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Recent Development in IoMT based Biomedical Measurement Systems: a Review

Imran Ahmed[1], Francesco Lanonaca[1]

[1] *University of Sannio, Benevento, Italy.*
iahmed@unisannio.it, flamonaca@unisannio.it

Abstract –Biomedical Measurement System (BMS) has provided new solutions for health-care monitoring and the diagnosis of various chronic diseases. With the growing demand of BMS in the field of medical application, researchers have a great deal of attention to bring advancement in these systems such as IoMT based BMS, which aims to improve the bio-processes, healthcare system, and technology for biomedical equipment. This paper is a state of the art review that presents the recent activities towards the development of IoMT based BMS for various medical applications. Thus, it leads to overcome the traceability issues of the recent developments in this field. The article presents, how different methods/ approaches are used to develop these systems, and what is their accuracy for the particular healthcare applications. The paper also discusses the shortcomings and challenges that need to be addressed within the current scenario, along with some possible solutions for future research activities.

I. INTRODUCTION

The measurement devices in the medical field play a key role in the development of Biomedical Measurement Systems (BMS). Biomedical measurement devices are typically used in BMS to acquire measurements of vital signs from human body. The measurements are then properly processed to aid doctors in the diagnosis of diseases or generate an alarm to timely suggest patients to go for a checkup. Acquiring the data from the human body without disturbing the routine activities (while working, swimming, hiking, etc) is a challenging task for old fashioned BMS [1] because most of them are invasive and require some other non-portable auxiliary instruments for their proper working. Therefore, in order to utilize BMSs in today's life style, it is important that they must be able to acquire the data in different scenarios [2] such as the collection of data from patients inside the hospitals, outside (industrial employees, mining workers, for sport men, and last but not least for defense and military forces) and in the home environment. Hence, the use of BMS in modern lifestyle demands that devices belonging to these systems must be compact, user friendly, allow comfort to the wearer and provide the same measurement accuracy even in a harsh environment [3],[4]. Based on these common requirements the recent research activities are devoted to improve these BMS by using the Internet of Things (IoT) [5]-[8] and by creating the new paradigm of Internet of Medical Things (IoMT) [9],[10]. The new provided solutions are mainly based on wearable and implantable biomedical measurement instruments [11] by using different sensors such as tactile [12], silicon [13], polymer [14], and optical-based sensors [15], [16], or sensors already integrated in common use devices such as smartphones [1],[4],[17]-[22].
The BMSs based on wearables typically include devices such as smartwatches, armbands, glasses, and smart helmets, digital hearing devices, and so on [2],[24]. Today many wearable devices are smart, i.e. they can locally process the signals that are acquired from sensors and transmit the measurement data through the network [6],[8].

Fig. 1 shows some smart wearable and smart implantable devices used for the measurement of different vital signs. These devices, indeed, already acquire measurement data, elaborate and sent them to local elaboration units for further processing and for the presentation to the clinicians or patients [11]. However, they can be considered the substratum to develop IoMT based BMS. In order to stimulate the research in the design of innovative BMSs able to monitor more and more vital signs and warranting accuracy, reliability, and the privacy of sensitive data, this paper presents the state of the art of the IoMT based BMS nowadays available. Although this article does not pretend to be an exhaustive overview, it would highlight BMS open issues and further potentialities.

The organization of the paper is presented as follows. Section II will explain the basic architecture of IoMT based BMSs. This section will also classify the IoMT based BMSs depending on diseases in which they are being used. Section III will discuss on the challenges related to some of the existing BMS and will explain some possible solutions to overcome those challenges. In the final section V conclusions of the article are presented.

