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Future of Drug Discovery: The Synergy of Edge Computing, Internet of Medical Things, and Deep Learning

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Abstract: The global spread of COVID-19 highlights the urgency of quickly finding drugs and vaccines and suggests that similar challenges will arise in the future. This underscores the need for ongoing efforts to overcome the obstacles involved in the development of potential treatments. Although some progress has been made in the use of Artificial Intelligence (AI) in drug discovery, virologists, pharmaceutical companies, and investors seek more long-term solutions and greater investment in emerging technologies. One potential solution to aid in the drug-development process is to combine the capabilities of the Internet of Medical Things (IoMT), edge computing (EC), and deep learning (DL). Some practical frameworks and techniques utilizing EC, IoMT, and DL have been proposed for the monitoring and tracking of infected individuals or high-risk areas. However, these technologies have not been widely utilized in drug clinical trials. Given the time-consuming nature of traditional drug- and vaccine-development methods, there is a need for a new AI-based platform that can revolutionize the industry. One approach involves utilizing smartphones equipped with medical sensors to collect and transmit real-time physiological and healthcare information on clinical-trial participants to the nearest edge nodes (EN). This allows the verification of a vast amount of medical data for a large number of individuals in a short time frame, without the restrictions of latency, bandwidth, or security constraints. The collected information can be monitored by physicians and researchers to assess a vaccine's performance.

Keywords: artificial intelligence; big data; deep learning; drug discovery; edge computing; internet of things; internet of medical things; natural language processing

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1. Introduction

The COVID-19 pandemic has created a medical crisis that has highlighted the need for integrated approaches to overcome the challenges facing the healthcare system. Digital healthcare mechanisms have emerged as reliable methods to solve this problem, offering effective solutions for mitigating the pandemic and treating chronic diseases. Due to the transmission of the COVID-19 virus, many countries have implemented strict restrictions that have negatively affected communication between physicians and patients [1]. In this context, emerging technologies have prompted a significant shift towards digital healthcare technologies, which are increasingly recognized as key solutions for addressing these challenges [2–6].

The use of Internet of Things (IoT) technology during the COVID-19 pandemic has been recognized as a valuable tool in managing and mitigating the impact of the virus. It can provide real-time data on the virus's spread, patient conditions, and resource availability, enabling healthcare providers and public health officials to make informed decisions. Furthermore, IoT devices can allow remote patient monitoring, reducing exposure risks and minimizing the strain on healthcare systems'. Overall, the integration of the IoT into healthcare and public health systems offers an innovative solution to the challenges posed by the pandemic, such as lockdown situations, providing an automated and transparent treatment process. This is especially important during these difficult times [7].

The importance and time-sensitive nature of this matter have driven the development of various new technologies. One such technology is edge computing (EC), which involves distributing computational resources closer to consumers to increase computation speed and enhance bandwidth utilization [8–10]. This technology involves performing the majority of computations on edge devices (EDs) located in close proximity to the areas in which Internet of Things (IoT) devices require data processing. Edge devices are robust resources that can improve pandemic situations by enabling the use of intelligent medical equipment (IME) and other support equipment. Various tools, such as webcams, drones, intelligent gadgets, sensors, and robots, are beneficial in pandemic situations. Therefore, a framework that combines deep learning (DL) and EC can significantly improve the efficiency and productivity of conventional methods [11,12]. In particular, an EC platform is proposed to expedite drug development during clinical phases. By contrast, existing medical methods for clinical trials do not use real-time technology to monitor vaccinated individuals. Our approach allows the symptoms and healthcare information of vaccine candidates to be monitored and managed through smartphones [12].

This paper is organized into six sections. In Section 1, we introduce the topic of EC and its potential applications in healthcare. Section 2 provides a background on EC and IoT technology. Section 3 explores state-of-the-art IoT applications in medicine. Section 4 delves into the intersection of EC, DL, the Internet of Medical Things (IoMT), and drug discovery. In Section 5, we provide a discussion of the key findings and potential implications of these technologies for the future of healthcare. Finally, in Section 6, we offer our conclusions on the potential impact of EC and IoT on the healthcare industry.

2. Edge Computing and IoT

Cloud computing (CC) refers to a centralized computing platform that grants access to cloud servers without disruptions [13]. These robust servers offer the computational resources necessary to extract patterns and useful insights by processing large volumes of data obtained from IoT devices and returning the resulting output. However, CC is not a suitable computing resource for delay-sensitive applications that require the transmission of vast amounts of data from devices through wireless communication [14].

In recent times, remarkable advancements in advanced technologies and AI-powered methodologies have given rise to innovative techniques to improve healthcare processes, facilitating the growth of medical systems [3,15]. The IoMT is a significant subset of the IoT that is used extensively in healthcare [16]. Furthermore, EC-based technology has emerged as a solution to address issues with latency and bandwidth in real-time systems. Edge computing involves moving computational and data-storage resources closer to where they are required, such as IoT devices. This means that the central part of the computation in a cloud is transferred to local trusted edge servers situated close to IoT devices. This approach not only reduces latency but also offers several advantages, including scalability, efficient bandwidth utilization, and improved privacy [17].

Deep learning has an important advantage in that its layers can be trained automatically without requiring manual design. This makes it applicable to a wide range of fields in science and engineering. In addition, numerous techniques and algorithms have been developed to identify complex relationships with nonlinear functions.

