Architectural Approach to the Multisource Health Monitoring Application Design

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***Abstract*—Forward-looking personalized health care services tend to utilize benefits of smart spaces. Particularly, a smartphone app can be used as a hub for collecting and preprocessing of the vital health parameters provided by various sensors. Thus, the IoT-enabled mHealth apps should be designed to be easy extendable for the new kinds of data sources and processing units. In this paper, the architecture of mobile app supporting several data sources is described. Also, implementation issues related to Android and Windows Phone platforms are discussed.**

I. Introduction

Currently, experts agree in opinion that modern healthcare is facing the challenges of rising costs and changing demographics [1], [2]. People live longer, and moreover, increasingly people are living longer with chronic diseases. Since the use of medical care services by adults rises with age and per capita expenditures on health care are relatively high among older age groups, overall health care spending tends to grow year by year. In fact, costs of healthcare grow faster than GDP.

From the other hand, under the influence of the Internet and social media, patients are more informed about their conditions and ways of treatment. Hence, they are more involved in their healthcare.

Experts predict that the adoption of mobile technologies and smart environments for the purposes of healthcare is a promising way to provide patient-centered and personalized medicine, and, consequently, to improve the quality of treatment. In particular, advances in technologies of wearable devices provide the possibility of remote monitoring of health parameters helping elderly people and patients with chronic deseases to control their health at home and thus to decrease costs of treatment significantly. In these continuous monitoring scenarios vital signs of an individual are obtained in a real-time manner and analyzed on the spot or sent to the cloud for further use.

There is a number of standalone mobile applications and services providing a monitoring of one or several health parameters. Vendors of monitoring devices usually offer their own applications, tools and online services. These services provide the possibility of storing and analysing health data and optional tools for physicians. This approach relieves users from difficulties related to healthcare environment setup. From the other hand, these services lock in the devices of the same vendor and cannot be used with other hardware. Below the short overview of typical heart function monitoring services is given.

Alive Technologies company provides free application and free unlimited cloud storage with their AliveCor device. Cloud-based service allows users to store their ECG recordings and notes. Also this service supports web-based dashboard for doctors, which help to review medical data [3].

Preventice company delivers their product BodyGuardian RMS. It is a mobile, flexible cardiac monitoring technology that allows physicians to monitor patient data and helps to maintain a constant connection between patients and their care teams. Cloud service is provided, and physicians can access their patients' data and review alerts at any time and from anywhere via the web. Additionally, physicians can set individualized alert thresholds for each patient. Hence, personalized care plans are supported [4].

REKA Health focuses primarily on medical centres and physicians. They provide web access for patients and doctors with their E100 device. It is the simple service for patients, where they can upload or view recordings or print them into pdf. But it has advanced tools for physicians [5].

CardiaCare [6], [7], [8] is the mobile app and service that is under development in Petrozavodsk State University. It is aimed continuous monitoring of patient heart function, detection of several kinds of arrhytmias on a smartphone and transmission the health data to the cloud for further processing. Currently CardiaCare app works only with the Alive Heart and Activity Monitor by Alive Technologies and lacks the possibility of different ECG sources integration and even more so other health or auxiliary data processing.

From the other hand, the market offers a variety of monitoring devices. It is also expected that the number of such devices will increase. Therefore, there is a problem of designing the application architecture providing easy integration of new data sources and processing data from different data sources simultaneously.

This paper details the architectural approach to the health parameters monitoring application design, that can work with a number of different sources of health and related data.

The paper is organized as follows. In the Section II an overview of heart function monitoring devices that could be potentially used as data sources for CardiaCare app is given. In Section III the proposed architecture is described. In Section IV some implementation issues are discussed.

II. Overview of health monitoring devices

Nowadays, there is a number of sensor wearable devices on the market that provide a possibility of registering of one or another vital sign and accessing the recordings from outside. Such devices significantly differ in characteristics.

From an end user point of view, the main characteristics of the device are size, battery life, usage simplicity (wires, buttons, etc.). Measurement accuracy is the vital feature for cardiologists. As for developers, the important characteristics are the support of open communication protocols and low energy standards, availability of open and well-documented API.

The overview of the devices that can be in the long term used as biosignal sources for CardiaCare application is provided below. In this analysis a priority is given to the needs of the developer, but other features are also described if available.

