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Toward an Open-Source Flexible System for Mobile Health Monitoring

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Project SHERPAM (Sensors for HEalth Recording and Physical Activity Monitoring) aims to provide an open-source, flexible, customizable solution to monitor continuously the health state of patients with chronic conditions during their daily activities at home or out of home, while detecting anomalies automatically, and reacting accordingly. This paper presents a typical usage scenario of the flexible system that is being developed in the context of this project, as well as this system’s architecture.

1 Introduction

There are now dozens of Quantified-Self (QS) applications and software development kits, with which data acquired by wearable sensors (e.g., smartwatches, digital armbands, heart rate monitors, etc.) can be transferred to a remote site in the cloud, where they can then be stored indefinitely, and kept available for authorized users.

Although such solutions are getting more and more popular, they can hardly be used in the medical field for a number of reasons. First, most of the sensors used in QS applications have never been certified for medical use [1]. Second, each model of sensor is usually distributed with its own dedicated application, which often cannot gather data from any other kind of sensor. Collecting data simultaneously from different kinds of sensors —possibly produced by different vendors— is therefore not possible. Third, most applications are hard-coded so they can only transfer data to a predefined remote site [2]. Users must therefore inherently trust the owner of this site when storing their data there, assume these data will be safe there, and most notably that they will not be disclosed or used without their consent. Finally, QS applications usually do very little processing of data, as most can only display nice curves or basic statistics.

In order to meet the higher expectations of the medical field, a health monitoring system based on wearable sensors should be designed so as to be versatile (i.e., capable of running with a large variety of sensors and analysis algorithms), extensible (i.e., capable of accepting new types of sensors and algorithms as and when needed), safe (i.e., preventing data alteration, data loss, and the fraudulent disclosure of data), and dependable (i.e., usable anywhere and at any time).

Some of these requirements have already been addressed in the works presented in [3], but to the best of our knowledge no open-source, flexible, customiz-

able system has ever been designed that can meet all these requirements at the same time. Developing such a system is one of the aims of project SHERPAM¹.

2 Usage scenario of the SHERPAM system

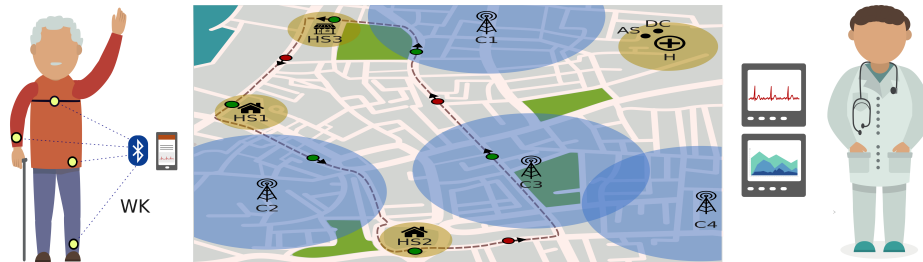


Fig. 1. Usage scenario of the SHERPAM system

One of the major objectives of project SHERPAM is that patients with chronic diseases should be allowed to move as freely as possible at home, but also out of their home. Figure 1 presents a typical usage scenario of the SHERPAM system, which encompasses all stages of data acquisition, transmission, and processing. A patient is equipped with a wearable kit (*WK*) that includes sensors and a smartphone. The smartphone serves simultaneously as a controller for the sensors, as a front-line data processing unit (data received from sensors can be processed locally, using algorithms that do not require too much computation power, so that warnings to the patient can be triggered immediately if an anomaly is detected in his current state), and as a gateway between the patient and medical personnel (data and/or notifications can be transferred to a remote aggregation server, *AS*). In the scenario depicted in Fig. 1 we assume the *AS* is located in a hospital's private data center (*DC*), but it can actually be deployed anywhere in the cloud. The *AS* stores the data it receives from all patients, and it can additionally forward selected data feeds to back-line processing units capable of running in real-time resource-greedy algorithms that require a lot of computation power, or access to large databases for pattern recognition. The whole system is meant to operate automatically, but if a processing unit detects a possible anomaly that requires confirmation by expert eyes, then a solicitation can be sent to medical personnel. In any case, visual and audible warnings can be returned to the patient's smartphone through the aggregation server.

