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Collecting and Distributing Wearable Sensor Data: An Embedded Personal Area Network to Local Area Network Gateway Server*

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Abstract – **The goal of the concept and of the device presented in this contribution is to be able to collect sensor data from wearable sensors directly, automatically and wirelessly and to make them available over a wired local area network. Several concepts in e-health and telemedicine make use of portable and wearable sensors to collect movement or activity data. Usually these data are either collected via a wireless personal area network or using a connection to the user's smartphone. However, users might not carry smartphones on them while inside a residential building such as a nursing home or a hospital, but also within their home. Also, in such areas the use of other wireless communication technologies might be limited. The presented system is an embedded server which can be deployed in several rooms in order to ensure live data collection in bigger buildings. Also, the collection of data batches recorded out of range, as soon as a connection is established, is also possible. Both, the system concept and the realization are presented.**

I. Introduction

The availability of care personnel and social security systems are being pushed to their limits in many industralized countries by a demographic change. In Germany, in 2009 every fifth person was 65 years or older, while in 2030 it will be every third. In the same time, the ratio of people over 85 years of age will double [1]. The number of people in need of care will increase by 50% and reach 3.4 million and rise [2]. The gap between needed and available care personnel will get wider, as it already accounted for 39,000 caregivers in 2005 [3]. In 2009, 62% of care costs incurred in inpatient care facilities while only 31% of people in need of care used this type of facilities [4]. Thus, it is clear that enabling people to stay at home as long as possible is important not only to keep a high quality of life but also to reduce care costs. A great effort is done worldwide to achieve this goal, also by means of technological aids. One approach is to collect and analyze health-related information (in our case, movement and behavior) in order to detect deviations and either provide help, alarm relatives or a care service. These data are collected using unobtrusive devices which are portable or wearable. Thus, a common challenge in the development of such a system, be it for use at home, in a nursing home facility or inside a hospital, is how to transfer the collected data from the wearable device to a back-end server, where it can be processed and reacted to accordingly with higher computing power. Therefore, a new concept and an embedded device which can be deployed in homes or bigger buildings is presented. We especially account for buildings such as nursing homes in which Wi-Fi connectivity might not be present in every room and the use of smartphones might not be desired or possible.

In the next section we an overview of the state of the art about devices for collection and distribution of wearable sensor data will be given. Then, after a task description, we will describe the concept and show a prototypical implementation.

A. State of the art in wearable sensor data collection and distribution

Several commercial products are available for monitoring various vital parameters during the day in the area of sport, fitness or management of chronic illnesses. Some examples are heart rate sport watches, chest straps as well as blood pressure, long term electrocardiogram (ECG) or glucose monitoring devices. The majority of these products, especially the medical devices, do not offer an interface for data export. In the sports and fitness domain most systems offer proprietary solutions by connection to a computer or, more and more, by (wireless) connection to a smartphone.

In research, in the last years many projects focused on the collection, processing and transmission of health-related data acquired unobtrusively. As a result, many prototypes and communication architectures have been developed and already explored in reviews [5][6]. In the following, a short overview will be given.

Known projects are MOBIHEART, AMON, MYHEART and WEALTHY [6]. In WEALTHY, several sensors for vital parameter acquisition are embedded into garments. The acquisition, processing and transmission of data is achieved with specifically designed electronics. The data are exported directly via a GPRS link [7]. In the Healthwear project the device has been improved [8]. A mobile system for sending ECGs over the internet using a PDA phone is presented in MYHEART [9]. A system with user feedback allowing the transmission of data on a server using the Scalable Healthcare Integrated Platform based on a mobile phone is also shown [10]. A PDA phone used for data upload interfacing a wearable body sensor network is presented in [11]. In [12], a Body Area Network including a PDA phone interfacing a Personal Health Manager is shown. A system with similar functionality using WLAN inside a hospital instead of Bluetooth is described in [13]. In [14], a smart shirt for ECG

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TABLE I
COMPARISON OF STATE OF THE ART IN WEARABLE SENSOR DATA COLLECTION AND DISTRIBUTION

DEVICE	SENSORS	GATEWAY	DATA EXPORT CHANNEL
[7]	ECG, Resp, Movement	DD	MPN
[8]	“	DD	MPN
[9]	ECG	PDA	MPN
[10]	ECG, Movement, Temp, Imp	Mobile phone	MPN
[11]	ECG, SpO_2	PDA	MPN
[12]	Env, Sound, SpO_2	PDA	MPN
[13]	ECG, SpO_2, Temp	PDA board	WLAN
[14]	ECG, Movement	DD	WPAN
[15]	ECG, Movement, Alerts	DD	ZigBee
[16]	ECG, SpO_2	DD	WPAN
[18]	Int	DD	RL
[19]	Movement	DD	RL
[20,21]	Movement	DD	RL

Temp=Temperature. Resp=Respiratory frequency. Env=Environmental Sensors. Imp=Impedance. Sound=Heart and respiratory sounds. BP=Blood pressure. Int=Interactions. SC=Skin conductivity. DD=Dedicated device. WLAN=Wireless Local Area Network. MPN=Mobile Phone Network. WPAN=Wireless Personal Area Network (not specified further). RL=2.4 GHz Radio Link.

and acceleration measurement is shown. A wearable system acquiring ECG, heart rate and acceleration data communicating and exporting it into an IP based network via a ZigBee Network deployed in a hospital is presented in [15]. A similar system for ECG and SpO_2 data collection is described in [16].

