Personalisation of Health - Current and Future Trends: How can we Move to Integrated, Intelligent and Adaptable ICT enabled Personalised Healthcare Systems

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***Abstract*— Advances in Information and Communications Technologies have led to a number of available services and devices for pervasive health monitoring. The primary goals of research and industry efforts are to facilitate clinicians in adopting the correct patient health treatment plan, to help patients continue with their daily life activities by making their monitoring and treatment services unobtrusive, and to provide appropriate alert mechanisms in case of emergencies, all tailored in integrated solutions. As personalised healthcare systems become mature and widely used, it is evident that, besides integrated solutions, methods for embedding intelligence and assuring adaptability in such systems are necessary to reach the full hype of their potential in healthcare delivery. In this regard, the experiences gained during the development of the integrated sensor platform of the SENSATION project are discussed, as well as our recent research efforts towards extensible, intelligent and adaptable integrated biosensor platforms for pHealth applications.**

I. Introduction

Pervasive healthcare systems for patient monitoring and personalized service provision have been widely explored in the last decade [1]–[3]. Their adoption in several application scenarios has emerged as a consequence of the necessity to ensure continuity of healthcare services, improve patient quality of life and rationalize healthcare costs. The effectiveness of such systems has been reported in several studies [4]–[5]. Towards this direction, small and fast sensor platforms comprised of microcontroller-transceiver modules with sensing capabilities have been designed for ubiquitous health monitoring. Such autonomous distributed devices are typically incorporated in Wireless Sensor Networks (WSNs) [6], which constitute a significant technological mean towards the construction of pervasive healthcare environments [7].

Recent advances in micro-nano technologies have led to the availability of various types of biomedical sensors, e.g., wearable, implantable, embedded in the user's environment, and so forth [8], that can be effectively used to deploy personalized monitoring scenarios. For example, Paradiso et al. proposed a wearable health care system that is comprised of a textile wearable interface implemented by integrating sensors, electrodes, and connections in fabric form, as well as advanced signal processing techniques and communication modules [9]. The system is capable of acquiring simultaneously several biomedical signals (i.e. electrocardiogram, respiration, activity) aiming to monitor individuals affected by cardiovascular diseases. Bader et al. proposed a wireless ad hoc network for patient monitoring within the hospital environment, aiming to monitor the physical activity of elderly people with particular emphasis on their localization [10]. The system integrates several sensors that may monitor in parallel physiological measurements such as oxygen saturation, pulse, blood pressure, or muscle activity.

The SENSATION EU project investigates approaches for pervasive monitoring in relation to wakefulness, fatigue and stress, both in medical applications, i.e. for insomnia and sleep apnea diagnosis and treatment assessment, and in industrial applications, i.e. for involuntary sleepiness in driving and working conditions. The main axes of the project include the development of novel micro and nanosensors of low-cost and high-efficiency for unobtrusive real-time physiological state monitoring, sensor communication technologies, including a wireless Body Area Network, a Personal Data Processing Unit and LAN\WAN components designed to allow the greatest flexibility and user/patient freedom, the integrated environment, along with development of new tools for processing the derived data in a meaningful way for the detection and prediction of human physiological states [11].

Recently, the HeartCycle EU-funded research project has been launched [12], aiming to provide a closed-loop disease management solution being able to serve both Heart Failure (HF) patients and Chronic Heart Disease (CHD) patients, including possible co-morbidities such as hypertension, diabetes and arrhythmias. This will be achieved by multi-parametric monitoring and analysis of vital signs and other measurements, employing state-of-the-art biomedical sensor technology.

Current sensor applications, however, face the problem of being tightly coupled with the sensor hardware technology involved, resulting in proprietary solutions. In addition, the field is characterized by several open issues and challenges, such as context awareness [13], embedded intelligence [14], and interoperability [15]. In the application of WSNs in healthcare service provision, quality and standardization issues as well as extensibility have to be taken into account. Hence, open architectures and standard ways of exchanging information and managing services in the application level are required, in order to integrate both sensor platforms and Body Area Networks (BANs), towards efficient intra-BAN and extra-BAN communication, respectively. Adoption of open architectures can facilitate the integration of sensor node services in the existing medical services infrastructure.

