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The Internet of Things in Healthcare: Innovations and Challenges in Precision Diagnostics Systematic Review

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ABSTRACT
The rapid evolution of information technologies characterizes this digital age, the mobile advancement of the smartphone industry, the rising trend of multi-omic technologies, and the availability of the 5 G network and the significant data era. By embedding the knowledge needed for detection and actionable intelligence into intelligent sensors, querying devices, digital imaging and smartphone-based diagnostic assay tools, and interconnected networked intelligence, diagnostics are poised to become more innovative and more accurate. Notably, the Internet of Things has had an immense impact on multiple sectors ranging from digital imaging, intelligent sensing, digital diagnostics, digital biotechnology, telemedicine, precision agriculture, point-of-care testing, smart home systems, city planning, intelligent retail, and automated R&D. Implementing IoT technology in diagnostics and healthcare can help deliver personalized medical care specific to individual needs and facilitate more extensive remote healthcare, and management. This review investigates digital diagnostics' theoretical and technological progress through IoT technology. It also highlights the prospects and challenges of IoT in developing diagnostic applications. Through all of this theoretical integration, IoT-based tools like diagnostic, sensing, and imaging devices can provide high levels of automation and accuracy that have never before been seen in diagnostic processes, with the potential to act as a catalyst for a broader transformation in biomedicine and e-healthcare.

Keywords: IoT, Digital Health, Wearables, Telemedicine, Digital Biomarkers.

INTRODUCTION
The Internet of Things (IoT) constitutes a broad idea with multiple applications and significant technological, industrial, social, and economic consequences. This is yet another application of internet -connected devices and broad data analytics, enabling companies to revamp work processes and transform everyday life across the globe. The IoT ecosystem generally comprises various devices, networks, protocols, connections, cloud systems, software applications, deep learning algorithms, and analytics databases [1-2]. IoT technology represents a channel within which information can flow between devices, commercial appliances, and handheld devices like mobile phones and little accessories through the web. Recent technological advancements allow for real-time and remote monitoring (telemonitoring) of patients' health. Wristbands and other wearable smart devices can also particularly calculate physiological parameters : heart rate, blood sugar, blood stress, and body fat. Health apps can complement these devices with valuable data for monitoring [3, 4]. Wearable smart devices consist of various embedded devices and sensors that can be placed on the body, such as wristbands,

watches, necklaces, headbands, belts, eyeglasses, shoes, shirts, caps, etc. They are continuously used in our daily activities [5,6,7]. These are essential for data collection, sending to software or database, analysis, and information to the individual and health care provider. IoT in health care can solve many biomedical problems and change lives for millions worldwide. For example, IoT devices in health care enable remote monitoring with personalized attention from medical professionals. These devices are used to count calories, sugar levels, heart rate, blood pressure, and medication reminders, essential for medical care services.

Such implantable in-vivo devices can provide continuous monitoring to improve treatment outcomes. For clinical patient monitoring and treatment IoT applications (e.g., pacemakers), a more holistic vision must involve human factors, the technical networking component, databases, and privacy aspects [8,9]. Modernization of e-medicine – The microelectronics and micro-technologies that have emerged over the past couple of decades have fundamentally impacted the miniaturization of the devices used for sensing, imaging, and diagnostics in e-medicine. Combining IoT technologies and diagnostic tools ha s changed the healthcare industry, providing new and intelligent systems for patients and healthcare providers. IoT platform-based Digital Diagnostics facilitates the remote diagnosis of the patient's condition, eliminating physical barriers and paving the way to the efficient delivery of healthcare services. Such developments in diagnostics technologies, such as IoT sensors, portable devices, wearable technologies, and smartphone applications, are revolutionizing the healthcare industry and leading to significant advancements in biomedicine and health-related areas. As technologies become more prevalent, healthcare services need to adapt and evolve to meet the needs of the worldwide transformation .

Conceptual Perspective of the Internet of Things (IoT)

The Internet of Things (IoT) represents a transformative technological paradigm where everyday objects are embedded with sensors, actuators, and communication capabilities, enabling them to collect, exchange, and process data. This interconnected network of "things" extends beyond traditional computing devices, encompassing a wide range of physical objects, from household appliances to industrial machinery and wearable devices. The IoT is poised to revolutionize various sectors, including health care, transportation, agriculture, and smart cities, by enabling real-time monitoring, automation, and data-driven decision-making.

