IoT-Based Health Monitoring System for Active and Assisted Living

Ahmed Abdelgawad[1], Kumar Yelamarthi[1(✉)], and Ahmed Khattab[2]

[1] School of Engineering and Technology, Central Michigan University, Mt. Pleasant, MI 48859, USA
{abdella, yelamlk}@cmich.edu

[2] Electronics and Electrical Communications Department, Cairo University, Giza 12613, Egypt
akhattab@ieee.org

Abstract. The Internet of Things (IoT) has been widely used to interconnect the available medical resources and offer smart, reliable, and effective healthcare service to the elderly people. Health monitoring for active and assisted living is one of the paradigms that can use the IoT advantages to improve the elderly lifestyle. In this paper, we present an IoT architecture customized for healthcare applications. The proposed architecture collects the data and relays it to the cloud where it is processed and analyzed. Feedback actions based on the analyzed data can be sent back to the user. A prototype of the proposed architecture has been built to demonstrate its performance advantages.

Keywords: Health monitoring · Internet of Things (IoT) · Medical devices · Sensors · Platform implementation · Cloud computing

1 Introduction

Remote healthcare has become a vital service with the growing rate of senior citizens. Health monitoring, rehabilitation, and assisted living for the elderly and medically challenged humans is an emerging challenge because they require seamless networking between people, medical instruments, and medical and social service providers. This motivates the need for affordable, low-power, reliable, and wearable devices that will improve the quality of life for many elderlies and physically challenged people.

The Internet of Things (IoT) platform offers a promising technology to achieve the aforementioned healthcare services, and can further improve the medical service systems [1]. IoT wearable platforms can be used to collect the needed information of the user and its ambient environment and communicate such information wirelessly, where it is processed or stored for tracking the history of the user [2]. Such a connectivity with external devices and services will allow for taking preventive measure (e.g., upon foreseeing an upcoming heart stroke) or providing immediate care (e.g., when a user falls down and needs help).

Recently, several IoT systems have been developed for IoT healthcare and assisted living applications. A multiple communication standard compatible IoT system for medical devices was designed by Wang et al. in [3]. Xu et al. proposed a resource-based

O. Gaggi et al. (Eds.): GOODTECHS 2016, LNICST 195, pp. 11–20, 2017.
DOI: 10.1007/978-3-319-61949-1_2

data accessing method (UDA-IoT) that is suitable for healthcare information-intensive applications [4]. Kolici et al. proposed and implemented a medical support system considering Peer-to-Peer (P2P) and IoT technologies. They used a smart box to control the situation of patients. Moreover, they performed several experiments to evaluate the implemented system for few different scenarios [5]. Sandholm et al. proposed an on-demand Web Real-Time Communication (WebRTC) and IoT device tunneling service for hospitals. The proposed system relies on intercepting key parts of the WebRTC Javascript Session Establishment Protocol (JSEP) and using local network gateways that can multiplex traffic from multiple concurrent streams efficiently without leaking any WebRTC traffic across the firewall except through a trusted port [6]. An acquisition and management of biomedical data using IoT has been proposed by Antonovici et al. They developed an Android application that aims to record the data measured (SBP-Systolic Blood Pressure, DBP - Diastolic Blood Pressure and Heart Rate) by the electronic sphygmomanometer that communicates via Bluetooth. The proposed system offers the possibility of transmitting medical data using any mobile device. Data will be compared with the normal values and when an abnormality is observed, the patient is notified. In the worst case, the emergency service and doctors will be notified as well. The patient with vision impairment who are suffering from diabetes, hypertension or obesity is also supported by adapting a “Text To Speech” engine that allows data to be transmitted as type string to the device [7]. Krishnan et al. presented a real-time Internet application with distributed flow environment for medical IoT. If the patient is out of range for the Wi-Fi, or the server is unavailable, the patent’s data will be stored locally and sent to the server when the patient arrives back in range of connectivity [8]. Azariadi et al. proposed an algorithm for electrocardiogram (ECG) signal analysis and arrhythmia detection on IoT-based embedded wearable medical platform, as suitable for 24-h continuous monitoring. A Galileo board is used to implement the design [9].

