Journal of Investigations on Engineering & Technology
Volume 4, Issue 2, 69-76, 2021
ISSN: 2687-3052

Review Paper

Health 4.0: Blockchain Applications in Healthcare

İbrahim KAYA[1], Sercan DEMİR[2]

(Alınış / Received: 26.09.2021, Kabul / Accepted: 09.12.2021, Online Yayınlanma / Published Online: 31.12.2021)

Keywords
Blockchain technology
Industry 4.0
Health 4.0
IoT
Medical cyber-physical systems

Abstract: During the last decades, the advancement in industrial technology manifested itself in the concept of Industry 4.0, which incorporates digitization, smart automation technologies, the Internet of things, self-monitoring, and optimizing machines. Health science, one of the most interdisciplinary fields, with its sub-disciplines, constitutes a platform open to novel technologies from various fields such as pure science, engineering, and management. One of the fields transformed by Industry 4.0 is healthcare. An umbrella term "Health 4.0" is derived to cover all the recent technology advancements in the health field. Some of these advancements are the Internet of Things (IoT), Internet of Services (IoS), Medical Cyber-Physical Systems (CPS), Health Cloud, Health Fog, Health Big Data Analytics, Mobile Communication Networks, and Blockchain Technologies. Health 3.0 focused on the patients, communication, and monitoring of patients using new technologies like smart sensors, wearable devices, and big data. Health 4.0 added real-time monitoring, prediction, and AI-supported diagnostics to Health 3.0. The main objective of Health 4.0 is to provide high-quality healthcare services, improved efficiency and effectiveness, and optimization of the costs and resources. Blockchain technology offers a promising solution for healthcare data management with exceptional features such as decentralization, enhanced security, and immutability. However, the potential of blockchain technology has not been investigated in detail. This paper examines the prominent blockchain applications and challenges in Health 4.0 and its impact on the health industry.

1. Introduction

As the longevity of the world population increases with the advancements in healthcare, the aging of the population will increase healthcare costs [1]. The amount of funds spent on the health sector is growing larger each year, which causes an enormous burden on the economic development of countries. The countries need to transform their health organizations into a cost-effective yet high-quality producing structure. This will be one of the main factors that enable a nation to reach high welfare and prosperity in the next century. This transformation requires the adoption of the recent technological advancements in the Industrial Revolution as well as science. The young population percentage decreases by the aging population, which jeopardizes traditional hospital-based healthcare services [1]. A radical paradigm shift in health care is required for a more sustainable and high-quality health service in the near future. This is one of the most important driving factors for the emergence of the Health 4.0 concept.

The main objective of this paper is to provide and present the potential of blockchain technologies in the healthcare field. The paper is organized as follows. In Section 2, the historical progress of Industrial evolution and the emergence of Industry 4.0 are summarized. In section 3, the evolution of health care technologies and the Health

[1] Department of Biomedical Engineering, İzmir Katip Celebi University, İzmir, Türkiye
[2] Department of Industrial Engineering, Harran University, Şanlıurfa, Türkiye

4.0 concept are introduced. In section 4, Blockchain technology, one of the emerging technologies in the Industry 4.0 era, is explained. In section 5, some applications of the blockchain in healthcare are discussed. Finally, a summary of the blockchain and Health 4.0 are discussed in the conclusion.

2. Industry 4.0

Although there is no defined rule for categorizing the advancements in industrial technologies over time, the evolution of industrial technology can be divided into four stages. The water and steam-powered mechanical manufacturing, mass production technologies powered by electricity, and the electronics and information technologies-based industrial processes constitute the first three industrial revolutions, respectively [2]. Following the computerized machining by Industry 3.0, the main motivations for Industry 4.0 are to improve autonomous and smart industrial operations, achieve cost reduction and high quality by optimization, automation, and the use of intelligent services [3]. Globalization in recent decades required better efficiency, competency, and competitiveness, leading to a demand for high-level industrialization, informatization, and manufacturing digitization by Industry 4.0 [4]. Completely integrated digital systems and end-to-end digitization are two essential properties of Industry 4.0 [4].