A. Definition and Evolution of IoT

The IoT is a global network of interconnected devices that communicate and exchange data using standard communication protocols. According to Atzori [10], the IoT can be viewed from three perspectives: things-oriented, internet-oriented, and semantic-oriented. The things-oriented perspective focuses on physical objects and their capabilities, while the internet-oriented perspective emphasizes the networking and communication protocols that enable these objects to connect. The semantic-oriented perspective deals with the data generated by these objects and how it can be processed and interpreted to provide meaningful insights. The concept of IoT has evolved over the years, with its roots tracing back to the early days of RFID (Radio-Frequency Identification) and Wireless Sensor Networks (WSNs). The term "Internet of Things" was coined by Kevin Ashton in 1999, during his work at Procter & Gamble, where he envisioned a world where physical objects could be connected to the internet, enabling them to share data and interact autonomously.

B. Key Components of IoT

There are multiple key components in any ecosystem working together to allow smooth communication and data exchange:

• Sensors and Actuators: These form the core elements of any IoT device, gathering information from the surroundings(sensors) and executing actions according to the provided data(actuators). Sensors can include temperature, humidity, light, and motion, and actuators control devices like motors, lights, and valves.

• Communication Protocols: IoT devices use several different communication protocols to send data, such as message queuing telemetry transport (MQTT), constrained application protocol (CoAP), and extensible messaging and presence protocol (XMPP). These protocols are lightweight and energy-efficient, making them ideal for IoT devices with limited energy resources.

• Cloud: The vast amount of data IoT devices create is usually stored and processed in the cloud. Cloud platforms offer storage, processing, and analytical data infrastructure, facilitating real-time decision-making and scalability.

• Data Analytics and Machine Learning: The data generated by IoT devices is typically processed using sophisticated analytics and machine learning algorithms to derive valuable insights. More recent developments include using that data to predict maintenance and types of anomalies and optimizing any number of processes.

C. IoT Architectures

Various architectures have been proposed to assist in developing and deploying IoT systems [13]. An example of such an architecture is SGS, Semantic Gateway as a Service, which offers interoperability between multiple IoT systems through the transition between different messaging protocols like XMPP, CoAP, and MQTT. The architecture of a Semantic Grid System (SGS) supports semantic interoperability and reasoning over sensor data through semantic annotation, for example, by using the W3C's Semantic Sensor Network (SSN) ontology [11]. The BIG IoT architecture is another example that offers a standard API and semantic descriptions of resources for cross-platform interoperability. The architecture of BIG IoT encompasses a marketplace through which IoT platforms and services can be discovered and accessed to facilitate the creation of rich IoT ecosystems [12,13].

D. Challenges and Future Directions

The potential of the IoT is immense, but some hurdles still need to be crossed before it can deliver on its promises. These include:

• Interoperability: The diversity of IoT platforms and devices often results in the absence of standardization, giving rise to interoperability challenges that hinder incorporating different systems.

• Security and Privacy: The large amount of data from IoT devices creates security and privacy issues. Ensuring that data is confidential, integrity, and availability is the cornerstone of building trust in IoT systems.

• Scalability: IoT devices are rapidly increasing, making IoT systems harder to manage and scale. How to design a resource-efficient and distributed computing approach to handling the scale of IoT deployments.

• Energy Efficiency: Many battery-powered IoT devices work in low -resource environments. Further, energy-efficient communication protocols and hardware must be developed to extend these devices' lifetimes.

– The Role of the Internet of Things (IoT)

Being one of the most relevant technological trends in recent years, IoT has shown great potential in several sectors, such as smart home technologies, smart cities, manufacturing, energy efficiency, environmental sensing, precision agriculture, research and development automation as well as e-health applications such as digital pathology and diagnostic imaging [14,15]. In agriculture, IoT technologies are a modern approach to food production that is environmentally friendly and clean. This approach combines features of contemporary information and communication technologies to reduce wastage and enhance agricultural yield. The usage of IoT helps to detect disease in plants , which makes monitoring extensive farmland even easier. IoT applications are used in the medical field, remote patient monitoring, IoT smart sensors, and advanced medical devices [16,17,18]. They help provide proactive patient care and maintain the quality of medical service offered. As one of the most innovative technologies today, the IoT successfully implement s advanced healthcare systems by interconnecting devices in the diagnostic and bio-imaging sectors like sensors, wearables, wireless networks, actuators, and imaging equipment to generate a considerable volume of data. Digital diagnostics and imaging have received significant interest due to their promise of improving healthcare outcomes. Several imaging, sensing, and diagnostics applications have been explored for specific IoT-enabled devices and platforms. IoT technology helps achieve many benefits over conventional methods in the healthcare sector, such as reliability, efficiency, cost-effectiveness, accuracy, real-time tracking, and reduced dependence on human efforts. IoT applications are not just limited to smartphones, which can help with better data analytics, image quality, better sensing, real-time sensing, execution of specific functions, data sharing, automation, etc. Amidst the challenges presented by the growing number of individuals and new experimental lifestyles, diseases have mounted to emerging conditions, and steps have been taken to innovate the field of medicine. Novel and efficient systems are needed for both the prevention and diagnosis of chronic illnesses, including AIDS, diabetes, cancer, tuberculosis, and cardiovascular diseases.