Mohan presented a cyber security framework for IoT Personal Medical Devices (PMDs) that enable enhanced mobility for the patient. In the meantime, it is facilitating better monitoring of the patient’s condition while moving. He presents the security threats and limitations of PMD IoT that makes addressing these threats challenging. He also presents some initial solution approaches in order to address these security threats [10]. Yeh et al. presented a cloud-based fine-grained health information access control framework for lightweight IoT devices with dynamic auditing and attribute revocation. They handled the potential security challenges and the cloud reciprocity issues. The results show that the proposed scheme is promising for cloud-based Personal Health Information (PHI) platform [11]. Porambage et al. proposed a secure lightweight authentication and key establishment protocol for end-to-end communication for constrained devices in IoT-enabled ambient assisted living systems. They used proxy-based approach to assign the heavily computational operations to more powerful devices in the neighborhood of the used medical sensors. The results are promising for the real world applications [12].

Yelamarthi and Laubhan [13] have designed and implemented a portable electronic travel aid for the blind. Utilizing ultrasonic range finders mounted on the belt, the assistive device was able find obstacles in front of the user, and provide respective navigation directions through a Bluetooth headphone. However, this device is limited in the distance and localization of obstacles with high accuracy. Yelamarthi et al. [14, 15] have presented a depth sensor based navigation system to detect obstacles in front of the user with high accuracy, and inform user of the same through vibro tactile feedback in the hand gloves. However, a limitation in majority of the work presented is lack of connectivity to the cloud to continually monitor the user data, and storage for health analysis when necessary.

Addressing this limitation, in this paper, we present a cloud-based IoT system that is applicable in different healthcare and active/assisted living applications. The proposed system is composed of 6 modules: the physical sensors that collects the user's information and provides the needed feedback, a sensor interfacing circuit, an indoor positioning module that helps locating the user, a low-power microcontroller that manages the data collection and forwarding process, a wireless transceiver that connects the system to the Internet, and a cloud server in which the data storage and processing take place. A prototype of the proposed system is built and tested to illustrate its different performance aspects.

The remainder of the paper is organized as follows. In Sect. 2, we present the proposed IoT health monitoring architecture. A preliminary set of result of a prototype of this architecture is presented in Sect. 3. The paper is concluded in Sect. 4.

2 Wearable Active and Assisted Living System

In this section, we propose a portable and customizable IoT system that can be used to collect the data needed to facilitate the independent living of senior and challenged citizens to improve their quality of life. The proposed system design philosophy targets having a low-power system that can be worn during the day and be turbo charged as necessary. The system is designed to be light and comfortable to wear. Furthermore, the system is implemented using low-cost components, which makes it an affordable system. An overview of the proposed wearable IoT system is shown in Fig. 1. The system is composed of six main components that are described as follows.

2.1 Physical Sensors

In order to collect the user information that reflect its activity and medical signs, multiple sensors are needed. These sensors are lightweight in order to be wearable. A pulse oximeter sensor is used to measure the amount of oxygen dissolved in the user's blood, based on the detection of Hemoglobin and Deoxyhemoglobin. Such a sensor is useful in the situation in which the user's oxygenation is unstable, and in need for supplemental oxygen or even intensive care. An electrocardiogram (ECG) sensor is used to obtain a side set of cardiac information such as the rate and rhythm of the heart, the patterns of abnormal electric activity that may predispose the user to abnormal cardiac rhythm disturbances, and how the heart is placed inside the chest cavity. Furthermore, the ECG sensor provides evidences of damages that occur to different parts of the heart muscle, any acutely impaired blood flow to the heart muscle, and increased thickness of the heart muscle. A nasal/oral airflow sensor is used to measure