A. ECG monitors

Since CardiaCare application is conceived for the arrhythmia detection most of attention is given to cardiac monitors. In this analysis the following devices are considered: AliveTec H-131 [10], AliveCor [3], eMotion ECG [11], eMotion Faros [12], cardiac ECG sensor BT3/6 [13], Mahaon [14], BodyGuardian RMS [4], Zephyr BioHarness 3 [15], AfibAlert [16], DiCare-m1CP [17], ECG Check [18], REKA E100 [5], [19].

This analysis also relies on the results of ECG monitoring devices comparison described in [19]. Characteristics of these devices are listed in Table I.

TABLE I. ECG monitoring devices characteristics

Device	Freq.(Hz)	Size (mm)	Weight	Battery	Interface
AliveTec H-131	150-300	90x40x16	55 g.	48h.	Bluetooth
AliveCor	300	–	40 g.	AAA	–
eMotion ECG	1000	35x35x15	16 g.	27h.	Bluetooth
eMotion Faros	1000	48x29x12	13 g.	–	Bluetooth
BT3/6	500	100x60x23	210 g.	13 h.	Bluetooth
Mahaon	8000	64x66x20	70 g.	7 days	Bluetooth
BodyGuardian	200-500	–	–	–	Bluetooth
BioHarness 3	1000	28(Diam)x7	85 g.	26 h.	Bluetooth
AfibAlert	–	150x70x22	130 g	-	USB
DiCare-m1CP	–	90x61x17	82 g.	–	USB
ECG Check	–	–	35 g.	–	Bluetooth
REKA E100	–	80x70x17	105 g.	1000 rec.	USB

As it is seen from the table each device has its own advantages and disadvantages. Devices with wireless connection facilities are more suitable but devices with USB interface can be also used.

BodyGuardian RMS and ECG Check seem to be vendor locked. BT3/6 and Mahaon seem to be quite difficult to use for ordinary person because they have more than two electrodes. Although Mahaon has good accuracy due to the high ECG sampling rate, the quality of Bluetooth transmission signal is reported to be low. Also, the price of this device is prohibitive for individual users. Sufficient accuracy is provided by the following devices: AliveTec H-131, AliveCor, eMotion ECG, eMotion Faros, Zephyr BioHarness 3.

AliveTec H-131, eMotion Faros, Zephyr BioHarness 3 are reported to have open API.

Therefore, it was shown, that despite the limitations there are several ECG monitors available on the market that can be used as data sources for CardiaCare application.

B. Heart Rate Monitors

Heart rate monitors market is very extensive. By design, such devices can be divided into built-in sensors (e.g., watch on wrist), chest sensors, finger or earlobe sensors. Chest sensors provide more accurate data. Next, short overview of devices that are reported to have an open API, is provided.

Heart rate monitor Zephyr HxM BT [20] is used for tracking heart rate, speed, distance and intensity level. User should just put on chest strap with clipped device and connect the device. It has the open API published on official web site.

Heart rate monitor WahooFitness TICKR X Workout Tracker [21] captures heart rate, calculates calories burn and has many other functions. It is also equipped with built-in memory. Device supports ANT+ and BLE standards.

Heart rate monitor Polar [22] provides qualitative detection of heart rate, but has low-quality Bluetooth transmission signal. Polar provides API for partners.

TABLE II. Heart rate monitors characteristics

Device	HR range	Weight	Battery	Interface
Zephyr HxM BT	25-240 bpm	-	26 h	Bluetooth
WTICKR X	0-255 bpm	8.5 g.	200 h.	Bluetooth LE
Polar	0-255 bpm	23 g.	150 h.	Bluetooth

C. Other devices

The market of health sensors develops and there are devices providing registration of other vital signs than cardiograms and heart rate and allowing interaction with computers and smartphones to deliver recordings. For this reason, the possibility of using such devices as electronic spirometers, stethoscopes, tonometers and so on is also considered. The following are examples of available on the market devices that provide connectivity features and therefore can be used.

Tonometer A&D UA911-BT or UA-767PBT provides the measurement of blood pressure by oscillometric method with range: 20-280 mmHg (pressure), 40-200 bpm (pulse). It gives accuracy $\pm 3\%$ mmHg (pressure), $\pm 5\%$ (pulse). Its weight is 300 g. and size is 64 x 147 x 110 mm. Measured data can be received via Bluetooth connection (Class1, version 1.2).

Other device example is Littmann Electronic Stethoscope 3200 [23]. The device is small enough and its weight is less than 185 g. Data is transmitted via Bluetooth. Stethoscope provides suppressing of environmental noise and sound amplification. Also it allows to record and store up to 12 tracks.