"By using IoT devices, one can effectively keep track of the delivery of clinical products in the healthcare sector and monitor the transit of donor organs in real-time to generate alerts if there is an anomaly or a damage." In the pharmaceutical industry, IoT has effective ly improved product quality testing at different manufacturing stages and product performance. Several studies report using various classes of IoT-based wireless devices, such as blood glucose meters, real-time glucose monitoring systems, smart insulin pens, insulin pumps, and closed-loop systems, for diabetes management [19,20,21,22]. IoT-enabled nasal airflow sensors are also used to track the respiratory rates of patients who need this type of support. Such devices usually comprise a flexible thread worn in the back of the ears, which introduces the two prongs into the hole of the patient's nose to facilitate the measurement of their breath. You can continuously monitor your health using IoT devices, which provide tremendous and valuable data insights on various physiological components from blood pressure to pulse to blood glucose level and calorie intake. Moreover, user-friendly, minimally invasive IoT diagnostic devices are expected to improve the accuracy of medical diagnoses, where the accuracy of diagnosing through the IoT significantly enhances user-friendliness using minimally invasive devices. In general, these portable and intelligent devices enabled by the IoT can help save costs significantly and enhance point-of-care diagnostics.

Advancements in Diagnostics: The Role of IoT

Incorporating diagnostic, sensor, and imaging devices in intelligent , innovative technology on the Internet of Things (IoT) network has dramatically changed the healthcare industry. These gadgets are critical in sensing, testing, diagnosing, monitoring, and analyzing the data to predict diseases and their complexities. This, in turn, helps better manage and care for patients. An IoT device can be anything from a wearable with embedded electronics, software, sensors, and actuators that can turn the device on or perform a function to network connectivity that together creates an interconnected and exchangeable system where actuators can perform a service, with corresponding sensor capabilities to receive and send the data as needed. These elements work together to collect, store, communicate, and transfer data. Some advantages of IoT are cost-effectiveness, fewer doctor or hospital visits, remote monitoring, better treatment outcomes, reliable diagnostic data, automation, and improved disease management. These advantages can return numerous benefits to diagnostic centers. IoT applications are distributed across different sectors of the healthcare market — telemedicine, healthcare management, clinical operations, diagnostic labs, and bi-imaging. Bluetooth, Wi-Fi, NFZ, Zigbee, RFID, and other networking technologies help facilitate these IoT-based digital health solutions. IoT gives patients and healthcare professionals access to dhealth-carereal-time, which they can analyze and introduce to treatment strategies. With IoT, we are introduced to remarkable advancements, one of them being efficient remote diagnosis through automated health assessments, which can be performed virtually or electronically. For mobile/portable use, researchers and companies have developed smartphone-based devices and software platforms for diagnostics, sensing, and imaging, which could be open to these remote diagnostic services. Flexera Software, Glassbeam avoids the need for many skills in parsing through log files by leveraging IoT technology, which helps companies perform remote diagnostics on their IoT-enabled devices. The IoT-driven applications in the diagnostic domain are a breakthrough in modern healthcare practice (close to e-medicine and better patient care).

