Integrated IoT Medical Platform for Remote Healthcare and Assisted Living

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***Abstract*—Ambient Assisted Living (AAL) is receiving significant attention due to its promise to uplift the healthcare sector in general, and to promote care for the frail and aging patients in particular. The Internet of Medical Things (IoMT) technology is a key facilitator for AAL. IoMT provides medical services that make smart hospital, doctors and patients interact in harmony leading to elevated healthcare levels. In this paper, we develop an integrated medical platform for remote health monitoring. The proposed multi-layer architecture senses and collects information about the patient vitals alongside his/her surrounding environment. Then, it relays such information to a cloud for storage and data analysis where further actions are applied for a better end user experience. Such data is accessible to the patient's healthcare providers and remote family members through a mobile application. We built and tested a prototype of the proposed IoMT architecture to illustrate how it achieves the AAL goals.**

***Index Terms*—Internet of Things; Ambient Assisted Living; wearable systems; platform implementation; cloud computing.**

I. Introduction

The aging population is growing at an unprecedented rate. According to the the United Nations, it is predicted that 15.7% of the total population in 2030 will be 65 years old and above [1], [2]. This massive increase in the number of frail elderly people has triggered the need to provide a persistent healthcare and remote health monitoring that insures active and independent lifestyle for such aging citizens without the aid of personal assistants.

The Internet of Things (IoT) is an enabling technology that has gained significant attention in our era due to its numerous capabilities and application domains. The concept of Internet of Medical Things (IoMT) emerged as an enabling technology to provide an advanced remote healthcare and telehealth through integrating IoT-enabled devices with medical equipment. The IoMT paradigm guarantees *(1)* accurate remote real-time health monitoring with reduced errors, *(2)* reduced medical management costs, *(3)* enriched patient experience and satisfaction, *(4)* time-efficiency through the elimination of painstaking wait and redundant doctor visits especially in rural areas, *(5)* better disease prediction, prevention and management, and *(6)* improved treatments outcomes via enhanced drug management.

In this paper, we propose a cloud-based IoMT platform that promotes ambient assisted-living (AAL), alleviates the need for unnecessary doctor visits, and cuts down on hospital stays and re-admissions whenever possible. The proposed platform is developed for home-use by patients that are not in critical condition but need to be constantly or periodically monitored either by a clinic/doctor or by remote family members. The proposed system monitors the patient's physical vital conditions such as the body temperature, and heartbeat as well as some environmental attributes such as the room temperature, the light condition, and the location of the patient with the ability to infer if he/she has fallen.

The proposed platform follows a layered architecture that is composed of three layers: *(1)* The perception layer which contains the sensors that collects all the medical information of the patient and his/her surrounding environment; *(2)* The network and gateway layer which transfers the data from the perception layer to the IoT network infrastructure, *(3)* The integrated application layer in which the data is stored. Thus, different processing, cloud computing and analytics can take place on this stored data. With dedicated software and algorithms, this raw data is transformed into useful information for both the caregiver and the patient. A prototype of the proposed architecture is built and tested to demonstrate its performance.

The remainder of this paper is organized as follows. In Section II, we review the related literature. The proposed IoMT based architecture is presented in Section III. A preliminary set of results of the prototype is presented in Section IV. We conclude in Section V.

II. Related Work

In this section, we discuss the literature of related IoT-based remote healthcare systems. In [3], the authors presented a ubiquitous healthcare prototype for hospitals only. An unobtrusive coordinator node is attached to patient's body to transmit the patient's health status to a base station connected to monitoring screen. Likewise, the authors of [4] presented LAURA, which is an integrated wireless sensor network based system that provides localization, tracking and monitoring for patients within nursing institutes. The authors of [5] proposed the UDA-IoT system for emergency medical services that collects, integrates, and interoperates data in heterogeneous information-intensive medical applications. Antonovici *et al.*

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developed an Android-based application designed for patients with vision impairments [6]. The application records the data measured by an electronic sphygmomanometer and communicates through Bluetooth with alert capabilities in emergency cases. In [7], the CRIP platform was proposed as a component of CareStore project, which goal is to manage health routines seamlessly via a sensor based network that uses Bluetooth for connecting with health devices and web services for further integration with other platforms. In [8], Azariadi *et al.* proposed a model for ECG analysis and classification. With the use of a Galileo board in the implementation, a 24-hour continuous real-time monitoring with classification accuracy above 97% is provided. The authors in [9] introduced a behavioral analysis and risk detection system for the City4Age project. The proposed system consists of two components: A positioning sub-system, which detects indoor user position, and a motility sub-system that constantly monitors and detects the body activities through a wearable device.