The virtualization of the physical systems by such technologies as the Internet of Things (IoT) and machine-to-machine communication enable the movement of technological perspectives from embedded electronic systems to Cyber-Physical Systems (CPS) [5]. To support this movement, smart factories are being developed to realize complex production schemes in CPS. Cloud technology using distributed resources and CPS by connecting physical and software entities provides better integration in physical and virtual domains [4, 6].

Hermann et al. (2015) proposed six design principles of Industry 4.0: interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity [7]. Interoperability stands for the capability of a system to share information with others to achieve a function or action. In cyber-physical systems, interoperability is key to completing the system loop and exchanging data without interruption [8]. Virtualization is the ability of a system to monitor physical processes by CPS and create a virtual copy. [7]. By decentralization, there is no necessity for a central trusted agency to process the data [9]. Real-time capability is the ability of a system to operate in real-time interactions with other systems or units to satisfy the system's integrity. Service orientation refers to more customer-centered services with Internet of Things (IoT), Internet of Services (IoS), and Internet of People (IoP) technologies. Modularity stands for the ability to replace or expand parts and adapt the system to changes flexibly [1].

3. Evolution of Healthcare Technology and Health 4.0

Technological milestones can analyze the evolution of healthcare technologies. Health 1.0 focused on the high utilization of computers for administration procedures; Health 2.0 focused on organizational data sharing using cloud computing [10]. Later Health 3.0 shifted the focus on the patients, communication, and monitoring of patients using new technologies like smart sensors, wearable devices, and big data. Finally, Health 4.0 added real-time monitoring, prediction, and AI-supported diagnostics [10]. The main objectives of the Health 4.0 can be summarized as high-quality healthcare services, improved efficiency and effectiveness, and optimization of the costs and resources. Health 4.0 introduces integrated healthcare platforms for all healthcare stakeholders by providing virtual, distributed, and real-time services to move healthcare services from empirical to personalized healthcare services [3]. Patients, medical professionals, medical equipment, hospitals, clinics, pharmaceuticals, and medical suppliers are connected to a smart healthcare network through Health 4.0 [3]. By Health 4.0, a new paradigm shift from the hospital-based professional system to a distributed patient-centered healthcare in the world [11]. With increased connectivity, mobile digital technology platforms (m-health) connect patients and caregivers across the globe. People in remote areas can easily access high-quality health services [12, 13]. Health 4.0 offers flexible, scalable, reliable, agile, cost-effective, and high-quality healthcare services and operations [14]. It requires highly complex design and implementation to build and provide Health 4.0 based applications. Advanced service-oriented middleware (SOM) framework with cloud computing, edge/fog computing, IoT, IIoT (Industrial IoT), CPS, and big data can satisfy the needs for such complex systems [3].

Internet of Medical Things (IoMT) is a connected health system where medical devices, systems, software, and services are connected for cooperation [15]. The benefits of IoMT can be summarized as improved patient outcomes such as decreased costs, improved drug management, enhanced patient experience, improved diagnostics and treatment, remote monitoring of diseases, improved disease management [16]. Internet of

