Wireless Sensor Network for "Intelligent" Acquisition and Processing of Physiological Information

Christian Peter
Fraunhofer Institute for Computer Graphics
Joachim-Jungius-Str. 11
D-18059 Rostock, Germany
christian.peter@igd-r.fraunhofer.de

Helmut Beikirch, Eric Ebert, Matthias Voss
Rostock University, IEF
A.-Einstein-Str.2
D-18051 Rostock, Germany
helmut.beikirch@uni-rostock.de

Abstract

Measurements of human physiological data allow inferring information on the mental and emotional state of a human. An increasing number of application developers and scientists of different domains want to make use of this additional information on users. To be accepted in practical application, systems of this sort have to be easy to use, should not intrude the user by wires, and it should be easy to integrate them into everyday applications. In this paper, a robust and reliable, mobile sensor array is presented which meets those criteria. It is integrated in a glove, functions wirelessly, and is thanks to its small form factor suitable for mobile use. Through consequent application of the concept of Self Validation (SEVA), reliable and validated data can be provided continuously. Multiple sensor arrays can be combined to a network, opening new research possibilities and solutions for a variety of disciplines.

1. Introduction

Scientists of a variety of disciplines show increasing interest in investigating the role of emotions in their field of research. Psychologists, doctors and sociologists have a long history of considering emotion in their work. Other disciplines are just starting their explorations in this field. Be it ergonomics, computer sciences, or the arts – emotions are more and more understood as an important human property.

In order to "detect" emotions for research purposes or considering them in new applications and systems, reliable, robust, and easy to use devices are necessary. They have to be light-weight and non-intrusive for the user and should continuously provide sensible data.

This paper introduces a system especially designed for mobile, non-intrusive acquisition of emotion-related physiological parameters. Sensors are integrated in a glove, transmitting their data wirelessly to a mobile system controller. All data get a unique time stamp and are validated within the system according to the SEVA standard [1], which guarantees continuous availability of validated data, along with status information on the actual measurement value and the sensors. Measurements are stored on an exchangeable memory card. They are also made available continuously in engineering units, allowing processing applications being designed much simpler, without the need of any sensor-specific knowledge, and eliminating the risk of conversion errors.

The system provides means for basic user interaction, data visualisation, and control of external applications or devices.

The architecture of the system allows setting up a distributed system with several sensor arrays, building a network of mobile sensor nodes.

The developed system is best suited for designing assistive applications which are aware of the current mental and emotional state of one or many users at any given time. It is very suitable for adding emotion-awareness to applications where human failures can lead to huge losses or even catastrophes, for instance flight controllers, pilots, train drivers, personnel of control rooms of nuclear plants or traffic control centres. It is applicable in psychological and medical studies, emotion-related HCI research, and other emerging research fields interested in emotion.

In the next section, the system is described in more detail, followed by a short analysis of investigations and an outlook to future developments.

2. System Description

The system's concept is based on a complex, distributed architecture with an arbitrary number of mobile sensor nodes, wirelessly connected to a central system controller. The system is open for any sort of sensor being integrated into it as long as it conforms to the system's communication protocol and data format.