Spirometer Spirobank II [24] SpO2 allows measuring SpO2 with range: 099%, and accuracy: 2% with 7099%. Its HR range is 30254 BPM and HR accuracy is 2 BPM or 2%. Spirometer's weight is 180g and size is 60 x 145 x 30 mm. It provides Bluetooth and USB interface types. In addition the device has a precision tool for pulse oxymetry analysis with calculation of SpO2 and heart rate.

Another example is MIR Spirodoc [25]. Its SpO2 range is 0-100% and accuracy is 2% (50-100% SpO2). It provides

20254 BPM HR range, 2 BPM or 2% HR accuracy. Its physical dimensions are 101 x 48 x 16 mm and it weights 120 g. Interface types are Bluetooth (optional), USB.

III. Proposed architecture

The CardiaCare mobile application is aimed to be a part of the system designed for collecting and analysing of health parameters and environment conditions that can influence on the health status of an individual. On the whole, the system operates as shown in Fig. 1.

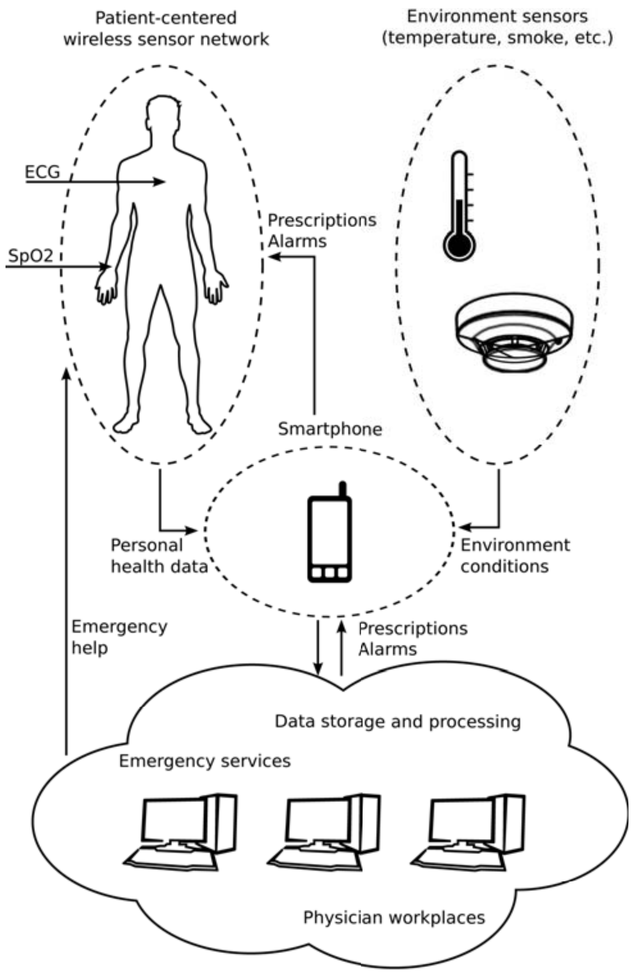

Fig. 1. Continuous health monitoring system operation

Once the app is started, it connects to external sensor hardware and set about harvesting data. It is important that not only different sensor equipment configurations can be utilized by different users, but also they can be switched dynamically. Moreover, the application can communicate with several sensor devices simultaneously.

Received data chunks are then processed on the smartphone and user is provided with an instant feedback. Currently, the only implemented scenario is the analysing the cardiogram recordings for the arrhythmia happening. In the case an arrhythmia is detected, the SMS is sent to the predefined phone number to inform relatives or doctor.

Next the app sends the data to the cloud services for further processing. Scenarios involving cloud services include the following ones.

- Biosignal recordings are simply stored on the remote server and user has the possibility to access and visualize them. That is the health status log.
- Second scenario is to inform emergency services in the case of critical situations for immediate help, e.g. when vetricular tachicardia or fibrillation happens.
- Third scenario implies the remote access for physicians to the biosignal recordings to control the treatment. Doctor can alter the prescriptions or invite patient to the hospital for detailed inspection.

As it was mentioned above, there is a lot of health monitoring devices and it is expected that the number of such devices will increase. Our goal is to provide a relatively simple way of new devices enabling.

The app is aimed on gathering and processing of the health data from different sources in a background. Therefore, the UI of the app is used only for switching between data sources and configuring how the data should be processed and transmitted to the server for further analysis and storage. From the user point of view the UI is quite simple. It isillustrated in Fig. 2.