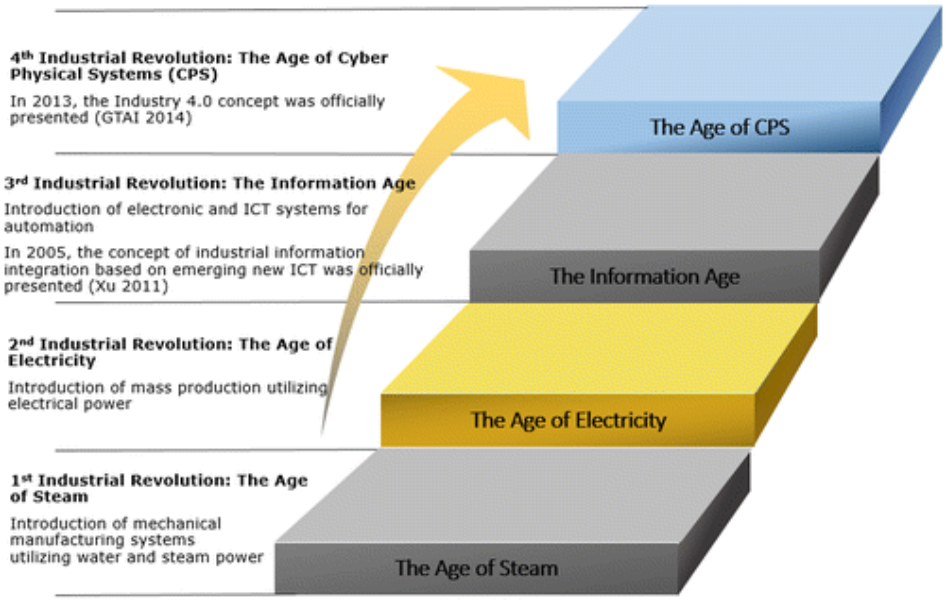

Figure 1. Industrial evolution stages. Adapted from [4]

Services is software-based medical devices, systems, and organizations provided via Internet interfaces [17]. Medical Cyber-Physical Systems, another Health 4.0 technology, are integrated systems of medical devices driven by embedded software and connected to networks that are distributed systems capable of monitoring and controlling patients' physiology [18]. With the digitization and particularly with the virtualization of healthcare, a higher quality of health services in the form of personalization for patients, professionals, and other stakeholders is available [19]. Another technology is health fog; in fog computing, three layers exist. They are the medical device, fog, and cloud layers [10]. Medical sensors are connected to the patient in the medical device layer, and data is collected by real-time monitoring via the Internet of medical things (IoMT) [10]. On top of the medical device is the fog layer, where sensor data is processed quickly and transmitted to the top cloud layer. The medical data is analyzed, stored, and provided to the clients, such as doctors and patients [10]. As another technology, Health Big Data Analytics enables better decision-making by learning from the enormous health data recorded over time using techniques such as machine learning. Healthcare big data is different from conventional databases. It has more complex and diverse formats, types, and contexts [19]. It is challenging to merge [19]. Moreover, Next Generation Mobile Communication Networks will allow new medical applications using the faster connection and smarter data management capabilities [3]. Finally, blockchain technology provides a decentralized and secure platform for critical health data management.

4. Blockchain Technology

Even though Stuart Haber and W. Scott Stornetta had started the research on digital ledgers in 1991, the first appearance of blockchain was in 2008. Blockchain has been invented with the idea of building a system that does not allow anybody to access or change document time-stamps. Developer(s) working under the pseudonym Satoshi Nakamoto conceptualized the first blockchain in 2008. Blockchain's design was based on Hashcash cryptographic algorithm [20]. Blockchain structure is illustrated in Figure 2. Each block represents a transaction. Every user has a digital signature, a private key, and a public key to sign transactions digitally in the signing phase [21]. In the verification phase, encrypted transactions and the original data are broadcasted to other users to verify the transactions using users' public keys [21]. Once the transaction has been validated at each user node, it is added to the blockchain, and money is transferred [22]. Blockchain technology offers advantages such as immutability, irreversibility, distributed system, decentralization, resiliency [22]. It is very hard to change or tamper with a transaction block with immutability. It is irreversible that money can not be double-spent. It is distributed that all the members have a copy of the ledger. It is decentralized that there is no central server mechanism to process. By resiliency, it is immune to safety attacks. Figure 2 represents the structure of blockchain. This structure consists of data, hash, time-stamp, and other information. The stored data in the blockchain is based on the service and application type. This data can be used in various applications like recording the transaction details, banking, contracting, and IoT. A hash function is responsible for taking an input of any length and generating the output with a unique fixed length. These functions are universally used in blockchain technology. They increase the integrity and trustfulness of data stored in blockchains. Timestamping is a method to record a document's creation and modification time, and it is crucial to saving these records every time a block is created. Other information in a blockchain system includes but is not limited to digital signatures, nonce values, and nBits [23].

