

A review of internet of medical things (IoMT) ó based remote health monitoring through wearable sensors: a case study for diabetic patients

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ABSTRACT

The latest advances and trends in information technology and communication have a vital role in healthcare industries. These advances are oriented to the Internet of Medical Things (IoMT) which provides a continuous, remote and real-time monitoring of patients. The IoMT architectures still face many challenges related to the bandwidth, communication protocols, big data and data volume, flexibility, reliability, data management, data acquisition, data processing and analytics availability, effectiveness data security and privacy, and energy efficiency. The goal of this paper is to find feasible solutions to enhance the healthcare living quality using remote health monitoring (RHM) and IoMT. In addition, the enhancement of the prevention, prognosis, diagnosis and treatment abilities using IoMT and RHM is also discussed. A case study of monitoring the vital signs of diabetic patients using real-time data processing and IoMT is presented.

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1. INTRODUCTION

Nowadays, healthcare and modern technology industries [1, 2] gained crucial intentions in integrating technology with the healthcare systems is to provide a better interfacing capability between patients and caregivers to improve the efficiency and accessibility of medical devices and services [3]. The main goal in integrating technology with the healthcare systems is to provide a better interfacing capability between patients and caregivers to improve the efficiency and accessibility of medical devices and services [4, 5].

Recently, Internet of Medical Things (IoMT) [9-11] played a vital role in remote healthcare monitoring (RHM) [12, 13]. The IoMT is mainly used to collect the remote data from patient through wearable sensors/devices [14] and store them in the cloud databases. These data are available for real-time analysis and application by caregivers [15]. The IoMT has three main stages: device layer (body sensor network (BSN)) Fog layer and cloud services [16-23] as shown in Figure 1

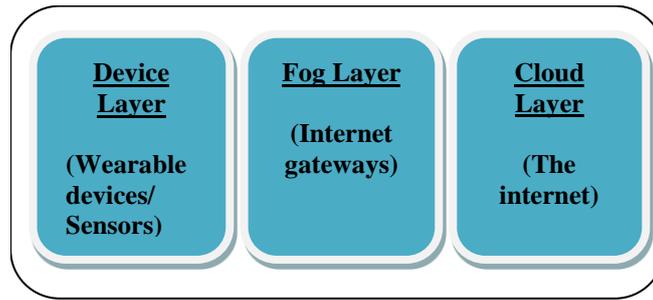


Figure 1. The architecture of IoMT

The main purpose of the device layer (sensing layer) is to establish an effective and accurate sensing technology to collect various types of health-based data. Table 1 shows wearable sensing technologies [24-29]. Communication technologies support network solutions and architectures of IoMT system [30, 31]. However, communication techniques include Bluetooth, RFID (NFC), WI-FI, IrDA, UWB, and ZIGBEE[32]. In the cloud layer (data layer)[33], the data is processed and stored [34]. Moreover, data become available for caregivers[36].

Table 1. Wearable sensing technologies

Sensor type	Example
Inertial sensor	Magnetic field sensors, Accelerometer, and Gyroscopes
Location sensor	GIS and GPS
Physiological sensor	Electrocardiogram (ECG), Electrooculography (EOG), Galvanic skin, and Spiromete
Brain activity sensor	Electroencephalogram (EEG)
Image sensor	Camera

RHM [37-42] is a continuous monitoring process of the health data. Data includes: physiological monitoring such as heart rate, temperature and blood pressure, physical activity monitoring, diet monitoring, medication tracking and behavior monitoring). The health data are wirelessly communicated to both the patient and caregivers through the cloud [43, 44]. Thus, IoMT offers real-time, fast, remote and reliable diagnosis of several types of disease and enhances the decision-making process. Through this process, large amount of data are received, analyzed and stored[45].

