Paradigm-Shifting Players for IoT: Smart-Watches for Intensive Care Monitoring

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Abstract. Wearable devices, *e.g.* smart-watches, are gaining popularity in many fields and in wellness monitoring too. In this paper we propose an IoT application to alert the medical doctor assigned to a critical unit by using a smart-watch. The wearable device improves the efficacy of monitoring patients at risk in hospital units allowing the medical doctor to access information at any time and from any place. A network was built to wirelessly connect bio-sensing platforms, which measure metabolites concentration in patients' fluids (*e.g.* blood), with a dedicated application running on the smart-watch. In case of anomalous measured values, incoming alert notifications are received to ask urgent medical intervention. The main advantage of this new approach is that the doctors, or in general the caregivers, can freely move in the hospital other structures and perform other tasks meanwhile simultaneously and constantly monitoring all the patients thanks to the technology on their wrist.

Keywords: Remote continuous monitoring · IoT · Biomedical devices · Wireless network · Android wear

1 Introduction

Wearable Technology is considered as the revolution in the area of *Internet of Things* (IoT) [1]. Indeed, IoT satisfies the increasing request of always-connected devices to provide information accessible at any time and from any place [2]. In this context, wearable devices, *e.g.* smart-watches, can be highly exploited also for wellness monitoring or real medical applications thanks to their small-size, low-cost, easy-to-use, and multiple functionalities [3]. Even if smart-watches and *Goggle Glasses* have been introduced in the market only few years ago, these advanced devices have been already considered for patient monitoring scenarios [4, 5].

F. Stradolini and E. Lavalle contributed equally to this work.

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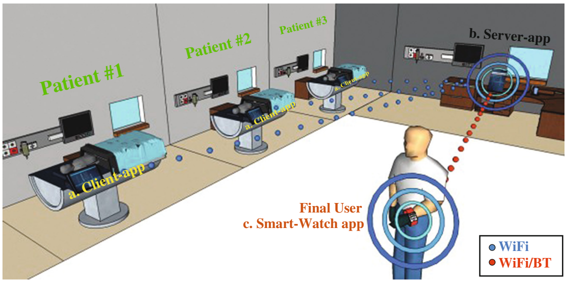

Fig. 1. IoT monitoring scenario: (*a*) Client-Android app gathers data from each patient's biosensor, (*b*) Server-Android app redirects data to a (*c*) Watch-AndroidWear app to keep the medical doctor continuously connected.

Most of the wearable applications are developed for patients' smart-watches to detect their body-motion, body-temperature, physical exercises and amount of sleep [6]. Otherwise, monitoring systems are also used in specialized medical applications, as for the home monitoring in dementia care [7] or for patients with specific illness [8, 9].

Continuous monitoring concept is extremely important and beneficial in hospital environment too, especially for critical patients in *Intensive Care Units* (ICUs) [10] or during surgery under anesthesia [11]. To address the necessity of keeping constantly under control vital parameters, some solutions have been proposed. A Nurse-Watch with vital sign monitoring and checklist reminders has been proposed to assist nurses with their daily responsibilities [12]. Although, this system does not allow nurses to freely move in the hospital without both the phone and the smart-watch. Indeed, the connection between these two devices relies on Bluetooth technology that can support only short-range distances. To overcome this limitation, we propose a system, shown in Fig. 1, where the smart-watch becomes the only center of a monitoring network for hospital environments. Indeed, it is connected via Wi-Fi to a series of independent bedside monitoring systems connected to each patient. The monitoring system consists of bio-sensing platforms able to detect different endogenous and exogenous metabolites in patient's fluids [13, 14] plus an Android device to display the measured data. In this way, a flexible and personalized monitoring is performed. The medical doctor or the caregiver, wearing the smart-watch, is able to remotely monitor, with different levels of responsibility, multiple molecular parameters of many different patients at the same time. Incoming alert notifications are received on the smart-watch in case of anomalous values that requires medical support. It is important to underline that another strength of our system is its flexibility in measuring different endogenous/exogenous metabolites by properly functionalizing the biosensors.