In contrast to the aforementioned work, we aim at developing a platform that alleviates the need for hospitalization. Furthermore, the target platform integrates different medical services which have been tackled individually in prior works. The captured data is stored and processed on the cloud and available not only to the patient but also to the caregiver through a configurable mobile application.

III. Proposed Cloud-Based IoMT Architecture

We propose a cloud-based IoMT platform whose architecture is multi-layered [10]. As shown in Fig. 1, our proposed architecture consists of three layers: Perception, network and gateway, and integrated application layers. In what follows, we discuss each layer and its implementation in detail.

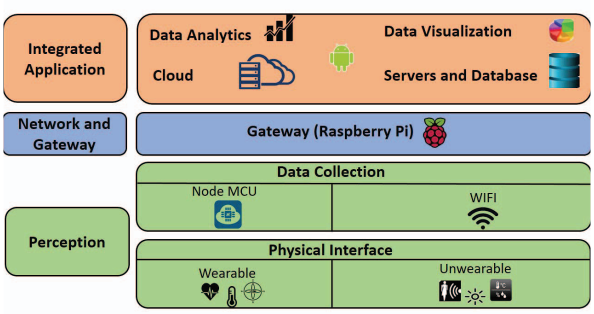


Fig. 1: Proposed cloud-based IoMT architecture.

A. Perception Layer

The perception layer is the core layer and information originator of any IoMT system. In this layer, the required data is perceived and aggregated to be further transmitted to the next layer, the network and gateway layer. The perception layer is the front-end of any IoT system and it consists of two main sub-layers:

1) Physical Interface: A set of sensors is used to collect the patient vitals and monitor the surrounding environment. We use two categories of sensors: wearable sensors and unwearable sensors. Each category is grouped into a separate node.

a) Wearable Node: Our wearable node consists of three skin-contact sensors to detect the main vital signs which are of high importance to the medical professionals and consistently checked by healthcare providers:

- **Heart Pulse Rate:** It is responsible for measuring the number of times the heartbeats per minute. Based on the fundamentals of optoelectronics [11], light is emitted using light-emitting diode from one side of the finger and then, the received light intensity is measured on the other side using a light dependent resistor.
- **Motion Detection:** Fall detection is one of the most critical issues for frail elderly. Based on accelerometers, this sensor consists of micro-machined structures on a silicon wafer which are designed to measure acceleration and magnetic fields in the Cartesian coordinate system.
- **Body Temperature:** This contact-sensor can be applied to the skin to detect any temperature-related abnormal activities such as fever or hypothermia. Such temperature sensors are great replacement of the traditional glass thermometers which lead to toxic environmental hazards.

b) Unwearable Node: The unwearable node is designed to keep track of the environmental conditions that surround the patient in order to provide advanced healthcare services. Our unwearable node contains the following three sensors:

- **Indoor Temperature and Humidity:** Both humidity and temperature are considered to be an extremely important factor in providing a comfortable environment.
- **Light:** Detecting the light intensity with a high resolution, providing low light level operation and a high sensitivity to detect even small change in light.
- **Passive Infrared (PIR):** Such pyroelectric sensors can detect the level of infrared radiation of objects and humans. We deploy many of such sensors in the patient's residency to keep track of his/her location.

2) Data Collection: This layer collects, processes and parses the data of the physical interface sub-layer and forward it to the next layer. Microcontrollers are typically used for this sub-layer. A microcontroller data collection system collects the data from its attached sensors (either wearable and unwearable), apply data arrangement and primitive processing and make the data ready to be transmitted to the gateway layer using a wireless transceiver. Microcontrollers have a built-in analog to digital peripheral that converts the analog reading coming from the physical sub-layer into digital readings.