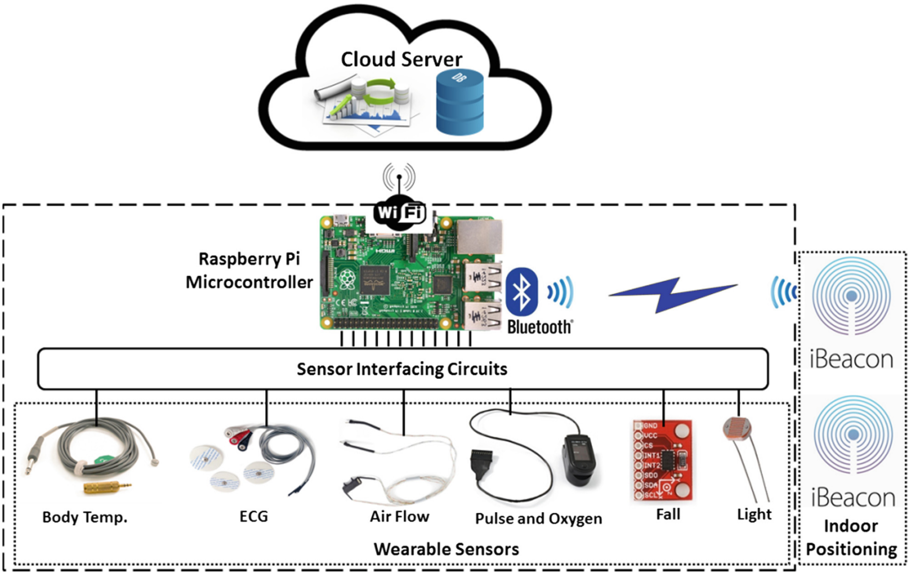

Fig. 1. Proposed IoT wearable system for active and assisted living

the breathing rate of the user to determine whether or not he or she is in need of respiratory help. A temperature sensor is used to measure the temperature of any part of the body, and can be moved easily in order to be placed over the body part where temperature measurement is needed.

In addition to the above medical sensor that capture the user's health signs, light and fall detection sensors are also used. The light sensor provides the information that can help the user adjust his/her ambience light, so as to help him/her navigate around with ease. For example, when the ambience light decreases, readings from this sensor can be used to turn on extra lights. The fall detection sensor is an accelerometer that is used to determine whether the user has fallen abruptly, such that warnings signals can be generated to provide the needed care.

2.2 Indoor Positioning Module

The second module of the proposed system is a Bluetooth Low-Energy (BLE) iBeacon which is widely used for indoor positioning [16]. Instead of using latitude and longitude information to determine the user's location, iBeacon transmits a Bluetooth low energy signal to infer the existence within its vicinity. Several iBeacon devices are installed in the environment in which the user is located. When the user moves to the proximity of an iBeacon, its ID is read by the microcontroller wirelessly using BLE. The iBeacon ID is sent to the cloud server to obtain the user's location. The BLE technology allows the iBeacon to be powered by a single coin cell battery for extended time intervals.

2.3 Sensor Interface Circuits

The signals representing the different sensed phenomena (e.g., blood oxygen level, body temperature, etc.) are then conditioned to be ready for input to the microcontroller. This is achieved through the use of sensor interfacing circuitry that converts any analog signals coming from the sensors into the corresponding digital format and performs any further signal conditioning functionality to ensure compatibility with the used microcontroller.

2.4 Microcontroller

The microcontroller is the core of the system. It is responsible for collecting the data of the different sensors interfaced to it, and communicating such a data to the cloud server for further processing, or for retrieving the iBeacon location information. We use the single-board Raspberry Pi 2 single-board microcontroller that is powered through a 3.7 V Li-Ion battery in our front-end nodes [17]. The Raspberry Pi is equipped with an on-board communication module that controls the data flow between the different sensors and the microcontroller using the I^2C protocol.

2.5 Wireless Transceivers

The proposed system has BLE and IEEE 802.11 WiFi wireless transceivers interfaced to the Raspberry Pi 2 microcontroller. The BLE transceiver is responsible for locating the system using the deployed iBeacons. It can be also used to provide feedback to the user through Bluetooth headsets for example. The WiFi transceiver is used to connect the proposed system to the Internet, and hence, the cloud server. The collected sensor data and the iBeacon location information transferred over the WiFi wireless interface.

2.6 Cloud Server

The collected user's data is communicated to a cloud server which is responsible for facilitating the accessibility of such a data anywhere through the Internet. The cloud server implements a wideset of data management services including data storage, data analytics, and data visualization in addition to providing an appropriate application program interface (API) and software tools through which the data can be accessed and manipulated. Our implementation of the cloud server is shown in Fig. 2.

The cloud server core is a large database that has enough space to accommodate the huge amounts of data for the different sensors for long times to track the history of the system user. The database is interfaced to a wide set of data analysis algorithms and APIs such as Google Sheets for data visualization. Data can be accessed through the Internet using dynamic webpages as shown in Fig. 2.

