Computer Communications 35 (2012) 1296–1305

Contents lists available at SciVerse ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Personal Health System architecture for stress monitoring and support to clinical decisions

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ARTICLE INFO

Article history:
Received 12 February 2011
Received in revised form 17 November 2011
Accepted 18 November 2011
Available online 25 November 2011

Keywords:
Pervasive healthcare architecture
Stress detection
Clinical decision support system
Autonomic sympathovagal balance
Autoregressive model

ABSTRACT

Developments in computational techniques including clinical decision support systems, information processing, wireless communication and data mining hold new premises in Personal Health Systems. Pervasive Healthcare system architecture finds today an effective application and represents in perspective a real technological breakthrough promoting a paradigm shift from diagnosis and treatment of patients based on symptoms to diagnosis and treatment based on risk assessment. Such architectures must be able to collect and manage a large quantity of data supporting the physicians in their decision process through a continuous pervasive remote monitoring model aimed to enhance the understanding of the dynamic disease evolution and personal risk. In this work an automatic simple, compact, wireless, personalized and cost efficient pervasive architecture for the evaluation of the stress state of individual subjects suitable for prolonged stress monitoring during normal activity is described. A novel integrated processing approach based on an autoregressive model, artificial neural networks and fuzzy logic modeling allows stress conditions to be automatically identified with a mobile setting analysing features of the electrocardiographic signals and human motion. The performances of the reported architecture were assessed in terms of classification of stress conditions.

1. Introduction

The medical knowledge is frequently updated and re-evaluated comprising new risk factors identification, new drugs and diagnostic tests, new evidences from clinical studies [1]. The challenges faced today are to incorporate the most recent and evidence-based knowledge into Personal Health Systems [2,3] and to transform collected information into valuable knowledge and intelligence to support the decision making process [4,5]. Several expert systems tailored to specific diseases are nowadays available in clinical research [6–11], often covering the topics addressed by European priorities [12]. Technology can play a key role to gain the continuity of care and a person-centric model, focusing on a knowledge-based approach integrating past and current data of each patient together with statistical evidences. In currently applied care practices, the emergence of clinical symptoms allows a disease to be discovered. Only then, a diagnosis is obtained and a treatment is provided. Currently, different healthcare practice models are used [12–14]. In some models, the Hospitals is the core of the care and any level of technology available at the patient site may help in providing information useful for both monitoring, early diagnosis and preventive treatments. In other models dedicated call centers or point of care act as an intermediary between hospital/heath care professional and patients. Many of the solutions available today on the market follow the above-mentioned model and call center services or point of care are used by the patients just as a complement to the hospital-centerd healthcare services [12–15]. In the more advanced Personal Health Systems [16–20] model focused on the empowerment, the ownership of the care service is fully taken by the individual. This model is suitable for any of the stages of an individual's care cycle, providing prevention, early diagnosis services and personalized chronic disease management. Under this model, the technological innovations can help each person to self engage and manage his/her own health status, minimizing any interaction with other health care actors. Solutions fully led by the patients are the overwhelming majority of those developed by research efforts

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doi:10.1016/j.comcom.2011.11.015

covering chronic disease management, lifestyle management and independent living. Even if, in the clinical practice this model has not been yet implemented, it can be considered as a target to be reached achieving at the same time the empowerment of the users and the reduction of workload and costs, preserving the quality and safety of care.

The main reasons for the lack of effective implementations of Personal Health Systems range from legal and societal obstacles, issues related to the real application of wearable devices, inappropriate use of decision support systems and the skepticism of many healthcare professionals. Wearable devices need to be non-intrusive, easy to use, and comfortable to wear, efficient in power consumption, privacy compliant, with very low failure rates and high accuracy in triggering alarms, especially if used for diagnostic purposes [18–21]. The decision support system must infuse clinical knowledge into methodology and technology, thus enhancing the reliability of high-level processing systems customized to his/her personal needs represents the next critical step. The currently used approaches are based on values of health-related parameters, often monitored instantaneously during a check-up [21,22]. Moreover, the correlations across physiological, psycho-emotional, environmental and behavioral parameters, such as a patient's physical activities or stress levels, are difficult to explore. Refer to this, the experience sampling method approach, i.e. a naturalistic observation technique that allows capturing participants' thoughts, feelings, and behaviors at multiple times across a range of situations as they occur in the natural environment, can be adopted in research and clinic [23,24], especially for psychological stress [25].