With nowadays busy life, majority of people skip routine medical checkup. In addition, the cost of the healthcare is rising and governments spend a large amount of money yearly for healthcare services. It is also noted that people in Europe and United States prefer home healthcare over going to hospitals. Therefore, there is a critical need for real-time healthcare monitoring to address the challenges. Continuous monitoring for patients and elderly people through wearable devices and sensors have gained a great attention [46-48]. The goal is to provide vital signs monitoring such as blood pressure, temperature and heart rate which has significant importance. According to the World health organization (WHO), the number of type 2 diabetes (T2D) patients is 422 million in 2014. That means 8.5 % of adults suffer from diabetes. However, WHO predicts that the number will reach to 500 million in 2030 [49]. Therefore, using RHM may reduce the risk for those who are more vulnerable by capturing the medical data and sending it to the caregivers [50], as shown in Figure 2. RHM uses the following [51-53]:

- 1) Diagnosing diseases
- 2) Diseases management
- 3) Diseases prediction
- 4) Diseases prognosis
- 5) Diseases prevention
- 6) Giving the suitable medications and treatments
- 7) Rehabilitation

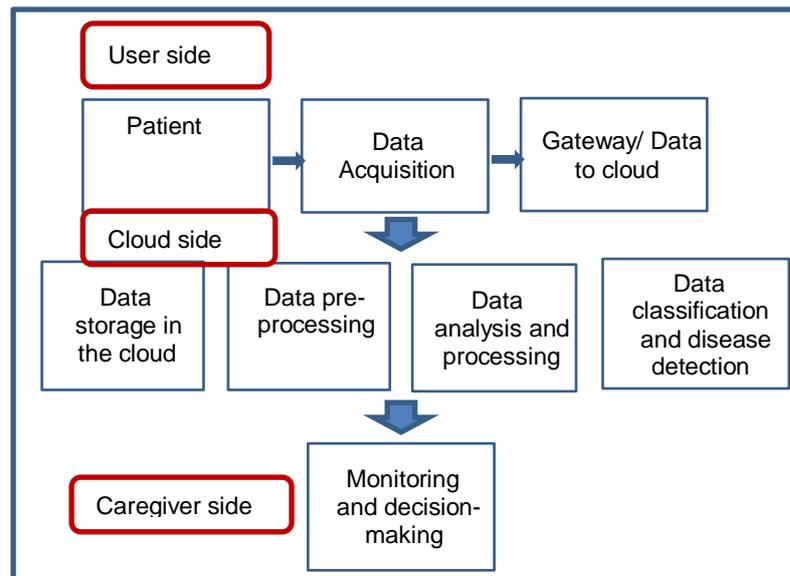


Figure 2. Proposed healthcare monitoring system

Diabetes is a chronic disorder, which needs a continuous monitoring [54]. Fortunately, with the help of IoMT, monitoring diabetic patients remotely is becoming more doable [55]. However, the management of diabetes using continuous glucose monitoring techniques is still a challenging process [56]. Figure 3 shows the IoMT based continuous glucose monitoring.

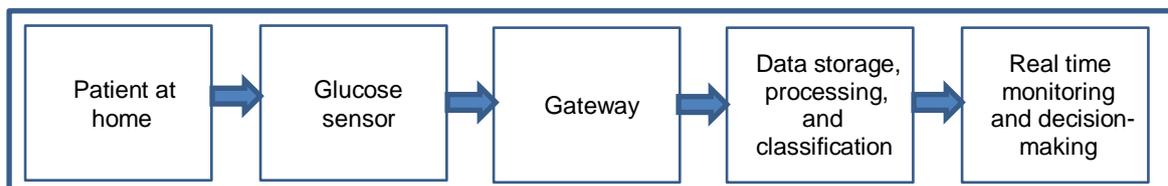


Figure 3. IoMT based continuous glucose monitoring

The main contribution of the proposed study is to enhance the healthcare living facilities using IoMT for RHM of diabetic patients. Patients with diabetes need 24/7 monitoring [57, 58] which can be achieved by measuring the blood glucose (BG) level using wearable sensors [59-62].

2. RELATED WORKS

In order to address IoMT related challenges, several studies have been conducted in IoMT based remote health monitoring for diabetic patients. Table 2 lists the main studies related to IoMT based remote health monitoring for diabetic patients.

