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CONTEXT-AWARE PLATFORM FOR LONG-TERM LIFE STYLE MANAGEMENT AND MEDICAL SIGNAL ANALYSIS

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ABSTRACT
We present a research platform for combined physiological signal acquisition and context-awareness. This platform seeks to be wearable, it has extended battery life, it offers enough computational power to run context-recognition algorithms and it is flexible so that a variable number of sensors can be added to it. So far the system is composed of a wearable physiological signal acquisition device, a variable number of miniature acceleration sensor nodes and a wearable data recording system capable of running context recognition algorithms, integrated in a belt. This paper describes our motivation, design goals and first results of the system and its performance characteristics.

KEYWORDS
Research platform, context-awareness, physiological sensors, healthcare, long-term monitoring.

INTRODUCTION

Context-aware computing aims to detect the "state" of the user (e.g. his location, activity, interaction, past history) in order to enhance man-machine interactions (e.g. proactive information delivery) or provide automated annotation of daily activities. Contextual parameters such as life habits, physical activities, social interactions or even cognitive states (e.g. stress, depression) have an impact on the user health prospects, because health is more than the absence of illness. Also the World Health Organization defines health as […] *a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity* [1].
Trends in chip and computing technology (Moore's Law) indicate that at some time in the future it will be possible to provide small and affordable sensors which can be worn inconspicuously during every-day life, enabling novel healthcare applications. The combination of physiological recordings with the knowledge of the user context, detected

automatically over long periods of time, offers promising outcomes in the medical field: e.g. sleep analyses taking into account user activity in past days, or correlations of medical outcomes with life style parameters. It may also enable new consumer applications such as *life style assistants,* which help the user to adapt his habits in order to improve his health prospects.

Whereas a wide research community in wearable computing has applied a variety of classification methods to short-term activity recognition (e.g. [2,3,4]), only a few researchers address long-term activities. An important contribution to the investigation of such long-term activities has been done by Clarkson [5], who collected 100 days of wearable sensor data using sound and video recording. He presented methods to identify detailed sequential scenes such as entering a building, walking up stairs and entering an office, recorded at different moments in time. In the health care field Lemke et al. [6] showed that there is a correlation between depression and gait velocity. Signs of depression may also be detected from vocal signals [7]. Using GSR, temperature and heart rate data, Lisetti et. al. [8] could separate five emotional states with a recognition rate better than 70%. That wearable systems are able to detect stress in an ambulatory setting was shown by Healey [9]. Bartsch et al. [10] analysed the phase synchronisation between heartbeat and breathing and found out that this synchronisation is significantly enhanced during non-REM sleep and reduced during REM sleep. This indicates that the synchronization is probably only due to a weak influence that is disturbed in the presence of long-term correlated noise, superimposed by the activity of the brain.

Although these examples illustrate the potential of context aware wearable devices and the wide range of possible sensors, the full potential of continuous on-line monitoring based on multi-modal sensors at the human body has not been explored yet. Several projects have been initiated to monitor the physical health or cognitive-affective state based on wearable systems. The MyHeart project[1] focuses on the design of a system capable of an early detection of cardiovascular disease, allowing early treatments. The exploration of sensor technologies which achieve unobtrusive detection and prediction of the human physiological state in relation to wakefulness, fatigue and stress is the objective of the Sensation project[2]. Exploring the potentials of detecting emotional states in real time is the goal of the AUBADE[3] and HUMAINE[4] project.

Despite the promising applications of wearable systems technical challenges hamper development in this field: systems that allow recording of physiological signals and contextual data are still uncommon or highly application specific and often do not meet requirements of wearable systems such as comfort, extended battery life, flexibility and computational power for online contextual awareness. We present here a research platform that tries to satisfy those requirements. This platform will be used to analyze long-term trends in daily habits. In addition, within the EU project Daphnet[5], it will be used in applications such as sleep disorders, cardiac and gait analyses.

