Cardiovascular and Diabetes Focused Remote Patient Monitoring

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Abstract— **Sensing becomes more and more important in healthcare and medical domains. Patients with chronic cardiovascular or diabetes problems can be monitored remotely by using various medical sensors. However large number of data sources (ECG, blood glucose meters, pulse meters, blood pressure meters) produce huge data quantities, which are difficult to process, to visualize or even to store. In the first part of the paper we will describe the motivation and state-of–the-art of remote patient monitoring solutions targeting cardiovascular and diabetes diseases. After that we describe the basic building blocks of our proposed system, show examples of the developed monitoring protocols, and finally detail its internal architecture and functionalities and draw conclusions.**

Keywords— **telemedicine, cardio and diabetes monitoring, biosignal DAQ, remote patient monitoring.**

I. INTRODUCTION

A. Remote patient monitoring

Remote patient monitoring provides alternative patient data acquisition, with almost the same accuracy and granularity as monitoring systems provide in hospitals outside the Intensive Care Units (ICU). One can identify various gains of using remote patient monitoring solutions:

- Patient should not leave its home environment for monitoring, transportation costs can be minimized.
- Monitoring can be non-stationary, and it is feasible to monitor patients abroad too.
- Non-stop (24/7) patient monitoring can be achieved.
- Prevention and trend monitoring are the major strength of remote patient monitoring, which otherwise requires significant amount of resources for a large scale population.
- Healthcare (e.g. hospital) resource consumption can significantly lowered (bed usage, human resources) with remote patient monitoring of chronic diseases.

B. State-of-the-Art

There are already a vast amount of remote patient monitoring solutions available such as the vendor specific monitoring solutions like MyHealthPoint [1] from Mygluecohealth, or Accu Check 360 [2], fitness focused solutions like MyFitnessCompanion [3], care focused solutions like iCare[4] (which provides medical guidance, emergency alarm functionality and collects personal health information), and other examples such as Microsoft HealthVault [5], which is web based generic medical data management solutions, supports care of elderly persons and provides online web interface to manage health information. In the premium medical service categories multiple sensors are used in parallel to monitor the patient's vital parameters. A single practitioner can monitor the vital parameters of hundreds of different patients in real time, up to several days or weeks. Remote patient monitoring has several advantage properties: the patient is monitored location independently, he/she not restricted physically to a single place, patient is not connected tightly to the doctor/to the hospital, patients can be monitored during their everyday life, within their normal environment, medication can be adapted to the patient's normal lifestyle and not to an artificial situation when they are hospitalized.

C. Biosignal handling

Our multi-layered data acquisition system requires more than just simple real-time sensor data collection and visualization. After the patient's sensor data has been acquired, it should be pre-processed (data filtering, cleaning and analysis of basic sensor data patterns) right before the visualization or manual analysis is starting.

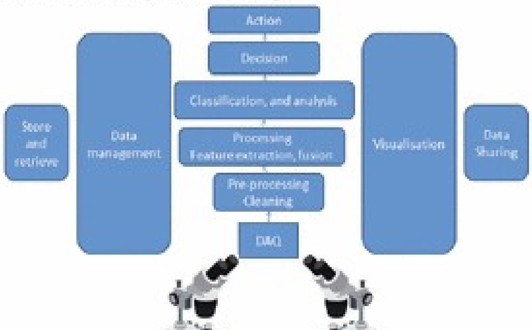

Fig 1. Overview of our whole biosignal handling process during remote patient monitoring

Within the processing task the sensor data fusion is one of the major challenges. Its complexity depends heavily on

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the amount and type of the used monitoring hardware devices.

II. DATA ACQUISITION ARCHITECTURE

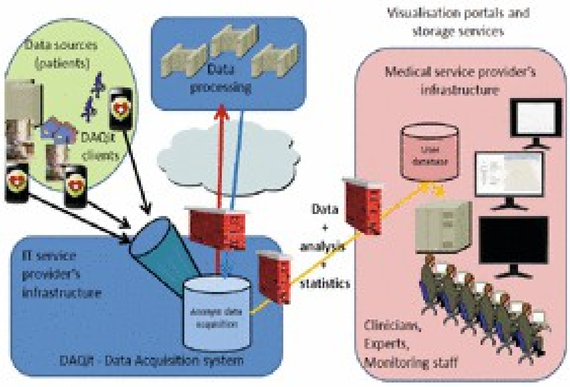

Fig 2. Generic remote patient DAQ system overview

A. Remote patient DAQ

At the client side a complex and intelligent sensor network is built up (shown in Figure 4.). DataHub (DH) is the local data acquisition device. DH collects and transfer data received from the lower level data collectors, or directly from sensor devices towards the Monitoring Data Center.

