On-body health data aggregation using mobile phones

Lama Nachman, Jonathan Huang, Raymond Kong, Rahul Shah, Junaith Shahabdeen, Chieh-yih Wan, Mark Yarvis

Corporate Technology Group, Intel Corp

The following describes research that could potentially lead to technology development which could provide health benefits. However, this does not describe an Intel product roadmap

ABSTRACT

Pervasive monitoring of vital signs has been proposed for many use cases in the health domain including post-operative, condition management, fitness and wellness and many others. In this paper, we present a research prototype of an end to end personal health monitoring system. This system provides pervasive monitoring of physiological data targeted for health applications. While we have targeted a post-surgical use case to drive the solution requirements, we also intended to provide a generic platform to support multiple health use cases with minimal customization. The system is centered around an on-body aggregator device, consisting of off-the-shelf mobile phone, running our application software. This device connects via Bluetooth to a collection of heterogeneous on-body sensing platforms capable of measuring physiological parameters (such as, but not limited to: ECG, SpO_2, skin conductivity, heart rate). The mobile phone provides data aggregation, processing and storage capabilities, as well as backend network communication to replicate the data to backend storage. Finally it provides a data display capability to the user, as well as a web-service to enable external data displays

Categories and Subject Descriptors

C.3 [**SPECIAL-PURPOSE AND APPLICATION-BASED SYSTEMS**]

General Terms

Design

Keywords

Pervasive sensing, body sensor networks, health monitoring.

1. INTRODUCTION

Pervasive monitoring of vital signs has been proposed for many use cases in the health domain including post-operative, condition management, fitness and wellness and many others. Advances in low cost and low power sensing, processing and communication have fueled considerable research in body sensor networks [1]. These systems usually consist of multiple small sensing devices mounted on the body, collecting some combination of data to enable a specific application. We observed that typically many of these solutions have common components (sensing, data storage, data processing, communication, etc). Hence, we implemented a generic end to end solution to support multiple health usages with as little customization as possible. Clearly some of the components within the solution are tightly coupled to the use case and will need to be customized accordingly (e.g. user interface, data storage). We designed a research prototype of an end to end personal health monitoring system, providing pervasive monitoring of physiological data targeted for health applications. We integrated existing heterogeneous sensing platforms to demonstrate physiological sensing (ECG, SpO2, heart rate, skin conductivity and temperature). This data is communicated from the various sensing platforms to an on-body aggregator using Bluetooth. The data is stored on the phone and is periodically pushed to a backend server. We implemented ECG noise filtering algorithms to improve the quality of the ECG data and generate more accurate heart-rate calculations. The phone displays the latest scalar data (heart rate, oxygen saturation, stress) giving the users instantaneous access to their health data.

While there are several existing platforms that support on-body sensing for healthcare applications [3][4][5], this paper describes an architecture based on off-the-shelf component that enables an extensible constellation of sensors and analysis components, thus supporting a variety of use cases. Such a platform enables a system that is customizable and extensible depending on specific usage requirements and user input.

2. System Description

An overview of the system is shown in Figure 1. On the left side, we show the different sensing devices that are connected to the mobile phone via the Bluetooth link. In the middle we show the mobile phone with the different software components, which we describe in more details below. On the right side, we show the backend server and external GUIs. The data is stored in a Mobile SQL database on the phone and is replicated periodically to a backend SQL server. We implemented a rich Matlab based display to show the historical ECG and accelerometer waveforms along with other sensed data and values computed by signal processing (e.g. heart rate). This display connects to the database server and retrieves the historical data for the requested time interval. This will enable a clinician and/or the patient to trend the sensed data over time and generate alerts where appropriate. In addition, the phone provides a web service for the low data rate parameters (SpO_2, heart-rate, body temperature) which can be consumed by external GUIs or other services.

2.1 Aggregator Device

2.1.1 Hardware

We chose to leverage off-the-shelf mobile phone and PDA devices (HTC's IMATE KJAM phone and Dell's Axim PDA) for the on-body aggregator device and developed a custom application on top. This choice was motivated by many factors. First these devices are open systems, run some version of Windows OS, and provide a good IDE for application development. Second, these devices typically provide the on-

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* Other names and brands may be claimed as the property of others

body communication capability (via integrated Bluetooth) and backend communication (via 802.11 or GPRS). Third they tend to have compelling form factors as well as good input/output capability and familiar user interfaces enabling a friendly user experience. Finally, many of these devices have suitable processing, RAM and storage capabilities that can be leveraged for data processing, aggregation and storage.