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[1]:http://www.hitech-projects.com/euprojects/myheart/
[2] http://www.sensation-eu.org/
[3] http://www.aubade-group.com/
[4] http://www.emotion-research.net/
[5] http://www.daphnet.eu/

DESIGN GOALS

Beside research prototype systems used in the studies mentioned above, there are several commercial systems available, which follow the principal of including sensors in “sensor shirts” or accessories that can be easily worn. Probably the most popular one is the Polar belt (http://www.polar.fi/), which accommodates a one-channel ECG and accelerometer. The analysis of the heart rate enables training support as well as management of weight and fitness. The Bodymedia HealthWear Armband (http://www.bodymedia.com) is worn on the back of the upper right arm and was designed for weight management. The armband measures movement, heat flux, skin temperature, near-body temperature, and galvanic skin response, which is used for energy expenditure calculations. VivoMetrics (http://www.vivometrics.com/) developed the “LifeShirt System”. ECG, accelerometers and sensors for respiratory measurement are embedded in an undershirt garment and an external PDA stores the data. The Stanford Lifeguard system (http://lifeguard.stanford.edu/) has been designed for extreme environments. It comprises physiological sensors (ECG/respiration electrode patch, pulse oximeter, blood pressure monitor), a wearable data logger and a Tablet PC as base station.

While research platforms based on wireless sensor nodes could accommodate various sensing modalities, they have limitations in terms of user acceptance due to size and battery life. Commercial systems tend to target specific applications, typically physiological data recording and transmission, and do not possess the required sensors to take into account detailed physical activity or social interactions. Furthermore they generally are not able to process contextual information on the body in real time.

Because we could not find an exiting hardware platform that meets our requirements, we built our own research platform. Usability criteria for researchers drove our design decisions. In particular the platform has to achieve high quality physiological signal recording, as well as it must provide the appropriate sensors for contextual awareness. As a research platform it should also be flexible so that algorithms and sensors can be adapted to various applications and new sensors can easily be included. The subject should easily be able to add and remove sensors during runtime without reconfiguration. In order to allow sending people home wearing the platform, ease of use and robustness is another key requirement. The system has to run for at least 8h without battery replacement or recharging, and if recharging is required it should be possible for a non-technical subject to perform this task. Finally the system should disturb the normal behaviour as less as possible.

PLATFORM DESCRIPTION

We envision a system composed of three parts: 1) a wearable centralized data recording system capable of running context recognition algorithms integrated in a belt, 2) a mobile physiological signal acquisition device, and 3) a variable number of miniature sensor nodes for contextual acquisition connected either wirelessly or by wire.

1) The centralized data recording system is a QBIC Belt Integrated Computer [11] which runs a Linux operating system and offers processing power comparable to an ultra-portable PC. The system offers by default USB and Bluetooth as extension interfaces.

Due to the general-purpose and energy-efficient processor the QBIC allows running a diversity of context recognition algorithms to detect e.g. physical activity (walking, running) or various resting positions from accelerometers data while the power consumption is between 1.5 and 2 Watt. The belt with integrated battery (3,7V, 700mAh) weights 360 gram. An extra battery pack (two battery cells combined to one pack, 3.7V, 4.3Ah, 110 grams, 37 x 65 x 18 mm in size) can be attached to the belt to increase the battery capacity.

2) Among the commercially available sensor system solutions, the Mobi system from TMSI Netherlands [12] meets our usability design goals concerning the physiological signal acquisition most closely. The Mobi system is a compact (114 x 98 x 37 mm, 165 gram) sensing unit, designed for the particular task of monitoring physiological signals. It is medically certified and allows acquiring 8 analogue physiological signals, 4 channels sampled with up to 2048 Hz, the others with 128 Hz. It includes in particular sensors for ExG, SpO2, galvanic skin conductivity, respiration and skin temperature. Sensor data is transmitted to the QBIC over a Bluetooth wireless link.