In this regard, our latest research focuses on the construction of open and extensible WSNs, capable of formulating dynamic and reconfigurable networks for personalised monitoring [16]. In particular, we have currently elaborated on the intra-BAN architecture and the data communication issues, which constitute the base for the realization of such a generalized framework. From a technical viewpoint, the WSN considered consists of sensor nodes able to apply appropriate data processing algorithms, in order to identify normal and problematic situations in a patient's condition and transmit data only when needed. Hence, processing and communication capabilities are not residing in a single control unit, i.e., in a centralized manner, formulating this way a distributed intelligence scheme residing in the entire WSN.

In the following, the experiences gained during the development of the integrated sensor medical platform of the SENSATION project are discussed, as well as our recent efforts towards extensible, intelligent and adaptable integrated biosensor platforms for pHealth applications.

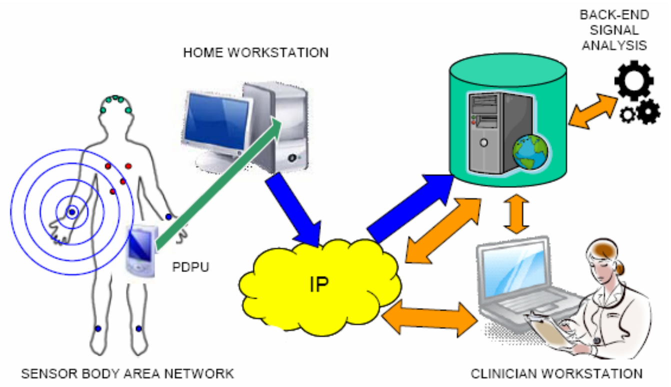

Fig. 1 The SENSATION personalised monitoring scheme

II. Integrated Monitoring Systems for pHealth: The SENSATION Experience

The SENSATION project is a CEC-funded research effort aiming at the development and adaptation of biomedical engineering technologies to achieve unobtrusive, cost-effective, real-time monitoring, detection and prediction of human physiological states in order to study wakefulness, fatigue and stress. Part of the project involves biomedical data acquisition from subjects at their home environment, in order to study sleep patterns, quality and disorders. Such a scenario does not explicitly require real-time data monitoring or processing. The same telemetry platform however was developed for use within a medical centre intensive care unit (ICU), taking advantage of the system's real-time monitoring capability to permit rapid medical response in case of emergency.

Figure 1 depicts the personalised monitoring scheme of SENSATION. Data originate through measurements taken by a body area network (BAN) of sensors attached to the subject's body, is wirelessly transmitted in real time to a portable data processing unit (PDPU) and subsequently uploaded to a home-based PC workstation. Upon receiving data from the PDPU and other optional sources, the home workstation integrates it into a single, automated and secure IP transmission for deposition into a centralized online data repository residing in a collaborating medical centre. The data repository server processes incoming data, analyses it and securely distributes it to certified medical workstations upon request. The integrated sleep-monitoring platform therefore has to accommodate home-based data acquisition, storage, analysis and distribution in a secure, flexible and cost-effective fashion, further meeting restrictions imposed by the home environment and the subject's lifestyle, as well as experimental and data-processing requirements defined by clinicians.

