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Internet of things for precision intensive medicine

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Abstract

Whereas the Precision Medicine approach plays a critical role in revolutionizing clinical decision-making, the accessibility of patient data in a customized way can empower this patient-centric clinical practice. Thus, successful utilization of the Internet of Things (IoT), is a technological booster for replacing the "one-size-fits-all" model to "patient-like-me" to tailor the treatment pathway according to the individual's variabilities in genetic profile, lifestyle, and environments indicators. This real-time and data-driven clinical decision-making model improves the quality of healthcare service, reduces side effects, cuts the cost of overt treatment, and saves more lives. This paper aims to highlight the significant role of IoT in emerging PM applications.

Keywords: Precision medicine; Clinical decision making; Intensive medicine; Internet of things, Real-time & data-driven model.

1. Introduction

Since the early 2010s the Internet of Things (IoT) started gaining attention, connecting sensors, devices, people, and applications in a wide range of industries through various frameworks (e.g., IoT healthcare, smart cities, smart home, smart transportations, and manufacturing) facilitates the digital transformation for achieving cost reduction and improving efficiency. One of the major benefits of adopting IoT, is real-time data collection from heterogeneous resources, where Data Analytics (DA) and Artificial Intelligence (AI) technologies enable knowledge discovery for personalizing the services.

There has not been a unique definition for IoT yet. However, the term "things-oriented" has been used widely in literature to present IoT as an ecosystem where things and people are connected anywhere and anytime via network connections. Moreover, companies such as IBM uses ''smarter planet'' and Cisco uses ''Internet of Everything'' as

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a replacement term for IoT [1]. Regardless of the type of industry, the intelligence and connectivity via IoT resulted in efficiency and advance prediction and optimization [2].

In a fragmented and data-driven domain such as healthcare, interconnected IoT architecture enables contributions of connected entities (e.g., people, devices, applications, and sensors) for updating medical information to propose the most promising data-driven clinical decision making [3]. Where, PM application takes advantage of the availability of rich personalized data for offering the best treatment performance based on the similarities in genetic, environmental, and lifestyle indicators. Therefore, the successful adoption of IoT in PM, not only improves the preventive care approach but also accelerates the adoption of a patient-centric clinical decision-making approach. This efficient clinical decision-making model enabled by IoT reduces the cost of overtreatment, increases the quality of services, and in general, positively influences population health [4].

PM approach aims to offer an accurate treatment pathway through the wide spectrum of population data, flowing from various resources where IoT empowers ongoing- high quality of health monitoring and management, accessibility, and continuous wide range of data collection for customizing health delivery. particularly for intensive care medicine which is relatively young and under the positive influence of healthcare digitization for better performance [5].

Progress in adopting AI, analytics, and IoT not only advances accurate predictive approach and care-based health service but also the availability of the high quality of wide range of individual patient data accelerates precise treatment and care-based service.[6] There are firms such as Amazon's Genomics in the Cloud, Google Genomics, IBM Watson Health, and SAP Health that have facilitated PM by offering infrastructures and relevant IoT devices [7], [8].

Collecting and accumulating patient-generated healthcare data from IoT devices is a key to population health management and ensuring high-quality patient care offered via a specialized service. Thus, the emergence of IoT in PM application has been a great advancement for improving clinical decision making which influences population health level.

This paper is organized in a way to explain the role of IoT for PM.

2. Internet of medical things (IoT) and precision medicine (PM)

2.1 Internet of Medical Things

The significant benefit of IoT applications (e.g., home healthcare, hospital healthcare, smart cities, and doctor's offices) [9] is to provide data from various connected resources (e.g., devices, applications, people, and sensors) for health analytic to perform over patient data. Discovering meaningful and actionable information improves clinical decision-making for obtaining precise medical scenarios. Besides, advanced technologies such as AI and cloud computing have made IoT technology a promising advancement for accelerating the emergence of PM.

Continuous patient health monitoring, advising the patient regardless of the geographical location, disease diagnosis, and using proper alarm systems when required are some of the considerable functionality of IoT to support the development of PM applications. This new clinical delivery approach resulted in personalizing the healthcare services cost-effectively and proactively [3].

According to table1, the general architecture of IoT technology contains four layers including application, real-time data processing, data storage & open EHR, network & communication, real-time data creation & acquisition.

