Architecture and Design of Mobile Telemetry System for Ambient Assisted Living

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Abstract. Mobile systems for ambient assisted living are of growing importance in present world. This article describes architecture and design of such system including it's logical partitioning into functional blocks and placement of these blocks. Although full description of discussed system is beyond scope of this paper, description of processed biomedical and other data is provided as well as implementation details including types of used parts, cooperation of these parts, intraction of system with user and used communication protocol.

Keywords: biotelemetry, measurement, microcontroller, ZigBee.

1 Introduction

Monitoring of vital functions is usually performed only in specialized medical facilities equipped with costly equipment. But it's desirable to perform monitoring of vital functions in user's home environment as well. As monitoring in home environment is performed without direct participation of medial staff, whole system has to be of autonomous nature. It's expected that home monitoring system is deployed for prolonged periods od time. Because of this, interference of system with standard behavior of user should be as small as possible. Whole system must be reliable as user's life may depend on monitoring of vital functions. Purpose of this article is to describe architecture of such system.

2 Architecture of System

Architecture of system for remote monitoring of vital functions can be partitioned into two partially independant functional blocks. First (inner) block is composed of devices located in space where user spends most of his time. Primary purpose of inner block is measurement of biometric and other values as well as forwarding of these data. Second (outer) block is composed of devices located in supervision centre. Outer block is common for multiple instances of inner block. It's primary purpose is evaluation and archivation of values measured in instances of inner block.

P. Chatzimisios et al. (Eds.): MobiLight 2010, LNICST 45, pp. 769–780, 2010.

2.1 Inner Block of Architecture

Entire instance of inner block is located in space where user spends most of his time. It's purpose is measurement of various values and forwarding of these values to outer block. Because of diverse nature of measured values, it's necessary to further partition inner block into functional elements. This partitioning can be seen in Fig. 1.

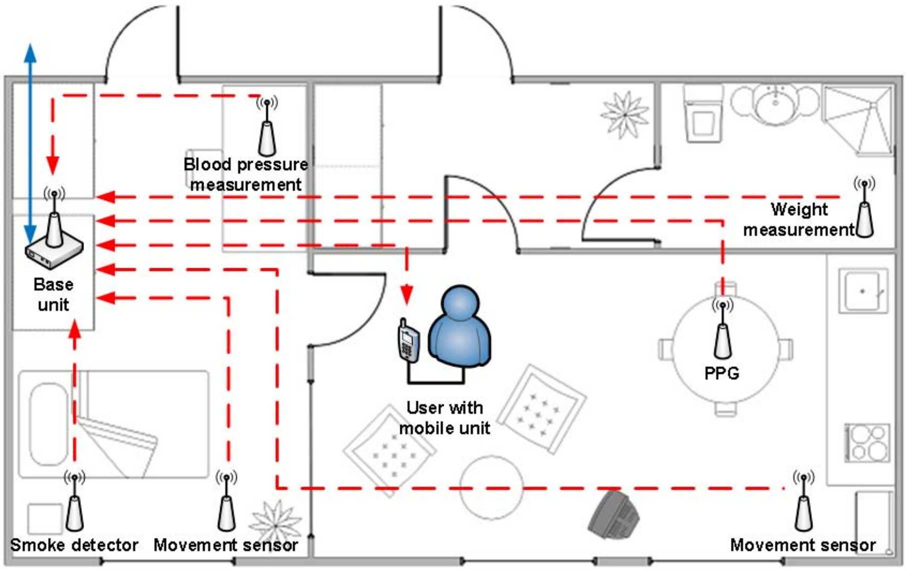

Fig. 1. Inner block of architecture

As can be seen in Fig. 1, measurements are performed by two classes of devices - by mobile unit, which is always in close proximity to user and by specialized stationary sensors. Some of measured biometric values, for example ECG, require continuous attachment of sensors to user's body. Other measured values should be measured periodically, for example temperature. These requirements can be fulfilled if user is equipped with mobile unit of suitable design. Another kinds of measures should be performed by stationary measurement devices, examples of these are measurements of blood pressure by sphygmomanometer. Values measured inside of inner block are transmitted to stationary base unit. It's task of this unit to transport these data outside of inner block or cache them temporarily in case of uplink connection failure. Wireless communication inside of inner block is marked red in Fig. 1, communication between inner and outer block is marked blue.