Table 2. IoMT based remote health monitoring for diabetic patients related literatures

Literature	Contribution	Sensing data	Highlights
[63]	Blood glucose monitoring system	Glucose sensor	Monitor the diabetes using IoT and artificial neural network
[64]	Non-invasive glucose monitoring device	Urine testing	Self-monitoring, non-invasive, accurate, reliable and effective system
[65]	IoT-based glucose monitoring algorithm to prevent diabetes complications	Glucose sensor	Architecture and prognosis algorithm used for elderly diabetic persons Prognosis of possible critical condition in the patient IoT-based embedded scheme for a diabetic insulin pump proposed
[66]	IoT-cloud to monitor the diabetic patients	Alaris-8100 infusion pump	Insulin pump implementation for control and monitoring diabetic patients Share health data on the cloud
[67]	Development of wearable physiologic monitoring devices for use in diabetes management	Fitness trackers and smart watches	Enhance continuous glucose monitoring. Measure glucose levels in tears Improve patient safety
[68]	Designing an Internet-of-Things (IoT) and sensor-based in-home monitoring system for assisting diabetes patients	Wireless persuasive sensing	IoT and wireless sensor based system to capture daily activity at home predictive blood glucose levels analytic models are developed
[69]	Continuous movement monitoring of daily living activities	Continuous movement monitoring sensor	Manage diabetes Prevention of diabetic foot ulcer by monitoring daily activities and blood glucose
[70]	Glucose monitoring in individuals with diabetes	Glucose clamps and spontaneous glucose excursions	Long-term implanted for sensor/telemetry system for glucose monitoring glucose control and management
[71]	Sensor-based method for glucose monitoring	FreeStyle Libre Flash glucose monitoring system	Accuracy, safety and acceptability of the glucose monitoring system in the paediatric population is proposed Accuracy, safety and user acceptability are discussed
[72]	Continuous glucose monitoring sensors	Continuous glucose monitoring sensor	Past and present algorithmic challenges of Continuous glucose monitoring sensors are introduced Automatic basal insulin attenuation methods Use of CGM for adjustment of insulin dosing, and automated interpretation
[73]	Continuous glucose monitoring to characterize glycemic variability	Continuous glucose monitoring sensor	Instantaneous real-time display of glucose level and rate of change of glucose, alerts and alarms Small, comfortable, user-friendly devices based on IoMT
[74]	Continuous glucose monitoring	Self-monitoring blood glucose sensor	Control and manage diabetes Reduce the risk of hypoglycemia
[75]	Type 2 diabetes (T2D) management	Home monitoring data (Genomics data repositories)	Big data technologies and IoMT to manage and control diabetes
[76]	T2D management	Continuous glucose monitoring sensor	Predictive T2D models using big data analytics machine learning algorithms
[77]	Remote patients with diabetes fog assisted system	Continuous glucose monitoring and ECG sensors	Fog-assisted personalized healthcare support system Monitor glucose level with physical activity and diet
[78]	Quality life improvement for diabetic patients by using IoMT	Continuous glucose monitoring sensor	Continuous glucose monitoring, activity, and diet tracking using IoT
[79]	Continuous glucose monitoring system for diabetes based on internet of mobile crowdsourcing health things	Continuous glucose monitoring sensor	Mobile fog computing, blockchain and IoT are used to control and manage diabetes remotely and continuously
[80]	Detection of diabetic foot ulcer	Flexi-force sensor	Design and implementation of IoT-based model for diagnosing of diabetic ulcer
[81]	IoT-based blood glucose monitoring system	Blood glucose sensor	Prototype of an IoT-based glucose testing meter low-cost and energy-efficient
[82]	Glycemic control using IoT	Photo-acoustic signal	Non-invasive intelligent blood glucose level monitoring system Alert signals using IoT is provided
[83]	Continuous glucose monitoring system	Blood glucose sensor	Fog computing, blockchain and IoT-based monitoring system Rapid, flexible, scalable, and low-cost mHealth system
[84]	IoT based detection of hypoglycemia	Blood glucose, activities, and dietary	IoT and big data analytics platform
[85]	IoT based intelligent diabetes management system	Activity trackers, continuous glucose monitoring, and implantable defibrillators.	Machine learning diabetes management application Smart, fast, and cost-effective
[86]	IoT cloud based automatic diabetes risk assessment system	Feet pressure sensor, blood pressure sensor, and ECG	Machine learning diabetes management application