3) Currently we are using two types of miniature sensor nodes to acquire contextual information. Both encompass a microcontroller and a 3-axis accelerometer to obtain physical activity. The first type is using USB to transmit the recorded data to the QBIC and is powered by the belt over USB. It is 42 x 35 x 6 mm in size and weights 10 gram and is used if the sensor is located near the waist. The second sensor node type sends data to the QBIC over a Bluetooth wireless link. The board itself is just 18 x 47 x 8 mm in size and weights less than 5 gram. It is powered by a rechargeable Li-ion battery (3.7V, 600mAh, 37 x 27 x 6.5 mm, 17 gram).

All the sensor subsystems stream binary data to the QBIC. In order to achieve a high degree of reliability of the overall system, we implemented a software architecture that allows connecting and disconnecting sensors during runtime. Therefore individual components that may fail do not affect the whole recording sequence. Also, the order in which devices are connected or turned on is not important which simplifies the use of the system. The data is stored on a 2GB MMC card which is plugged in the QBIC.

The system can easily be extended to include additional node types if required. Any sensor with USB or Bluetooth output can be attached to the system with little software adaptation. The miniature sensor nodes were designed in order to accept additional analogue sensors (light, temperature, …) with little change to the hardware and firmware.

RESULTS

Using the design described above, we have been able to create a basic research platform and software framework that allows receiving data from several sensor nodes and provides the computational power for online context recognition. The entire system as worn by a user is illustrated in figure 1. Up to now the platform is capable of acquiring and storing up to 8 channels of physiological signals and several acceleration channels with a sample rate of 128 Hz. Additional accelerometer nodes can be seamlessly connected to the QBIC to provide additional detailed data about the users’ activity.

With one external battery, the operating time of the QBIC with attached sensors is more than 8h. The Mobi runs on 2 rechargeable AA batteries up to 12h while streaming data. The weight of the system including sensor nodes, Mobi, QBIC with belt and external battery pack is below 1000 gram. Storing the data of 2 acceleration sensors (each 3-axis), 2 channel ECG, 1 channel respiration and 1 channel GSR all sampled with 128 Hz the system can record data for more than 150h on a 2 GB MMC card.