Communication between the smartphone and the aggregation server relies on common wireless transmission technologies such as Wi-Fi and 2.5G/3G/4G, but special attention is paid to tolerating networking disruptions without ever losing data. A patient's home is usually equipped with a Wi-Fi access point and

¹ SHERPAM: Sensors for HEalth Recording and Physical Activity Monitoring.

thus constitutes a hotspot (*HS1*) in which continuous connectivity is ensured between the patient’s smartphone and the AS. Whenever the patient goes out, however, this connectivity becomes erratic. When out of home the patient may move through other Wi-Fi hotspots (*HS2* and *HS3*), through areas covered by cell-phone networks (*C1*, *C2* and *C3*), but he may also occasionally move through “white areas” where no wireless connectivity is available whatsoever. To ensure that no data is lost in such circumstances the application running on the smartphone implements disruption-tolerant networking techniques: data collected from the sensors are assembled in “bundles”, that constitute transmission units between the smartphone and the AS. Bundles are first stored on the smartphone, and they are transferred to the aggregation server when network connectivity is available. Different strategies can be applied for bundle ordering, depending on the nature of the data they contain.

3 Architecture of the SHERPAM system

The main software components of the SHERPAM system are presented in Figure 2. The client side is the application deployed on the wearable kit, and the server side is composed of several sub-systems dedicated to data aggregation, visualization, and processing. Arrows show how data flow in the system.

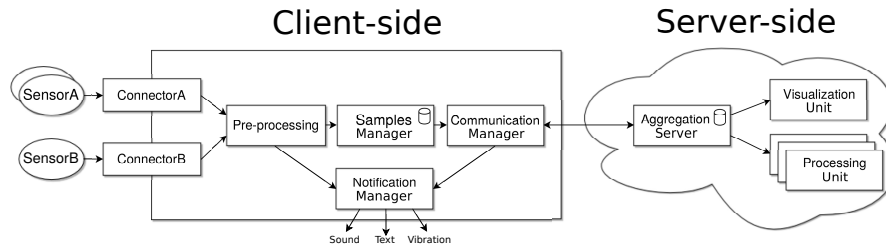


Fig. 2. Data flow and logical components in the SHERPAM system

On the client side, the data generated by the sensors enter the SHERPAM system via dedicated connectors. A connector is a software module that can drive a specific kind of sensors, and each connector is plugged in the application as and when needed. Extending the application for a new type of sensor mostly comes down to implementing a new connector module. Data processing algorithms can be embedded in the pre-processing unit. Data filters and compressors can thus be used to reduce the amount of data that must be transmitted to the AS, and pattern recognition algorithms to detect anomalies and trigger notifications to the patient locally. Such notifications are handled by the notification manager, that can generate audible or visual signals for the patient. After being pre-processed, the data samples are forwarded to the sample manager, so as to be assembled in bundles, encrypted, and stored locally in the smartphone until

they can be sent to the AS. Communication with the AS is managed by the network manager, which is responsible for selecting the most appropriate radio technology (e.g., Wi-Fi, 2.5G, 3.75G, 4G) at any time, based on criteria such as network availability, power consumption, and transmission needs (i.e., nature and importance of the data to be transmitted).

On the server side, data bundles received by the AS are stored in a database. Specialized subsystems can be deployed in the cloud to access this database through a dedicated API. Visualization subsystems can thus be used by authorized users –typically medical staff– to browse the database online, using a standard Web browser. Data processing subsystems can also be deployed to run advanced pattern recognition algorithms on selected data feeds in real-time, and to notify a patient or medical personnel when an anomaly is detected.

4 Conclusion and future work

The SHERPAM project aims to provide a flexible, customizable, open-source system capable of monitoring continuously the health state of patients during their daily activities, covering all steps of data acquisition by wearable sensors, data gathering and pre-processing by an Android application, and data transfer to a remote aggregation server for storage and advanced analysis.

The development of the system is under way, although the main elements have already been implemented, and tested in real conditions. A one-year medical trial is planned in 2017, during which the system will be used to monitor the health state of patients with different kinds of chronic conditions (cardiopathy, arteriopathy, etc.).

Acknowledgment

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