0-7803-9402-X/05/$20.00 © 2005 IEEE

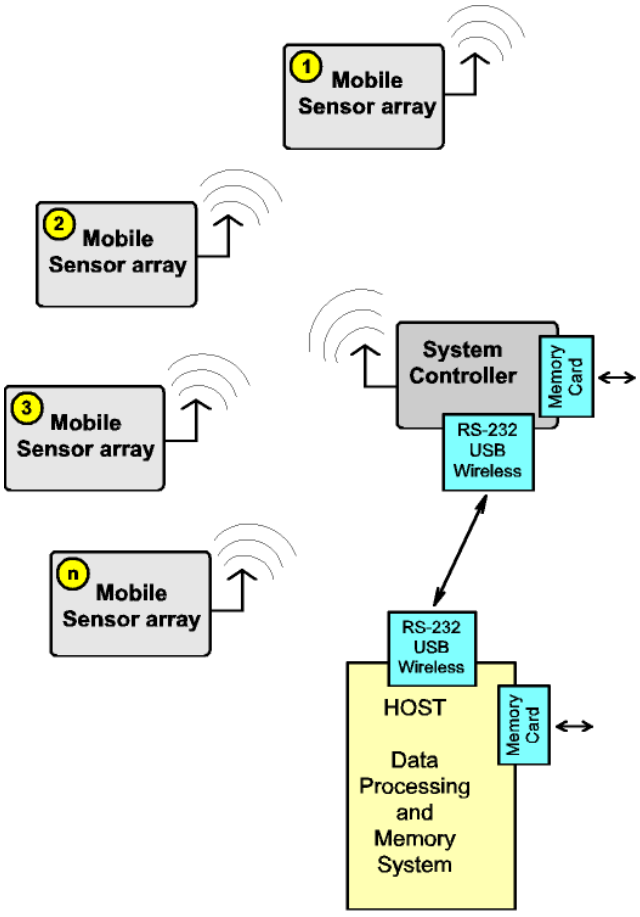


Figure 1: System conception overview.

One main requirement on a system for acquisition of physiological parameters to be used by lay-persons is its easy usage and non-intrusiveness. This can be accomplished by integrating the sensors in clothing or by using devices the user is already used to. The prototypical system described here uses a glove to hold the sensors for skin resistance, skin temperature, and ambient air temperature, and a conventional chest belt for heart rate information. The glove also accommodates a microcontroller which controls all the data acquisition, calculates measurement values, and performs pre-processing of the data, evaluation of sensor states, and communication of the data to the system controller [5].

2.1. Mobile sensor array

Nearly all the sensors are included in the glove. Only the *heart rate* is wirelessly received from a conventional heart rate chest belt (transmitter from Polar [2]). The sensor array's microcontroller calculates the heart rate from the beat-to-beat impulses received from the transmitter and provides them immediately.

Skin temperature is collected by two digital temperature sensors arranged as a Wheatstone bridge, resulting in a resolution of 0.01 K. The temperature range for skin temperature is 26 to 36 Celsius.

The *skin resistance* of humans comprises two emotion-related components: the slow-changing skin resistance level (SRL), and the fast-changing skin resistance response (SRR). A circuitry designed for collecting emotion related skin resistance has hence to be able to detect both, slow and fast changes of the measurand. Having two independent sensors at two different locations provides a good means to verify measurement results. In the current design, skin resistance is taken at two locations of the user's hand. The circuitry is based on a multivibrator with its output being dependant on the resistance of the skin. The sensor array's microcontroller translates the resulting series of impulses to the according resistance values of the skin. The resolution of the sensors can be configured as needed. In the current design it is set to 300 kilo ohms, which is fully sufficient for emotion-related measurements and allows for a wide range of data. A critical issue worked out to be the design and arrangement of the electrodes to measure the skin resistance. A new electrode design has been developed especially for measuring emotion-related changes of the skin resistance.

As an auxiliary measurement, the *ambient air temperature* is taken using a single digital temperature sensor with a resolution of 0.1 K. This allows for a more accurate evaluation and validation of the skin temperature as well as the skin resistance data, since both vary with a changing environmental temperature.

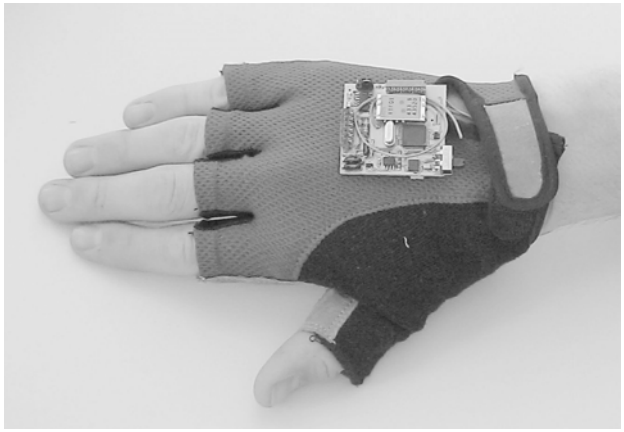


Fig. 2: Glove with uncovered sensor circuitry.