- Application layer:

The role of the application layer in IoT enabled PM, is to propose high-quality services via the user-friendly interface for end-users. Applications such as continuous health monitoring, assisted living, therapy, personal digital assistants (PDAs), persuasive wellbeing, emotional wellbeing, fitness programs, emergency response, re-habitation, and elderly care aiming to track the patient health and to detect the patient at risks [10].

Furthermore, decision support systems help physicians for interpreting the results and helping clinical decision-making. Besides, hospital IoT medical systems that have been developed and have operated through medical structures such as Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), smart mobile technologies, and wearable medical devices, offer high performance medical and clinical services [9]. Where mobile

technologies are the essential part of the scenario[4].

Mobile health applications facilitate communications between the patient and physicians and collect data related to lifestyle and environmental factors, which are critical for proposing precise treatments. Furthermore, Wireless Body Area Network (WBAN), Body Sensor Network (BSN), cloud-based speech, face recognition platform enables doctors to monitor the physiological status of the patient regardless of the physical location of patients [7], [3]. Furthermore, smart rehabilitation application is another one-stop service specialized for elderly and disable people, also useful for those with chronic illness to monitor the wellness and checking the status of vital signs (e.g. temperature, heart rates, blood pressure, etc.) when they are at home in a real-time manner [11]. According to the United Nations (2019), the world's population of people at the age of 65 or above reached 703 million in 2019, and it is expected to reach 1.5 billion in 2050 [12]. Therefore, the growing aging population and consequently increasing chronic diseases, have become another important reason for accelerating the adoption of PM in healthcare and IoT plays a vital role in preventive treatment, early diagnostic, and identifying new diseases.

Moreover, devices that are used in the form of watches and tags, can track the movement and location of the patient during the activities such as running, walking, sleeping, and swimming. These types of data are significant for creating analytical patterns and also to figure out the lifestyle indicators which is a type of data needed for PM [12].

Another functionality of integrating IoT in PM applications is to overcome challenges related to administrations, particularly, dealing with a long waiting list for an initial health check. For example, self-monitoring biological indicators (body temperature, blood pressure) by mobile applications connected to sensors facilitates partial treatment at home regardless of the physical location of the patient. This monitoring tackles the challenges related to the long waiting list, administration procedures and speeds up the treatment pathway[2].

- Real-time data processing, data storage layers

The data processing layer performs via Extraction, Load, and Transform (ELT) were improving the accuracy and validity of health data are critical for algorithms and analytics to demonstrates the best possible performance [4].

One of the major aspect associated the adoption of IoT for PM is about the features of data, which comes from various resources and with different formats. In other words, data are pulled from heterogeneous connected sensors such as wearables that need to be integrated with EHR. On the other hand, EHR itself caries structured (e.g., ICD-9 diagnosis codes, administrative data, charts, and medication) and unstructured (e.g., clinical notes), particularly big omics data which is high dimensional. This characteristic has challenged health analytics performance and accordingly influences the accuracy of decision-making. Besides, the quality of data also faces limitations where the health records show missing information, mistakes in data entry tasks, miss interpretation which are the consequences of clinician's teamwork [13].

Advance technologies that influence the quality of data processing are cloud computing, health analytics, AI/ML algorithms, and also approaches such as medical image processing and signal processing. X-rays, cardiographs, ultrasounds, and other images are important for diagnostics of individual patient's diseases. Medical Imaging techniques are projected for creating images from different parts of the human body for disease diagnostics and further treatment. In 2015, three leading medical imaging companies Siemens Healthcare, Philips Healthcare, and GE Healthcare together built up a strategy for establishing an "All-in-one Health Cloud" to shift computer-based image processing into the health could ecosystem[7]. Cloud technology is introduced as an alternative to solve the challenges and limitations of physical storage management in terms of hardware and software[14].

- Network connection & communication layer

The network layer is responsible for providing a secure, reliable, and effective connection between "things" (e.g., people applications, hardware, and devices). Therefore, adopting standards, effective architecture (Service Oriented) and infrastructure (used IPv6 or 6LoWPAN) systems impact the interoperability and security required for IoT to perform efficiently [4]. Furthermore, since IoT recognizes existing objects in the network infrastructure, it offers an opportunity for interpretability and direct integration of related data. This approach increases the accuracy and efficiency in decision-making and reduces human intervention[3].

Many devices and applicators are connected via IoT infrastructure. This network needs to be expandable, compatible reliable, and secure for data collection [2]. For example, battery shortage or the poor quality of wireless connectivity leads a device to be disconnected from the network [1]. Thus, the lost network connection to the cloud