Two NodeMCUs [12] are used as the data collectors in the proposed architecture: one for the wearable node and the other for the unwearable node. NodeMCU is an open-source firmware and development kit with a self-contained IEEE 802.11 Wi-Fi networking capability. In our platform, the used NodeMCUs are equipped with ESP8266 Wi-Fi modules which are powered by a 3.3 voltage battery.

B. Network and Gateway Layer

The network and gateway layer works as a bridge between the sensor network (perception) and the servers and database (application layer). In the proposed platform, a Raspberry-Pi 3 [13] microcontroller acts as the system gateway due to its high capabilities. The gateway is used to gather all the data from the two MCUs wirelessly through the Message Queue Telemetry Transport (MQTT) protocol [14], [15] and then it relays this data to the cloud. MQTT is a broker-based publish/subscribe messaging protocol, which is designed for light weight and machine to machine (M2M) communication that guarantees a one-to-many communication [16]. As a publish/subscribe protocol, whenever a client publishes a message with a certain topic, this message is received by all the clients that have subscribed to this particular topic. MQTT also allows parallel multi threading and thus, it ensures large number of connected devices in addition to real-time communication [17].

We implement a MQTT broker on the Raspberry-pi 3 microcontroller using python [18]. The nodes are arranged around the broker in a star topology. The two NodeMCUs transmit their data through Mosquitto [19]. Mosquitto is an open source message broker that implements the MQTT protocol. Once a node publishes a message including a topic, the broker dispatches this message from the sender to the rightful receiver subscribed to this topic as shown in Fig. 2.

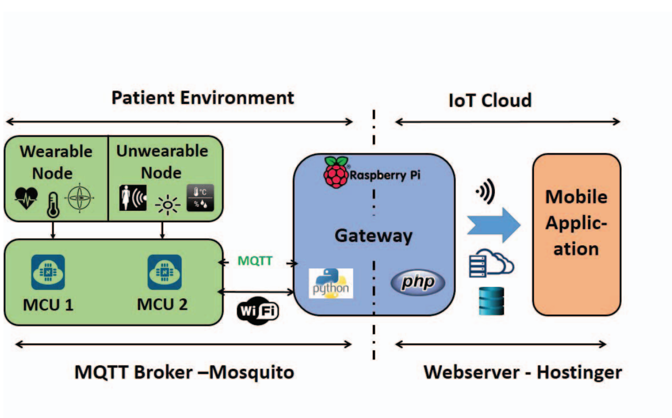


Fig. 2: Network and Gateway.

C. Integrated Application Layer

The integrated application layer is the back-end for any IoT system. It gives the end user deep insights on the sensed data. This layer resembles the IoT infrastructure from database servers till clouds and fogs. Clouds are a key component of IoT. They are composed of virtual dedicated servers that allow high flexibility, security, scalability and stability when compared to the traditional servers. For our platform, cloud hosting is implemented through a web hosting server (hostinger) [20], where the patient data is saved, backed-up and analyzed to issue warrnings upon up-normal situations of the patient (e.g., when the heartbeat rate exceeds a certain threshold).

1) Android Based Mobile Application: Our prototype aims to facilitate ambient assisted living for the frail elderly independent patients or patients with cognitive or physical disabilities. Therefore, we developed a mobile application which has two user interfaces:

- **Doctor Interface:** In this interface, the doctor accesses his/her assigned patients' profiles. Each patient profile contains the vital reading from both the wearable and unwearable nodes. In case of emergency, an immediate notification alert is sent to the healthcare providers.
- **Patient Interface:** This interface is dedicated to the patient, where he/she can track his/her record history and current vitals.

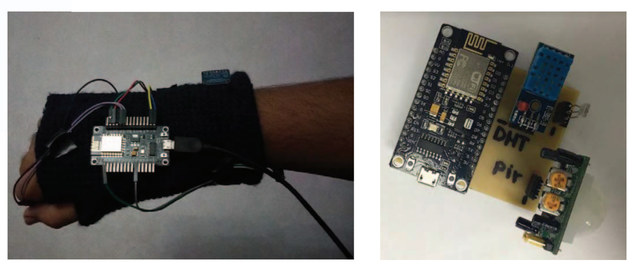
XML programming language is used to design the layout of the user interfaces, and JAVA programming to interact with user events.

