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A Sensor Network to iPhone Interface separating Continuous and Sporadic Processes in Mobile Telemedicine

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***Abstract* – In this contribution, a new concept for interfacing sensor network nodes (motes) and smartphones is presented for the first time. In the last years, a variety of telemedicine applications on smartphones for data reception, display and transmission have been developed. However, it is not always practical or possible to have a smartphone application running continuously to accomplish these tasks. The presented system allows receiving and storing data continuously using a mote and visualizing or sending it on the go using the smartphone as user interface only when desired. Thus, the processes of data reception and storage run on a safe system consuming less energy and the smartphone's potential along with its battery are not demanded continuously. Both, system concept and realization with an Apple iPhone are presented.**

I. INTRODUCTION

INDUSTRIALIZED countries are facing a demographic change which will push the social security systems to their limits. In Germany, the ratio between people older than 65 and between 15 and 64 is expected to surpass 50% until 2030 [1]. The number of older people living alone and cannot be taken care of and assisted by their families will also increase. This will lead to a significant increase in health care need and in a loss of quality of life for people dependent of care. For these reasons a great effort is done worldwide to develop systems able to keep people in good health through prevention, early diagnosis and short hospital stays. Assuring that elderly people with cognitive or physical impairments keep self-sufficient is also often issued. Many of these systems use sensor networks to collect health information about the individual in their home or outside and to process it in order to detect deviations and give help based on the findings or alarm relatives or clinicians. As smartphones and small handheld electronic devices are spreading, it makes sense to use their processing power and their user interfaces without needing to embed them redundantly in assistant devices, increasing their mass, volume and price [2]. In this contribution, we present a new concept for interfacing assistant devices and smartphones aiming at increasing the combined system's energy efficiency and security.

After a state of the art overview about mobile systems for telemedicine and a task description, the concept will be described and a prototypical implementation will be shown.

A. State of the art in mobile systems for telemedicine.

Within the fitness and monitoring of chronic illnesses domains there are many commercial products able to monitor specific vital parameters over the day, e.g. chest straps and sport watches for heart rate, long term electrocardiogram (ECG) or blood pressure monitoring as well as glucose monitoring. Most of these products do not interface smartphones and do not enable mobile uploading of recorded data to a server.

In research, many project focus on mobile acquisition, processing and transmission of vital parameters through personal health management systems (PHMS) enabling telemedicine and e-health solutions. Among those are AMON, MOBIHEART, WEALTHY and MYHEART, to name a few [3]. In WEALTHY, various vital parameter sensors are embedded into garments. Data acquisition, processing and transmission takes place in specifically designed electronics. There is no direct visual feedback for the user [4]. The device has been improved in the Healthwear project [5]. In MYHEART, a mobile system able to send an ECG using a PDA phone over the internet is presented [6]. In [7], a mobile phone based system with direct user feedback is presented. The system also allows data transmission on a server using the scalable Healthcare Integrated Platform (SHIP). A wearable body sensor network interfacing a PDA phone for data upload is presented in [8]. A Smart Personal Health Manager interfacing a Body Area Network with a PDA phone in order to instantly show acquired data is presented in [9]. A similar system using a WLAN infrastructure inside a hospital instead of Bluetooth is presented in [10].

Several groups also work on acquiring behavioral information rather than vital parameters. Activity Recorders and Transceivers are sensor nodes capable of detecting and storing information about interaction [11]. One example is the Eventlogger presented in [12] which uses radio modules to detect interactions with objects. In [13], a platform for acquisition and display of vital parameters measured by body-worn or car-embedded sensor is presented.

An overview of the presented systems and their main characteristics is given in Table I.