3. Background: State-of-the-Art IoT Applications and Medicine

The healthcare system has been the focus of many studies on the potential of IoT and EC technologies. Table 1 provides an overview of the current state-of-the-art applications of IoT and EC that can be leveraged to develop a drug-discovery ecosystem. One example is the use of IoT sensors to collect data for the predictive maintenance of devices and equipment, which can help to develop a resiliency plan for the industry. Li et al. proposed using DL for IoTs in an EC ecosystem [8]. Edge computing is a computing architecture that is designed to bring computation and data storage closer to where they are needed, such as IoT devices. Their aim is to reduce latency and improve performance by minimizing data transmission to and from a centralized cloud server. Instead, computational resources are distributed to local trusted edge servers, allowing the faster processing of data in real time. Additionally, EC offers benefits such as increased privacy, scalability, and reduced bandwidth usage [8].

Feriani et al. proposed an end-to-end IoT platform that utilizes mobile EC to collect and analyze real-time data on the physical conditions of human subjects for healthcare purposes. The platform employs a representation-learning technique to extract valuable insights from large amounts of data with varying dimensions, which are obtained from IoT-EDs that are equipped with specific monitoring equipment [17]. The data collected are then used for the real-time observation and analysis of symptoms. This platform aims to improve the accuracy of diagnoses and to offer personalized treatments for patients, thereby enhancing the overall quality of healthcare services [3]. The proposed IoT-based platform can help address the limitations of traditional monitoring systems by leveraging EC and specific monitoring equipment to collect and analyze the real-time data obtained. The extracted information is then transferred to the cloud for further analysis and processing. Overall, this platform can provide more actionable insights and improve the tracking and monitoring of healthcare ecosystems.

The study conducted by Amano et al. proposed a real-time-monitoring platform that utilized mixed reality (MR) and augmented reality (AR) devices to visualize locations that pose a high risk of infection, including shopping malls, stations, airports, and restaurants. In this system, a single spatial database is used to store and aggregate public information related to these high-risk locations, including the overcrowding and congestion levels of shops and floors. This aim of this platform is to assist in the monitoring and control of the spread of infectious diseases by providing real-time information about crowded places and identifying potential sites of high levels of infection. The use of MR and AR devices allows a more immersive and interactive experience, enabling users to navigate through virtual representations of real-world environments and identify potential sources of infection [2]. The system provides key factors that can help the industry to survey the feasibility of wearable AR equipment for detecting and monitoring activity spaces in intelligent ecosystems without infringing on privacy [2].

Nguyen et al. proposed a novel approach that combines blockchain technology and shareable databases for a reliable monitoring platform over narrowband Internet of things (NB-IoT) connectivity. The proposed system aims to address the challenges of data security, data integrity, and data availability in IoT-based healthcare applications. The authors proposed a blockchain-based distributed database system that enables the secure and reliable sharing of medical data among different healthcare providers, while also ensuring data privacy and confidentiality. The system utilizes the low power, low cost, and wide coverage features of NB-IoT to transmit medical data to the cloud, where it is stored securely and can be accessed by authorized users. The results of the study showed that the proposed system provides reliable and secure data storage and transmission, making it a promising approach for IoT-based healthcare applications [18]. The suggested database relies on distributed ledger technology (DLT), which is commonly employed to synchronize, replicate, and distribute information across various locations, organizations, sites, and decentralized networks. The findings indicated that utilizing blockchain with IoT systems amplified the burden on the downlink channel. Consequently, merging NB-IoT monitoring methods with blockchain technology has numerous advantages for various applications, particularly those that involve confidential data [18]. Sufian et al. conducted research on the possibilities of and obstacles against utilizing EC-boosted deep-transfer learning (DTL) to alleviate the impact of the COVID-19 pandemic [15].

Table 1. Summary of the state of- the art of EC technology and IoT-based systems in medicine.

Author(s)	Journals	Application of IoT or Edge Devices	Methodology or Equipment	Main Findings
Li. et al. [8]	IEEE Network	• Learning IoT in edge: Deep learning for the Internet of Things with edge computing	Ten different convolutional neural networks (CNN)	Applications of IoT and edge computing within a framework
Feriani et al. [3]	IEEE Internet of Things Magazine	• eHealth monitoring in general • COVID-19 symptoms in particular	Hierarchical multi-access EC (MEC) framework	Monitoring COVID-19 symptoms using MEC
Amano et al. [2]	IEEE Internet of Things Magazine	• Understanding the activity space • Sharing the detected data among those residing in the space	Wearable AR/MR devices Secure Connected AR Platform (SCARP)	Applications of AR/VR in spaces
Nguyen et al. [18]	IEEE Communications Magazine	• A monitoring system based on NB-IoT • Reducing the risk of COVID-19 infection in places	Distributed ledger technologies (DLTs)	Using NB-IoT and DLTs for monitoring purposes
Hossain et al. [4]	IEEE Network	• Diagnosing COVID-19 using chest-CT-scan and X-ray images • Developing a surveillance platform for monitoring objectives	The algorithms are first come, first served (FCFS), highest value first (HVF), and shortest job first (SJF)	Using FCFS and HVF on a a surveillance platform for diagnosing COVID-19
Sufian et al. [15]	Journal of Systems Architecture	• Possibility of using EDs, including IoT devices, drones, webcams, and smart equipment, to combat the COVID-19 pandemic • Reviewing relevant technical backgrounds and state of the art	DTL and DL techniques	Review and assessment of state-of-the-art IoT devices for COVID-19 monitoring
Rahman et al. [19]	IEEE Network	• Introducing a COVID-19-management framework • Presenting a Beyond 5G (B5G) framework to improve COVID-19 diagnosis, decrease the latency, and increase the bandwidth	Mobile edge computing	Presenting a 5G (B5G) framework to improve COVID-19 diagnosis based on mobile edge computing

The researchers were motivated to use DTL due to the substantial difficulties in applying DL to devices with limited computing resources. The effectiveness of DTL in EC is attributed to its training process, since DTL can be trained on one task and subsequently applied to another task. The study also showcased the current state of the art, recent technical basics, and the practical applications of DTL with EC to address any future pandemics.