II. IOT BASED BIOMEDICAL MEASUREMENT SYSTEMS (IOMT)

The main advantage of IoMT based BMS is to provide online monitoring of patient's health for a quick response in an emergency and to offer remote access to doctors to analyze

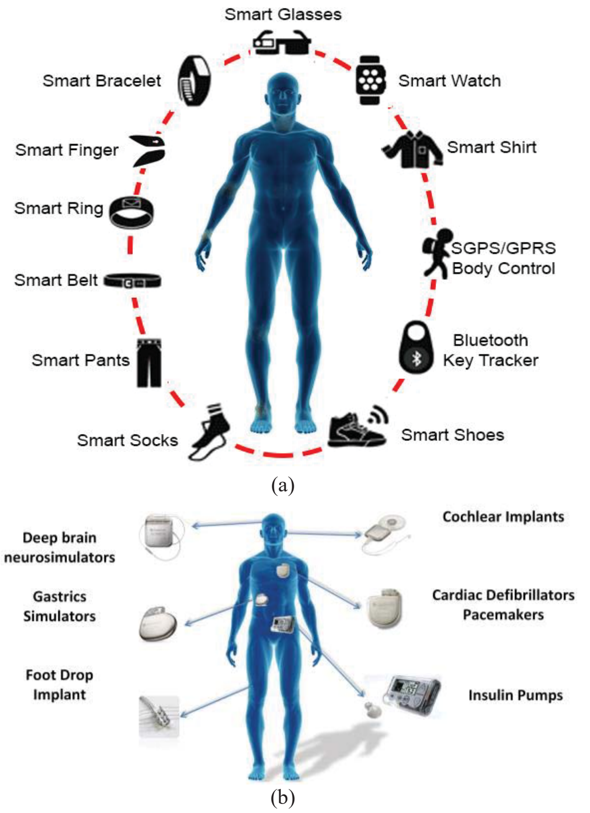

Fig. 1. Smart biomedical measurement devices, (a) smart wearable measurement devices, (b) smart implantable measurement devices [23].

patient's vital signs, relatives, and of course the patients themselves [25].

To this aim, some characteristics typical of IoMT based BMS are: (i) do not disturb the daily life routine, (ii) able to generate a timely alarm in an emergency, (iii) use affordable measurement devices.

As a consequence, the final aims of an IoMT based BMS include: (i) reduce the cost of hospitalization, (ii) optimize the public health costs, (iii) increase the independence and the quality of life of aged people, (iv) help the care of hospitalized and critical patients.

The general architecture for IoMT based system is shown in Fig 2. Differently from the other architectures presented in literature, that are specific for the applications for whom they are designed, this is a general architecture that reports the common parts belonging to all the IoT based BMS: (i) *Physical layer*, (ii) *Data integration layer*, (iii) *Application service/Presentation layer*.

In the *Physical layer,* IoMT based biomedical measurement system mostly use the wearable devices (smartwatches, smart bracelets, glasses, and so on) to evaluate the vital signs (heart rate, pulse rate, body temperature, blood pressure, oxygen concentration, lungs contraction vol., blood sugar level, respiration rate and so on) from the subjects under monitoring. This measurement data is first stored in the storage memory from where it is transferred to the *Data integration layer* (Fig.2) by using internet/Bluetooth or any other communication protocol. At the *Data integration layer*, the received data is processed and sent to the *Application service/Presentation layer*. Nowadays, various software are available to extract useful information to aid doctors in making decisions. At the *Application service/Presentation layer*, the data is analyzed by the doctor, subjects under monitoring and so on. Some of the IoMT based measurement systems that are applied for the diagnosis of various diseases are discussed below.

III. ADVANTAGES AND CHALLENGES OF EXISTING IOMT BASED BMS

A. IoMT based BMS for heart diseases

The earlier detection of heart disease is very important for saving human life and IoMT could play a vital role to achieve this aim.

In the *physical layer*, IoMT based system generally take numerous measurements such as chest pain, sugar concentration level, cholesterol level, heart rate and pulse rate, and other vital signs by using various of sensors, which are then pre-processed and encoded to send it to the *Data integration layer* through the internet or could base servers [26]. This data is then analyzed by the doctor at the *Application service/Presentation layer* on the mobile app or web page. Additionally, nowadays further algorithms based on Artificial Intelligence are available and integrated into the *Data integration layer* in order to further aid the doctor in the diagnosis [27]. For example, using the IoMT framework, a heart disease prediction method is presented in [27]. The system first measures cardiovascular data such as heart rate, blood pressure, pulse rate, etc by using smart wearable heart rate and blood monitoring devices, this cardiovascular data is then processed using support vector machine SVM and transmit it to the could server using WEKA framework. The Authors in [27] reported an evaluation accuracy of 97.53%.