Summing up, most presented systems can be distinguished between systems transmitting acquired data

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TABLE I
COMPARISON OF STATE OF THE ART IN MOBILE SYSTEMS FOR TELEMEDICINE

DEVICE	SENSORS	CENTRAL DEVICE	VISUAL USER INTERFACE	DATA UPLOAD
[4]	ECG, Resp, Movement	DD	No	MPN
[5]	“	DD	No	MPN
[6]	ECG	PDA	Yes	MPN
[7]	ECG, Movement, Temp, Imp	Mobile phone	Yes	MPN
[8]	ECG, SpO_2	PDA	Yes	MPN
[9]	Env, Sound, SpO_2	PDA	Yes	MPN
[10]	ECG, SpO_2, Temp	PDA board	Yes	WLAN
[11-13]	SpO_2, SC, BP, Movement, Int	DD	Yes	-

Resp=Respiratory frequency. Temp=Temperature. Imp=Impedance. Env=Environmental Sensors. Sound=Heart and respiratory sounds. SC=Skin conductivity. BP=Blood pressure. Int=Interactions. DD=Dedicated device. MPN=Mobile Phone Network.

directly to a server or using a mobile phone or handheld consumer electronic device for both data transmission and direct user feedback. Systems transmitting data directly could be expanded in order to offer user interfaces. However, this would increase system price, mass and volume as well, in most cases, be redundant, as the user carries a mobile phone anyway. However, using a mobile phone for reception, processing and transmission of private medical data and for time-critical or safety-critical processes can be very risky, especially considering that modern mobile phones are getting more and more complex. Regardless of whether they use an open or a proprietary operating system; proprietary operating systems strongly constrain developers and may abruptly disable third party applications while open operating systems may get unstable or allow running applications which may interfere or stop the telemedicine application.

B. *Task description*

The goal of the presented concept is to offer a telemedicine platform distinguishing between continuously running time-critical or safety-critical processes and sporadic processes like complex user interaction or user-operated uploads of big data amounts. It should be possible to run the continuous and the sporadic processes on two different devices, in order to optimize the system's safety and energy expenditure.

II. SYSTEM CONCEPT

A. *Static system concept description*

The presented concept employs a dedicated device, called management device, which is part of the sensor network used to acquire health information and a smartphone. The management device can receive data from a variety of sensors, e.g. the Eventlogger presented in [12] for behavior recognition, the sensor unit described in [13] for car-embedded vital parameter acquisition or the garment described in [14] for fall detection.

B. *Dynamic system concept description*

The continuous processes, e.g. data acquisition, processing and time-stamped storage, run on the management device. Should a safety-critical function like alarming also be needed, the management device must also contain a module for this function, e.g. a GSM module. For sporadic processes like user interaction or data visualization, the management device is connected to a mobile phone or smartphone, and data is exchanged between the management device and the smartphone.

In Fig. 1, the proposed concept's components and processes are displayed and compared with a conventional telemedicine system with mobile-phone based user interaction.

III. SYSTEM PROTOTYPE

A. *Materials and methods*

In the following, only the management device and one exemplary smartphone application developed to demonstrate the concept will be presented.

The management device is very similar to the Eventlogger presented in [12], as it already includes modules for data reception, processing and storage. The first addition is transistor-transistor logic (TTL) level converter for the serial interface of the management device's microcontroller, allowing communication between the smartphone and the