A framework for Beyond 5G (B5G) was suggested that facilitates high-speed and low-latency communications to aid in the diagnosis of COVID-19 [19]. The proposed platform consisted of a distributed DL model, in which each COVID-19 edge adopts a three-phase approach, with the DL structure operating globally while employing its own local DL structure. In this approach, the local DL structure runs on the edge nodes, while the global DL structure operates in the cloud. The local DL model is trained on the dataset available near the edge, which is then validated by domain experts before being applied to the DL model located in the cloud. The proposed platform was also enhanced using semantic visualization and feedback from experts [19].

Hossain et al. presented a B5G healthcare framework that incorporates a mass-surveillance system and AI to analyze chest-CT-scan or X-ray images, as well as establishing a monitoring system that manages mask wearing, body temperature, and social distancing [4]. The proposed framework employs three DL-based techniques, namely Deep Tree, ResNet50, and Inception v3. Additionally, the blockchain method was incorporated to enhance healthcare-information security [4].

The key features that ensure the effectiveness and performance of IoT-based systems for medical purposes include network adaptation, real-time healthcare-information processing, security, and efficient monitoring. The latest IoT and EC frameworks have demonstrated that combining EC and IoT is a valuable approach to developing technically sound medical networks. Additionally, DL is a powerful method for solving and diagnosing complex issues in real time when numerous sensors generate a significant amount of health data [20]. This is because DL can identify meaningful relationships between inputs and outputs without requiring human involvement on a real-time IoT platform. However, additional research is required to leverage the ability of emerging technologies to optimize the process of developing antiviral drugs, which has become a challenging and time-consuming task, despite some positive developments in vaccine development using conventional methods.

Based on the capabilities and potential of the techniques introduced in prior research [1–6,9,10], we were motivated to use these characteristics to design and develop an intelligent ecosystem for drug discovery, especially in clinical trials. To meet the requirements of designing a new environment with a focus on drug development, we leveraged the ideas demonstrated in previous research [2–4,21] to design a healthcare-monitoring platform while also utilizing specific characteristics of the framework introduced in [8,14,15,19] to support our platform with DL and EC techniques.

4. EC, DL, IoMT, and Drug Discovery

This section discusses the potential of integrated approaches that utilize deep learning, CC, and EC to support drug discovery [11,22]. The proposed framework surveys software components, such as CC, EC, and DL, as well as hardware components, such as edge devices (ED) and IoMT, to enhance the traditional process of designing and approving drugs and vaccines. In order to present this framework, it is important to focus on cutting-edge EC technology and consider recent advancements in the field. While this framework has shown promise in accelerating the process of designing COVID-19 vaccines, it can also be applied to discovering vaccines for other diseases, and it serves as a novel and intelligent approach in drug discovery [23,24].

The framework for drug discovery is represented in Figure 1, which shows a schematic diagram of the seven layers involved in the process. The layers are the virus identification, the prediction of suitable virus antigens, the identified antigens, the immunization of animals, the analysis of the animals' responses, clinical trials, and approved vaccines. Although Layer 6 (clinical trials) is the most significant part of the framework, as it uses EC to monitor vaccine candidates and analyze potential vaccines, the entire platform demonstrates how emerging technologies can be integrated to achieve the best results. Each layer can be examined from different perspectives, such as its purpose, the techniques used, and its inputs and outputs. The framework was designed to leverage the latest technological achievements and state-of-the-art EC to improve the traditional process of designing and approving drugs and vaccines. The platform has already shown its effectiveness in accelerating the process of COVID-19-vaccine design and can also be used as an intelligent approach for discovering vaccines for other diseases. In drug discovery, Layer 3 refers to the experimental phase, in which the antigens identified in Layer 2 are analyzed in various ways. This stage is critical in developing new methods for treatment and diagnosis. One useful tool in this stage is repertoire analysis, which allows the performances of adaptive immune systems to be analyzed and addressed. Through repertoire analysis, researchers can better understand the connection between antigen receptors and their specifications, leading to novel high-throughput approaches for describing these structures. Overall, Layer 3 is an important phase in drug discovery that can contribute to the development of new and effective treatments and diagnostic methods.

The specific roles of each of the seven layers in the proposed framework are presented below.

The first layer, referred to as Layer 1, is primarily concerned with the identification of viruses. This is an important task, and the methodologies used in this layer have been extensively researched and deployed in numerous investigations and medical studies. Virus identification involves a complex process of examination and analysis, which requires the use of various experimental techniques and analytical tools. In particular, bioinformatics play a crucial role in enabling the identification of viruses. Through bioinformatics operations, the crystal structure of the virus can be modeled and analyzed, leading to the identification of important biological features and sequence chains.

It is worth noting that two critical outcomes can be derived from bioinformatics operations in virus identification: the biological assembly and the sequence-chain perspective. These outcomes provide valuable insights into the nature and behavior of the virus, which can be used to inform further investigations and studies. Overall, Layer 1 serves as a critical starting point in the proposed framework, enabling the identification of viruses and laying the groundwork for subsequent layers to build upon. Through a combination of experimental and analytical techniques, and with the aid of bioinformatics operations, Layer 1 provides a robust and reliable means of identifying viruses and advancing our understanding of their biology.