2.2 Measured Values

Home care platform allows monitoring of many values. Some of these values are not of biomedicinal kind. Measured values can be divided by their semantics and periodicity of measurement. Semantically are measured values divided to values of biometric kind and other values. By periodicity of measurement are measured values divided to values measured synchronously and values measure asynchronously. List of measured values can be seen in Tab. 1.

Table 1. Measured values

Measured values	**Sync. measurements**	**Async. measurements**
Biometric values	Two channel ECG	Blood oxygen saturation
	Body temperature	Pulse frequency
	Change of user's position	Blood pressure
		Body weight
Non-biometric values	Ambient temperature	Person occurance in room
	Change of mobile unit's position	Smoke occurance in room

Measures are performed by two classes of devices - by multipurpose mobile unit performing synchronous measurements and by dedicated sensors performing asynchronous measurements. Division of measured values by type of measuring device can be seen in Tab. 2.

Table 2. Division of measured values

Generating device	**Type of measurement**
Mobile unit	Two channel ECG
Mobile unit	Body temperature
Mobile unit	Change of user's position
Stationary sensor - PPG	Blood oxygen saturation
Stationary sensor - PPG / blood pressure meas.	Pulse frequency
Stationary sensor - blood pressure meas.	Blood pressure
Stationary sensor - weight measurement	Body weight
Mobile unit	Ambient temperature
Mobile unit	Change of mobile unit's position
Stationary sensor - movement sensor	Person occurance in room
Stationary sensor - smoke detector	Smoke occurance in room

Biometric sychronously measured values are two channel electrocardiograph (ECG), body temperature and changes in user's position. Some values of non-biometric type are measured synchronously as well. Examples of these are ambient temperature and changes in position of mobile unit. By measuring changes in position of both user and mobile unit, it's possible to detect fall of user or drop of mobile unit. Asychronous measures requiring user's direct participation are measurements of blood oxygen saturation, pulse freqency, blood pressure and body weight. Asynchronously measured values of non-biomedical type are monitoring of smoke occurance and presence of persons in user's flat. These measurements are rather of security character. Every measured character is specific and has associated it's own data type. Synchronously measured values are sampled with specific sampling frequency. List of these parameters can be seen in Tab. 3 and Tab. 4.

Table 3. Parameters of measured values

Type of measurement	Range of data sample	Range of meas. val.
Two channel ECG	12 bits,4096 values (for each chan.)	0.1000 - 10.0000 mV
Body temperature	8 bits,256 values	30.0000 - 45.9375 C
Change of user's position	10 bits,1024 values (for each axis)	-3.0000 - 3.0000 g
Blood oxygen saturation	8 bits,256 values	0 - 100 %
Pulse frequency	8 bits,256 values	0 - 255 pulses/s
Blood pressure	8 bits,256 values (sep. syst./diast.)	0 - 255 mm/Hg
Body weight	16 bits,65636 values	0.0000 - 4095.9375 Kg
Ambient temperature	8 bits,256 values	-64.0 - 63.5 C
Change of mob. unit's pos.	10 bits,1024 values (for each axis)	-3.0000 - 3.0000 g
Person occurance in room	1 bit,2 values	yes - no
Smoke occurance in room	1 bit,2 values	yes - no

Table 4. Parameters of measured values (cont.)

Type of measurement	Granularity of meas.	Meas. per 1 sec
Two channel ECG	0.0024 mV	300
Body temperature	0.0625 C	1/120
Change of user's position	0.0059 g	125
Blood oxygen saturation	1 %	—
Pulse frequency	1 pulse/s	—
Blood pressure	1 mm/Hg	—
Body weight	0.0625 Kg	—
Ambient temperature	0.5 C	1/120
Change of mob. unit's pos.	0.0059 g	125
Person occurance in room	—	—
Smoke occurance in room	—	—

2.3 Communication in Inner Part of Architecture

Basic building block of communication inside of inner part of architecture is ZigBee wireless technology. ZigBee is specialized communication technology optimized for industrial and medicinal deployment. Raw bandwidth of ZigBee network is 250 kbps. Real throughput of ZigBee network is somewhat lower but is still more than sufficient for data transmission in home care system. Individual instances of inner block are identified by locally unique ZigBee Personal Area Nework Identification (PAN ID) number. This way it's possible to operate multiple instances if inner block and their respective ZigBee networks in close vicinity. Communication is encrypted by 128-bit Advanced Encryption Standard (AES) cipher. Scheme of communication can be seen in Fig. 2.