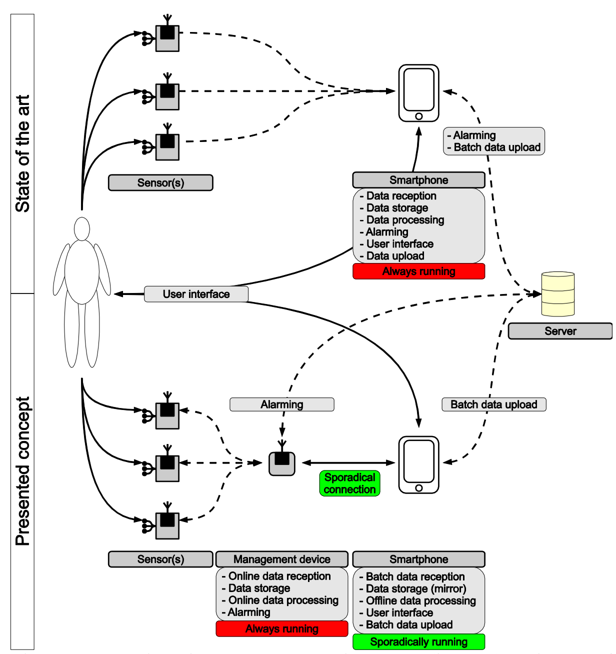

Fig. 1 Comparison between presented concept (bottom) and state of the art (top) in mobile telemedicine systems with smartphone-based visual user interface.

management device. The second addition is a connection between the smartphone's power output pin and the management device's charging pin, allowing to read out the management device with the smartphone even when its battery is empty. A system overview is given in Fig. 2. A third addition, namely a GSM module, is needed to cover all functions according to the presented concept. However, the presented prototype focuses on demonstrating the interface between the management device and the smartphone.

As a smartphone, we used the Apple iPhone 3G. When we chose the smartphone platform, this was the only phone offering a user interface consisting almost exclusively of a touch display, a very good software development kit and thus the ability to easily design intuitive and adaptive user interfaces. The downside of this platform is the very restrictive proprietary operating system, in which both processes of application authorization and becoming a licensed developer are far from transparent. The latter is especially needed when developing applications requiring access to the serial interface, which is the case here. Thus, the presented application can only run on a jailbroken device. However, this is not the case for other smartphones, on which this concept is also applicable.

The management device has a built-in connector which is compatible with the Apple Dock Connector. In addition to this, some pins can be used to program and debug the management device's microcontroller using the Joint Test Action Group (JTAG) interface. The pin assignment is illustrated in Fig. 3.

The management device has been built in two variants; the first one enables continuous connection between iPhone and management device. The second one is an adapter transforming the Eventlogger presented in [12] into a management device just during the connection with the iPhone, i.e. containing the additional components needed to use the Eventlogger as a management device. Prototypes of both devices are shown in Fig. 4.

B. Smartphone application

The realized iPhone application enables transferring the data stored on the microSD card inside the management device to the iPhone via the serial interface. It is stored into an SQLite database and visualized (data being acquired as

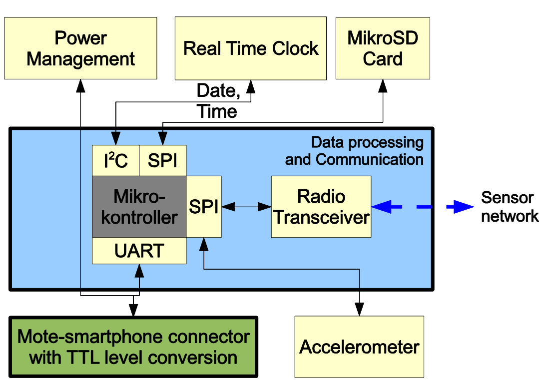

Fig. 2 Parts and interfaces of the management device prototype.

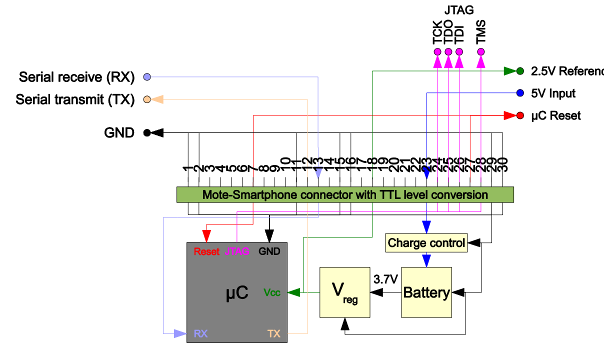

Fig. 3 Pin assignment of the mote-smartphone connector.

well as data stored previously) on the iPhone's display.