A large number of crystal structures of molecule fragments that bind to the principal protease of the virus that causes COVID-19 were generated by a large-scale screening method. Therefore, independently of all the other valuable steps in the discovery of drugs for COVID-19, it is worth researching these structures. One of the significant issues in this layer is understanding the role of ribonucleic acid (RNA), a major polymeric molecule, from various biological perspectives, such as the presentation of genes, regulation, coding, and decoding. In summary, this layer is used for virus identification, and many achievements have been obtained in this area by using bioinformatics. Even if we ignore the use of AI methods to improve the performance of this layer, the bioinformatics-based method can be enhanced using DL or EC.

Layer 2 of the proposed framework builds upon the virus identification in Layer 1, focusing specifically on the development of drug compounds that can be used to treat viral infections. Numerous potential drug compounds can be developed, with thousands of methods available for de novo drug development. To effectively navigate this vast array of potential drug compounds, an autonomous architecture is required to facilitate the discovery of suitable compounds. In this layer, DL techniques are used in combination with CC to predict suitable antigens, as well as B-cell and T-cell epitopes. This approach allows the rapid and accurate identification of potential drug candidates, streamlining the drug-discovery process and reducing the time and resources required. Characterizing T-cell immunity is a crucial aspect of this layer, as it plays a significant role in the development of vaccines and the treatment of virus-related infections. By identifying suitable T-cell epitopes, it becomes possible to design drugs that specifically target the virus and stimulate the immune system to fight off the infection. This approach is a powerful tool in the fight against viral infections, offering new possibilities for the development of effective treatments and vaccines [25]. The study of RNA-binding proteins is crucial for identifying the underlying causes of many disorders and diseases, as well as developing effective models for regulating biological systems. To achieve this, it is essential to develop a deep understanding of the sequence characteristics of RNA-binding proteins. However, this is a complex and challenging task, as there is a vast amount of data to process, and traditional methods may not be sufficient to handle the volume and complexity of the information involved. Fortunately, DL-based methods offer a promising solution to this problem, as they are capable of processing large amounts of data quickly and accurately. By utilizing DL algorithms in the CC framework, it is possible to develop highly effective predictors for RNA-binding protein sequences. This combination of methods is a practical and useful area of research, with the potential to revolutionize our understanding of these critical biological components. With the ability to process vast amounts of data and identify important sequence characteristics, DL-based methods hold great promise for advancing our understanding of RNA-binding proteins and their role in biological systems [14]. Another aspect of this stage involves profiling small molecules through image-based analysis. A critical aspect of understanding disease pathogenesis and cell physiology is identifying the pathways and intracellular molecules involved in cellular communication. The ability to decipher these complex interactions is crucial for developing effective treatments and advancing our understanding of cellular processes [26]. This stage has the potential to significantly expedite the prediction of the critical parameters necessary for vaccine design. By utilizing innovative techniques, such as multicolor multicycle molecular profiling (M3P) technology, in conjunction with staining imaging methods, comprehensive research has shown promising results for advancing drug discovery, molecular diagnostics, and gene-expression investigations. The integration of these cutting-edge technologies is a powerful tool for developing effective vaccines and enhancing our understanding of disease mechanisms. With the potential to accelerate the discovery and development of new treatments, this stage holds great promise for improving healthcare outcomes and advancing scientific research [26].

Layer 3 in the framework comprises the experimental phase of the drug-discovery process, and it is specifically focused on the antigens identified in the previous layer. This stage is critical to drug discovery in various ways, as it enables the analysis and assessment of the adaptive immune system's performance. Repertoire analysis is a powerful tool in this phase, providing insights into how the immune system responds to specific antigens and facilitating the development of new treatments and diagnostic methods. One of the key benefits of this layer is the ability to use novel high-throughput approaches to describe antigen receptors and connect these structures to their specifications in antigens. This can inform the design of more effective treatments and vaccines. By leveraging the power of repertoire analysis and other cutting-edge techniques, this layer represents a critical stage in the drug-discovery process, offering further possibilities for improving healthcare outcomes and developing scientific research.

Layer 4 plays a crucial role in developing drugs using animal-envenoming therapy by creating protective immunity in animals. However, traditional animal trials may not be effective in producing some highly efficient antibodies, such as broadly neutralizing monoclonal antibodies. This can lead to increased costs and errors. Therefore, the fifth layer in the drug-development process is an intelligent approach that aims to address these weaknesses and overcome the limitations of traditional animal trials.

Layer 5 is designed to predict the effects of animal antibodies when combined with drug candidates. Using the CC platform shown in Figure 1, this layer facilitates the use of DL computations to estimate the behavior of antibodies in human trials.

However, due to the limitations of traditional ICT equipment, many companies are turning to CC as an effective approach to combine different data-mining methodologies and handle the vast amounts of data generated by animal trials. As a result, this layer is a strong candidate for analyzing the big data produced by animal trials in Layer 4. By leveraging the power of CC and DL, researchers can more accurately predict the behavior of antibodies in human trials, ultimately leading to more effective drug development and faster times to market. Overall, this layer plays a critical role in the drug-development process by enabling researchers to make informed decisions based on the data generated by animal trials.