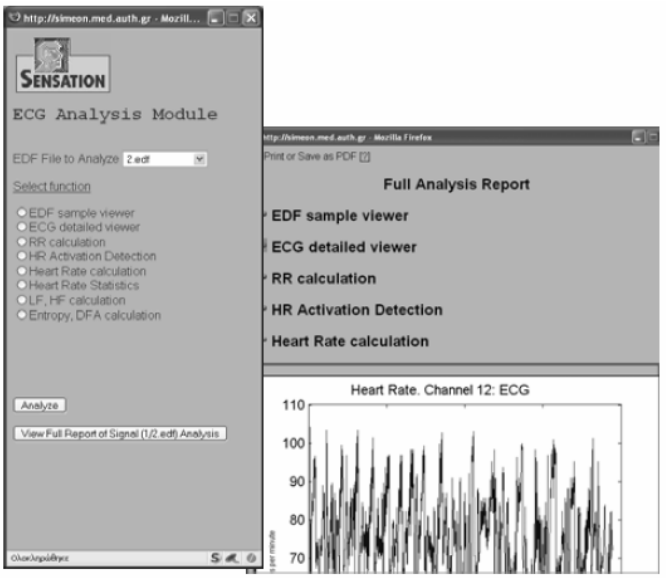

Fig. 2 Screenshot of the signal analysis and report generation module, a web-based application available through any Javascript-enabled browser (an ECG analysis request form and subsequent results window are depicted).

Clinicians use a thin-client workstation to view subject records, modify clinical information and access acquired signal data from multiple sensors and monitoring sessions. This is performed via a graphical user interface (GUI) which was developed using the Java programming language in order to ensure compatibility across various operating systems. The clinician may further request signal analysis for any signals stored in the medical center database. This is performed by the analysis module, a Web-based application developed using the PHP programming language and made available by the database server. It is accessible via any Javascript-enabled browser and guides the clinician through the process of configuring a signal analysis request form (Fig. 2). It subsequently securely relays the request to the database back-end analysis module (Matlab), and presents the results produced by the analysis module on screen in the web browser interface, making them also available for download.

III. Towards Intelligent and Adaptable pHealth Schemes

Based on the experience gained during the development of the SENSATION personalised monitoring platform, we elaborated further on the interoperability, maintainability and extensibility issues that arise in pervasive monitoring systems. In particular, we focused on the intra-BAN communication and data exchange mechanism, towards the construction of a novel WSN, the functionality of which will be configurable by medical personnel. As regards to the monitoring application, our focus is on an open architecture extensible with additional sensors. The approach followed was inspired by the Sensor Web Enablement framework, which envisions Web resident sensors that are easily detectable and accessible through the Internet. Specifically, the framework relies on the SensorML model language [17], which provides a standard XML-based mean for encoding and describing any process of measurement by sensors and the instructions for deriving higher-level information from observations. For each process, all input, output, parameters, methods, as well as relevant metadata are described using SensorML.

In this regard, and as more advanced sensors become available with respect to computational resources, we consider scenarios in which processing capabilities are not residing in a single control unit. Instead, the WSN consists of sensors capable of incorporating appropriate data processing algorithms and sending data to the medical personnel only when required. This reduction in processing burden is indispensable when compared to the communication cost savings, considering an alternative scenario in which all data recorded by each sensor is transmitted.

More specifically, the constructed WSN relies on three basic quality attributes: a) *formal sensor description*, i.e. sensors provide standard self-descriptions and processes, so as the entire network can be sufficiently described; b) *openness*, i.e. sensors can be easily added or removed from the network in a plug-and-play mode, provided that the sensor is appropriately self-described; and c) *configurability*, i.e. sensors can be configurable in run-time, in the sense of adapting their operation logic. The abovementioned attributes are released by using SensorML as a means to describe sensors' functionality.

In this context, the dynamic update of BAN behaviour becomes possible, according to the requirements specified by the medical personnel, while sensor discovery and interoperability assurance is achieved in the entire WSN. Compared to the SENSATION integrated platform, in this case the PDPU is equipped with more advanced processing capabilities, enabling this way the application of SensorML-based serialization and de-serialization of data, coordination of network tasks and communication with sensors in an efficient manner. Accordingly, each sensor processes the recorded data according to the specified parameters and is also equipped with efficient mechanisms for serialization and de-serialization of data.