In addition to financial applications, blockchain technology is crucial for healthcare. The use of blockchain technology in the medical field has been urged by the need for data share across departments of the same hospital, for an updated set of records for reference across multiple healthcare facilities, for the exigency of trusted and transparent documentation of individual health data [24].

5. Prominent Applications of Blockchain in Health

Blockchain technology has a great potential to improve business processes by virtue of its immutable, time-stamped, secured, and decentralized consensus feature [25]. Blockchain technology can be implemented in many industrial and technical areas. The inherent decentralized structure is one of the strongest points of blockchain technology. Each participant in a blockchain system can view the transaction records; however, they cannot change and delete them. For this reason, blockchain technology builds up transparent, immutable, and secure digital systems [26].

Blockchain technology consists of many interdisciplinary techniques: cryptography, algorithms, economic models, and mathematics. This technology merges or combines peer-to-peer networking and distributed consensus algorithms [23].
Some of the prominent applications of blockchain technology are illustrated in Figure 3. Blockchain technology has many potential application areas such as finance, healthcare, mobile technologies, defense systems, automobile, and the IoT. Among these application areas, blockchain has a wide range of applications and prominent uses in healthcare. Mettler (2016) states that blockchain technology can be implemented in healthcare, such as public health management, the pharmaceutical sector, medical research, and consumer-oriented healthcare [27].

Even though the research endeavors of blockchain technology in the healthcare industry have started in recent years, its applications will have widespread impacts in the healthcare industry in upcoming years. Some of these research areas in healthcare include, but are not limited to, management of electronic medical records, biomedical research, and education, remote patient monitoring, health data analytics [28]. Gordon & Catalini (2018) analyze the challenges encountered during the transition from institution-driven interoperability to patient-driven interoperability [29]. The authors investigate the applicability of blockchain technology on patient-driven interoperability.

Blockchain applications have started with the cryptocurrency Bitcoin and evolved to cover many other areas, including healthcare. Blockchain technology is expected to positively impact the healthcare industry [28]. One instance is IBM's Healthchain application. It was developed on Blockchain infrastructure, enabling confidentiality, scalability, and security in health informatics [30]. Another application is offered by a Netherland-based data security firm, Guardtime. The blockchain-based application helps to validate patients' identities. The patients' records, such as patients' private health information and appointment scheduling, are registered in the blockchain and kept secure and auditable. MedRec is another blockchain-based application that is the joint venture of MIT Media Lab and Beth Israel Deaconess Medical Center. This application allows patients to control the entities who can access their healthcare data [31]. Healthcoin is another example of a blockchain application in healthcare.

