A review of internet of medical things (IoMT) – 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. Theses advancements led 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, cost effectiveness, data security and privacy, and energy efficiency. The goal of this paper is to find feasible solutions to enhance the healthcare living facilities 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 also presented.

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1. INTRODUCTION

Nowadays, healthcare and modern technology industries [1, 2] have gained crucial intentions in everyday’s life including healthcare systems [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 [4-8].

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 for patient through wearable sensors/devices [14] and store them in the cloud databases. These data are made 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 service [16-23] as shown in Figure 1.
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 infrastructures 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, cloud get patient’s data to perform analysis, processing and storing [35]. Thus, data become available for caregivers [36].

Table 1. Wearable sensing technologies

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inertial sensor</td>
<td>Magnetic field sensors, Accelerometer, and Gyroscopes</td>
</tr>
<tr>
<td>Location sensor</td>
<td>GIS and GPS</td>
</tr>
<tr>
<td>Physiological sensor</td>
<td>Electrocardiogram (ECG), Electrooculography (EOG), Galvanic skin, and Spirometer</td>
</tr>
<tr>
<td>Brain activity sensor</td>
<td>Electroencephalogram (EEG)</td>
</tr>
<tr>
<td>Image sensor</td>
<td>Camera</td>
</tr>
</tbody>
</table>

RHM [37-42] is a continuous monitoring process of the health data. This includes: physiological monitoring such as heart rate, temperature and blood pressure, physical activity monitoring, diet monitoring, medication tracking and behavior monitoring). The health-related data are wirelessly communicated to both the patient and caregivers through the cloud [43, 44]. Thus, IoMT supports 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 monitored [45].

With nowadays busy life, majority of people don’t have thier 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 remote real-time healthcare monitoring to address all these challenges. Continuous monitoring for patients and elderly people through wearable devices and sensors have gained a 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 of today’s healthcare world. 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 expects 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 send them to the caregivers [50], as shown in Figure 2. RHM uses include 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
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.

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

<table>
<thead>
<tr>
<th>Literature</th>
<th>Contribution</th>
<th>Sensing data</th>
<th>Highlights</th>
</tr>
</thead>
</table>
| [63]       | Blood glucose monitoring system | Glucose sensor | • Monitor the diabetes using IoT and artificial neural network  
|            | 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  
| [66]       | IoT-cloud to monitor the diabetic patients | Alaris-8100 infusion pump | • Prognosis of possible critical condition in the patient  
| [67]       | Development of wearable physiologic monitoring devices for use in diabetes management | Fitness trackers and smart watches | • IoT-based embedded scheme for a diabetic insulin pump is proposed  
| [69]       | Continuous movement monitoring of daily living activities | Continuous movement monitoring sensor | • Insulin pump implementation for control and monitor the diabetic patients  
| [70]       | Glucose monitoring in individuals with diabetes | Glucose clamps and spontaneous glucose excursions | • Share health data on the cloud  
| [71]       | Sensor-based method for glucose monitoring | FreeStyle Libre Flash glucose monitoring system | • Enhance continuous glucose monitoring  
| [72]       | Continuous glucose monitoring sensors | Continuous glucose monitoring sensor | • Measure glucose levels in tears  
| [73]       | Continuous glucose monitoring to characterize glycemic variability | Continuous glucose monitoring sensor | • Improve patient safety  
| [74]       | Continuous glucose monitoring | Self-monitoring blood glucose sensor | • IoTMT and wireless sensor based system to capture daily activity at home  
| [75]       | Type 2 diabetes (T2D) management | Home monitoring data (Genomics data repositories) | • Predictive T2D models using big data analytics and machine learning algorithms  
| [76]       | T2D management | Continuous glucose monitoring sensor | • Long-term implanted for sensor/telemetry system for glucose monitoring  
| [77]       | Remote patients with diabetes fog assisted system | Continuous glucose monitoring and ECG sensors | • glucose control and management  
| [78]       | Quality life improvement for diabetic patients by using IoMT | Continuous glucose monitoring sensor | • Accuracy, safety and user acceptability are discussed  
| [79]       | Continuous glucose monitoring system for diabetes based on internet of mobile crowdsourcing health things | Continuous glucose monitoring sensor | • Past and present algorithmic challenges of Continuous glucose monitoring sensors are introduced  
| [80]       | Detection of diabetic foot ulcer | Flexi-force sensor | • Automatic basal insulin attenuation methods  
| [81]       | IoT–based blood glucose monitoring system | Blood glucose sensor | • Use of CGM for adjustment of insulin dosing, and automated interpretation  
| [82]       | Glycemic control using IoT | Photo-acoustic signal | • Instantaneous real-time display of glucose level and rate of change of glucose, alerts and alarms  
| [83]       | Continuous glucose monitoring system | Blood glucose sensor | • Control and manage diabetes  
| [84]       | Continuous glucose monitoring system of hypoglycemia | Blood glucose, activities, and dietary | • Reduce the risk of hypoglycemia  
| [85]       | IoT based intelligent diabetes management system | Activity trackers, continuous glucose monitoring, and implantable defibrillators. | • Big data technologies and IoMT to manage and control diabetes  
| [86]       | IoT cloud based automatic diabetes risk assessment system | Feet pressure sensor, blood pressure sensor, and ECG | • Predictive T2D models using big data analytics and machine learning algorithms  

*Note: IoMT stands for Internet of Medical Things.*
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 centers, and insurance companies. Moreover, patients living in remote areas do not have an easy access to the hospitals and caregiver centers. Thus, they need to travel for long distances to seek health care. IoT in RHM has the ability of interoperability, communication and information exchange, and data transfer that improve healthcare services. In addition, RHM provides a continues monitoring for chronic diseases (i.e. diabetes) [87]. Table 3 shows the advantages and benefits of RHM based IoMT for patients, caregivers and insurance companies [88-90].

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

4. CHALLENGES AND FUTURE TRENDS

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

1) Cost effective and non-obstructive sensing devices [97]: 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 devises in a short time is hard to store and manage if the access to cloud is unavailable.
3) Security and privacy [101, 102]: medical sensor data and electronic patient records are very 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 for IoT.
6) Reliability and availability [108, 109]: several connected devices, software, services, and users are 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, services is 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 have to discussed more [115].
13) Size of the wearable 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 IoMT era, remote healthcare monitoring (RHM) represents the future of the healthcare industry. Importantly, in order to improve the people’s quality of life, vital signs of humans’ body such as glucose level can be monitored. Globally, the number of diabetic patients is continuously increasing which leads to more challenges in the healthcare society. Thus, benefitting from the latest advances and trends in information technology and communication (i.e. IoT) is vital. The proposed review study has covered the IoMT – based remote health monitoring for diabetic patients. In addition, the associated challenges and future trends are discussed and highlighted.

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compressed sensing


A review of internet of medical things (IoMT) – based remote health monitoring... (Omar AlShorman)