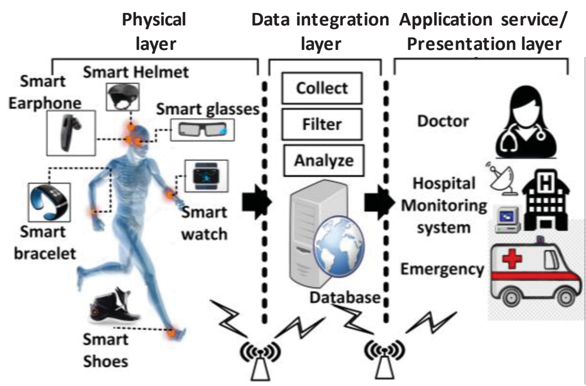

Fig. 2. General architecture for IOMT systems

Recently, in [28] an IoMT based detection system for the monitoring of heart-related diseases based on deep belief network model and high order Boltzmann machine was presented. The system collects the data of heart patient and continuously transmit it to the healthcare center, where deep network learns features of heart disease from past analysis and improve its accuracy by manipulating complex data. The accuracy reported by Authors is 99.03% which shows this system can accurately predict heart disease leading to minimizing the mortality by generating a timely alarm for the subject under monitoring and clinicians.

An IoT based BMS for heart disease is presented in [29] which uses an android app, pulsometer, and pedometer as a sensor to collect the data from the human body. Similarly, an ECG based heart disease recognition system is presented in [30] in which a mobile application is used for real-time diagnosis and monitoring of coronary artery disease or heart disease and this application raises alarm whenever an emergency occurs. The system is capable of predicting heart disease by using an intelligent classifier and a machine learning algorithm which are pre-trained on the clinical data. The Authors have reported a 100% detection rate for monitoring algorithm and classification accuracy of more than 85%.

B. *IoMT based system for blood pressure*

Blood pressure is a serious issue that affects elderly people as well as to young adults, and it must be monitor and keep under control otherwise it may lead to a serious condition such as heart failure or brain stroke. Therefore, blood pressure must be daily checked up by the patients and hopefully several times at days. To make this task easier for the patient, IoMT based blood pressure measurement system could help. An automatic blood pressure measurement system using the oscillometric technique is presented in [31]. The system is capable of monitoring both systolic and diastolic pressure, which are used to define arterial blood pressure. The values are continuously updated by using Wi-Fi on the database and can be accessed remotely, where this data is then compared with already existing data to ameliorate the accuracy of the results. The accuracy of the system declared by the Authors is 7mmHg. In [32] an IoT based smart system is presented for measuring blood pressure by using Electronic Blood Pressure Monitor (EBPM). EBPM system acquires the data from the human body and displays it to the user. This data is then sent to the *Application service/Presentation layer* using the Internet. In [33] Qardio Arm system is used to develop a smart blood pressure measurement system, in which the acquired oscillometric data are transferred to smart mobiles for analysis and visualization. The accuracy of the system is evaluated by comparing its results with the OMRON M3 device and the results show almost similar performance, also this device complies with the European Society of Hypertension International Protocol. In [34] OMRON HeartGuide is introduced. It is a smartwatch approved by FDA as a blood pressure measurement device. This device can measure BP by using an inflatable cuff within the smartwatch bracelet. The smartwatch sent the data to the *Data integration layer* by using the internet and then further sent it to the *Application service/Presentation layer* where it is available for the doctor that can access it in real-time. Similarly, an IoMT system IBP Auralife is presented in [35] for blood pressure measurement by using a mobile phone and without the use of any external hardware. IBP Auralife extract the blood pressure values from the Photoplethysmogram (PPG) signal, that is acquired by using flash led light and a mobile camera. The accuracy of the system is evaluated with standard BP measuring instruments and it is around 10-12 mmHg. In [36] a smart bracelet is reported for blood pressure measurement named as DreamCare Blood Pressure Monitoring Smart Bracelet. This device uses Bluetooth for data communication with the user mobile. Another device named as "Asus VivoWatch BP" is reported in [37] in which an ElectroCardiogGram (ECG) sensor on the back of the watch acquires an ECG signal from the wrist and an optical sensor on the front of the watch for PPG signal measurement from the index finger. This data is then automatically processed and results are displayed to the user.