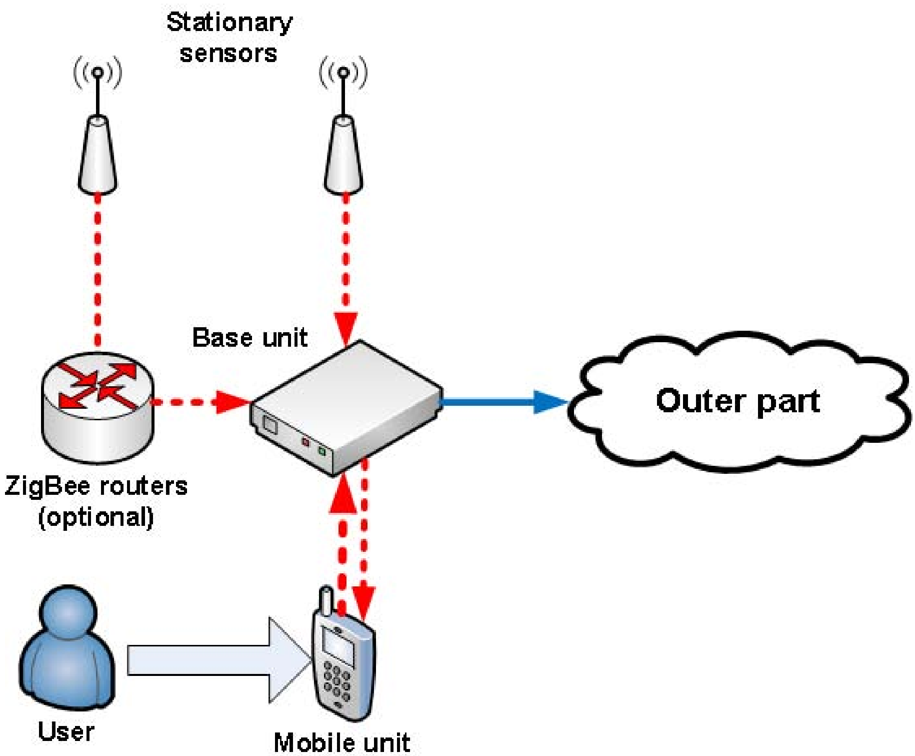

Fig. 2. Communication in inner part of architecture

Every flow of measured data is identified by logical address in ZigBee network. This is address of ZigBee cluster. ZigBee cluster is logical data channel transporting individual types of measured data. Data generated by class of stationary sensors are forwarded to mobile unit by base station. This way, user can be presented with full scale of his own measured values.

3 Construction of Inner Part of Architecture

Central part of mobile unit is power efficient 32-bit reduced instruction set computer (RISC) microcontroller (MCU) of ARM7TDMI microarchitecture. Clock frequency of microcontroller is set at 48 MHz. With this clock frequency, microcontroller provides computational performance of approximately 43 million instructions per second (MIPS). ZigBee network is implemented using dedicated ZigBee chipset offloading ZigBee networking tasks. Measured data are temporarily stored in fast nonvolatile FRAM memory in case of ZigBee network failure. Mobile unit itself resembles mobile phone with LCD display and keyboard allowing interaction with user. Controller of LCD display and keyboard is implemented using simple 8-bit MCU. Peripheries are connected to central 32-bit MCU by SPI (4 Mbps) and I2C (100 kbps) serial busses.

4 Interaction with User

Low power CMOS 8-bit MCU based on Atmel AVR core is used as user interface controller. Main function of user interface MCU is to receive respective measured values from central ARM MCU and provide user with them. User can interact with mobile unit using simple pushbutton keyboard. Clock frequency of MCU is set to 12 MHz, maximal frequency for used 3.3 V power rail voltage. Current requirement is about 7 mA in active mode and 0.2 A in stand-by mode. User interface MCU allows for communication with other components of user interface, namely LCD, keyboard, external data flash memory and external components like central ARM MCU. Block diagram of entire mobile unit can be seen in Fig. 3.