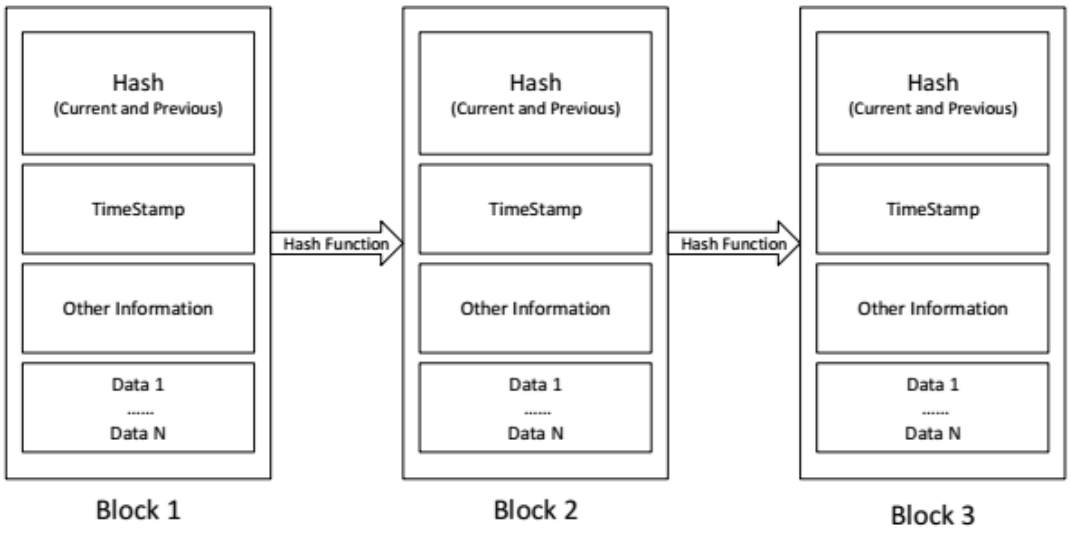

Figure 2. Structure of blockchain [23]

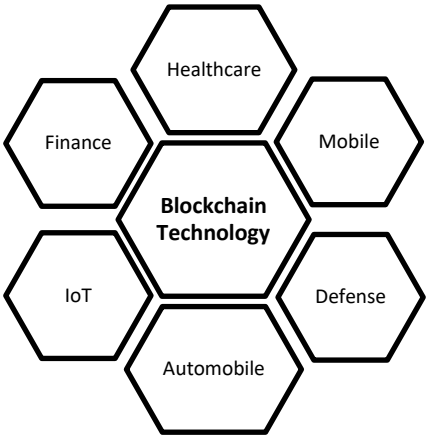

Figure 3. Application Areas of Blockchain Technology [23]

It has been started to help people with diabetes symptoms and later extended its aim to be a global electronic health record system. The application has a patient-centered information control mechanism based on three principles: giving the complete data to the users, allowing users to channel their data to its best use, and allowing users to broadcast outcomes with mechanisms to certify the broadcasted information [32]. Blockchain technology can be applied to many areas in healthcare, such as device tracking, clinical trials, pharmaceutical tracing, and health insurance. Blockchain technology has a great potential to create robust systems against counterfeit and unapproved drugs. Some of the issues within the modern healthcare industry are healthcare data interchange, nationwide interoperability, medical device tracking, and drug tracking [33]. Some of the benefits of blockchain technology in the healthcare industry are shown in Table 1. According to Engelhardt (2017), entrepreneurs focus on four main areas to deal with the challenges in health data management. These are; putting the patient at the center, privacy and access, completeness of information, and cost.

Table 1. The benefits of blockchain to healthcare applications (adapted from [28])

Decentralization	Blockchain technology can be the foundation for decentralized health data management systems from where the system's participants can access the same health records. There will be no central authority in this system that controls the health data.
Improved data security and privacy	The immutability property of blockchain guarantees the security of health data. Once the health data is inserted into a blockchain system, it cannot be deleted, corrupted, or altered. The data on a blockchain system is encrypted, time-stamped, and stored in chronological order.
Health data ownership	The cryptographic structure of blockchain and smart contracts offers solutions to protect patients' data and prevent them from being misused by unauthorized parties.
Availability/robustness	The records on a blockchain system are held on multiple nodes. This feature of blockchain creates a robust and resilient system against possible data losses, data corruption, and attacks.
Transparency and trust	The healthcare stakeholder will be more willing to trust the blockchain-based applications due to their open and transparent nature.
Data verifiability	The integrity and validity of the data records can be verified on blockchain nodes without the need for accessing plaintexts. Fast and easy verification of records yields productive processes in pharmaceutical supply chain management and insurance claim processing.

A comparison of an open-ended loop for a prescription process and a blockchain-based solution for the same process is given in Figure 4.