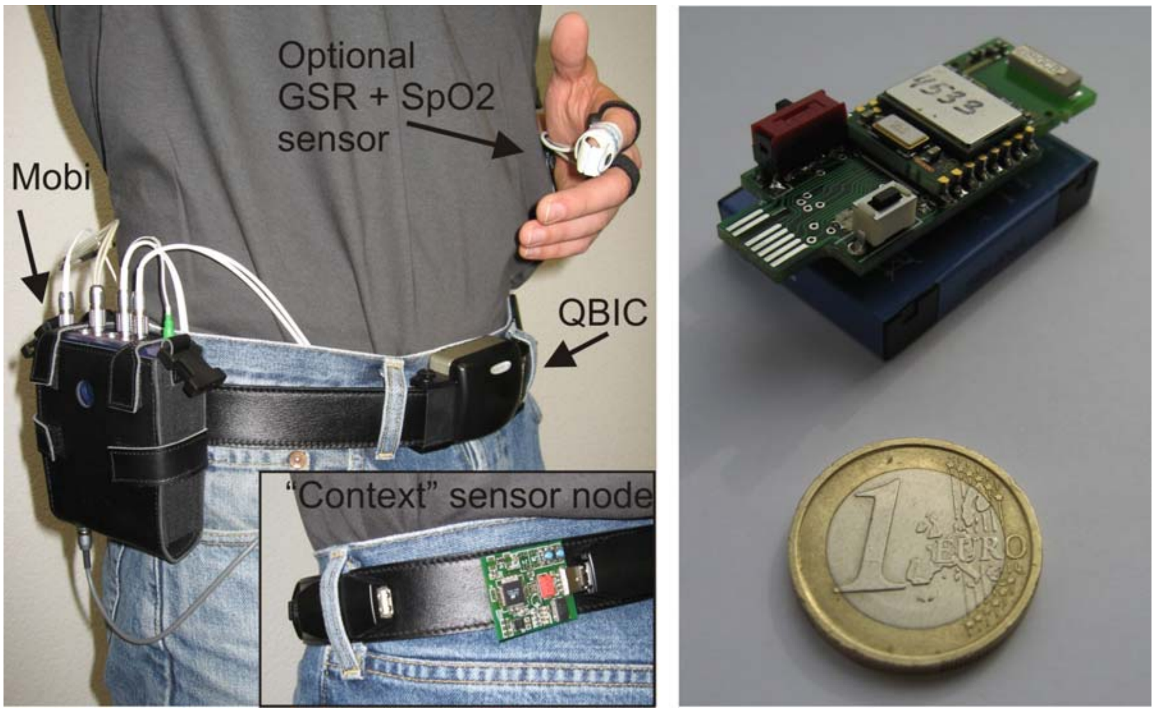

Figure 1 –Left: Entire platform as worn by a user. This setup consists of the QBIC integrated in the belt-buckle, a physiological acquisition device (Mobi from TMSI) attached to the belt and one context sensor node directly connected via USB *("context" sensor node)* Right: Bluetooth miniature sensor node.

The handling of all system components is kept very simple. The user just has to switch on each component which has its own power supply and plug in the wired sensors to the USB connector. The QBIC will detect all connected sensors and start processing. The two LEDs of the QBIC are used to indicate the state of the system and changes of the sensor setting. Recharging of the QBIC and the wireless sensor nodes is of similar complexity as charging a mobile phone. When the Mobi is running out of battery the user has to change two AA batteries.
Figure 2 shows a 35 min extract of recorded data during everyday tasks.