The paper is organized as follow: *Sect.* 2 describes the system architecture; *Sect.* 3 collects the solutions developed for realizing the system. The validation of the network is presented in *Sect.* 4, and, finally, *Sect.* 5 concludes the paper.

2 Network Architecture

Figure 1 sketches the proposed scenario based on three main building blocks: (*a*) a *Client Android*^{TM} *interface*, running on a bedside tablet, that continuously receives and displays all the data measured by the biosensing platform on the patient, (*b*) an *Android* *intermediary Server-side*, running on a tablet/smart-phone in a central workstation, that collects data from different clients and enable the bidirectional communication with them, and (*c*) a *Smart-Watch application* on the doctor watch device. The *Android intermediary Server-side* is unavoidable to enable the multi-patients monitoring from the *Smart-Watch* since the wearable can be paired, by default, to only one device. Hereafter, a detailed description is provided separately for each system component.

2.1 Client Android Interface

The client Android application collects data from several hardware biosensors that directly measure metabolites of each patient. In this way, the concentrations of the most critical biomolecules measured by the sensors are available to be immediately displayed on a tablet placed near patient's bed. The aim is to offer the same potentialities of the already largely used patient monitors. Filtering options on incoming raw data are provided to reduce noise and to ensure smooth traces of the measured concentrations.

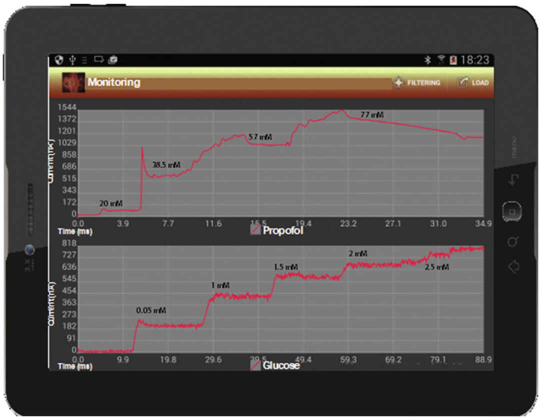

Fig. 2. Measure values displayed on bedside Client tablet. Monitored parameters are: endogenous glucose and exogenous propofol anesthetic.

Moreover the acquired values are stored in files on the memory of the device to allow *a-posteriori* consulting. The connection between the biosensors and the Android interface exploits Bluetooth® technology because it provides a standard, reliable, economic, wireless and secure method for the exchange of data via a short-range radio frequency. Moreover it does not interfere with medical equipment if fully certified [15].

Figure 2 shows an example of monitored values displayed on the bedside client-tablet interface. Starting from an application previously developed and validated by our group [16], the updated client-Android app offers new functionalities based on a Wi-Fi protocol for the communication with the intermediary-server. Thus, security mechanisms must be in place to prevent malicious attacks since sensible personal data are transmitted [17]. Securing the Wi-Fi connection is an important element of protecting the exchanged data. Basic points to be implemented are: to change the network name (*Service Set IDentifier* - SSID) from the default one and to adopt *Wi-Fi Protected Access* (WPA) security protocol [18].

2.2 Android Intermediary Server-Side

The server-side application is a completely new part of the present system we have realized to the aim of this paper. It gathers the monitored data from all the patients that, now on, could be seen as the clients connected by the network. In this way, it is possible to overcome the limitations of having the smart-watch connected to only one patient at time and one patient to a single doctor/caregiver. The intermediate server acts as a bridge between the doctor/caregiver application on the smart-watch and the patient applications on the client tablets. Indeed we wanted to maintain a bedside tablet near each patient to show the real-time trend of all the metabolite concentrations in time and for *a-posteriori* consulting of patient data. On the other side, the smart-watch receives data *on-demand* or alert without saving the received values in order to keep lightened the wearable app. To enable this scenario, the intermediate server pushes data to the smart-watch *on-demand* and, moreover, sends automatic messages to the doctor/caregiver in case of anomalies in recorded values. All these messages exchanged between the server and the smart-watch contain explicitly the patient identifier and the parameter-of-interest. Both the connections server–to-clients and server-to-SmartWatch adopt Wi-Fi communication. Indeed, we also assessed the implementation of the network through a Bluetooth® *piconet*, but the distance restriction would be too limiting in the final application [19].