A doctor provides a prescription to a patient, and then the patient delivers the prescription to a pharmacist himself in an open-ended loop. In this process, the pharmacist has no knowledge about the prescription's originality, accuracy, or any modification made on it. Transactions can be stored access and permission to add data to the blockchain. When a doctor adds the prescription to the system, the pharmacist can check the original document in the closed-loop prescription process. After that, the pharmacist can record his actions on the prescription, and the doctor can see the prescription status [32]. The illustration of two different system design is given in Figure 4.

Blockchain technology can address prescription drug fraud such as modification of prescriptions, duplication of prescriptions, collection of many prescriptions from different doctors. One safety gap in an open-ended loop is the

lack of a sufficient feedback mechanism between prescription writers and prescription fillers. Blockchain offers fast and secure access to the time-stamped prescription documentation against prescription fraud [32].

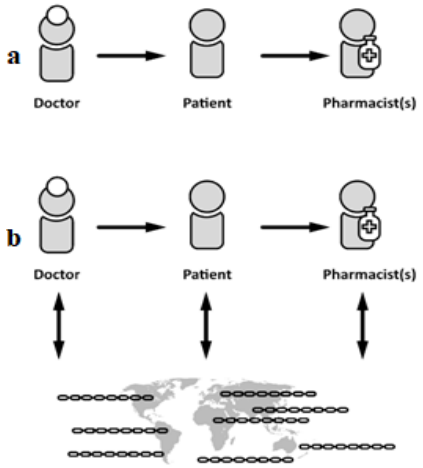

Figure 4. Traditional open-ended loop for a prescription process (a) vs. blockchain-based solution to a prescription process (b) [32].

Convenient medical care increases its popularity in today's medical system. The connectivity feature of smart devices can bring patients and doctors without the need for physical meetings and save time and energy. Many healthcare companies offer 24/7 access to healthcare services, and mobile applications continuously monitor patients' health status and send a report to the health service providers.

Zhang et al. (2018) depict a high-level conceptual infrastructure (see figure 5) where a Blockchain (represented as the dashed ellipse) is connected to disparate health database systems (represented as cylinder database objects) [34]. The keyed file symbol represents a smart contract, and it is used to regulate the data transaction among these systems. These execution operations are based on smart contracts' mutual agreements, and all transaction records are kept properly. Figure 5 is a simple explanation of the blockchain-based health database systems; however, more components exist in the structure in practice.

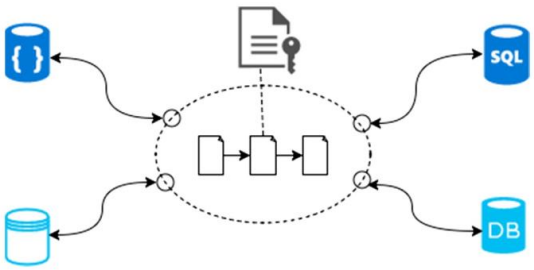

Figure 5. Blockchain-based conceptual infrastructure to connect different health database systems [34].

6. Conclusion

Following the Fourth Industrial Revolution, many technological advancements are available for manufacturing and service-based industries. As digital transformation takes place in everyday life, the healthcare industry is being revolutionized by these emerging technologies. These reforms in the healthcare field can be manifested as Health 4.0, which allows higher quality, efficient and effective healthcare products and services, optimizing the costs and resources. In order to achieve these goals, Health 4.0 utilizes such technologies as the Internet of Medical Things, Internet of Services, Medical Cyber-Physical Systems, Digitization and Virtualization, Fog Computing, Cloud and Health Big Data, Next Generation Mobile Communication Networks and Blockchain. The main contribution of this paper is to investigate the potential use of blockchain technology in healthcare. First, we review the evolution of healthcare technologies and how these development stages changed the way patients get treatments. Second, we explore blockchain technology and its potential benefits in many sectors. Finally, we discuss the integration of blockchain technology with the healthcare system and provide some insights regarding the potential gains.