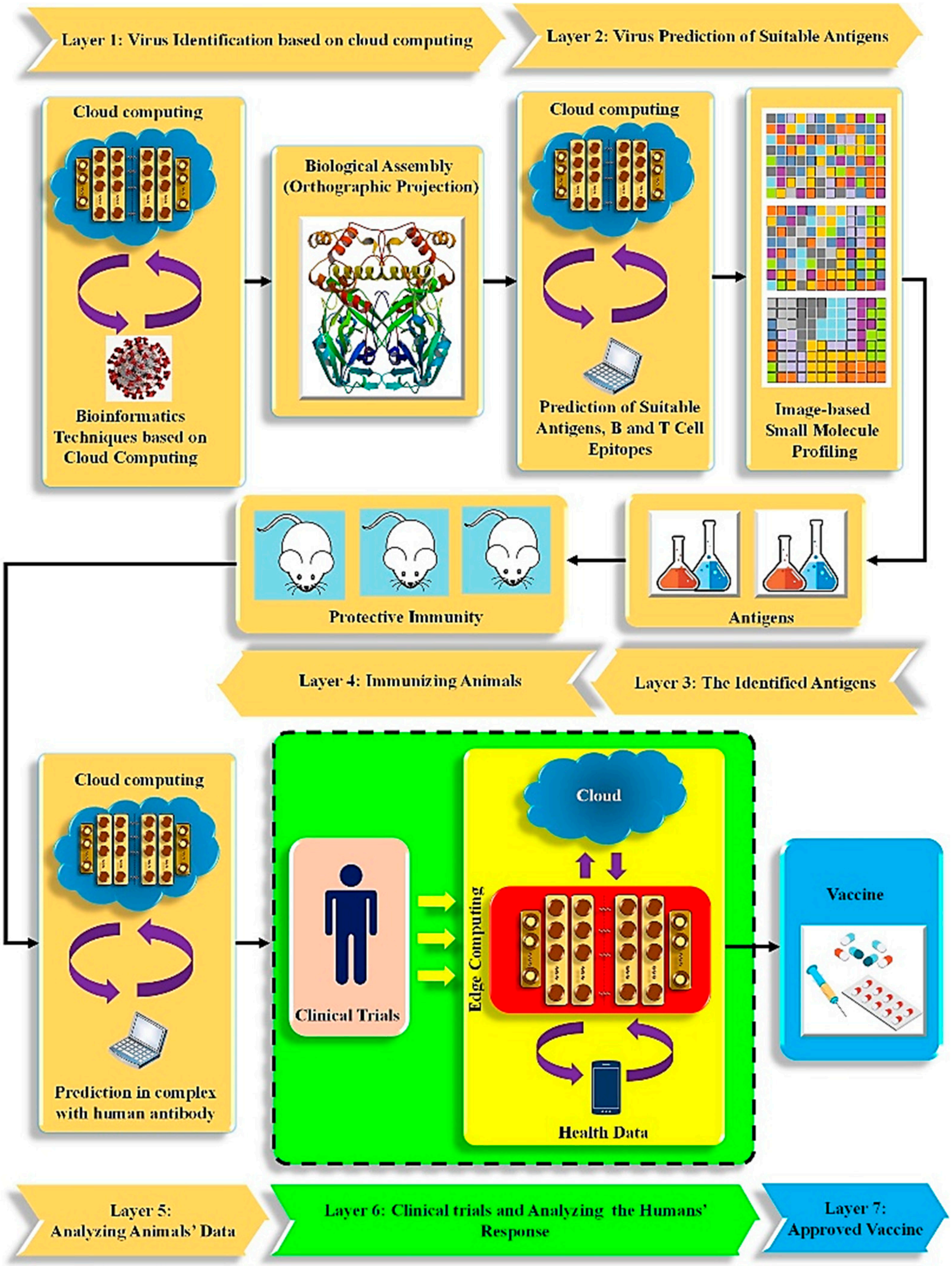

Figure 1. Proposed AI-Powered Strategy for Vaccine Development: A Seven-Layer Approach from Crystal-Structure Modeling to Approval. This schematic diagram illustrates a novel approach to vaccine development that leverages the power of Artificial Intelligence (AI) across seven layers. The process begins with the modeling of crystal structures, which are shown in the diagram to explain how the proposed method works. By using AI algorithms to analyze large amounts of data and make predictions about vaccine candidates, researchers can optimize the efficacy and safety of potential vaccines. This strategy has the potential to significantly accelerate the development of effective vaccines, as it allows researchers to prioritize the most promising candidates for further testing and clinical trials. The crystal structures shown in the diagram were extracted from [27], indicating that the proposed AI-powered strategy is based on previous research and findings in the field of crystallography.

Layer 6 is designed to serve as an automated platform that uses a combination of cutting-edge technologies, including DL, EC, IoMT, and CC, to facilitate the human-trial phase of vaccine and drug development. By utilizing this platform, significant improvements can be ensured in the design of vaccines and drugs, thanks to the numerous advantages and features it provides. It is important to note that this layer represents a modernized approach to the traditional method of conducting human trials and has the potential to expedite this crucial stage in the drug-development process. There are several reasons why this phase is crucial for discovering anti-coronaviral drugs, including the fact that since the COVID-19 pandemic began, scientists have studied at least 166 potential vaccines in different stages, including preclinical and clinical examinations [28].

To ensure reliability in this phase, it is imperative to incorporate DL-based methods in the development of these platforms. Furthermore, research has suggested that individuals who receive vaccines in the initial stages may not develop strong immunity against the virus, necessitating the development of subsequent generations of anti-coronaviral drugs. Therefore, it is critical to employ advanced technologies and reliable methods to expedite the drug-development process, especially given the urgent need for effective treatments during the ongoing pandemic [28].