In Yang's proposal [4], the remote pain monitoring system based on the Internet of Things (IoT) relies on facial surface Electro-Myo-Gram (sEMG), and the relevant signals are sent to the cloud for processing. This study employed a wireless wearable device with bio-sensing technology to measure the patient's pain levels based on activity in their facial EMG. The system consists of a wireless sensor node that can take up to eight channels of sEMG and is connected to an Internet of Things (IoT)-based pain monitoring. It allows simultaneous collection, analysis, and transmission of pain data to a mobile web app. The real-time streaming of high-volume sEMG data, digital signal processing, interpretation, and visualization provided by the proposed novel system, utilizing a sensor node, web browser, wireless communication, and cloud-based web application, is demonstrated. These results show a scalable IoT solution for on-field measurements and propose a wearable solution with great potential for automated pain assessment from facial expressions (23). An integrated intelligent IoT pattern was developed by [24], which is utilized for automatically detecti ng cardiac variability. Abnormal cardiac events during clinical evaluations are uncommon. They recommended a mobile-based development and evaluation system for real-time monitoring and detection of cardiovascular issues associated with heart rate variability. They integrated an IoT e-Health kit based on Arduino and validated heart rate variability algorithms to propose a low-cost, reliable, and scalable solution. In addition, a mobile platform based on an Android app was used with the Pan and Tompkins algorithm and a module that performs real-time electrocardiography retrieval through Bluetooth [24]. There are multiple studies supporting the use of IoT in digital diagnostics; the Lifelens Project is an example. Key Points: Researchers described a mobile application for diagnosing malaria (malariaMg), a point-of-care tool with important implications for malaria detection and treatment. The solution was tested on blood samples at different laboratories and achieved 94.4% accuracy. As such, Lifelens has revolutionized approaches to traditional methods of testing for malaria where one would add an unreliable cotton swab to see if a patient would darker yellow blood, using high definition, high-magnification camera (magnification scaling of up to 350 times) coupled with a state-of-the-art image analysis software to improve diagnosing precision [25]. The procedure involves taking a blood sample from the patient, placing it on a slide, and digitally examining it using a lens attachment that provides higher magnification and resolution. The smear is then imaged and diagnosed through the easily downloadable Lifelens application. Patients feel empowered and can use this tool to perform user-friendly diagnoses with low training. In this regard, emerging platforms such as IoT can link various physical objects (e.g., smartphones and medical instruments) to the internet, thereby [...] improving applications in digital pathology, digital biomarkers, digital imaging, digital diagnostics, and e-healthcare. A smartphone-based instrument capable of accurately evaluating upper limb tremors in Parkinson's Disease (PD) was developed by Kostikis [26]. Their study recruited 31 PD patients with 22 aged-matched healthy controls using smartphone accelerometers and gyroscopes. The authors write that this method may be a useful tool to help physicians monitor patients and could allow for remote assessments, potentially reducing visits to the clinic. Smart wearable technologies are significant in managing PD through IoT, as observed by Pasluosta [27]. Klimova [28] also described the application of IoT in the assessment, diagnosis, and care of Parkinson's Disease. Neurological conditions such as PD are long-term conditions that require medical treatment; therefore, there is an urgent need for scalable and cost-effective solutions aimed at addressing the challenges of PD diagnosis and monitoring. Their findings show that IoT holds significant potential in health care . It provides a sustainable, inexpensive, and accessible way forward with the management of PD and other chronic neurological illnesses. Gait impairments are common and require diagnostic tools. They can be seen in both musculoskeletal and neurological disorders. Gait sensor-equipped wearable devices are emerging promising tools for the monitoring, tutoring, and guidance of gait performance. Ferrari described a new testing method for estimating spatiotemporal gait parameters using smartphone technology supported by shoe-worn inertial sensors [29]. The gait analysis system with zero-velocity update has been implemented based on a Kalman filter and commercially available inertial sensors worn in shoes. It analyzes gait events and estimates step lengths based on pathological gait patterns. They also presented an Android application that enables fully wearable and stand-alone real-time gait analysis. An additional study by Ellis [30] investigated the feasibility of a smartphone mobile app, Smart MOVE, to evaluate gait and gait variability in PD. They included smartphone tech, heel-mounted footswitch sensors, and sensor-infused walkways for evaluation and potential testing. The results indicate that this smart-based application could be a creative evaluation method. Istepanian [31] shows an example target of IoT systems can be non-invasive glucose level sensing, which could lead the way in a global, world-class challenge (worldwide, every 10th individual suffers from it, including children and older people), given there is Type 1 and Type 2 diabetes. This is the first time IoT-operated stringless diabetes management was used with the help of non-invasive glucose monitoring via the latest opto-physiological assessment methods. From the perspective of mobile healthcare, it suggests a framework for intelligent identification and management in a heterogeneous connectivity environment. In addition, it enables intelligent mediation pathways between mobile patients and care services based on novel IP-based networking architectures. According to Klonoff [32], Fog and Edge computing architectures are promising approaches to processing data from connected devices that can significantly promote diabetes management. This is when the computing models come into play: edge computing, fog computing, and cloud computing, each of which provides better speed of data transmission as well as lower costs and less dependence on the limited broadband and DSL connections, more privacy, and more excellent security compared to the traditional cloud computing. Fog or Edge computing solutions offer an efficient and fast tool for diabetes care management through the interconnection of diabetes-connected devices. But one major global health issue that often goes overlooked is Diabetes and the widespread worry of diabetic foot Ulcers (DFU) and their complications. One study [33] focused on health sensors and IoT in diabetes care and management. And they highlighted the rise of IoT and smart devices, including smartphone-based monitoring systems. In the med-tech space, a home-care revolution is coming, providing the opportunity to create value-added solutions that can lower DFU-associated costs by up to 60% while improving patient care.

