical sector, to collect data and monitor patients remotely, has been on a constant rise. These IoT devices use sensors and collect multiple physiological data such as vital signs, medication adherence, activity levels, etc., to name a few. Wearable gadgets, such as fitness trackers, smartwatches, and patches, may also capture various physiological data, such as heart rate, blood pressure, body temperature, and blood oxygen levels. These readings can then be used to monitor individuals suffering from chronic diseases, such as diabetes, heart disease, and hypertension. Data about certain medical problems may be gathered via IoT-enabled medical equipment like blood glucose monitors, spirometers, and ECG machines. This information may be used to keep tabs on a patient's health, modify treatment regimens, and, if necessary, initiate early intervention.

We understand that simply gathering and analyzing medical data may not be sufficient for a robust system as we would need to identify every patient uniquely while keeping the security and integrity of the data intact. For this purpose, we intend to use smart contracts.

Smart contracts are self-executing agreements with the contract's terms written into code, which is one approach to creating a Blockchain-based incentive structure. Smart contracts would specify the parameters for obtaining incentives, such as walking a certain number of miles daily or hitting a specific weight loss goal. They would automatically execute rewards if these conditions were met. Smart contracts would allow for real-time monitoring of healthy behaviors and transmitting safety data among stakeholders.

We now outline the procedure for incentivizing patients whose health metrics meet a minimum threshold value determined by practitioners or standards. In this system, patients automatically receive Bitcoins or other incentives through the use of Blockchain technology when their health records demonstrate improvement beyond the prescribed threshold. The assessment of health record outcomes is based on investigation results, considering the provided test description and observed values in relation to a standard biological reference (male/female) suggested by the practitioner.

The incorporation of technologies such as Blockchain and IoT helps ensure that the intended incentives are exclusively received by the intended recipients. Consequently, the development of reward mechanisms based on foundational technologies like Blockchain, AI, and game theory becomes imperative for the facilitation of long-term IoT networks and systems. For instance, Bitcoin can serve as a motivational tool for distributed data exchange in IoT, empowering IoT users to maintain control over data sharing while reaping benefits. Agreements that streamline user rewards can be employed to establish rules governing consumer privacy and data sharing.

Finally, neuroscientific ideas can be augmented into the reward program by creating tailored incentive programs that adapt to an individual's unique brain and behavioral patterns utilizing machine learning algorithms and real-time feedback. This method, known as neuroadaptivity, will allow us to develop more effective and long-lasting therapies. We may also apply neuroscientific concepts to enhance the incentive algorithm by offering incentives that are more effective at promoting behavior change, such as immediate and tangible rewards.

An alternative approach to integrating neuroscience with Blockchain and IoT-based incentive schemes involves leveraging social support and responsibility. Existing studies have demonstrated the significant influence of social support on promoting behavioral change, particularly through the efficacy of peer support groups in fostering positive behaviors. By incorporating social elements, such as social awards and peer support groups, into Blockchain and IoT-based incentive systems, we can establish a more supportive and accountable environment.

Outcomes of the Study

By integrating neuroscience findings into Blockchain and IoT-based incentive systems, this framework has the potential to transform the approach to promoting positive behaviors. This integration enables the development of highly effective and individualized therapeutic interventions that enhance patient outcomes and simultaneously reduce healthcare expenses. Leveraging the brain's reward circuitry and the power of social influence, we can pave the way for significant advancements in this field.

Discussion

There are a few issues we must address which relate to operational implementations of our framework. The first one relates to the use of Blockchain. What kind of Blockchain would fit in this framework; public, private, or both?

To this end, this framework does not restrict itself to any one type of Blockchain. The healthcare service providers, in consultations with the stakeholders, may decide to use either their own Blockchain system or outsource it to any external secure system. One of the possible mechanisms could be using an online digital wallet such as DigiLocker, a digitization service provided by Govt of India for storage and retrieval of documents. Information stored on DigiLocker can be shared securely with any other authenticated party.

Incentivization

Another issue could be the mode of incentive disbursement. It is emphasized here that the incentive need not necessarily be a monetary one. The incentive could be in the form of redeemable points, goodwill, tokens, etc., to name a few. The financial industry has already been using this model globally where the credit rating of customers decides the eligibility of financial products and services they can avail. On the similar lines, the system may generate the health score of an individual, and based on the score, a person could be eligible for discounts not only on medical services but also on similar products, such as free health checkups, health insurance, etc.

For example, for anyone maintaining the optimum health parameters, companies can offer an additional month free on buying paid subscriptions to their products, such as Fitbit and related services.

Finally, the financial requirement for implementing our incentivization framework may not be huge as money saved through efficient use of medical infrastructures can be rerouted to this end. Additionally, the application of such schemes will result in a lot of time becoming available for doctors and medical professionals, thereby reducing the overall manpower cost.

Implementation Challenges

Implementing this framework presents a range of complex challenges. First, ensuring the security and privacy of sensitive healthcare data within the Blockchain is paramount, requiring robust encryption and access control mechanisms. Integration with the existing healthcare systems and diverse IoT devices can be intricated due to interoperability issues and the need for standardized communication protocols. Scalability poses a concern, as Blockchain technology can face limitations in handling a large volume of transactions quickly. Moreover, developing effective neuroadaptive algorithms that accurately tailor incentives to individual behaviors is a research-intensive endeavor. User acceptance and engagement with personalized incentives must also be carefully designed to drive the desired behavioral changes. Addressing regulatory compliance, such as adhering to healthcare data protection laws, and navigating ethical considerations surrounding data ownership and consent are significant hurdles. Furthermore, the implementation demands substantial investments in infrastructure, staff training, and ongoing maintenance. A multidisciplinary approach and meticulous attention to these technical, regulatory, and operational challenges are essential for the successful deployment of such a framework.

Conclusion and Future Research Directions

The present study introduces a novel approach to alleviating the strain on medical infrastructure by incentivizing patients. Our argument contends that leveraging Blockchain and Internet of Things (IoT) technology in incentivization programs can lead to improved patient outcomes and significant reductions in healthcare costs. Specifically, our proposed solution merges Blockchain and IoT methods with the conventional diagnostics and treatments, and we have presented a detailed process for awarding incentives in the form of cryptocurrency to patients who surpass a practitioner-prescribed minimum threshold for treatment outcomes or medical test results. Moreover, we propose that integrating neuroscientific principles into these programs through neuroadaptivity can enhance their effectiveness and customization. With machine-learning algorithms and real-time feedback, neuroadaptive programs can create tailored incentives to an individual's unique brain and behavioral patterns, leading to more sustainable and effective behavior change. While this approach holds much promise, further research and implementation are needed to fully comprehend and exploit the benefits of integrating neuroscience knowledge with Blockchain and IoT-based incentivization programs in the healthcare industry.

The current study presents opportunities for future research in several areas. Specifically, the technical implementation and cyber security and privacy issues, although not within the scope of this paper, represent crucial domains warranting further investigation. Of particular concern is the need to ensure the unique identification of incentive recipients while also preserving the privacy of all subjects, a complex task given the constantly evolving legal frameworks governing privacy. Moreover, novel incentive structures should be explored, and their implementation assessed for compatibility with medical infrastructure and patient needs. Ultimately, addressing these critical issues can have significant implications for the efficacy and ethical implementation of incentive programs in healthcare contexts.

Declarations

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest. No funding was received for this study by any of the author(s). This article does not contain any studies with human participants or animals performed by any of the authors.

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