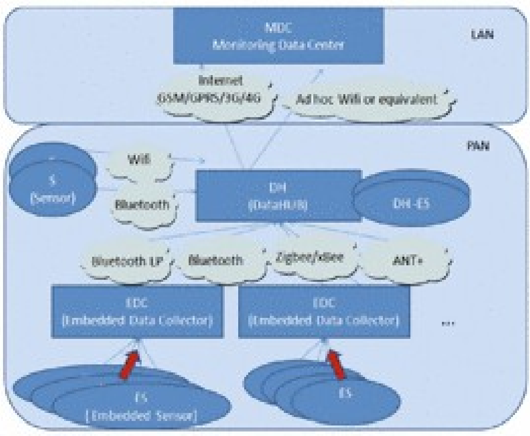

Fig 3. Realized DAQ system overview

DH based on our mobile data acquisition framework called DAQit. DAQit Framework is a generic sensor network data acquisition (DAQ) solution, which collects biosignals, store, analyze (if needed also visualize) the received data and optionally sends it towards to the Monitoring Datacenter (MDC) for further processing. The DAQit framework is ported to various mobile platforms (Android, Windows, etc.) and able to collect information from a large set of various wireless (Bluetooth, WiFi, or other ISM range devices) and wired (USB) sensors. Sensors (S), Embedded sensors (ES)/DH ES are connected to the DataHub directly or via a low level Embedded Data Collector (EDC). PAN communication channels (wired, and wireless such as Bluetooth, ANT+, Zigbee/XBee) are used to connect the sensor devices to the DataHub (DH).

III. BIOSIGNAL SENSOR SETS

Sensors can provide a large range of information about the patient's psychophysical status and performance. The system collects biosignals from different type of sensors. We are using mostly Commercial Off-The-Shelf (COTS) sensors. All the sensor drivers at Data Hub (client side) are written carefully by our team, and here we are implementing a generic adaptation layer to all the proprietary and incompatible communication channels.

A. •Diabetes monitoring

Table 1 Diabetes monitoring sensor set

Model type	Manufacturer	Connection type
Breeze II.	Bayer AG	wired, via USB
Mygluecohealth	Mygluecohealth Ltd.	wireless, BTv2
Accu-Chek Active	Roche Ltd.	wired, via smartpix/USB wireless infrared (via ir2voice)
Dcont Personal Optimum	77 Elektronika Kft.	wireless, infrared (via ir2voice)
Dcont Partner	77 Elektronika Kft.	wireless infrared (via ir2voice)

B. Cardiovascular disease monitoring

a) Hypertension monitoring

Table 2 Hypertension monitoring sensor set

Model type	Manufacturer	Sensor type	Connection type
Cardioblue	Meditech Inc	Mobile ECG	wireless, BTv2
BlueBP	Meditech Inc.	ABPM/mobile blood pressure	wireless, BTv2

b) Cardio monitoring

Table 3 Cardio monitoring sensor set

Model type	Manufacturer	Sensor type	Connection type
UA-767 PBT	AND Ltd.	Blood pressure monitor	wired (USB), via Roche Smart Pix™ [6]; wireless infrared (via Ir2Voice)
HxM	Zephyr Technology Ltd.	Pulse monitor	wireless, Bluetoothv2
Bioharness	Zephyr Technology Ltd.	DAQ harness: pulse, posture, R-R, Heart rate.	wireless, Bluetoothv2
Onyx II 9560	Nonin Medical Inc.	Pulse oxymeter	wireless, Bluetoothv2

Fig. 4. COTS sensor set and client side DAQ devices (smartphone and tab) for human individual monitoring

IV. MONITORING PROTOCOLS

For treatment purposes both cardiovascular and diabetes problems have well defined consensus protocols in the literature. We have identified a large set of monitoring protocols to standardize our measurement biosignal acquisition end evaluation tasks. In almost every case we are reusing the consensus protocols created by medical experts, and we are extending it with finer monitoring granularity and longer monitoring duration. Good example is hypertonia monitoring, where we are doing 72 hours (3 days) holter measure-

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ments instead of the normal 24 hours (single day) holter monitoring. To measure with the sensors in most of the cases we need to pre-program the devices in advance. Pre-programming task is carried out with the DataHubs (DAQ client devices), and it needs sensor specific knowledge. Additionally acquired data provides more accurate information about the patient's health status. another good example here is the cardio monitoring. According to our monitoring protocol, long term ECG measurement duration is 168 hours (1 week), and during infarct rehabilitation trainings we are measuring and analyzing the following key parameters:

- ECG
    - S-T elevation: How much elevation (+/-) S-T has (<2mm)
    - Q-R-S length (0,12-0.15ms) + heart rate monitoring (120-130)
    - R-R homogeneity: ΔR-R deviation from average calculated
    - Q-T length: elongation is measured
- SpO_2
    - During rehabilitation trainings after every 5 minutes
- Pulse
    - Non-stop pulse frequency variability analysis during the whole rehabilitation training
- Work intensity
    - Calorie calculation from pulse values
    - Metabolic equivalent (MET) calculation

Our monitoring protocols are defined with a workflow language and stored together with the patient data.