In our implementation of the cloud server, both Apache and MySQL run on the same virtual machine (VM) running Ubuntu 14.04. This VM is just one of the many VMs that constitute a larger VSphere implementation. The VSphere control panel is

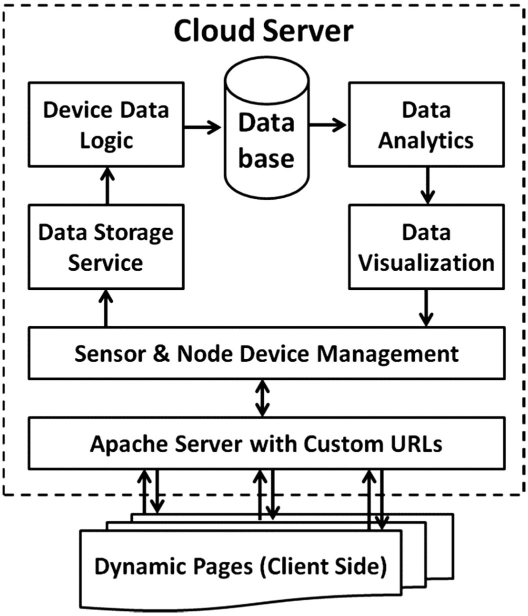

Fig. 2. Cloud server architecture.

used to increase the resource allocation of the VM (such as memory and disk space) with a minimal downtime and without data corruption. It is worth noting that if the health monitoring system requirement exceeds the available hardware resources, the implemented VM can be easily moved to a dedicated cloud hosting platform such as an EC2 instance on Amazon Web Services (AWS).

3 Experimental Evaluation

As a proof of concept, a prototype system has been implemented to evaluate the proposed IoT active and assisted living healthcare system. The system has been configured to collect data from all the listed sensors. However, in what follows, we only present the data of the indoor positioning, the fall detection, and the light sensor. The readings of the other wearable sensors have been validated in the lab as well.

Figure 3 shows the results of the fall detector sensor. In this experiment, we have the user walking for a few seconds then abruptly fall on the ground, to mimic real-world scenario. As shown in Fig. 3(a) and (b) the x- and y-axis acceleration of the user changes while the user is walking, but not the acceleration on z-axis. When, the user falls down, there was a small change in acceleration in x- and y-axis, and a significant spike in the acceleration of z-axis demonstrating that the proposed system can detect sudden falls, as applicable in health care sector.

Figure 4 shows the indoor positing results using the iBeacon sensors. We deployed several iBeacon transmitters in the building where the experiment was conducted.

