Telemonitoring system and central real-time data processing for preventive medicine research

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Abstract

This paper describes a telemonitoring system that allows the examination of preventive-medicine subjects in daily routines. The system combines the acquisition of different physiological data and the subjective workload of the subjects. A mobile handheld/smart phone depicts the data node of the afield system part and organises the data flow of the sensor system and integrated questionnaires. It continuously transfers the data to a central process management system, which stores the data in a database and executes the real-time data processing via different modules. The modules contain different regression and fuzzy models for an individual analysis of the data. All results are also stored by the process manager and the important results are sent to a medical information management system to provide examiners and subjects with the data.

The developed system reduces the effort for the examiner and increases the quality of research studies significantly. Moreover, concerning the direct supply of raw and processed data during and after the examination, the system is time-saving with regard to the examiners.

1 Introduction

In the preventive medicine, investigations afield play an important part to identify physiological and psychological impairments at usual daily routines. The measurement in a subject's real environment (at leisure, at work or at sports) returns results of its true workload. Just for psychological and emotional studies, e.g. at work, are very difficult to reconstruct in a laboratory, if at all possible.

A mobile digital solution, which allows the acquisition of physiological data as well as different psychological and emotional information about a subject, would increase the quality of a study significantly as compared to alternative solutions. Moreover, when this system allows the continuous transmission of the acquired data to the examiner, he/she has the chance to observe the current state of his subject and to intervene if some technical (e.g. shifted or ripped sensors) or medical problems occur. By using mobile radio standards an untethered movement of the subject can be achieved.

The direct availability of the data enables the possibility for central, real-time diagnostic processes, which prepare the needed data individually for the review by an examiner. Even processing intensive diagnostics can be realised by a powerful server system.

The paper describes the development of the telemonitoring system, the handling of the data by the process management system and their supply via a medical information management system.

2 Method

The developed system separates into two main areas:

- the mobile area afield and
- the central stationary area.

At the mobile area side the system is based on a smart phone, which here works as the control unit. Smart phones are characterised by a considerable repertoire of integrated communication standards, a programmable operating system and a favourable human-machine interface.

For the acquisition of physiological data a convenient sensor system is needed, which have to be light, small and comfortably to wear. Naturally, this sensor system in first place has to accomplish the requirements of the medics concerning the needed parameters. Therefore, two sensor systems were applied. The first one is the Equivital from Hidalgo Ltd. (Cambridge, UK). It is a sensor module, which works in combination with a sensor belt. Inside this belt three textile electrodes are integrated for the acquisition of a two-channel ECG. Moreover, it contains a strain gauge for the detection of the breathing by raising and lowering of the thorax. An integrated thermistor returns the skin temperature and a capacitive acceleration sensor (3-axis), integrated in the module, allows the returning of the current activity (in tree steps) and the orientation of the subject. Other parameters, like heart rate, rr-intervals and breathing rate, are also processed by the module from the mentioned raw data [7, 8].

The second sensor system is the Zephyr HxM from Zephyr Technologies. It is very light and a low-priced chest-belt system, which allows the acquisition of rr-intervals, heart rate, distance, instantaneous speed and stripes [20].

Both systems transmit their data continuously via the serial port profile by an integrated Bluetooth module and grant a life time of 24 hour and more. The smart phones’ integrated Bluetooth standard can be used to receive the current data measured by the sensor system. Besides, the smart phones include a list of activity types [19], which could be chosen by the subject to create daily activity profiles. It also includes a range of standard-
ised questionnaires (adapted for digital use), like the NASA-Task Load Index (NASA-TLX) [6], the Self Assessment Manikin (SAM) [3], the Borg-Scala [12] and the Physical Activity Rating (PFA) [5]. All together 15 questionnaires are integrated, which are activated by three different kinds of integrated triggers. The first trigger is a fixed time delay, the second one is the choosing of a current activity and the last trigger is realised by an automated monitoring of designated physiological data (looking for special physiological patterns between the parameters). The results of the questionnaires are synchronised with the continuous incoming data of the sensor system and creates a context between the different data types.