Blockchain technology is one of the emerging technologies, and it offers great potential in improving the healthcare processes where healthcare data is processed fast, secure, and transparent. Blockchain technology eliminates the need for a third party between system participants and develops the healthcare process to minimize time and

effort. Having a direct interaction between healthcare system participants builds trust, minimizes disinformation, and accelerates the process. The healthcare data is recorded in blocks where participants can access the data at any time, anywhere. Each patient's data is stored, viewed, and analyzed without the risk of loss or intervention under his digital ID. Hence, blockchain technology reduces inefficiencies across patient or provider record keeping. Blockchain already has a wide range of applications and uses in the healthcare industry, even though it is new. In the future, blockchain technology will continue to improve security, reliability, privacy, and operational efficiency in the healthcare industry by offering robust and effective digital solutions.

References

[1] Thuemmler, C., & Bai, C. (Eds.). (2017). Health 4.0: How virtualization and big data are revolutionizing healthcare, 2168-2194. Cham Switzerland: Springer International Publishing.

[2] Drath, R., & Horch, A. (2014). Industrie 4.0: Hit or hype?[industry forum]. *IEEE industrial electronics magazine*, 8,2, 56-58.

[3] Al-Jaroodi, J., Mohamed, N., & Abukhousa, E. (2020). Health 4.0: on the way to realizing the healthcare of the future. *IEEE Access*, 8, 211189-211210.

[4] Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. *International Journal of Production Research*, 56,8, 2941-2962.

[5] GTAI (Germany Trade & Invest) (2014) . Industries 4.0-Smart Manufacturing for the Future. Berlin: GTAI.

[6] Gürdür, D., El-Khoury, J., Seceleanu, T., & Lednicki, L. (2016). Making interoperability visible: Data visualization of cyber-physical systems development tool chains. *Journal of Industrial Information Integration*, 4, 26-34.

[7] Hermann, M., Pentek, T., Otto, B., Pentek, T., & Otto, B. (2015). Design principles for industry 4.0 scenarios: A literature review. Technische Universität Dortmund.

[8] Thuemmler, C., & Bai, C. (2017). Health 4.0: Application of industry 4.0 design principles in future asthma management. In Health 4.0: How virtualization and big data are revolutionizing healthcare (pp. 23-37). Springer, Cham.

[9] Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017, June). An overview of blockchain technology: Architecture, consensus, and future trends. *In 2017 IEEE international congress on big data (BigData congress)* (pp. 557-564). IEEE.

[10] Karboub, K., Tabaa, M., Dandache, A., Dellagi, S., & Moutaouakkil, F. (2019). Toward Health 4.0: Challenges and opportunities. *In International Conference on Innovation and New Trends in Information Technology*, 20-21.

[11] Kagermann, H., Wahlster, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group. Forschungsunion: Berlin, Germany.

[12] Bause, M., Esfahani, B. K., Forbes, H., & Schaefer, D. (2019, July). Design for health 4.0: exploration of a new area. *In Proceedings of the Design Society: International Conference on Engineering Design* ,1, 1, 887-896, Cambridge University Press.

[13] International Telecommunication Union (2018), "M-health for NCD". [online] Available at: https://www.itu.int/en/ITU-D/ICT-Applications/Pages/mhealth-for-ncd-behealthy-bemobile.aspx [Accessed 14. November 2018]

[14] Mohamed, N., & Al-Jaroodi, J. (2019, April). The impact of Industry 4.0 on healthcare system engineering. *In 2019 IEEE International Systems Conference* (SysCon),1-7, IEEE.