C. *IoMT based system for brain diseases*

Several people are affected by brain diseases such as brain tumors, dementia, headache, brain stroke, chronic pain in the head, Tourette syndrome, Alzheimer, Parkinson, and Epilepsy, and many others. The development of IoMT based BMS in the field of brain-related diseases is a promising solution for the monitoring of patients suffering from such diseases, to timely detect such diseases or to timely detect that a crisis occurs. Typical devices that are used in the IoMT based BMS for brain-related diseases are ECG electrodes, smartwatches, galvanic skin response sensors, cameras. In this context, some of the IoMT brain-related BMSs are used for monitoring brain signals and then to generate an alarm in the case a crisis occurs. In [38] a high definition camera is used to analyze the motion of the patients for neuro-degenerative diseases. The result in the article shows an evaluation accuracy of the neuro-degenerative parameter in the range 2 % - 5 %. In [39] an IoT based BMS is reported in which deep brain simulation method is used to gather the information of brain activities which then passes to the *Data integration layer* where *heuristic tubu optimized sequence modular neural network* examine the information to predict the changes occurring in brain activities. The accuracy of the method is evaluated on experimental data and it is 98 %. In [40] an IoMT based BMS is presented using deep learning approach named as *stress-lysis* that is applied to detect the stress level. The system learns the stress level parameter from the human body such as skin temperature, heart rate, and sweat during physical activity. The evaluation accuracy in the range

98.3% to 99.7% it is reported by Authors. In [41] an IoMT based BMS is presented for the detection of brain tumors. The algorithm named as *Partial Tree* is applied to recognize the brain tumor from the initial stage to the final stage. The accuracy of the system is validated by using evaluation methods such as *precision*, *recall*, and *F-measures*. In [10] seizure detection IoMT system is demonstrated by using a Discrete Wavelet Transform (DWT), Hjorth parameters, and a k-NN classifier. In this method, EEG signals are decamped by using DWT, and then Hjorth parameters are extracted from decomposed signals, which are then classified by using the K-NN method. The article reported an evaluation accuracy in the range 97.9 % to 100.0 %. In [42] a measurement of blood pressure is used to monitor the stress level of the patient. In this work, the BP values and pulse rate is sent to the mobile to be processed and the results are shown on the screen to aware the user about his stress level. In [43] a system is presented to measure the temperature of the brain by using NMR spectroscopy, microwave radiometry, near-infrared spectroscopy, ultra-sound thermometry technique. The acquired data is sent wirelessly to the *application service/presentation layer* for analysis and visualization of the data. The accuracy and performance evaluation of the system is not presented by the Authors.

D. IoMT based system for blood sugar disease

Diabetic or blood sugar disease occurs when the human body is weakened to process blood sugar [44]. Therefore, patients that suffer from this disease need regular checkup of the blood glucose level and take care of their diet to keep this disease under control. Even though a large amount of devices are available to test the blood sugar at home, they are not suitable to provide feedbacks from doctors. The recent research is devoted to apply IoMT paradigm to overcome this issue with the aim to allow the sharing of measurement data with physicians and then giving promptly feedback to patients. Some of the available IoMT based BMS nowadays available are discussed in the following paragraph.