Undoubtedly, analyzing and surveying the health information of diverse populations using conventional methods without deploying AI-based techniques has worsened the situation. Therefore, we propose a technology-based framework to overcome these challenges. In this context, Layer 6 is the central component of the proposed framework, as depicted in Figure 2.

Through a comprehensive EC-based platform, people who receive vaccines at various stages can be monitored and controlled. The proposed framework for clinical trials comprises three main parts that allow the collection and real-time processing of health data in the shortest possible time. Using IoMT devices and smartphones, the proposed method extracts various health-data points from each vaccinated individual, including data on heart rate, voice signal, blood pressure, body temperature, electrocardiography (ECG), electroencephalography (EEG), pulmonary-function tests (PFT), and pulse oximetry. By leveraging these advanced technologies, we can gain valuable insights into the effectiveness of vaccines and optimize the drug-development process.

Edge computing can enhance the performance of conventional IoT and IoMT devices and mitigate the challenges associated with real-time systems in cloud computing. These challenges include limitations on bandwidth, processing restrictions, and concerns related to the security and privacy of medical information. Ordinary IoT platforms often face difficulties in collecting and transferring large volumes of health data from various points, which can result in structural limitations and a range of complex issues. By leveraging EC in the proposed framework, we can address these challenges and achieve greater efficiency and accuracy in the collection and processing of health data in real time, facilitating the creation of a more seamless drug-development process [3].

Internet-of-Medical-Things devices designed to meet healthcare requirements can be used to extract meaningful information from complex health data. The IoMT paradigm is an amalgamation of conventional medical systems with IoT, and it is used to effectively diagnose and treat diseases and expand the infrastructures capable of processing and sensing big data. Equipping IoMT devices with wearable medical sensors can create a powerful tool for monitoring the health information of millions of people, since, in this way, IoMT devices can permanently transmit the medical information of a vaccinated person to the nearest ED. Once the ED receives the data, it classifies and analyzes the information and sends the results where physicians and researchers at medical centers in the form of charts, graphs, tables, and notes. In an emergency, the system immediately alerts an ambulance and relevant doctors.

To facilitate the analysis of large amounts of data, the platform must be connected to CC servers to enable easy updates. If there are any bugs in or updates to the DL methods or the natural language processing (NLP) programs installed on the ED, the connection to CC allows the system to be updated easily to keep up with the latest advancements in COVID-19 diagnosis and treatment, as well as AI methods.