Upon starting the application, if the management device is connected to the iPhone, the iPhone-internal SQLite database is synchronized with the data on the management device. To do this, a request is sent to the management device to transmit all the data recorded since the last synchronization (batch data reception, see Fig. 1). Subsequently, a message to synchronize the real time clock inside the management device with the iPhone's time information is sent out from the iPhone application. While the application is running, a request for current data is sent out regularly. Hence data can also be displayed promptly on the iPhone upon acquisition.

The graphical user interface is divided in three views (see Fig. 5):

1) Main view
2) Graph view
3) Options view

In the main view, all the measured variables supported by the database are shown in a table. For each variable, normal upper and lower limits can be set. If a measured value is out of these limits, it is displayed in a distinctive color. The upper and lower limits can be set in the options view (see below).

The graph view is also structured as a table in which each row is associated to a variable. In contrast to the main view, here only rows corresponding to variables for which values are available are being shown. This is done to optimize the display space usage. Values are displayed in a graph on the

Fig. 4 Prototypes of management devices in two variants: integrated into a smartphone cover (left) and as Eventlogger with adapter for smartphone connection (right). On the left, the application for vital parameter visualization is running.

left side of the screen. New values are added scrolling the graph automatically. On the right side, the value is shown as a number along with the corresponding unit and current maximum and minimal value measured. The graph height adapts to these values. Tapping and wiping on the left side, the automatic scrolling can be stopped and the user can scroll through current and older values. Older data sets can also be loaded and displayed. With a double tap, the graph scrolls back to show current values on the right end and the automatic scrolling is reactivated.

In the options view, the user can set the upper and lower limits for each variable using a picker wheel. A screenshot of all three views is shown in Fig. 5.

IV. CONCLUSION

In this contribution, a new concept separating continuous critical processes and sporadic processes in sensor networks for telemedicine applications executing them on separate platforms is presented. Running continuous processes like detection of critical situations and alarming on a stable, reliable platform known to the developer avoid the stability and security risks of using a complex platform like a modern smartphone. Running sporadic processes like user interaction on a complex platform like a mobile phone or smartphone offer their advantages, i.e. an intuitive visual user interface, without the need of integrating big, expensive and energy consuming components like touch displays or keeping them active all the time.

A prototype has been presented connecting a mote and an iPhone in order to show how the concept can be realized with the first smartphone offering a touch-based user interface, although the access to its external interfaces is far from developer-friendly.

As future work, it is planned to extend the application and the system interoperability in order to also show interaction data and to find a method of implementing the presented concept without the need of jailbraking a smartphone.

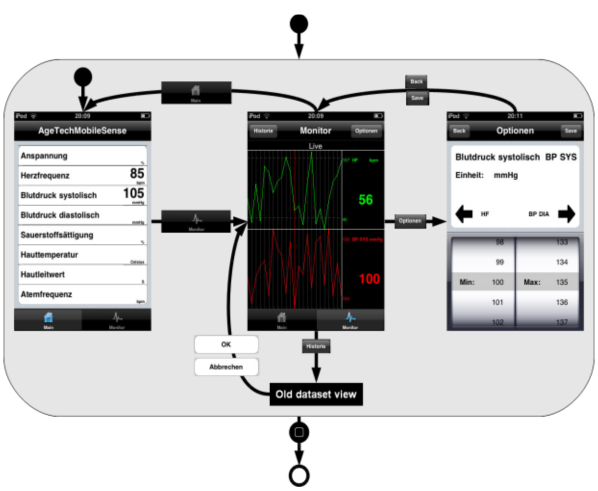

Fig. 5 Screenshots of the iPhone application visualizing acquired vital parameters live and previously recorded datasets.

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The scope of the research consortium is to develop technology based solutions which will help elderly people but eventually also other social groups at home, at their workplace and in their mobility.