Instead of vital parameters, several groups also work on the acquisition of behavioral and movement information. Information about interaction is detected and stored by sensor nodes called Activity Recorders and Transceivers [17]. The Eventlogger is one example shown in [18]. It detects interactions with objects using radio modules. The Motionlogger presented in [19] collects movement and movement state information while carried in a pocket. In [20] and [21], a washable shirt or pants for wearable movement acquisition have been described.

The main characteristics of the mentioned systems are given in Table I. Wrapping up, in order to export acquired data to a back-end server most systems use either the mobile phone network (connecting to a smartphone via a Wireless Personal Area Network, WPAN or directly) or a WPAN relay network. Smartphones are useful especially in mobile applications because they also offer a good user interface. However, in [22] our group already suggested using a separate device in addition to smartphones for mobile data collection and alarming in case of time or safety critical data. This might still not be practical for scenarios in which people do not carry smartphones with them, e.g. in residential buildings such as at home or in a nursing home. It is more practical to use a WPAN relay network here. In environments already equipped with a local area network (LAN), however, it might be even simpler to transfer the data to the LAN directly, without using a WPAN relay network.

B. Task description

The presented concept's goal is to offer an embedded server acting as a direct WPAN/LAN gateway collecting data from wearable sensors and making it available directly in the LAN. This device should be deployable in any room of a home or nursing home. It should be able to connect to the WPAN of the devices developed in our group and first described in [18-21] and thus use the same 2.4 GHz radio link. It should offer push or pull communication as alternatives for data access.

II. SYSTEM CONCEPT

A. Static system concept description

A new device, called embedded network gateway server (ENGS), is employed in the presented concept. It communicates directly with the sensors worn by the user. It consists of a radio chip and microcontroller equal to the ones employed in the wearable sensor systems for communication and activity detection, storage space for incoming data, a microcontroller and TCP/IP chip interfacing the LAN as well as a flash memory storing HTML files (see Fig. 1). These are used as a basis to display webpages upon visiting the device's IP.

B. Dynamic system concept description

The system is able to work in two operation modes: the push and the pull mode. We developed these modes in order to cope with two different scenarios. Upon startup, the ENGS loads the desired operation mode along with other settings from a microSD-Card. Then, the real time clock is automatically updated from an internet time server. The processes following depend on the operating mode.

In the first scenario, for which the pull mode was developed, the ENGS is not within range of the user all the time, and there is no need of transmitting the collected data directly after it has been acquired. This is the case when the

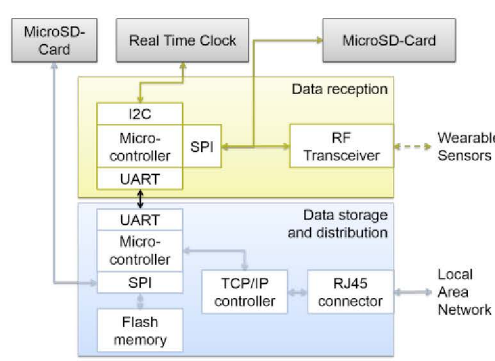

Fig. 1 Static system concept of the embedded network gateway server. It consists of components for data reception from the WPAN, timekeeping and data storage (upper part) and of components for communication in the LAN (lower part).

system only analyses long term changes in movement or behavior and is not intended as an alarming system. In this case, the data is time-stamped and stored on the wearable sensor system as long as it is not within the ENGS's range. The ENGS, however, sends a signal and its local time 50 times every second. As soon as a wearable sensor system detects the ENGS's signal, it updates its local time and transfers the collected data to the ENGS. The ENGS stores these data in its memory and waits for a back-end server connected to the network to request it for further processing. This is currently implemented as a website showing the data in form of a table whenever the ENGS's IP is invoked. Thus, the data is easily readable for a human visiting the website while for automatic data processing it is necessary to parse the data from the HTML file.

The push mode was developed for the second scenario, in which it is necessary to forward the data upon its collection. Thus, it must be made sure that an ENGS is always within range of the wearable sensor system. In this concept, having at most one ENGS per room is required to be enough to meet this demand in any building. Upon data collection, the wearable sensor system does not store the data but sends it to the nearest ENGS. The ENGS then time-stamps it and forwards it to a predefined IP via UDP packets.

Once the data is on the back-end server, it can be processed with higher power than on the ENGS and further options of communication with the user or other personnel are available.

In Fig. 2, the processes of the proposed concept are shown for both scenarios and compared with a typical state of the art wearable sensor network architecture based on a WPAN network (as opposed to GSM based architectures).