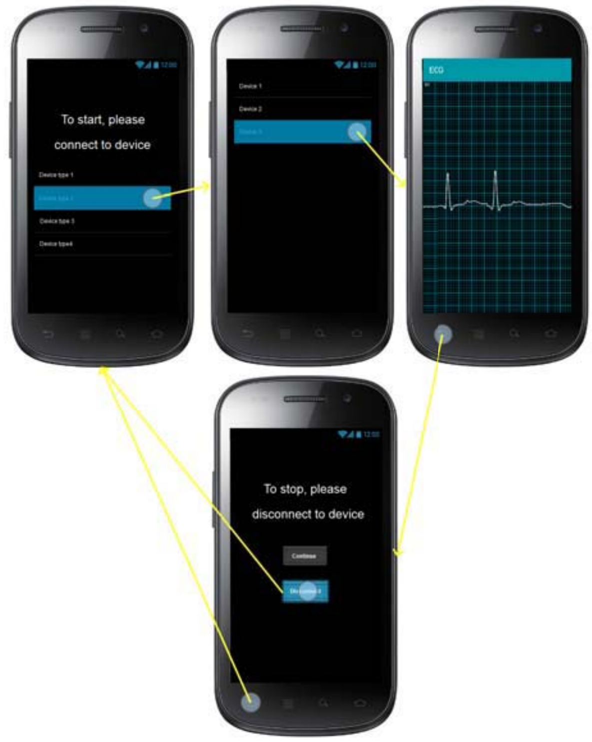

Fig. 2. User interface of monitoring app

The main design decision is to provide a module that could operate independently of the current UI screen or even app state. Let the Service be the background component for running the data receiving and processing units. The high-level architecture is presented in Fig. 3. The interface between UI and Service includes the following operations:

- when the app is started the UI requests a list of supported data sources from the Service to enable the user to switch them;
- when the user selects the data source from the list then the UI requests a form to enable the user to configure the data source, e.g. connection to the external hardware monitor;
- the UI can contain visualization components and is able to set the handlers for new data receiving events.

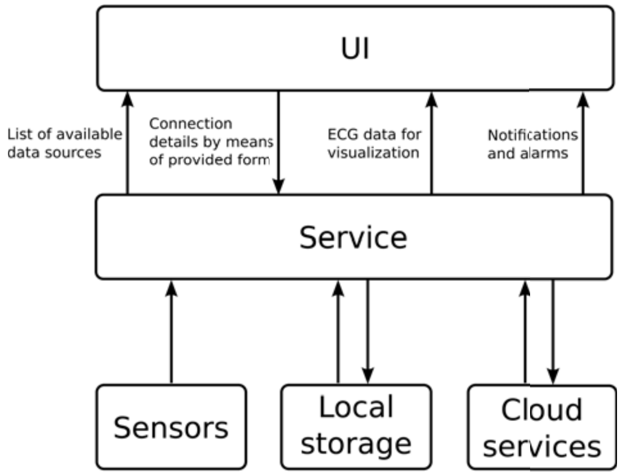

Fig. 3. A top-level architecture of the CardiaCare app

The Service manages a set of data sources, each contains a description of the configuration form and a driver responsible for communication with the monitor. Received data chunks are sent to the data manager. The data manager temporarily stores recordings in the data queue and in according to the settings synchronizes the queue contents with the local storage on SD card.

The is a set of data processing units that can operate in a pipeline. Pipelines are organized as in a GStreamer project.

Data processing results can be returned to the data queue and bound to the samples as overlays. Components to synchronize data to the server also can be implemented as data processing units.

Details of Service design are presented at Fig. 4.

IV. IMPLEMENTATION ISSUES

For the purposes of continuous monitoring, receiving of health data from sensors should be possible even the app is inactive because a user should be able to answer the calls and run other apps. To fulfill this requirement, biosignal data capture and processing should be implemented as a background service since on the main mobile platforms inactive apps could be paused or even closed automatically for the reasons of the economy of the battery charge or in case of low memory.

The options of implementing background computations on recent versions of Android and Windows Phone platforms are discussed below.