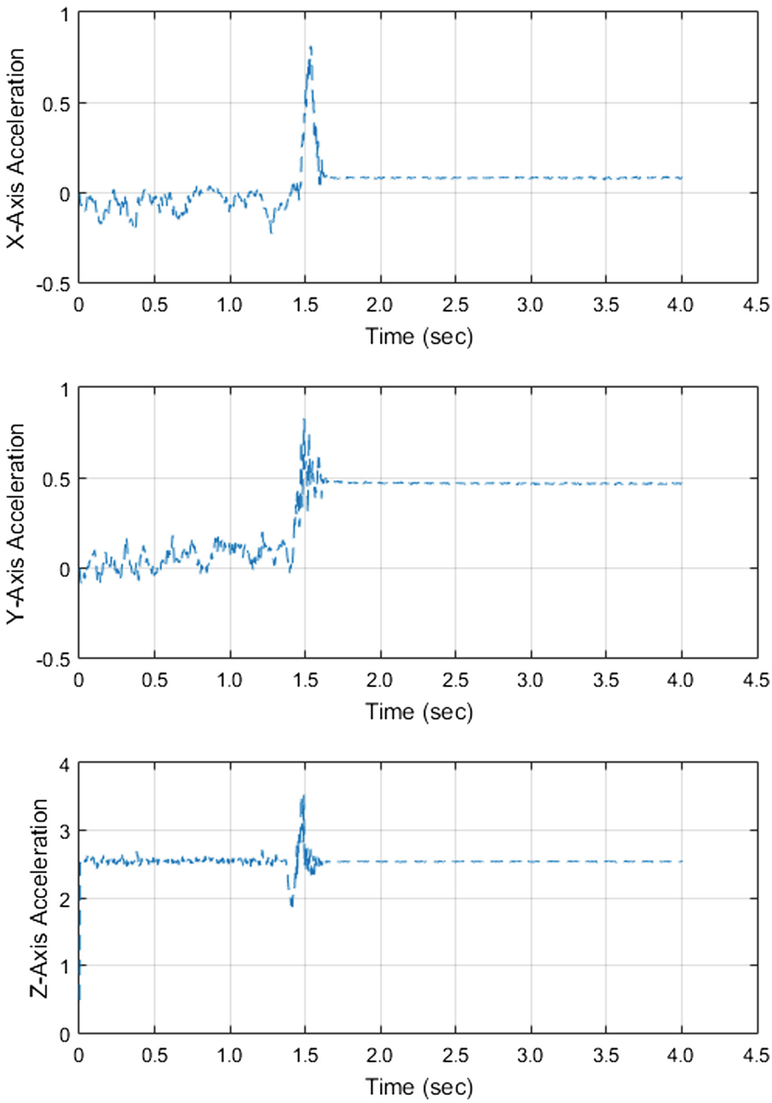

Fig. 3. The results of the fall detector.

When the IoT system worn by the user moves close to any iBeacon, the current location of the user is obtained from the cloud server. The user's current position, the red circle, is stored in the cloud and keep track the all the position history. Moreover, the user or any authorized person can check the user's location.

Light condition is critical for some elderly; some time we need to control the light according to the health condition of the user. The proposed system can monitor the light condition and control it accordingly. Figure 5 shows the light sensor data. The light sensor reports different voltage values in accordance with the different lighting

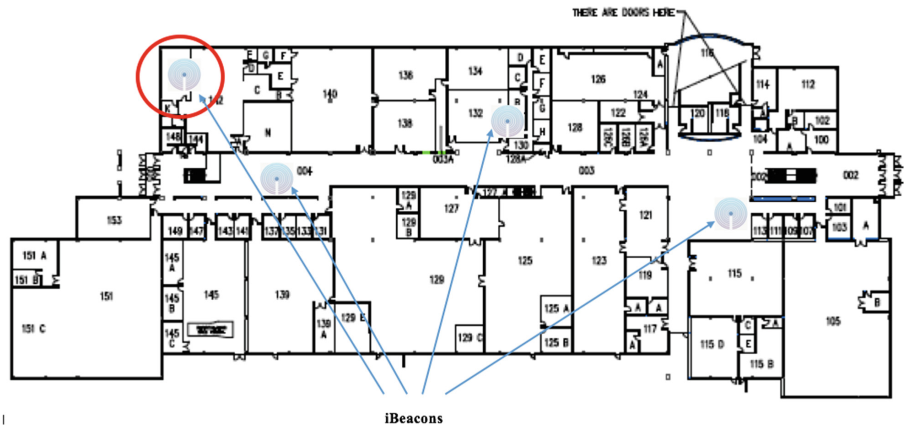

Fig. 4. Indoor positioning using iBeacon transmitters.

conditions. The lighting conditions considered in this experiment are: (1) intensive light, (2) normal light in the lab, (3) partial shade, (4) full shade, and (5) complete black out. We manually change the lightning condition about every 15 s from normal, to intensive, then back to partial shade, full shade, and complete black out, then back again to the normal light condition. As shown in Fig. 5, our system is able to capture these changes in the lighting conditions.

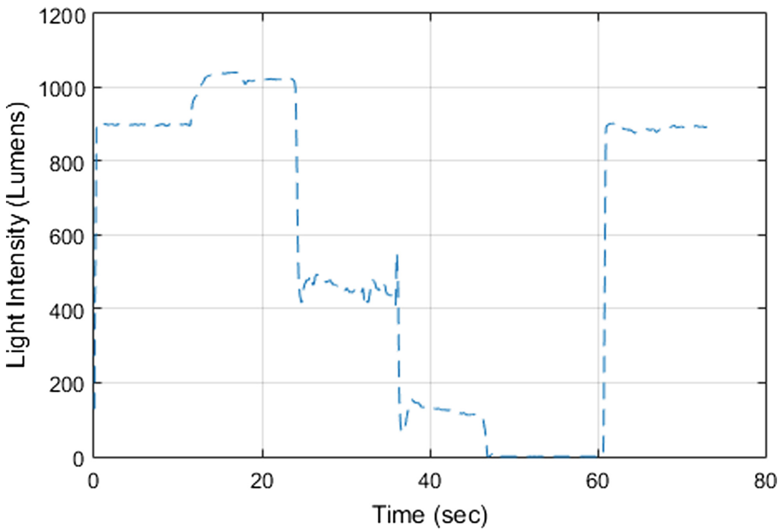

Fig. 5. Lighting condition results.