V. DATA PROCESSING, ARCHIVING AND VISUALIZATION

Measured data is collected at the Monitoring Data Center side from all the DataHubs. We are using the same core service architecture and database infrastructure to store raw diabetes and cardiovascular disease monitoring DAQ data received from the clients. Data Center is using secure communication towards to the DataHubs. The system supports multiple Data Center built up in a hierarchical manner. Communication between the Data Centers is also encrypted and secured.

A. Data processing

Processing of health care smart system's generated data is a special Big Data problem. Sensor data pre-processing is by definition a complex task. The measured sensor data is processed and analyzed in background due to their computational intensive manner. Different healthcare sensor types at patient's home are producing different amount and type

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of data, and the way of processing should be adapted to their requirements. The measured elementary data size can be vary from the very small as a few bytes to a some thousands of bytes. For example small data is created by weight scales or blood glucose meters, on the other hand large amount of data is produced by mobile ECG equipments (e.g.: 1200/600 Hz , 12 channels) or mobile EEG systems (2048 Hz, 14 channel). If we look at the number of already available data sources and their data sending frequency and intensity it immediately turns out, that even simple large scale health care monitoring tasks (e.g.: measure pulse, ECG, or SpO2) requires more processing resources than conventional systems can effectively handle in real-time. To overcome issues of the built up communication and data intensive smart system networks we are using different type of data processing alternatives such as international HPC infrastructure (maintained by the European HP-SEE[7], or PRACE [8] projects), clouds, grids, and our own GPGPU equipped local cluster infrastructure.

B. Data storage

We are combining both structured (MySQL) and non-structured (MongoDB) databases to store the data in a hierarchical manner.

C. Visualization

The Data Center infrastructure contains a portal based graphical user interface. The GUI is a Liferay [9] based open source, service-rich front-end. Each DAQ system needs totally different data visualization. A large set of portlets have been developed to show the collected data according to user requirements.

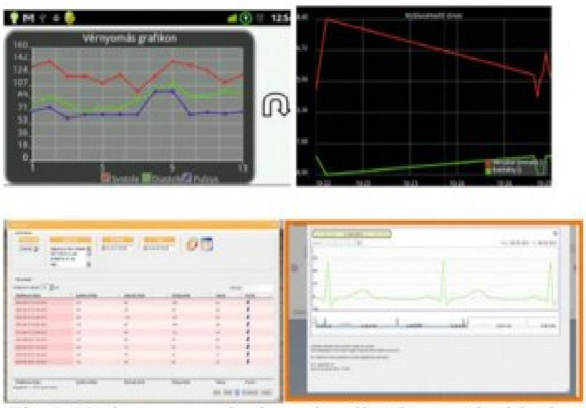

Fig 5. Various example data visualization on the biosignal DAQ client side and server side (portlets)

VI. CONCLUSIONS

Due to the different - in most cases proprietary and incompatible- COTS sensor solutions, it is a hard task to create reliable, generic, user friendly biosignal DAQ systems for cardiovascular and diabetes monitoring. According to our field tests, we are able to measure vital signs and provide reliable and secure communication channels to forward in near real-time the acquired patient data to the medical experts. We have defined and developed not only the biosignal DAQ system, but identified new monitoring protocols with longer monitoring durations, and finer measurements to assess cardiovascular and diabetes trends at the patient. Both at the DataHub and at the central we are able to visualize near real-time patient's health status parameters. Our solution is already used in two hospitals as major biosignal DAQ and remote patient monitoring system.

VII. FUTURE WORK

Nowadays DAQ systems are constantly emerging. New smart sensors with advanced feature sets and communication protocols are hitting the market constantly at a high rate. We are searching and including the latest sensors into our system to enable more accurate, more robust, multimodal biosignal and micro environment sensing for our customers. We are recently focusing on the complex problem of the sensor data fusion, beside that our development targets are the more customer specific visualization solutions and large scale automatic workflow based data processing.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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