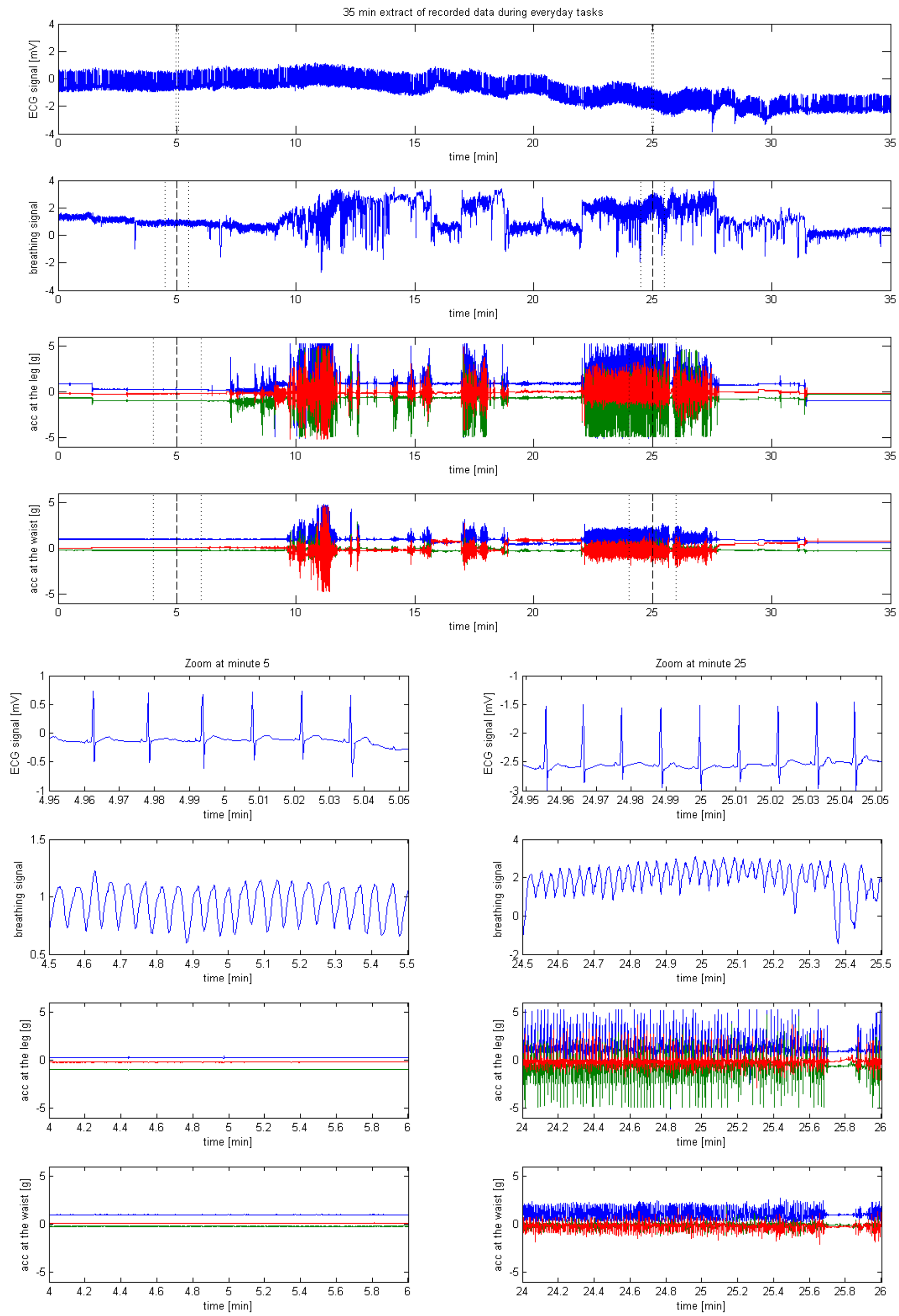

Figure 2 –A 35 min extract of recorded data during everyday tasks. [Minute 0 – 8]: office work; [10 – 12]: hurrying to the tram; [13 – 22]: tram ride with train change in-between; [23 – 28]: walking home; [28 – 35]: sitting / lying on the sofa. The 8 small figures are zoom plots of the above ones: the 4 left plots at minute 5 the right at minute 25. The centre is for each column at the same time, the zoom level is different to better visualize the signals time scaling.

DISCUSSION

With the system described in this paper we achieved a working platform for data acquisition. It includes physical and physiological sensing which is required for context-aware computation in combination with medical applications. Due to the high requirements of medical applications most sensors still require a close and permanent contact to the users' skin to ensure sufficient signal quality. The system is mobile, offers many sensing modalities and provides enough computational power for online data processing. From a technical viewpoint future work include automatic data transfer from the acquisition system to a database for off-line processing. The integration of other third party devices, e.g. a polar heart rate may be a valuable addition to the system for all scenarios where one is only interested in the heart rate and the complete ECG is not required. Such additions could be made in future work without impacting the performance characteristics of the other sensor types.

In addition to technical improvements we will use this platform to develop algorithms to quantify long-term trends in daily habits and to correlate them with subjective feedback from the user. Trend analysis requires the identification of meaningful patterns within data. Since the relevant patterns may not be known beforehand, we will investigate methods based on self-similarity analysis that can automatically identify recurrent and changing patterns in daily activities. The combination of physiological sensor data and context awareness may allow inclusion of social interactions, environmental parameters as well as possibly cognitive aspects in the evaluation.

CONCLUSION

The development of a wearable platform capable of context-awareness and high quality physiological signal recording is challenging but promises to offer interesting outcomes for medical and consumer applications. Future proactive health care technologies must be affordable, lightweight, unobtrusive, non-invasive and flexible to ensure that the general population will adapt to them. While this platform does not satisfy all these requirements our objective was to develop a platform to study correlations between physiological and context on long periods of time. This system allow researchers to get a greater insight on physical and physiological parameters and their relation to health outcomes or even well being. Based on this knowledge new devices may be developed with the objective of becoming "life style management" devices, capitalizing on the knowledge of the user's physiology and context.

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