2.3 Smart-Watch Application

Finally, we have also realized the Android application that runs on the smart-watch. The main advantage is that it allows the doctor to freely move in other areas of the hospital and to perform different tasks in parallel without leaving the constant and simultaneous monitoring of all the critical patients under his responsibility. In other words, the critical values of all the patients connected to the network are constantly taken under control even if the doctor is not physically present in the same room. The bidirectional communication between smart-watch and intermediate server could be both via Wi-Fi or Bluetooth depending on the convenience. Indeed, normally the smart-watch prefers to communicate with the server tablet via Bluetooth to save battery enabling reliable data transmission, but in case of far distances Wi-Fi is necessary and automatically adopted.

3 Proposed System

3.1 Communication Protocol

As already explained, three are the main peers that interact in the proposed system: (*a*) the *Client Android interface* for patient monitoring, (*b*) the *Android Server* running on a tablet that can be placed in any room of the ward, and (*c*) the *Smart-Watch application* for doctors/caregivers (*final users)*. Figure 3 shows the communication protocol based on two main processes: *requesting* data (the blue process on the top of

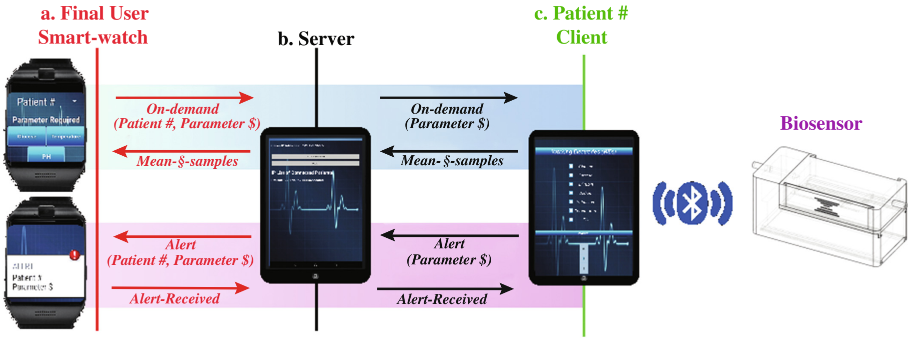

Fig. 3. Wi-fi Communication protocol: (*a*) Client – Patient #, (*b*) Server and (*c*) SmartWatch – Final User. Bluetooth data transmission is adopted between Client and sensing platform. (Color figure online)

Fig. 3) and *alerting* user in case of anomalies in recorded values (the purple process on the bottom of Fig. 3).

The *requesting process* allows the user to query a specific client in order to obtain the value of a parameter. A message containing the selected patient and the requested parameter (*On-demand (Patient #, Parameter $)*) is sent to the server from the smart-watch. Therefore, the server re-directs this query to the # client asking for the $ parameter (*On-demand (Parameter $)*). When the client # receives the request, the mean of the last § samples is algorithmically evaluated and sent back to the server (*Mean-§-samples*), which re-transmit to the smart-watch.

The *alerting process* occurs when there is an out-of-safe-range parameter. The involved client # sends a message to the server explicating the parameter (*Alert (Parameter $)*). The server, on its side, pushes the warning to the smart-watch (*Alert (Patient #, Parameter $)*). The notification on the smart-watch occurs as a strong vibration and with a pop-up that shows the number of the involved client (*Patient #*) and the anomalous value (*Parameter $*).

