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Designing a low-cost real-time group heart rate monitoring system

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ABSTRACT

The aim of this paper is to present two different architectures for evaluating individual or group stress levels. First, the cloud architecture is presented in which a client device is used simply to detect an ECG (electrocardiographic) or PPG (photoplethysmographic) signal and transmit it in raw form to a server, where all the signal processing and evaluation is then carried out. The second architecture consists of a stand-alone client device that measures the signal and also performs signal processing, indicating the level of stress. Here the server merely receives the processed data and is mainly used to perform additional data analysis while providing a platform to show the stress (and other) evaluation results. We compared both architectures regarding the amount of data transmitted between the client and the server, the power and memory consumption of the client, and accuracy of the QRS algorithm detection where QRS refers to the heart's ventricular depolarisation and is represented by three deflections observed on a typical electrocardiogram. The QRS detection algorithms were tested with the MIT-BIH Arrhythmia Database and real-life data. The results indicate the accuracy of the QRS detection on the stand-alone device compared to that on the server side. A hybrid approach is more user-friendly because the stress-level results are displayed directly by the device rather than by an additional device such as a smart phone, whereas the server side allows for the long-term analysis of stress levels. These two client devices also have comparable prices, although the price of the stand-alone device is somewhat higher due to the graphical stress-level indicators. Therefore, we propose the hybrid approach when one is seeking a high-quality, miniature and low-cost solution that directly shows the stress level in real-time.

1. Introduction

The term stress is often defined as a feeling of strain and pressure, whether physical and/or psychological, placed upon an individual [1]. It is related to many illnesses, such as cardiovascular, upper respiratory, autoimmune etc. [2]. The response to stress comprises two phases. The first is the response of the sympathetic nervous system to a very stressful event that requires the increased metabolic demands to be met (higher heart rate, higher blood pressure etc.). When the stressful event finishes, the parasympathetic nervous system is activated to commence the rest and repair processes [3]. The body is in balance when the sympathetic and parasympathetic systems are in equilibrium. Chronic stress occurs when the sympathetic response is constantly stronger than the parasympathetic one. It is therefore vital to monitor the level of stress to prevent the response of the sympathetic nervous system overpowering the parasympathetic nervous system.

Stress monitoring is closely related to personalised prevention-oriented healthcare. Typically, certain vital signs are measured and transmitted to a long-distance health-monitoring centre [4]. This centre comprises information technology and competent persons whose task is to detect possible abnormal conditions and contact persons appointed for this event [5].

Such a classical health-monitoring system usually includes a client device that transmits measurements of vital signs to a server that analyses the data [6]. Only then can the results be viewed on a monitoring device, such as a laptop computer or smart phone, which introduces some time delay between the abnormal condition event and the individual's response. To keep the sympathetic nervous system under control, it is essential to know the stress level in real-time without the delay imposed by the traditional client/server system for monitoring vital signs.

Hence, the goal was to develop a stress-level-monitoring architecture that meets the following requirements:

- the stress monitoring is performed in real-time;
- the signal can be read from the ECG sensor;