DISCUSSION

By 2020, an estimated 43% of Internet of Things (IoT) technologies were health-related, a testament to IoT's benefits through connectivity, device management, and data analytics. This includes integrating health data, deep learning algorithms, and improved accuracy in decision-making and management of medical care. IoT systems and platforms enable the intelligent use, processing, storage, transfer, and analysis of software-generated data across multiple industries. Data for remote or real-time applications can be used through distributed servers using cloud computing, sensors, and actuators. The IoT application in the biological field requires flexibility and interactivity in imaging and diagnostics methods and the healthcare, research, and development fields. For biologists, IoT technologies will accumulate tremendous potential, and thus, there is a need for a bridge between IoT technologies and biologists. The Integration of IoT in home-based patient medical care would catalyze the digital transformation of the medical care domain for patients and create value for patients in terms of patient engagement, personalization of care, and innovative management through timely, appropriate, and effective telecommunications, data mining, and personalized feedback to ensure optimal and continuous care. The emergence of recent trends in voice-activated command technology and increasing interconnectivity based on IoT of smartphone-native devices have paved the way for novel opportunities to consolidate the already central role of the patients themselves in managing their health in the context of a digital healthcare ecosystem. Sudha [34] summarized the implications of IoT in medical diagnosis using Arduino technology, which speeds up communication and improves the Convolution of diagnostics for analysis. Through connected devices and web portals, healthcare providers can gather patients' key details, such as pulse rates and temperature values, among other things. This data can be communicated to patients to process it in real-time or remotely, depending on their requirements. Many articles have explored temperature-based sensor applications streamlined through IoT with which patients or other users can continuously check body temperature, underlying how important these temperature sensors are to patient care. Also, blood pressure is measured with devices that measure variations of blood pressure, separating systolic (during heartbeats) and diastolic (between beat relaxation), which also include reports of being monitored. The miniaturization of diagnostic devices, combined with advances in information technology, multi-omics sequencing, and data science, profoundly affects the industry regarding innovation in research and development and the biomedical sector. This movement guides a revolution to enable precision medicine, point-of-care testing, and digital diagnostics. Innovations like the Internet of Things (IoT) and medical/IOT devices (IoTM/IOTD) could improve medical treatment by enabling patients to reduce the time needed to be at the site where medical professionals work.

However, IoT has its fa ir share of challenges and disadvantages. Many medical devices and the massive amounts of data they create can inundate a medical center's IT team, making it challenging to monitor, manage, store, transfer, secure, and analyze these large datasets. Moreover, there is increasing pressure to keep patient data secure, especially while moving between different devices. Potential Disconnect ing IoT for Distant Health Care and Health Surveillance The Internet of Things (IoT) sector, which caters to remote medical attention and health monitoring, is quickly growing and offers massive medical possibilities. Technological progress has brought several implantable electronics and IoT devices integrated with bio-interfaces and sensors for various healthcare applications. Biomedical devices, sensors, diagnostic systems, radio-frequency devices, circuits, and bio-imaging systems are up-and-coming devices that are efficient transfer systems of data, diagnosis, imaging, monitoring, and analysis. Various devices, circuits, and applications for non-invasive diagnostics based on smartphones have also been reported. Furthermore, applying innovative optical tools, enhanced sensing devices, imaging detectors, digital cameras, diagnostic chips, and intelligent connected IoT devices can also help raise diagnostic capabilities in cancer screening and bring them into infectious disease detection applications.

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