2.2. Wireless connection

Data are transmitted wirelessly between the sensor arrays and the system controller. According to national regulations, appropriate ISM (Industry, Scientific, and Medical) band transmitters are used (315.0 MHz, 433.92 MHz, 868.35 MHz). It is possible to use a multi-channel transmission to allow multiple sensor arrays being

connected to the system controller (see figure 1). In this case, an appropriate data transmission protocol is required. Thanks to the low energy consumption of the sensor arrays, a continuous 6-day operation with radio transmission is possible with two 2400 mAh accumulators.

Data transmission is secured by a CRC check sum. This way it is guaranteed that only correct data are being used in consecutive processing steps.

Bluetooth [7] or WLAN [8] are wireless communication technologies with to much power supply and a relative high effort.

For low power operation of the mobile sensor arrays it`s unconditional necessary a low power radio electronics.

Therefore is implement in the first step of system realization a proprietary wireless network access with a special transmit protocol, optimized for a low power supply in the 433MHz-ISM-Band [6].

In future is a good possible way for a low power wirelss connection the utilization of the new ZigBee-Standard (lower layer in IEEE8015.4) [9], the chirp technology by nanoNET [10] or Ultra wideband solutions [11].

2.3. System controller

The central component of the sensor system is the system controller. It is designed for mobile use and performs the following functions:

- receiving data from sensor array;
- CRC check for received data;
- Validation of received data (SEVA calculations);
- Time stamp for synchronisation of collected data with other events;
- Storage of data on memory card for offline availability of the data;
- Preparation of the validated data for transmission to PC, including sensor and measurement value status;
- Display of data for increased system reliability and monitoring;
- User interaction;
- Measuring environmental temperature;
- Event generation for external devices.

Only validated and hence useful data are transmitted to a processing host or stored on the memory card. This means that wrong or corrupt data (CRC) will be detected and corrected by the SEVA algorithm (figure 3). This allows for continuous data transmission of always sensible data, providing for a simplified data handling by the processing applications. Measurement data are provided in engineering units, allowing for further simplification of processing applications and eliminating the risk of conversion errors.

2.4. Processing of data, Sensor Validation

Data are processed and evaluated in three steps. First, data are evaluated within the sensor arrays with respect to the actual sensors sending new data, old data, or no data at all. Also, basic data quality checks are performed detecting insufficiently fitted sensors.

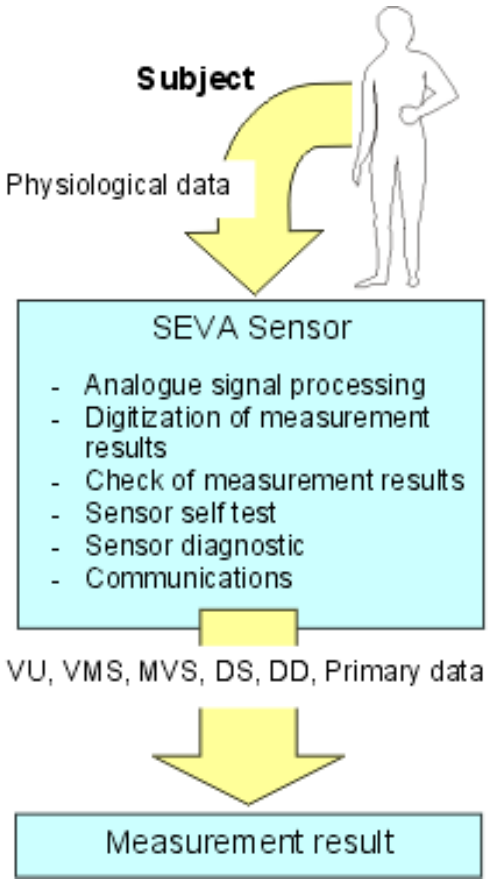


Figure 3: Measurement principle overview.

In a second step, the system controller checks the CRC check sum for the received data and corrects them where necessary. In a third step, data are evaluated using the SEVA approach. SEVA stands for Self Validation and is part of a British standard for data quality metrics [1], developed at Oxford University [3, 4]. The aim of SEVA is to always provide a validated measurement value (VMV), together with a validated uncertainty (VU) of the correctness of the VMV, discrete information on the actual measurement (MV Status) and the device status (DS). For validation, stored information on typical values and development characteristics for each measurand are used and VMV, VU, MV Status and DS are calculated accordingly. Different from the SEVA standard, also the raw, not validated data are made available to processing applications. This might be particular important for investigative applications or

comparative studies which include other, not validating sensors.