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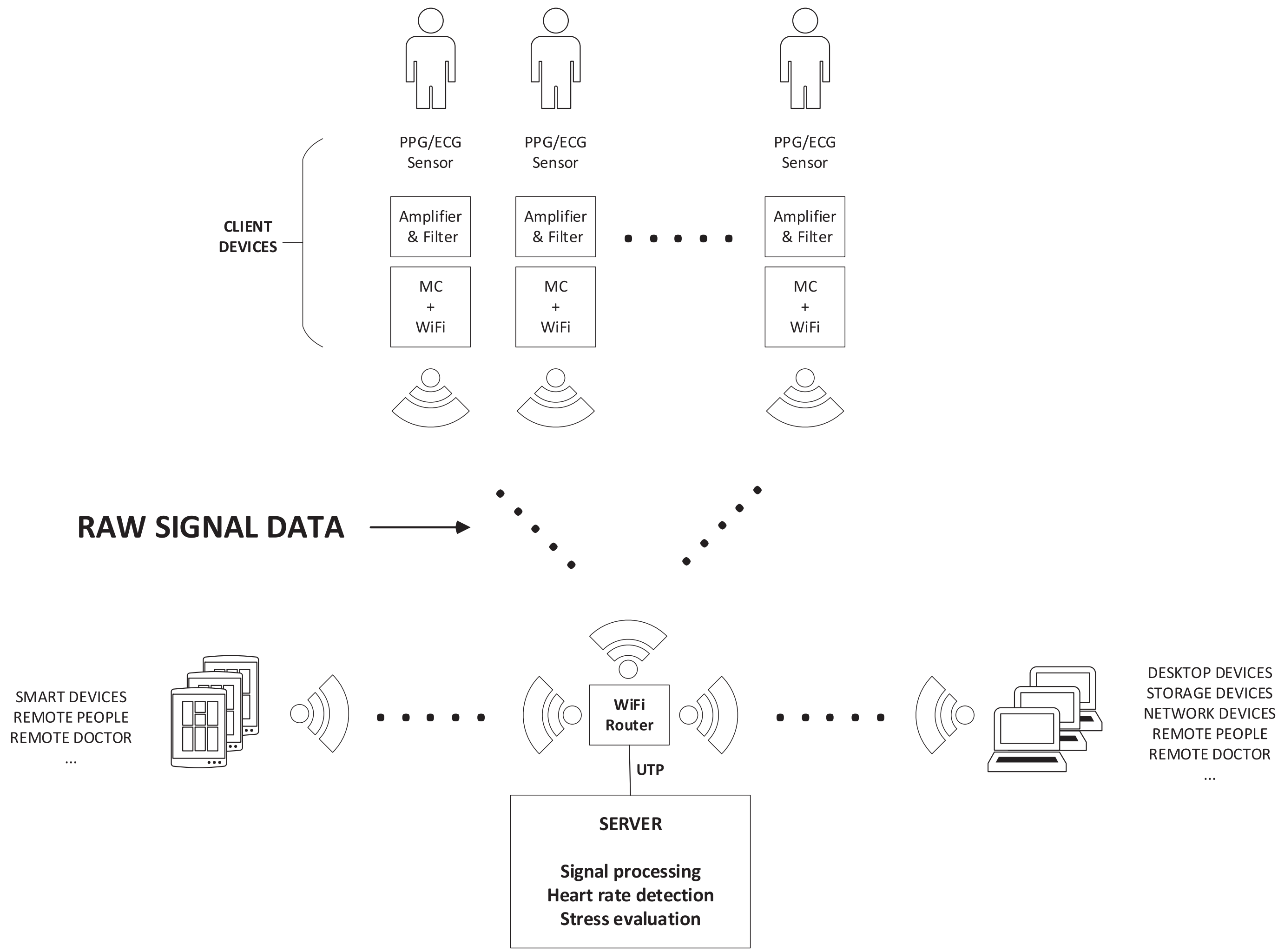

Fig. 1. Cloud architecture for gathering and processing heart-rate data for group stress detection.

- a low-cost stand-alone device should be used to accurately detect the heart rate and monitor the stress level;
- the stand-alone device should not use much power;
- the amount of data traffic between client and server should be low; and
- the server allows monitoring of group stress levels.

The remainder of the paper is structured as follows. The systems architectures are presented in Section 2. In Section 3, the software architecture is shown while Section 4 presents the results of a comparison of the two proposed architectures. Finally, conclusions are drawn, and future research guidelines are outlined in Section 5.

2. System architecture

The rapid development of technology has triggered recent research interest in cloud-based healthcare systems [7, 8]. Extending the work of [9], who proposed a prototype of group heart rate monitoring architecture, we present a similar cloud-based architecture for monitoring stress. We also propose a new architecture that includes a stand-alone device for stress-level monitoring and enables a cloud connection to the cloud. Both architectures are described below.

2.1. Cloud-based architecture

Our cloud-based architecture shown in Fig. 1 extends the work of [9]. Similar to their work, it is a client/server architecture. The client device contains an ECG or PPG sensor which is connected to a module that amplifies and filters the signal from a sensor, e.g. an AD8232 Heart Monitor. This pre-processed signal is then fed into the module with a microcontroller (MC) and a communication device, e.g. Wi-Fi, Bluetooth or similar. The signal in this module is merely transformed into a form suitable for transmission via the communication device. The raw signal data is then transferred from the client device to the server over the receiver, e.g. a Wi-Fi router, which is connected to the actual server. The server side is responsible for signal processing, QRS detection, stress-level evaluation, data storage and providing a way to display the results on desktop or smart devices. The user is therefore able to store significant amounts of data that then allow detailed analysis over longer time periods.

This architecture's advantages include the large cloud-based storage and high computational power available that allow sophisticated and complex applications for signal processing and QRS detection to be run as well as advanced signal analytics and a good user interface, enabling modern and complex data visualisation techniques. The physical distance between a client and server can be fairly good if Wi-Fi technology is used as opposed to Bluetooth technology. Developing the software is also less complex when us-