REFERENCES

[1] Federal Statistical Office (2009): „Bevoelkerung Deutschlands bis 2060“. 12th coordinated population forecast. Wiesbaden, Germany.

[2] Lueth, T.C.; D'Angelo L.T.; Czabke A. (2010) : "TUM-AgeTech – A New Framework for Pervasive Medical Devices", in Pervasive and Smart Technologies for Healthcare: Ubiquitous Methodologies and Tools, editors Antonio Coronato and Giuseppe De Pietro, Hershey, USA, Medical Information Science Reference, pp. 295-321.

[3] L. Gatzoulis and I. Iakovidis: "Wearable and portable ehealth systems". Engineering in Medicine and Biology Magazine, IEEE, 26(5):51-56, Sep.-Oct. 2007.

[4] R. Paradiso, G. Loriga, and N. Taccini: "A wearable health care system based on knitted integrated sensors". Information Technology in Biomedicine, IEEE Transactions on, 9(3):337-344, Sep. 2005.

[5] R. Paradiso, A. Alonso, D. Cianone, A. Milsis, T. Vavouras, and C. Malliopoulos. "Remote health monitoring with wearable non-invasive mobile system: The healthwear project". In Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE, pages 1699-1702, 20-25 2008.

[6] Villalba, E.; Ottaviano, M.; Arredondo, M. T.; Martinez, A.; Guillen, S. (2006): "Wearable Monitoring System for Heart Failure Assessment in Mobile Environment", Computers in Cardiology, 33, pp. 237 – 240.

[7] Wenxi Chen, D. Wei, Xin Zhu, M. Uchida, S. Ding, and M. Cohen: „A mobile phone based wearable vital signs monitoring system". In Computer and Information Technology, 2005. CIT 2005. The Fifth International Conference on, pages 950-955, Sep. 2005.

[8] D.G. Guo, F.E.H. Tay, L. Xu, L.M. Yu, M.N. Nyan, F.W. Chong, K.L. Yap, B. Xu : „A long-term wearable vital signs monitoring system using bsn". In Digital System Design Architectures, Methods and Tools, 2008. DSD '08. 11th EUROMICRO Conference on, pages 825-830, Sep. 2008.

[9] D. Ayyagari, Yongji Fu, Jingping Xu, N. Colquitt : "Smart personal health manager: A sensor ban application: A demonstration". In Consumer Communications and Networking Conference, 2009. CCNC 2009. 6th IEEE, pages 1-2, Jan. 2009.

[10] B.M. Jang, Y.K. Lee, S.K. Yoo : "Development of the portable monitoring system based on wireless body area sensor network for continuous acquisition and measurement of the vital sign". In Consumer Electronics, 2008. ICCE 2008. Digest of Technical Papers. International Conference on, pages 1-2, 2008.

[11] D'Angelo, L.T.; Czabke, A.; Somlai, I.; Niazmand, K. ; Lueth, T.C. (2010): "ART – A new Concept for an Activity Recorder and Transceiver", EMBS, 32nd Annual International Conference of the IEEE, pp. 2132 – 2135.

[12] Czabke, A.; Neuhäuser, J. ; Lueth, T.C. (2010): "Detection of Interactions with Objects Based on Radio Modules", Pervasive Computing Technologies for Healthcare, Fourth International Conference on, pp. 1 – 8.

[13] D'Angelo L.T.; Parlow J.; Spiessl W.; Hoch S. ; Lueth, T.C. (2010): "A System for Unobtru-sive In Car Vital Parameter Acquisition and Processing", Pervasive Computing Technologies for Healthcare, Fourth International Conference on, pp. 1 – 7.

[14] Niazmand K.; Jehle C.; D'Angelo L.T.; Lueth T.C. (2010) : "A new washable low-cost garment for everyday fall detection", EMBS, 32nd Annual International Conference of the IEEE, pp. 6377 – 6380.