3. THE SIGNIFICANCE OF IoMT BASED RHM

RHM based on IoT can make a healthcare easier and more efficient in terms of cost, accessibility, visibility, reliability, accuracy, affordability, continuity, and real time monitoring. For example, hospitalized patients cost a huge money on the patients, healthcare providers, and insurance companies. Moreover, patients living in remote areas do not have an easy access to hospitals and caregiver centers. Thus, they need to travel for long distances to seek health care. IoMT has the ability of interoperability, communication and information exchange, and data transfer that improve these services. In addition, RHM provides a continues monitoring for chronic diseases (i.e. diabetes) [88]. Table 3 shows the advantages and benefits of RHM based IoMT for patients, caregivers and insurance companies [88-90].

Table 3. Advantages of using IoMT for RHM for diabetic patients

Patients side	Caregivers side	Countries and insurance companies side
Sufficient monitoring	Better reliability and accuracy	Better accessibility
Reduce the duration of stay	Less cost	Less cost
Centralized data	Better accuracy	Better visibility
Prevent emergencies and reduce emergency wait time	Better reliability and accuracy	Better accessibility and less cost
Real time monitoring and on-time alert	Continuous monitoring	Better accessibility
Better quality of treatments	Real time monitoring	Better visibility
Improve the convenience	Better reliability and accuracy	Better visibility
Improve the efficiency	Better reliability, accuracy, less cost, and real time monitoring	Better visibility, accessibility, and less cost
Reduce medication errors	Better reliability and accuracy as well as less cost	Better visibility and accessibility
Solve the long distance problem	Better reliability and accuracy as well as less cost	Better visibility and accessibility
Mobile health (mHealth) capability	Real time monitoring	Better visibility and accessibility
Fast data processing	Better reliability and accuracy	Better affordability
Fast collecting data	Better reliability and accuracy	Better visibility and less cost
Efficient reporting capability	Better reliability and accuracy	Better visibility

4. CHALLENGES AND FUTURE TRENDS

This section summarizes the challenges of the remote monitoring of the diabetic patients through wearable sensors [91-96]. This include:

- 1) Cost effective and non- obstructive sensing devices design and evaluate a non- obstructive sensing devices with low cost is a challenging issue.
- 2) Data processing [98] and big data problem [99, 100]: Big data originate from sensing devices in a short time is hard to store and manage if the access to cloud is available.
- 3) Security and privacy [101, 102]: Medical sensor data and electronic patient records are critical and sensitive. However, it is crucial to protect these data from potential internet threats.
- 4) Uncontrolled environment [103] and Noise interfere [104]: Various noise levels may occur.
- 5) Wireless technology [105-107]: No connectivity and wireless technology standards.
- 6) Reliability and availability [108, 109]: several connected devices, software, services, and users a connected which leads to increase the failure rate.
- 7) Energy efficiency [110]: real time continuous sensing consumes the power.
- 8) Intelligent algorithms used for data processing require sufficient and big training data. However, available datasets are laboratory datasets [111].
- 9) New intelligent feature extraction and classification algorithms need more computational time [112].
- 10) Performance and accuracy [113]: develop medical accurate devices, algorithms, methods, devices highly required.
- 11) Wearable sensors placement and user safety [114]: location of sensor and placement safety issues are critical factor in design.
- 12) Single sensor modalities: data fusion body sensor techniques to discussed more [115].
- 13) Size of the wearbale sensor must be comfortable [116].
- 14) Wearable devices must be comfortable [117].
- 15) Wearable devices must be protected from water and sweat [118].
- 16) Integration of multiple protocols and devices [119, 120].

5. CONCLUSION

In the IoT era, remote healthcare monitoring (RHM) represents the future of the healthcare. Blood glucose level can be monitored. Globally, the number of diabetic patients is continuously increasing which leads to more challenges in the healthcare societies. Benefitting from the latest advances and trends in information technology and communication (i.e. IoT) is vital. The proposed review study has covered the IoT based remote health monitoring for diabetic patients. In addition, the associated challenges and future trends are discussed and highlighted.

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