[15] Andrew Steger (2020) How the Internet of Mediucal Things is Impacting Healthcare https://healthtechmagazine.net/article/2020/01/how-internet-medical-things-impacting-healthcare-perfcon

[16] Deloitte Retrieved 13 June 2021, from https://www2.deloitte.com/global/en/pages/life-sciences-and-healthcare/articles/medtech-internet-of-medical-things.html

[17] Cardoso, J., Voigt, K., & Winkler, M. (2008, June). Service engineering for the Internet of services. *In International Conference on Enterprise Information Systems,* 15-27, Springer, Berlin, Heidelberg.

[18] Lee, I., Sokolsky, O., Chen, S., Hatcliff, J., Jee, E., Kim, B., ... & Venkatasubramanian, K. K. (2011). Challenges and research directions in medical cyber–physical systems. *Proceedings of the IEEE*, 100,1, 75-90.

[19] Khayamian Esfahani, B., Bause, M., & Schaefer, D. (2019, July). Health 4.0: How Digitisation Drives Innovation in the Healthcare Sector. *In The 2019 International Conference on Systematic Innovation* , 75-81, The Society of Systematic Innovation.

[20] Soni, N. (2020). Evolution of blockchain. medium. retrieved 8 June 2021, from https://medium.com/@nehasoni1812/evolution-of-blockchain-f243f7509fe6.

[21] Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017, June). An overview of blockchain technology: Architecture, consensus, and future trends. *In 2017 IEEE international congress on big data* (BigData congress) ,557-564, IEEE.

[22] Chatterjee, R., & Chatterjee, R. (2017, October). An overview of the emerging technology: Blockchain. *In 2017 3rd International Conference on Computational Intelligence and Networks (CINE)*, 126-127, IEEE.

[23] Joshi, A. P., Han, M., & Wang, Y. (2018). A survey on security and privacy issues of blockchain technology. *Mathematical Foundations of Computing,* 1,2, 121.

[24] Mukherjee, P., & Singh, D. (2020). The opportunities of blockchain in health 4.0. In Blockchain Technology for Industry 4.0, 149-164, Springer, Singapore.

[25] Chang, S. E., Chen, Y. C., & Wu, T. C. (2019). Exploring blockchain technology in international trade: Business process re-engineering for letter of credit. Industrial Management & Data Systems.

[26] Golosova, J., & Romanovs, A. (2018, November). The advantages and disadvantages of the blockchain technology. *In 2018 IEEE 6th Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE)*, 1-6, IEEE.

[27] Mettler, M. (2016, September). Blockchain technology in healthcare: The revolution starts here. *In 2016 IEEE 18th international conference on e-health networking, applications and services (Healthcom)*, 1-3, IEEE.

[28] Agbo, C. C., Mahmoud, Q. H., & Eklund, J. M. (2019, June). Blockchain technology in healthcare: a systematic review. *In Healthcare,* 7, 2,56. Multidisciplinary Digital Publishing Institute.

[29] Gordon, W. J., & Catalini, C. (2018). Blockchain technology for healthcare: facilitating the transition to patient-driven interoperability. *Computational and Structural Biotechnology Journal*, 16, 224-230.

[30] Ahram, T., Sargolzaei, A., Sargolzaei, S., Daniels, J., & Amaba, B. (2017, June). Blockchain technology innovations. *In 2017 IEEE Technology & Engineering Management Conference (TEMSCON)*, 137-141, IEEE.

[31] Angraal, S., Krumholz, H. M., & Schulz, W. L. (2017). Blockchain technology: applications in health care. *Circulation: Cardiovascular quality and outcomes*, 10,9, e003800.

[32] Engelhardt, M. A. (2017). Hitching healthcare to the chain: An introduction to blockchain technology in the healthcare sector. *Technology Innovation Management Review*, 7,10.

[33] Bell, L., Buchanan, W. J., Cameron, J., & Lo, O. (2018). Applications of blockchain within healthcare. *Blockchain in healthcare today*.

[34] Zhang, P., Schmidt, D. C., White, J., & Lenz, G. (2018). Blockchain technology use cases in healthcare. *In Advances in Computers* ,111, 1-41.