**Image 1** base user-interface of the smart phone and included questionnaires.

All these results will also be transmitted continuously via mobile radio standards, which allow the subject to move about freely in its familiar environment. The destination of the data is a communication server [13, 14], which receives the data of different clients parallel, then stores their data in a temporary data base and triggers the diagnostic processing via a process management system.

The base of the process management system is the process manager. It starts and controls the individual processing of the subjects' data, it stores the data and organises their transfer to or from a medical information management system (MIMS) [1]. In frame of the project eHealth-MV the MIMS eHealth-System became realised by Infokom GmbH Neubrandenburg. The base function of this system is the organisation of planned examinations as well as the organisation of the subjects' reference data and the significant results of the individual examination. Before starting a new examination it is necessary to register the subject, to store their reference data and to allocate the equipment for the examination as described in [2, 18].

When the process manager perceives the trigger, it requests the MIMS for reference data (e.g. age, sex, results of spiroergometry and anthropometry) of the subject, which can be identified by the used equipment. While all processes, from the acquisition via storing to the processing, are working absolutely anonymously, only the MIMS is working with identifiable information of the subject.

After receiving the required data from the MIMS the process manager starts the import of all data from the temporary data base and stores it in a subject-dependent data base. Parallel, the process manager starts the diagnostic processing of the data. Therefore, different processing modules encapsulated as a web service are available on pertinent powerful servers [1].

For the project eHealth-MV different modules were provided for the real-time analysis of the subjects' data concerning physical fitness and psychological stress. Two regression models were included, each in one module, for determining fitness. Both tests are based on anthropometric data and details about the sportive activity of the respective subject [4]. One of the tests also includes a physical test, which is based on the heart rate and the time needed [15]. The results of the modules indicate the individual fitness levels of the subjects [16].

The estimation of the psychological stress is based on a stochastic fuzzy analysis. The model, which is trained by physiological data and the subjective assessment of the individual subject, returns a stress level between 0 - 100 Percent [9-11]. The module is adapted for processing of continuously incoming data and after a training time, which depends on the count of valid answered questionnaires, it returns a result every five minutes.

The provision of the processing modules as web services simplifies the integration of analysing methods and other useful processing steps, like correction or filtering processes. For that the process manager enables the creation of processing threads, which consist of different modules in a needed specific order to reach the required results (output of one module is input of the next module, as seen in fig. 2). Furthermore, a periodical processing during the examination time, in which the results of the preceding processing are needed, is also possible. It is required, e.g. for calculating the standard deviation of a parameter for the past examination time (see fig. 2).

**Image 2** handling of processing threads by the process management system.

All results of the single modules are returned to the process manager, which stores them in the data base. If the processing thread has more modules the process manager forwards the results to the next.

The significant results are transmitted to the eHealthSystem and provided for patients/subjects and medical/examiners [2, 18]. The patients/subjects can also use the smart-phone browser for consulting their own results.
The developed telemonitoring system permits one examiner to monitor the physiological and subjective raw data as well as the analysed results of several mobile subjects at different locations at the same time. The examiner can view the data on one time line, which realises a higher quality. Moreover, the system works fully automated and reduces the effort and the time exposure of the medical staff. An appraisal session for the subject after having finished the examination is directly possible as the post-processing time for the examiner can be waived. For the subjects the eHealth-System provides a simplified output of the results enabling them to get information on their respective status themselves.

In a study on the handling of the system and the user compliance (103 participants), 88% predicate that the system is very easy or easy to handle (others predicate okay) and 90% predicate that the subjects do not feel bothered by the system in their daily routine [17]. These results show that the system also simplifies the handling for the subjects, who do not need to manage the answering of the questionnaires on their own (e.g. remembering to answer, note answering time) as required in paper-based solutions. Furthermore, the availability of the physiological data synchronised with the questionnaire results and their combination with the results of the analysis on the same time line, offer a clear and precise reflection of the subjects' statuses.

References