III. SYSTEM PROTOTYPE

A. Materials and methods

We built several ENGS prototypes in order to demonstrate the concept and to deploy our wearable sensors in a nursing home in which the inhabitants don't carry mobile phones on them and using WLAN is not preferred.

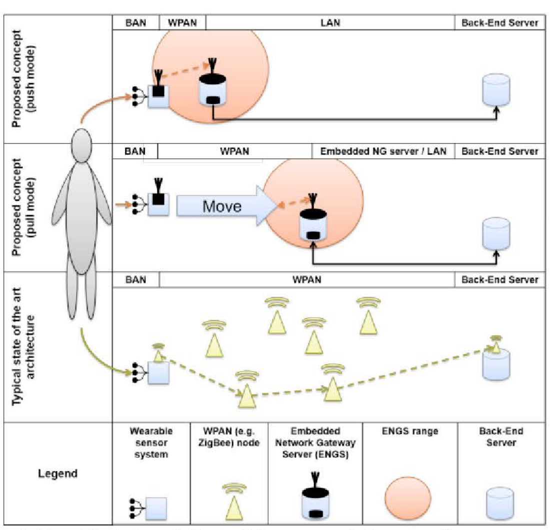

Fig. 2 Graphical description of the presented concept's processes in push mode (top) and pull mode (middle), compared to a typical state of the art wearable sensor network architecture (bottom).

The ENGS's prototype's core is a Wiz200Web module by WIZnet, which we used to realize the communication in the LAN (lower part of Fig. 1). To this module we added a NanoLOC AVR module by Nanotron to realize the connection to our wearable sensors [18-21], which use the same module for communication and activity detection. As real time clock we added the RV-3029-C2 by Micro Crystal, and use standard microSD-Cards by Transcend for storage of data and configuration files.

B. Characteristics

In the following we will describe the ENGS prototype's system characteristics based on the chosen components' specifications.

1) Dimensions

The ENGS prototype measures approx. 80 mm x 70 mm in length and width and is 30 mm high. Fig. 3 shows the prototype with and without the case.

2) Computation

For computation, the ENGS offers two microcontrollers: the ATmega644 inside the NanoLOC AVR module and the ATmega128 inside the Wiz200Web module. The first one is used to handle the communication with the sensor network and is reprogrammable over a Joint Test Action Group (JTAG) interface accessible only from inside the ENGS's case. The second microcontroller receives and stores incoming data, updates the real time clock via a configurable internet time server and forwards the data via UDP in push mode or builds the device webpage in pull mode. This microcontroller is reprogrammable over the network using a software provided with the Wiz200Web module.

3) Communication

The NanoLOC AVR module contains a NanoLOC TRX Transceiver which is used to communicate with the wearable sensors. It uses the 2.4 GHz ISM band and enables data rates of up to 2 Mbps with a current consumption of 30 mA in transmission (the low current consumption, of course, is mainly of importance for its use in the wearable sensors). The reception range can be varied in 64 steps and can reach up to 5 m in free field.

The Wiz200Web contains a W5300 embedded TCP/IP controller supporting 10/100 Mbps Ethernet. The serial flash memory (512k) on the module is used to store the webpages displayed by the module, which can be filled with live data during run time.

4) Storage

The module offers sockets for two microSD-Cards. One is used to store a text file specifying the device configuration. The second one is used to store up to 4 GB of data in pull mode and to store another text file used to configure network parameters.

5) Interfaces

In addition to the mentioned microSD-Card sockets the ENGS offers a power inlet interface requiring 5 V DC input, a RJ45 connector and three LEDs indicating the power on state, data transmission and error states (e.g. missing microSD-Card).

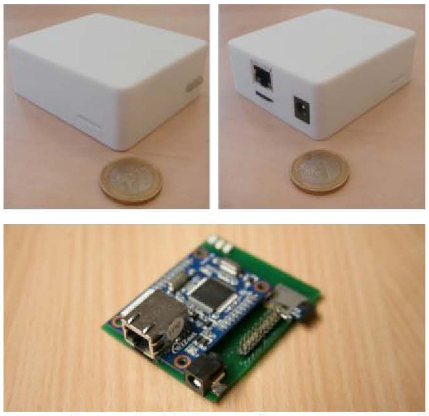

Fig. 3 Prototype of an embedded network gateway server. Front view with status indication LEDs (top left), back view with ethernet and power supply connectors (top right), view without case (bottom).

IV. Conclusion

A new concept developed to collect data from wearable sensors inside environments which don't need or allow the use of mobile phones is presented in this contribution. In opposition to the state of the art approach of using a WPAN relay network, this approach uses so called embedded network gateway servers (ENGS), which receive data wirelessly directly from the sensor device without using a relay network and make it available in the building's LAN. A prototype ENGS and its characteristics have been described. However, an extensive validation with subjects in order to specify system characteristics such as operating range or the time stamp accuracy in push mode is still missing.

In the future, it is planned to use this system setup to collect data inside a nursing home to monitor changes in resident movement and behavior as well as support the care personnel in documentation tasks.

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