In order to face Internet unavailability, the alert/messages are sent several times until the smart-watch notifies the correct receiving through a broadcast message (*Alert-Received*). In this way we ensure to not lose any alert/message since when the Internet connection is re-established the data transmission is successfully accomplished.

3.2 Compatible Hardware

Given the flexibility and portability of our system, any Android application can be connected via Wi-Fi to the proposed network as client. This means that any type of monitoring sensor and/or biosensor that provides wirelessly the measured data can be connected at the central server thanks to a dedicated Android application. In this way the remote monitoring through the smart-watch is enabled and correctly assured. In order to test the portability of the realized network, we adopted as client both the application described in [13, 14]. Both the hardware prototypes mount a RN42 fully certified Bluetooth 2.1 module by Roving [20] that reaches a max transmission rate of 240 Kbps (in slave modality). In [13] a portable wireless system for measuring key metabolites (*e.g.* glucose, lactate, bilirubin, calcium, potassium, temperature, and pH) in ICUs is presented. Briefly, the system consists of a 3D-printed case, which integrates a fluidic system for patient body-liquids, a series of biosensors and the hardware platform to read those biosensors. The hardware platform also includes a Bluetooth module to transmit data to a mobile Android interface installed on a tablet. On the other hand, [14] presents a portable multichannel potentiostat able to detect simultaneously different blood molecules thanks to independent electrochemical biosensors on board. The system aims to provide continuous monitoring during surgeries in order to help in delivering anesthesia compounds. With this portable multichannel potentiostat, propofol (an anesthetic), paracetamol (an analgesic) and etoposide (an anti-cancer compound) have been actually detected. Even in this case, a Bluetooth module on board enables the transmission of acquired data to an Android application on a tablet.

We have integrated these two Android systems with the new protocol here proposed to make possible the communication with the server. This communication handles messages from the server and sends values-*on-demand*, meanwhile alerts are automatically transmitted to the server if any monitored parameter exceeds its physiological range.

4 Network Validation

4.1 Methods

All the interfaces were developed in *Android Studio 2.1* using Android and Android Wearable SDK Tools. Three tablets were used for the network: a *Galaxy Note pro 12.2 in* with Android 4.4.2 KitKat, a *Galaxy Tab 2* with Android 4.2.2 Jelly Bean both connected as clients and a Nexus 7 with Android 5.0.2 Lollipop as server. The smart-watch worn by the final user is a *Sony Smartwatch 3*. The server requires a minimum Android version 4.3 to be paired with the smart-watch. The pairing is enabled by the dedicated Android Wear application downloadable in *Google Play Store*. The other connections (client-to-server and client-to-biosensors) are provided by our developed applications.

4.2 Validation

The system has been validated by creating a network with two tablets as client units, one tablet as server and one smart-watch worn by the final user. Adopting this architecture, we tested all its functionalities:

- The clients simultaneously connect to the server via Wi-Fi and to the monitoring biosensors via Bluetooth. We have modified and tested both applications described in [13, 14] to that aim.

- The server connects multiple clients storing their IP addresses. Every time a new client is paired, a *Spinner List* on the smart-watch is automatically updated. The doctor handles/allows the client connection and disconnection.
- The smart-watch queries the server for receiving parameter $ from client #. In few seconds, the user receives the desired parameter from the correct patient. We tested the Internet transmission latencies by connecting to a personal hotspot obtaining less than 2 s for *on-demand* queries and less than 3 s for alerts receiving. Of course, these delays may vary accordingly to the Internet connection available.
- The alarm message is sent to the smart-watch if x values received from the monitoring biosensor exceed the physiological threshold. The threshold varies depending on the parameter and the number of acquired samples (x) to be averaged for the comparison with the threshold. This x value changes depending upon the desired medical application.
- The correct receiving of alert notifications on smart-watch also in case of Internet unavailability. The alarm is sent as soon as the connection is re-established and a notification is properly broadcast from the smart-watch.