2.5. Interaction, communication and storage of data

The mobile system controller is fitted with three programmable buttons for user input. For instance, one could be used to configure the device, the second for controlling the display, and the third for setting user events. Of course, any combination of the buttons is conceivable, including a menu-guided version.

For visualisation of system states, actual data, or user menus, a 7-segment Display or a graphical display can be used. Data are also transmitted immediately to a PC which could run more powerful visualisation software. Data can be transmitted to the PC either via cable (e.g. RS232), or wirelessly (e.g. Bluetooth). Data are also stored locally on an exchangeable CompactFlash card within the system controller.

For controlling external applications or devices, signals can be generated and communicated serially via an optical coupler. It is also possible to send control commands to the system controller via a serial link.

3. Analysis of Investigations

The developed prototype of the described system is much easier to use than comparable commercial solutions. The data are provided as validated measurements, in engineering units, allowing processing applications being designed much simpler, without the need of any sensor-specific knowledge. Accuracy and resolution of the implemented sensors for heart rate, skin resistance and skin temperature are in the range of available commercial products, or better. Data get a unique time stamp for easy synchronisation with other events in data processing applications. The user can monitor data on a display and interact with the system at a basic level. The used ISM band transmitter for sending data from the sensor array to the system controller guarantees a very good transmission quality for 10 meters indoors and up to 300 meters outdoors. Local storage of data within the system controller works well on all CF cards available.

4. Outlook

The circuitry especially of the sensor arrays will be made more robust against environmental influences. Ideally, it should be able to wash the glove in a washing machine without the need of removing the circuitry first. In the near future, improvements of the heart rate sensor (optical) and implementation of a respiration sensor are planned. Operation of a network with more than one sensor array requires an optimized wireless transmission technology meeting the requirements of the increased amount of data and the more complex signal dynamics (see figure 1). Investigations on suitable transmitters with a cycle time of 10 milliseconds have to be performed.

References

[1] BS 7986: *Industrial process measurement and control – Data quality metrics*, Available from BSI Customer Services, email: orders@bsi-global.com 2004.

[2] Internet site of Polar: www.polar.ch.

[3] Henry M.P.: *Self-Validating Sensors – Towards Standards and Products*, Automatione e Strumentazione, 2001.

[4] Zhou, F., Archer, N., Bowles, J., Clarke, D., Henry, M., Peter, C.: *A general hardware platform for sensor validation*, IEE Colloquium on intelligent and self-validating sensors, Oxford, 1999.

[5] Ebert, E.: *Weiterentwicklung und Verifikation eines Messsystem zur Erfassung humanphysiologischer Sensordaten unter Berücksichtigung des SEVA-Konzepts*, Diplomarbeit, Universität Rostock, IEF, Institut GS, 2005.

[6] *FM Transmitter and Receiver / Hybrid Modules (FM-RTFQ1/FM-RRFQ1),* www.rfsolutions.co.uk/acatalog/DS069-7.pdf, RF Solutions Ltd., Lewes (Sussex, GB), 2004

[7] Lührs, C.: *Bluetooth in Multi-Profile Applications,* Proceedings, embedded world conference 2005, WEKA -Verlag Poing, p 485 – 490.

[8] WLAN Homepage: http://ieee802.org/11/pub/

[9] Sikora, A.: *IEEE802.15.4 and ZigBee for Sensor and Actuator Networks,* Proceedings, embedded world conference 2005, WEKA -Verlag Poing, p 189 – 197.

[10] Jozefini, B.: *nanoNET – eine neue Funktechnologie und ihre Eignung für den Einsatz in der Automatisierungstechnik,* VDI-Berichte 1843 „Funkgestützte Kommunikation in der industriellen Automatisierungstechnik“, S. 25-35, VDI Verlag Düsseldorf, 2004.

[11] *An Improved Direct Sequence Ultra-wideband (DS-UWB) Proposal for IEEE,* UWB Forum (www.uwbforum.org/), 2004