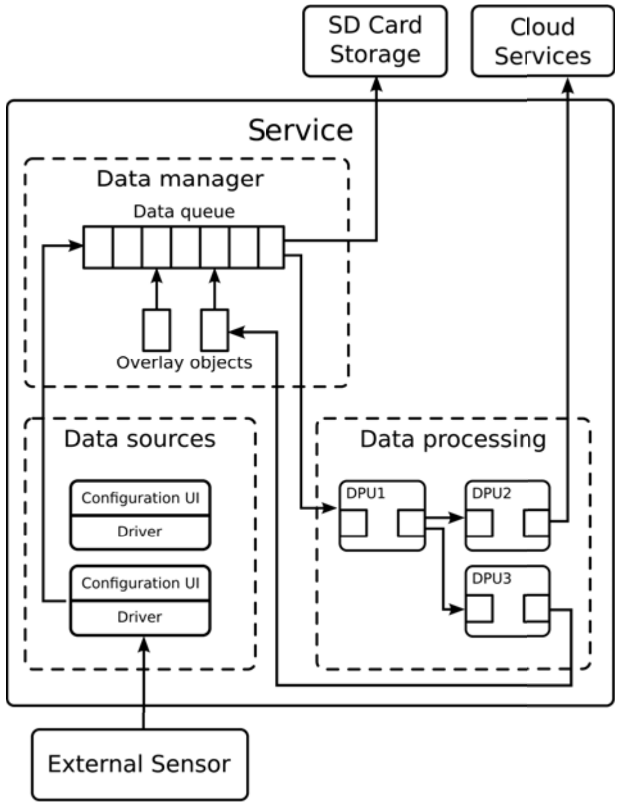

Fig. 4. Background service architecture

A. Android

Android defines an unified tool for background tasks implementing, namely, Services [26]. These are the app components for long-running operations in the background. The platform guarantees that the Service will continue to run in the background even if the user switches to another application.

There are a variety of methods to communicate with the Service. Since a lot of communication is happening between Service and Activities a hybrid approach have been adopted. Firstly, since the only one instance of the Service is used to serve all background tasks, service object is implemented as a singleton and have a static reference to the service available for activities. The Binder is used to returns the Service instance to the Activity, and then the Activity can access public methods in the Service. To send data back to the Activity from the Service, Callbacks interface is used.

B. Windows Phone 8.1

Windows Phone 8.1 platform provides several different tools for executing the code in the background thread. These are BackgroundWorker, BackgroundTask and BackgroundAgent.

BackgroundWorker enables to carry out any operation in a separate dedicated thread. This is necessary when there is a time-consuming task that is not associated with the UI. It avoids long delays of user interface and accordingly increases productivity of the application [27]. Nevertheless, if the app is in the dormant state, all BackgroundWorkers are suspended.

The simple trick to avoid stopping the thread is to declare it as performing geolocation tasks [28] but it should not be considered as appropriate solution.

BackgroundAgent enables the application to execute any code, regardless of whether the application is in the active mode. There are two kinds of BackgroundAgents: periodic and resource-intensive. Periodic agents can work up to 25 seconds and run every 30 +/- 10 minutes. Resource-intensive agents work within the approximately 10 minutes time interval and when the phone satisfies to the set of requirements associated with the activity of the CPU, power supply and connection to the network. Also, the battery charge must be at least 90%. There should be no active calls. Resource limits for BackgroundAgents are 25 MB of memory [29].

BackgroundTask is easier class, that is run in the background by operating system. BackgroundTasks can be used to execute the code when the application is suspended or not running [30]. Background task is started in case of a system event. It can be carried out only once or run each time when the specified system events happen [32].

Windows Phone provides DeviceUseTrigger, that enable applications to access the sensors and peripheral devices in the background even when your foreground application is suspended. Background tasks that use DeviceUseTrigger enable an application to communicate via a variety of protocols and API, such as Bluetooth RFCOMM GATT Bluetooth. There are no restrictions on the frequency of operation running. However, the application can carry out only one operation of DeviceUseTrigger s background task at the same time and initiates a background task, only when the application is running in the foreground [33].

Finally, when running on Windows Phone 8.1 application is dormant, it suspends its work and the work of all of its threads. Consequently, BackgroundWorker is not suitable. Method which uses geolocation as a solution is not suitable too, because it is necessary that the device has geolocation function enabled. BackgroundAgents are useless for CardiaCare because of restrictions on operating time. After Background Tasks features and especially its method DeviceUseTrigger were analyzed, it may be concluded that they are suitable for using in CardiaCare application.

V. Conclusion

The analysis of the market of wearable devices designed for health parameters monitoring resulted in consequence that there are a variety of devices that can be used as data sources for mobile application. In this paper the approach to designing the architecture of health status monitoring application aimed the problem of simultaneous obtaining of vital sign recordings from different sensors was described.

Solutions of this approach technical implementation on Android and Windows Phone platform were also discussed.

Proposals for the architecture of multisource mobile health monitoring application are scheduled for implementing in coming-soon release of CardiaCare app.

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