IV. Prototype Experimental Evaluation

In this section, we present the performance evaluation of the implemented prototype under different set of test cases and scenarios. The sensors and microcontrollers used in our prototype are summarized in Table I. The wearable and unwearable nodes are shown in Fig. 3.

TABLE I: Prototype Components.

Device	Model
Heartbeat Sensor	Sunrom-1157
Fall Detection Sensor	LSM303DHLC
Body Temperature Sensor	YSI 400
Indoor Humidity and Temperature Sensor	DHT11
Light sensor	TSL235R
PIR Sensor	HC-SR501
NodeMCu	ESP8266
Raspberry Pi	3 MODEL B



(a) Wearable node (b) Unwearable node.

Fig. 3: The implemented prototype of the proposed platform.

A. Heartbeat Monitoring

First, we evaluate the performance of the heartbeat sensor. In the first 30 seconds, our patient was in a calm relaxed state, then the patient starts some light exercises for the following 30 seconds. Figure 4 depicts the heartbeats per minutes over the observation interval in seconds. As shown in Fig. 4, the patient

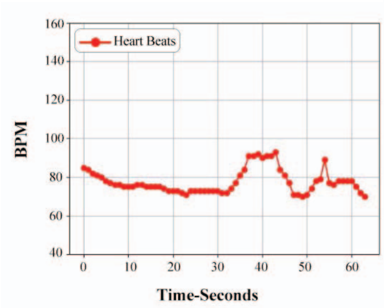


Fig. 4: Heartbeat activities.

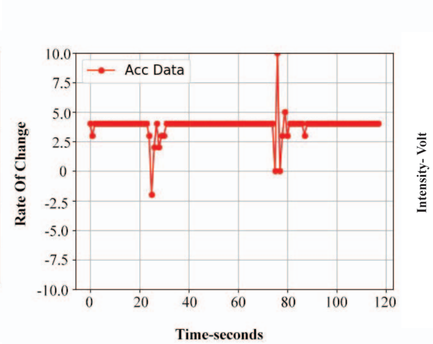


Fig. 5: Patient fall detection.

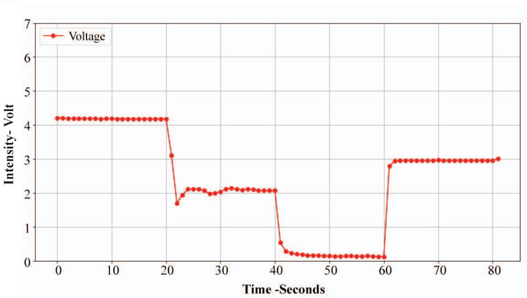


Fig. 6: Examination of different Light intensities

exhibits a steady pulse rate due to his stillness in the first 30 seconds, then the heartbeat readings increases and fluctuates depending on the patient physical activity.

B. Fall Detection

Next, we evaluate the fall detection capability of our prototype. In this experiment, we have our patient walking freely and then he drops down suddenly twice. Upon falling, the motion detection sensor should report no acceleration except in the z-axis which is caused by gravity. Figure 5 shows the rate of change for the z-axis and time in seconds. The acceleration remains constant while the patient is walking. When the patient falls down and stands up, the sensor reading changes as in the 22^{th} and 78^{th} seconds.

C. Light Intensity

The above experiments were dedicated for testing the wearable node. Here, we evaluate the unwearable node behavior. To assess the light condition monitoring, we vary the light intensity at the patient's room. For the first 20 seconds, the room is under direct sunlight exposure. For the following 20 seconds, the room is exposed to a dim low light intensity. Next a 20 seconds of complete darkness. Finally, the room is lighted up with a high intensity light. Figure 6 presents the voltage level corresponding to the different lighting conditions. Our prototype is able to precisely detect any change in the patient surrounding light intensity even in the case of drastic changes in a small time interval.