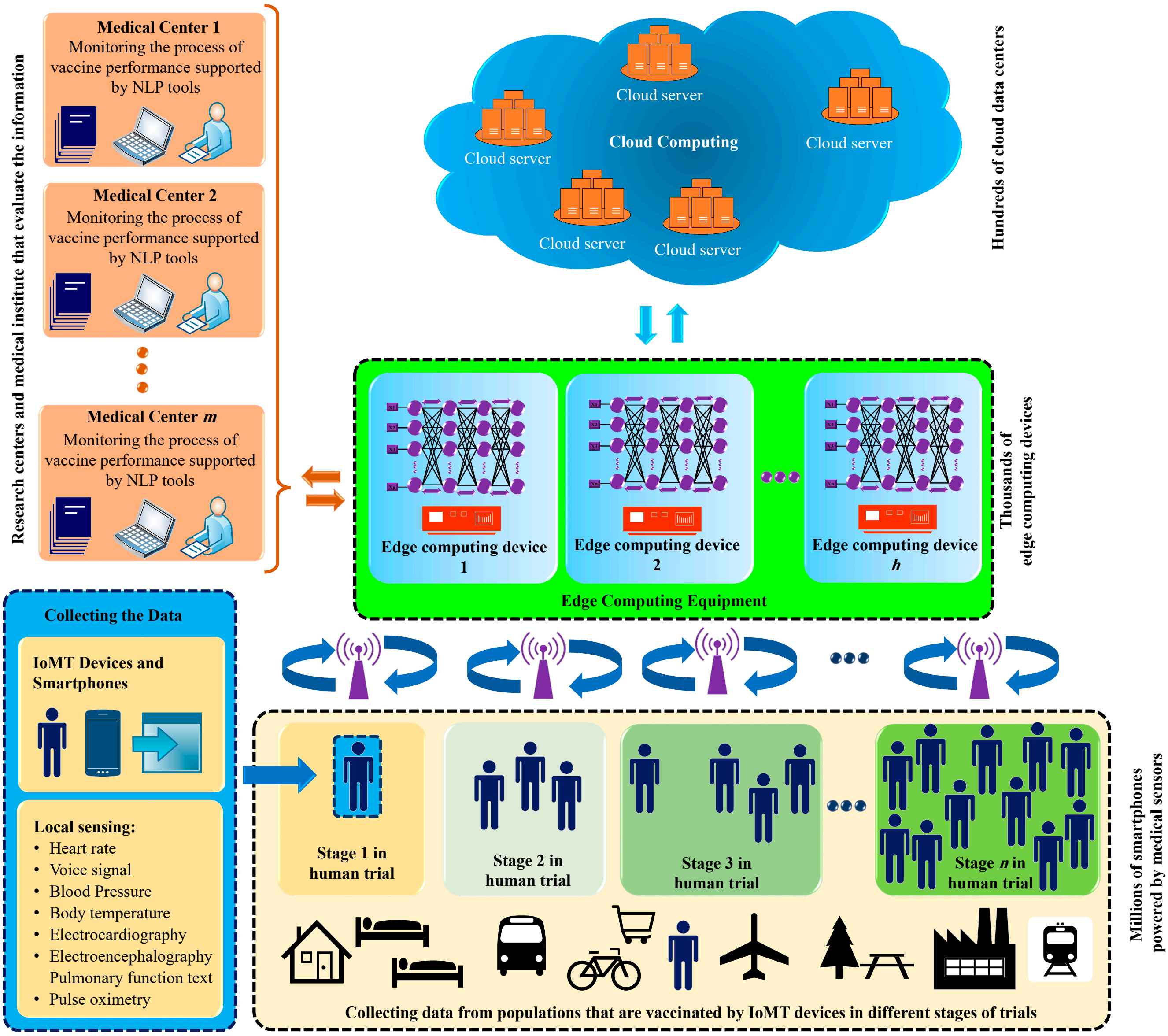

Figure 2. Layer Six: Architecture for Vaccinated Persons' Health-Data Monitoring and Control. The proposed architecture for Layer 6 in a framework for monitoring and controlling vaccinated persons' health data is composed of three main sections. Firstly, a number of sensors and IoMT devices are used to collect health data from individuals. Secondly, an EC (edge computing) platform processes the collected data at maximum speed, and a network of physicians, researchers, and natural language processing (NLP) tools supervise the process. Thirdly, CC (cloud computing) servers support the EC-platform infrastructure but do not directly participate in processing the health data [29]. This framework provides real-time monitoring and analysis of health data, which can be used to identify potential health concerns or track the effectiveness of vaccination programs. The use of sensors, IoMT devices, and NLP tools ensures that the framework operates efficiently and accurately.

The proposed framework for developing drugs and vaccines in trial stages involves using NLP to analyze clinical-examination reports and other unstructured data. This analysis can help identify patterns and insights that can be useful in drug development and vaccine trials. Natural language processing can assist in detecting potential health risks and generating control comments, which frees up healthcare professionals to focus on patient care rather than manual data analysis. The ability of NLP to quickly and accurately process large amounts of data is valuable in extracting important information from unstructured data sources. This information can be used to identify areas that need improvement or potential health risks. In addition, NLP can improve the accuracy of diagnoses by detecting patterns and trends that humans might miss. This leads to the earlier identification of health problems and better treatment options. By using NLP in health-data monitoring and control, healthcare processes can be made more efficient and accurate, resulting in better patient outcomes and improved overall health in the context of drug- and vaccine-development trials.

Furthermore, IoMT devices may require updates due to medical or technical reasons, and with millions of devices connecting to thousands of EDs, coordinating the software, hardware, and data can be challenging. However, the primary advantage of this approach is its support for CC servers. Although CC servers do not have real-time connections with the IoMT devices or managing platforms at medical centers, they can receive the latest instructions from operators via EDs. Consequently, they can update the DL methods based on necessary modifications, and IoMT devices receive essential updates from the EDs. As a result, the whole system can be updated quickly, depending on the volume of updated requirements. Therefore, this proposed method not only accelerates monitoring operations but also ensures that the system is continually updated.

In the context of the proposed IoMT system for the monitoring of vaccinations, the process of vaccine development and approval involves several stages, including clinical trials to test the safety and efficacy of vaccines. Once a vaccine has been tested and its performance has been analyzed, the results are reviewed by the regulatory organizations responsible for ensuring their safety and quality. If the vaccine meets the necessary criteria for safety and effectiveness, it can then be approved for commercialization and production by other companies.

The final stage of this process is referred to as Layer 7, and it represents the culmination of the development-and-approval process. At this stage, the vaccine has undergone rigorous testing and analyses to determine its safety and efficacy, and it has been deemed suitable for widespread use. At this point, the regulatory organizations responsible for approving vaccines grant permission for the vaccine to be produced and distributed by other companies. This process ensures that vaccines are safe and effective before they are made available to the public.

5. Discussion

In order to increase efficiency and productivity in the pharmaceutical industry, it is necessary to process the vast amount of data generated by IoMT devices [22]. However, companies that rely on traditional computing methods may face challenges in monitoring, analyzing, and managing these data [1]. The COVID-19 pandemic has highlighted the limitations of conventional methods in drug and vaccine development, and new computing paradigms, such as AI, DL, and EC, can be utilized to address these challenges [5,30]. Smartphones, smart gadgets, and other intelligent devices have become essential tools for data sharing and communication, particularly during emergencies [31]. Furthermore, the continuous advancements in mobile communication systems should be considered by medical-service providers. As more services become available online, it is predicted that the internet will play a significant role in satisfying the needs and expectations of both companies and customers.

This section discusses the advantages and potential outcomes of using an EC approach for drug discovery. It highlights how increasing technological capacity has created the infrastructure to support EC-based strategies.

- One of the benefits of this approach is the option to utilize DL-based methods and other AI-enabled computing techniques to strengthen healthcare systems. The demand for DL approaches in medical procedures is increasing, and more flexible technologies are needed to support different types of IoMT device.
- Another benefit is the shifting of the main aspect of data processing, pattern recognition, and classification from the cloud to edge devices (EDs) located near users and vaccine candidates. This reduces latency and improves the speed of data processing, which is critical in emergency situations.