An IoMT system with a novel framework to measure and monitor the glucose level is presented in [44]. In this system, the signal retrieved from the interaction of radio frequency signal with biological tissues is firstly characterized and then monitored. A very low power Bluetooth protocol is used for the transmission of measurement data to the user mobile. In [45] an IoMT based BMS for glucose monitoring is presented. The evaluation of the concentration of the blood glucose, is performed by applying a suitable regression model on the signal obtained by the light absorbance at 940 nm wavelength of the blood in a fingertip. The evaluation of the method is performed by comparing the achieved results with referenced blood glucose concentrations using SD-check one touch glucometer. The mean absolute difference, mean absolute relative difference, average error and RMSE are 5.82 mg/dl, 5.20%, 5.14% and 7.50 mg/dl respectively. In [46] a new IoMT based wearable device is presented, which is used for accurate measurement of glucose level in blood. The device uses infrared spectroscopy and IoMT paradigm for remote accessibility of data for doctors/users. In order to validate the performance of the device, the Authors use the prediction of capillary blood glucose and reported 6.07% Average Error and 6.08% Mean Absolute Relative Difference.

E. IoMT based system for other diseases

Some of the IoMT applications for other diseases are discussed in this section. In [47] a wireless-based monitoring system is demonstrated for the fall detection of elderly people. Similarly, an IoMT system to monitor the elder people at their home is presented in [48] by getting the information of the patient's movement with an accelerometer. In [49] a smart wheelchair is developed for the fall detection of elder people by monitoring the physical condition and motion of the person at their home. The doctor gets the alerts remotely by an alarm system in the hospital whenever any fall detection occurs. In [50] an IoT based tooth mounted system to monitor the teeth and food level. In this system, the tooth chip is placed via filing inside the mouth that gather the information and analyze the food quality by using bacterial optimization and adaptive deep neural network. The system provides 99.23% accuracy as reported in the article. In [51] the Authors proposes a portable cytometer able to acquire pictures of the cells and transmit them to hospitals in all over the world by deploying the satellite communication. It was a first attempt to introduce the IoMT for laboratorial analysis. In this case the main issue to solve is the automatic process of the images [52] and the uncertainty introduced by low quality images [53],[54].

IV. CHALLENGES AND FUTURE OUTLOOK

There are several issues related to the IoT based BMS that are needed to be addressed for their large scale implementation in the health care sector. As we know, in IoMT based BMS, a high number of *smart things* (smart medical devices) are connected through the network and shared big amount of measurement data. Also, in IoMT based BMS, the patients and healthcare staffs have to use their own personal devices (mobile or smart phone) in order to access, deliver and process the data. Hence, the high chances of data hacking, which lead to the serious challenge of privacy and security [55]. Therefore, to safeguard the privacy of users and healthcare staffs, the IoT based BMSs need for new standard security and privacy protocols that able them to manage in an optimized way, the heterogeneous health data shared on internet. Another critical challenge is the management of data; as the IoT based BMS creates a large amount of medical data and metadata to be processed. This big amount of data need to be processed by utilizing intelligent algorithms for example based on machine learning or heuristic processes. This will help to increase the efficiency of IoMT based BMS and make it possible to take effective and fast decisions in case of emergency [56]. IoMT based BMS also required improvement regarding their robustness: they must be capable to work in a harsh environment such as in high temperatures, humid and wet environments. This will lead to improve the IoMT systems in terms of continuous monitoring of patients without any interruption [11]. Some other important research lines to boost the usefulness of IoMT based BMS, concern with the development of: high performance batteries, efficient battery charging system, energy harvesting system and more energy-efficient smart measurement devices [11].

V. CONCLUSION

IoMT based Biomedical Measurement System (IoMT-BMS) play an important role for the diagnosis of various diseases such as blood pressure, heart attack, brain tumor, Alzheimer, Parkinson, epilepsy and so on, as well as widely used for health-care monitoring, monitoring of disease progression, and in biomedical research. The rapid growth and increasing demand of IoMT-BMS in modern lifestyle make it essential that these systems must be accurate, fast, user-friendly, allow comfort to the wearer, and provide stability and accuracy even in the harsh environment. Based on these common requirements, scientists are trying to improve these BMS and providing new solutions. This state of the art aims to stimulate the research in this field and offers a general overview with some highlights about the IoT based BMS for specific diseases. The paper has also highlighted the major challenges that need to be addressed within the current scenario. Such issues will open the path to come up with new multidisciplinary approaches to design better IoMT systems, and thus, leads to warranty the continuous monitoring of human health, timely generation of alarm on one hand and the privacy of the users on the other.

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