5 Conclusions

In this paper we designed and tested a new IoT application to be used in medical critical-environments. The system is based on a network that allows doctors and caregivers in charge to monitor continuously and simultaneously key parameters of several critical patients thanks to a dedicated smart-watch application. The wearable device enables the request for metabolite concentrations and the reception of alerts in case of anomalous values. The short latencies for data/messages transmission ensure rapid medical interventions in case of incoming alert notifications. Thanks to the proposed system, the doctor is then able to freely move in the hospital area and to perform different tasks in parallel without loosing the control on the patients under his responsibility. Future work will be to carry out the usability of the network in medical daily practices and to further investigate on the security of the wireless communications.

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References

1. Cuartielles Ruiz, D., Göransson, A.: Android wearables. Vrox (2015)
2. Murar, M., et al.: Monitoring and controlling of smart equipments using Android compatible devices towards IoT applications and services in manufacturing industry. In: AQTR. IEEE (2014)

3. Rawassizadeh, R., et al.: Wearables: has the age of smartwatches finally arrived? Commun. ACM **58**, 45–47 (2014)
4. SmartWatch (© *SmartMonitor*, San Jose, CA, 2016)
5. Zhang, Y.S., et al.: Google glass-directed monitoring and control of microfluidic biosensors and actuators. Sci. Rep. **6** (2016)
6. Subramaniam, S.: Smartwatch with multi-purpose sensor for remote monitoring of a patient, U.S. Patent No. 20,150,238,150 (2015)
7. Boletsis, C., McCallum, S., Landmark, B.F.: The use of smartwatches for health monitoring in home-based dementia care. In: Zhou, J., Salvendy, G. (eds.) DUXU 2015. LNCS, vol. 9194, pp. 15–26. Springer, Cham (2015). doi:10.1007/978-3-319-20913-5_2
8. De Lara, E., et al.: Feasibility of using smartwatches and smartphones to monitor patients with COPD. Am. J. Respir. Crit. Care Med. **193**, A1695 (2016)
9. Embrace Watch (© *Empatica Inc.,* Milan, Italy, 2016)
10. Sutter Health CPMC, What is the ICU (Intensive Care Unit)? (2014)
11. Brown, J.M., et al.: Improving operating room productivity via parallel anesthesia processing. Internat J. Health Care Qual. Assur. **27**(8), 697–706 (2014)
12. Bang, M., et al.: The nurse watch: design and evaluation of a smart watch application with vital sign monitoring and checklist reminders. In: Proceedings of the AMIA Symposium (2015)
13. Basilotta, F., et al.: Wireless monitoring in intensive care units by a 3D-printed system with embedded electronic. In: BioCAS. IEEE (2015)
14. Stradolini, F., et al.: Simultaneous monitoring of anesthetics and therapeutic compounds with a portable multichannel potentiostat. In: ISCAS. IEEE (2016)
15. Wallin, M.K., Wajntraub, S.: Evaluation of bluetooth as a replacement for cables in intensive care and surgery. Anesth. Analg. **98**(3), 763–767 (2004)
16. Stradolini, F., et al.: Wireless monitoring of endogenous and exogenous biomolecules on an Android interface. IEEE Sens. J. **16**(9), 3163–3170 (2015)
17. Ng, H.S., et al.: Security issues of wireless sensor networks in healthcare applications. BT Technol. J. **24**(2), 138–144 (2006)
18. Wi-Fi Alliance, Discover Wi-Fi: Security (2016). http://www.wi-fi.org/discover-wi-fi/security
19. Friedman, R., et al.: On power and throughput tradeoffs of wifi and bluetooth in smartphones. IEEE Trans. Mob. Comput. **12**(7), 1363–1376 (2013)
20. Roving, Bluetooth module RN42 datasheet. http://ww1.microchip.com/downloads/en/DeviceDoc/rn-42-ds-v2.32r.pdf