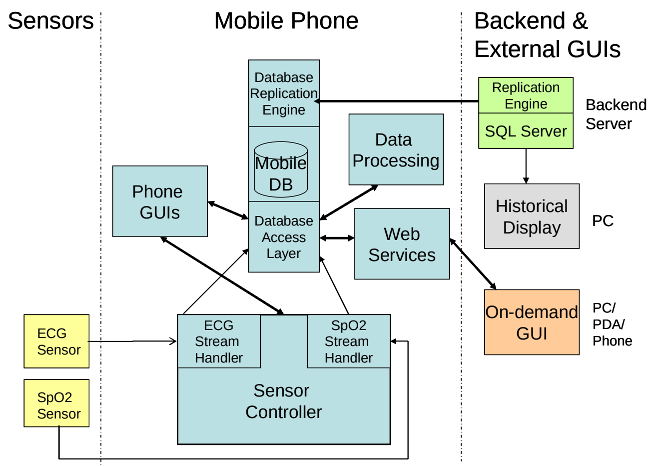

Figure 1: System Overview

2.1.2 *Application Architecture*

We targeted the Windows Mobile 5 operating system, .NET compact framework and C#, which enabled rapid development and support for multiple hardware options. The application architecture running on the Mobile phone consists of four main components, the sensor controller, the GUI, the database and the web service. The database serves as the central repository of the data, and all components share data through it.

The *sensor controller* is responsible for establishing and maintaining wireless connections with the on-body sensors, receiving sensor data, parsing it and storing the information in the database. It abstracts out the common aspects of connectivity into a generic controller. Small sensor-specific modules are included to interpret and process data from specific sensors. This approach allows rapid integration of new sensors. In addition to processing within the handlers, separate data processing modules are added to retrieve, process and store computed data (e.g. heart rate)

The *graphical user interface* consists of a data display component and a configuration component. The data display retrieves the latest scalar data from the database and displays it to the user. The configuration component allows the user to configure the sensing devices and manipulate some of the operating parameters of the aggregator (e.g. frequency of data push to back end).

We used the *SQL mobile database* on the aggregator and developed generic schemas to support all the different sensors that we intend to support. We also developed an access layer to the database to pull together all the common functionality and simplify the database interface to the different application components. Finally, we implemented a replication mechanism to support periodic synchronization of sensor data and configuration parameters with the backend database.

To support external consumption of sensed data (scalar parameters only) by peer nodes, we implemented a *web service* on the aggregator. This service is used by external GUIs to display sensed data on connected PCs. We envision this service as useful for sharing a person's data with friends in collaborative settings or with a piece of exercise equipment.

3. APPLICATIONS

This research prototype can be used in various applications that benefit from user interaction along with physiological monitoring. Obvious examples might include fitness, weight management, and hypertension management. For example, the weight management solution might enable the user to easily provide annotations of activities, dietary consumption, etc. The system might interact with the users to make them aware of their progress and provide some coaching tips to help them achieve their preset goals.

While the first research prototype was targeted to individual health management, its use could also be extended to community health management. Pervasive 24/7 monitoring of health data could enable researchers to immediately discern trends related to pollution, pollen, infectious disease spread etc. To enable this usage, suitable sensors need to be integrated and security and privacy policies need to be implemented. Finally, environmental sensors or localization systems like such as the PlaceLab [2] could enhance the medical information with location information.

4. PARTICIPATORY RESEARCH SUPPORT

This architecture is well suited for participatory research as it enables the user to be involved in the sampling process. We highlight below some of the advantages of this architecture

- Easy integration of off-the-shelf sensors which provides the user with a large selection of sensors. This flexibility is a result of three different factors. First, using Bluetooth which is very ubiquitous today and leveraging the serial port profile as it is typically used in Bluetooth implementations. Second, the design of a flexible sensor controller that separated the manageability and connectivity of the communication from the sensor data format, enabling minimal code customization as new sensors are added to the system. Finally, the design of extremely generic database schemas to support different data types, sampling rates and data sizes. We verified this flexibility by connecting different sensors including accelerometers, SpO2, ECG, temp, humidity and GSR.
- The design of a database schema that supported annotations of the data. We designed two main tables for the data, an observation table which stores all the raw information received from the sensors and an annotation table, enabling the user and/or the device to annotate the observation data with more information. Again, due to the generic schemas, these annotations can be of different types including text, location, audio, etc.
- The web service implementation allows for collaboration among users in data collection and annotation. One possible usage is to have different users expose a subset of their sensor data to other users to enhance the system capability. For example, if one

user had GPS capability, it could serve this info to users in the vicinity, and allow them to annotate their data with location information (or weather, digital presence, etc). In addition the users consuming this data could provide some extra context and annotation back to the source.

- Local display of sensed data enabling the user to be aware of the current state and take actions and/or annotate the data accordingly. For example, the GSR sensor could indicate that it detected that the user is highly stressed. The user could then annotate the data with what he is doing or what he perceives as the cause of stress at that moment.

We believe that all of the factors mentioned above make this system very suitable for participatory research.

5. SUMMARY

We implemented a research prototype of an end to end personal health monitoring system, providing pervasive monitoring of physiological data targeted for health applications. The solution centers around a mobile phone that collects sensed data from on-body sensors, then aggregates, processes, stores, displays and forwards the data. The system is designed to be extensible to different use cases in the health domain, including the use of different sensors, algorithms, and user interfaces. This architecture enables system designers and users to customize an application to specific user requirements.

6. ACKNOWLEDGMENTS

We'd like to acknowledge Intel Research and the Digital Health Group (Health Research and Innovation group and Advanced Technology Group) for providing various sensing platforms.

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