V. Conclusions

Aging is one of the main concerns of this era due to the increasing population of the elderly people. In this paper, we have presented a cloud-based IoMT platform for ambient assisting living (AAL) using a three-layer architecture. We have built and tested a prototype to verify the performance of the proposed platform. A set of preliminary results was presented to assure that the presented architecture will satisfy the AAL requirements and positively impact the health life of frail patients.

References

[1] World Health Organization, *World report on ageing and health*, 2015.

[2] United Nations Department of Economic and Social Affairs – Population Division., "World population aging 2015 report," http://www.un.org/en/development/desa/population/publications, ISBN 978-92-1-057854-7.

[3] M. Aminian and H. Naji, "A hospital healthcare monitoring system using wireless sensor networks," *J. Health Med. Inform*, vol. 4, no. 02, 2013.

[4] A. Redondi, M. Chirico, L. Borsani, M. Cesana, and M. Tagliasacchi, "An integrated system based on wireless sensor networks for patient monitoring, localization and tracking," *Ad Hoc Networks*, vol. 11, no. 1, pp. 39–53, 2013.

[5] B. Xu, L. Da Xu, H. Cai, C. Xie, J. Hu, and F. Bu, "Ubiquitous data accessing method in IoT-based information system for emergency medical services," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 2, pp. 1578–1586, 2014.

[6] D.-A. Antonovici, I. Chiuchisan, O. Geman, and A. Tomegea, "Acquisition and management of biomedical data using internet of things concepts," in *IEEE International Symposium on Fundamentals of Electrical Engineering (ISFEE)*, 2014.

[7] J. Miranda, J. Cabral, S. R. Wagner, C. Fischer Pedersen, B. Ravelo, M. Memon, and M. Mathiesen, "An open platform for seamless sensor support in healthcare for the internet of things," *Sensors*, vol. 16, no. 12, p. 2089, 2016.

[8] D. Azariadi, V. Tsoutsouras, S. Xydis, and D. Soudris, "ECG signal analysis and arrhythmia detection on IoT wearable medical devices," in *IEEE 5th International Conference on Modern Circuits and Systems Technologies (MOCAST)*, 2016.

[9] V. Mighali, L. Patrono, M. L. Stefanizzi, J. J. Rodrigues, and P. Šolić, "A smart remote elderly monitoring system based on IoT technologies," in *International Conference on Ubiquitous and Future Networks (ICUFN)*, 2017.

[10] K. Yelmarthi, A. Abdelgawad, and A. Khattab, "An architectural framework for low-power IoT applications," in *IEEE 28th International Conference on Microelectronics (ICM)*, 2016.

[11] J. Arora, A. Singh, N. P. Singh, S. S. Rawat, G. Singh *et al.*, "Heartbeat rate monitoring system by pulse technique using HB sensor," in *IEEE International Conference on Information Communication and Embedded Systems (ICICES)*, 2014.

[12] "Espressif-nodeMCU," http://nodemcu.com/, Accessed: October, 2017.

[13] "The Raspberry Pi Foundation," https://www.raspberrypi.org/, Accessed: October, 2017.

[14] "Message Queue Telemetry Transport," http://mqtt.org/, Accessed: October, 2017.

[15] A. Glória, F. Cercas, and N. Souto, "Design and implementation of an IoT gateway to create smart environments," *Procedia Computer Science*, vol. 109, pp. 568–575, 2017.

[16] M. Collina, G. E. Corazza, and A. Vanelli-Coralli, "Introducing the QEST broker: Scaling the IoT by bridging MQTT and REST," in *Proc. of IEEE International symposium on Personal indoor and mobile radio communications (PIMCR)*, 2012.

[17] L. Hou, S. Zhao, X. Xiong, K. Zheng, P. Chatzimisios, M. S. Hossain, and W. Chen, "Internet of Things Cloud: Architecture and Implementation," *IEEE Communications Magazine*, vol. 54, no. 12, 2016.

[18] "Python," https://www.python.org/, Accessed: October, 2017.

[19] "Eclipse Mosquitto," https://mosquitto.org/, Accessed: October, 2017.

[20] Web Hosting, "Hostinger," https://www.hostinger.com/, Accessed: October, 2017.