The stress system represents an essential alarm system that is activated whenever a discrepancy occurs between the expectation of an organism and the reality it encounters. Lack of information, loss of control, unpredictability or psychosocial demands can all produce stress responses. Allostasis, i.e. the adaptive response of the organism to a stressful agent, is produced by the joint activity of the central nervous system, the hypothalamus–pituitary–adrenal axis and the immune/proinflammatory system [26]. It appears clear that stress as it relates to illness has been studied by a variety of disciplines with differing research traditions. Each medical subspecialty emphasized the capability of stress in participating in the pathogenetic process of disease of competence. It resulted a varied plethora of detailed physiologic models in which psychological stress can intervene in regulation of different organ system activity (for example variation of blood pressure and heart rate, platelet activation, immune and inflammatory response under mental stress), but are not included in an integrative model to outline the coordinated individualized biological response of the entire body response to current challenging circumstances, which is the primary means of connecting experience with resilience or risk of the disease.

Presently, distributed wireless systems for stress monitoring consisting of biomimetic wearable suits for the unobtrusive monitoring of physiological and behavioral signals and decision support systems are continuously improving [19,27–30]. Such systems integrate sensors together with on-body signal conditioning and pre-elaboration, as well as the management of the energy consumption and wireless communication systems. Previous interesting results indicate a correlation between physiological cues and stress levels [27–31]. Some works demonstrate the feasibility of detecting stress acquiring physiological measurements, but using complex sensor architectures during the experiments and complex labeling methods often based on judgement of human coders [27,28]. Other simpler approaches indicate that HRV may represent an inexpensive methodology for the objective assessment of human reactions under stress, but the results are only preliminary and stress is detected just by means of a manual post-processing method [29,31].

In this work an automatic simple, compact and efficient pervasive architecture for the evaluation of the stress state of individual subjects in a natural environment with a minimal discomfort for the subject is reported. Differently from the state-of-the-art, our system is suitable for prolonged stress monitoring during normal activity. The innovative contribution of the paper relies on the processing approach able to automatically identify stress conditions of the patient from physiological and behavioral information. Moreover, our architecture and method is able to remotely (anytime and anywhere) acquire and analyse heterogeneous medical data originating from historic data, medical knowledge sources, collection of vital sign data by wearable sensors and handheld devices, as well as it is able to control all modules of the elaboration chain, including clinical protocol management and the sensor interfaces, and to support clinical decisions. The architecture is modular, flexible and simple, and has the potentiality to empower the user to take a more proactive role in prevention of stress, guided by data coming from sensor networks and personal health profile.

2. Mobile pervasive architecture for patient-centered systems

From a general point of view, a mobile pervasive architecture consists of different wireless modules cooperating in order to perform data acquisition from multiple sensors, data analysis and decision through several techniques and data redirection and feedbacks. The architecture here proposed addresses the design of a flexible instrument for data acquisition, management, elaboration and decision suitable for those systems which are equipped with distributed remote wearable devices, where a particular attention is paid to the heterogeneous medical information flow and interprocess communication (Fig. 1). Moreover, the possibility to operate in real time imposes critical efficiency requirements to each single module.

The core of the architecture is the Personal Digital Assistant (PDA), which collects data from the Personal Mobile Sensing Platform using a configurable time resolution and dedicated Bluetooth communication channels. A data pre-processing step is performed on the sensor electronic board, so that the wireless communication with the PDA is significantly reduced.

The PDA is able to integrate the time-aligned wearable sensor information and to store relevant data in its own local DataBase (DB). The PDA performs a provisional analysis of device-mediated responses (Lite Processing), being able to take into account context information (GPS, motion activity) and physiological data (e.g. hearth rate, heart rate variability, breath rate) to obtain a provisional score (Mobile Reasoning Module). The provisional score triggers a more accurate analysis in order to perform the local feedback strategy and allows the user to get as feedback the output of the analysis.

In the case of a provisional score higher than a fixed (configurable) threshold, the PDA is able to establish a connection with the remote central DB and to upload the collected data for further and more accurate analysis. The remote central DB I/O communication layer is implemented through a Web Services Description Language (WSDL) interface. The WSDL interface design pays attention to the management and the synchronization of data and processes. Pattern recognition algorithms, knowledge-based and rule-based models are defined as running processes inside the analysis module.

In the PDA a data fusion approach is implemented in order to act as a buffer for the flow of information coming in from different sensors. With this strategy sensor data fusion is gained enabling an abstraction with respect to the specific technology of the transducers. Signals coming from the sensors are gathered in parallel and encoded according to a dedicated protocol. A specific filter for each