Furthemore, asynchronous ways of communication like Short Message Service (SMS) and/or MMS (Multimedia Messaging Service) are currently investigated for providing appropriate notifications to the medical and technical personnel, according to the monitoring outcome, aiming to close the loop between the patient and the healthcare provider and to ensure quality services. As for the data management issues in the medical site, we have presented in [18] a multiagent system highlighting interesting patterns of patient interaction with a personalised system for chronic disease management, among which the deterioration in patients' health according to the bioparameters monitored.

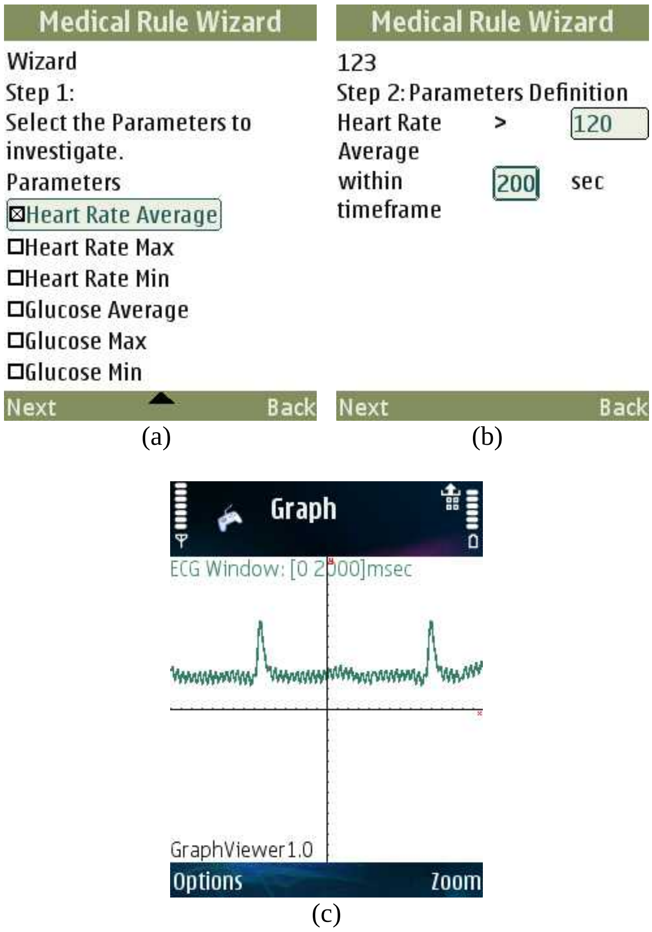

Fig. 3 (a), (b) Screenshots of the adaptive user interface for medical rule creations, and (c) visualisation of an ECG signal received by the BAN.

In Fig. 3, screenshots of the adaptive user interface developed are illustrated for defining the personalised monitoring scheme (via the medical rules wizard) and the depiction of an ECG recording.

A major advance of this approach is the embodiment and distribution of intelligence within the entire WSN. Thus, events and actions triggered by events may be described for each sensor leading to different severity levels. From an implementation viewpoint, we currently emulated the PDPU via a personal digital assistant (PDA) and two biosensors, one for heart rate monitoring and the other for blood glucose observations, using J2ME (Java 2 Micro Edition) enabled mobile terminals.

IV. Conclusions

As personalised healthcare systems become more mature and widely used, the potential of offering added value and qualitative services is increasing. Interoperability issues play a significant role towards the achievement of flexible, extensible and qualitative health delivery systems which are based on medical devices and ICT solutions. Thus, the underway personalised healthcare service certification procedures, such as Continua Alliance [19], are expected to take into account interoperability features as markers of added value and quality.

Furthermore, the technical solutions for integrated and interoperable personalised healthcare environments will facilitate the introduction of new information flow and information processing approaches, evolving to distributed intelligence solutions, that efficiently enhance and extend the medical procedures to home environments without creating new processing bottlenecks and patient safety deterioration to the healthcare providers.

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