4 Conclusion

In this paper, we have presented a low-power wearable IoT system for active and assisted living healthcare applications. We have outlined the main components of the proposed system and explained their implementation details. We have built a prototype to illustrate the different performance aspects of the proposed system. The preliminary performance evaluation results have demonstrated the efficiency of the proposed system – despite being a low-cost one. This makes the proposed system a good candidate for implementing a wide set of wearable healthcare systems. Our future work will include how to secure the access of the data and will develop a mobile application that allows access of the data on handheld devices.

References

1. Yin, Y., Zeng, Y., Chen, X., Fan, Y.: The Internet of Things in healthcare: an overview. J. Ind. Inf. Integr. **1**, 3–13 (2016)
2. Sullivan, H.T., Sahasrabudhe, S.: Envisioning inclusive futures: technology-based assistive sensory and action substitution. Futur. J. **87**, 140–148 (2017)
3. Wang, X., Wang, J.T., Zhang, X., Song, J.: A multiple communication standards compatible IoT system for medical usage. In: IEEE Faible Tension Faible Consommation (FTFC), Paris, pp. 1–4 (2013)
4. Xu, B., Xu, L.D., Cai, H., Xie, C., Hu, J., Bu, F.: Ubiquitous data accessing method in IoT-based information system for emergency medical services. IEEE Trans. Ind. Inf. **10**(2), 1578–1586 (2014)
5. Kolici, V., Spaho, E., Matsuo, K., Caballe, S., Barolli, L., Xhafa, F.: Implementation of a medical support system considering P2P and IoT technologies. In: Eighth International Conference on Complex, Intelligent and Software Intensive Systems, Birmingham, pp. 101–106 (2014)
6. Sandholm, T., Magnusson, B., Johnsson, B.A.: An on-demand WebRTC and IoT device tunneling service for hospitals. In: International Conference on Future Internet of Things and Cloud, Barcelona, pp. 53–60 (2014)
7. Antonovici, D.A., Chiuchisan, I., Geman, O., Tomegea, A.: Acquisition and management of biomedical data using Internet of Things concepts. In: International Symposium on Fundamentals of Electrical Engineering, Bucharest, pp. 1–4 (2014)
8. Krishnan, B., Sai, S.S., Mohanthy, S.B.: Real time internet application with distributed flow environment for medical IoT. In: International Conference on Green Computing and Internet of Things, Noida, pp. 832–837 (2015)
9. Azariadi, D., Tsoutsouras, V., Xydis, S., Soudris, D.: ECG signal analysis and arrhythmia detection on IoT wearable medical devices. In: 5th International Conference on Modern Circuits and Systems Technologies, Thessaloniki, pp. 1–4 (2016)
10. Mohan, A.: Cyber security for personal medical devices Internet of Things. In: IEEE International Conference on Distributed Computing in Sensor Systems, Marina Del Rey, CA, pp. 372–374 (2014)
11. Yeh, L.Y., Chiang, P.Y., Tsai, Y.L., Huang, J.L.: Cloud-based fine-grained health information access control framework for lightweight IoT devices with dynamic auditing and attribute revocation. IEEE Trans. Cloud Comput. **PP**(99), 1–13 (2015)

12. Porambage, P., Braeken, A., Gurtov, A., Ylianttila, M., Spinsante, S.: Secure end-to-end communication for constrained devices in IoT-enabled ambient assisted living systems. In: IEEE 2nd World Forum on Internet of Things, Milan, pp. 711–714 (2015)
13. Yelamarthi, K., Laubhan, K.: Space perception and navigation assistance for the visually impaired using depth sensor and haptic feedback. Int. J. Eng. Res. Innov. **7**(1), 56–62 (2015)
14. Laubhan, K., Trent, M., Root, B., Abdelgawad, A., Yelamarthi, K.: A wearable portable electronic travel aid for the blind. In: IEEE International Conference on Electrical, Electronics, and Optimization Techniques (2016)
15. Yelamarthi, K., DeJong, B.P., Laubhan, K.: A kinect-based vibrotactile feedback system to assist the visually impaired. In: IEEE Midwest Symposium on Circuits and Systems (2014)
16. What is iBeacon? (2016). https://support.apple.com/en-gb/HT202880
17. Raspberry Pi 2 Model B (2016). https://raspberrypi.org/products/raspberry-pi-2model-b/