- Using EC-enabled IoMT devices can also increase the storage space for big data generated by IoMT devices, thus facilitating the handling of vast amounts of data.
- Moreover, deploying this method can increase the level of security, especially regarding medical information. Any problems with safety can have fatal consequences for individuals and damage medical products. Therefore, boosting the security of the network is critical.
- Lastly, reducing latency is the most significant benefit of using EC-enabled IoMT devices, as it can play a crucial role in saving lives, especially in emergencies. In summary, using an EC approach for drug discovery offers many advantages and capabilities that can improve the efficiency and productivity of the pharmaceutical industry.

The assessment of the performance of high-tech platforms is crucial, and their applicability and implementation are among the key factors to consider. In this regard, the proposed platform is a promising solution, and there are some compelling pieces of evidence to support its potential. For example, a study investigating the potential of utilizing DL techniques for the IoT in an EC environment was conducted [8]. The authors demonstrated that DL can be a valuable tool with which to accurately extract information from raw sensor data in complex environments. To overcome the limitations of EC nodes' processing capabilities, the researchers developed a novel offloading strategy to enhance the performances of DL applications for the IoT. They evaluated the performance of this approach by executing multiple DL tasks in an EC environment and discovered that it outperformed other optimization solutions for DL in the IoT. The authors showed that it is possible and practical to apply deep learning to the IoT in an edge-computing environment, and that their new offloading strategy can help to improve the performances of IoT-based deep-learning applications in these environments [8].

Further evidence that the presented approach can be implemented is supplied through the research presented in an article highlighting the potential of DTL to mitigate pandemics [15]. The article explained that modern-day AI, especially DL, can be used in different ways to address disease spread, diagnosis, treatment, patient care, and drug discovery during pandemics. However, DL requires large datasets and powerful computing resources, which may not be readily available during a pandemic. The paper presented a scholarly study of the potential and challenges of using DTL and ED during pandemics. It reviewed recent research and drew a pipeline of DTL over EC as a future method to assist in the mitigation of any pandemic [15].

The evidence presented in a previous study demonstrated that the proposed approach was successfully implemented [2]. The approach involved the use of wearable AR/MR devices, which had advanced sensing technologies to determine individuals' surroundings and detect potential situations that may increase the risk of infection, such as crowded places, high body temperature, and contaminated objects. To securely share this information among individuals in the same space, the authors developed a privacy-aware platform called Secure Connected AR Platform (SCARP), which enabled the sharing of detected information without the need for personally identifiable digital IDs. The proposed approach aimed to reduce the risk of COVID-19 infection in public areas, including airports, shopping malls, and restaurants. Based on the evidence presented, it can be concluded that the proposed approach was successful in reducing the spread of COVID-19 in these public places [2].

Some future directions for implementing the proposed approach of using EC, DL, and the IoMT to improve efficiency and productivity in the pharmaceutical industry are as follows:

- Collaboration between pharmaceutical companies, medical-service providers, and technology firms to develop an integrated system that leverages EC, DL, and the IoMT to enhance the vaccine-development process.
- Research on and development of more advanced and specialized EC-enabled IoMT devices with high computational power, storage capacity, and communication capabilities to handle the vast amounts of data generated by IoMT devices.

- Building a secure network infrastructure that can withstand cyber-attacks and maintain the privacy of sensitive medical information.
- Continued advancements in mobile communication systems to support the increasing demand for online services and communication during emergencies.
- Utilizing DL-based methods and other AI-enabled computing techniques to strengthen healthcare systems and support different types of IoMT device.
- Bringing data processing closer to the edge of the network, reducing latency, and improving the speed of data processing, which is critical in emergency situations.
- Increasing storage space for big data generated by IoMT devices, thus facilitating the handling of vast amounts of data.

6. Conclusions

The conclusion of this study emphasizes the urgent need for a reliable and efficient technique to accelerate the vaccine-development process, which is currently time-consuming and costly, especially during the clinical phase. While pharmaceutical companies can easily monitor and control the symptoms of a small group of candidates, verifying the performance of large groups comprising several hundred thousand individuals under testing is a significant challenge. The viewpoint proposes a solution using EC, DL, and the IoMT to accelerate human trials and improve the efficiency and productivity of vaccine development.

The proposed integrated-vaccine-design framework utilizes DL and EC to create an appropriate online infrastructure to care for thousands or millions of vaccine candidates during examination. This framework enables physicians and researchers to comprehensively observe the clinical statuses of candidates while accessing a variety of charts, tables, graphs, and recommendations generated by DL-powered methods. The proposed approach offers several benefits, such as increasing flexibility by using DL-based methods, bringing data processing closer to the edge of the network, boosting storage capacity, enhancing network security, and reducing latency.

In summary, this study highlights the significant potential of EC, DL, and IoMT to revolutionize the vaccine-development process and offers a comprehensive framework to maximize its efficiency. By adopting this approach, pharmaceutical companies can reduce the time and cost of developing new vaccines, while healthcare systems can benefit from more flexible and efficient technologies for managing different types of IoMT devices. Ultimately, this can lead to better healthcare outcomes, especially in emergencies, in which reducing latency and increasing the speed of vaccine development can save lives.

The future directions below can be used to develop an integrated system that uses EC, DL, and the IoMT to enhance vaccine development and improve the efficiency and productivity of the pharmaceutical industry.

- The development of advanced EC-enabled IoMT devices.
- The construction of a secure network infrastructure.
- The development of advanced mobile communication systems to support online services and communication during emergencies.
- The utilization of DL-based methods to strengthen healthcare systems and support different types of IoMT device.
- The shifting of data processing closer to the edge of the network to reduce latency.
- Increasing the storage space for big data generated by IoMT devices.

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