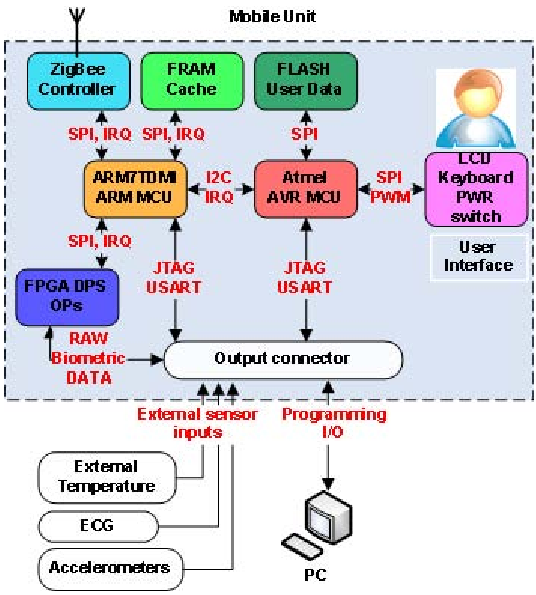

Fig. 3. Block scheme of mobile unit

4.1 User Data Flash Memory

Flash memory with SPI interface is used as external data flash memory. Its 8 Mb of space is organized as 4096 pages of 256 or 264 bytes each. Flash memory allows for intelligent memory operations like selective page programming and flexible erase operations (page, block, sector, chip erase). 100 000 program/erase cycles per page are guaranteed.

User data flash memory contains following data:

- Image data (icons, user menu panels, battery and signal strength states, map of monitored area) are stored in uncompressed RGB format suitable for direct LCD operations.

– Fonts (3 font styles 6x8, 8x8 and 8x16 pixels).
– Trend data (temperatures, blood pressure, blood oxygen saturation, body weight and others).
– Various settings.

4.2 Content of Data Flash Memory

Application designed in Mathworks Matlab is used for manipulation of user data flash memory. Connection between mobile unit and workstation is achieved by RS232 interface. Graphical user interface of application can be seen in Fig. 4.

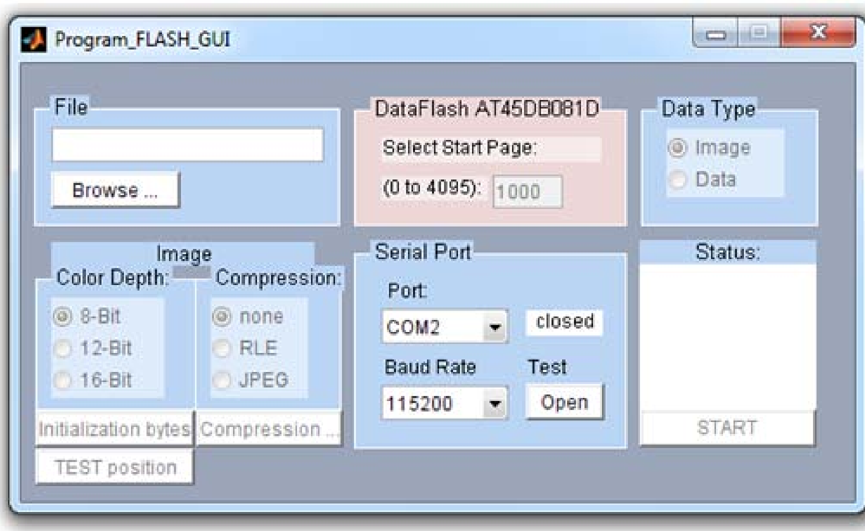

Fig. 4. Data flash management application

Images have to be stored in flash memory in format suitable for displaying on LCD screen. Used PCF8833 LCD controller supports 3 data formats; 8-bit, 12-bit or 16-bit colors. Uploaded images have to be corresponding format.

4.3 LCD Interfacing

LCD is controlled by Philips PCF8833 driver. PCF8833 is single chip low power CMOS LCD controller, designed to drive color Super-Twisted Nematic (STN) displays of 132 rows and 132 RGB columns. All necessary functionality for LCD operation is provided in single chip, including 209 kbit (132 x 12-bit x 132) of RAM. PCF8833 is connected by 3-wire serial interface. PCF8833 has 2 types of accesses. Access for definition of operating mode of the device (instruction) and access for actual RAM operations (data). Efficient data transfer is achieved by autoincrementing of RAM address pointers. The LCD has simple serial interface using 9-bit long words with clock speed of 6.6 MHz. LCD has LED backlight powered by 7 V power source. Its necessary to use the DC-DC step-up converter for LED backlight power supply. Suitable step-up converter is MC34063 switching regulator. Backlight intensity is regulated by PWM signal generator embedded in MCU.

4.4 LCD User Interface

User can display waveforms of vital functions and additional data. User also has option of executing an emergency call. Display is partitioned into several areas. Each of these areas is of specific purpose as can be seen in Fig. 5. Visualisation of various trenda data can be displayed by selection of appropriate menu item. Examples of these visualisations can be seen in Fig. 6, Fig. 7 and Fig. 8.

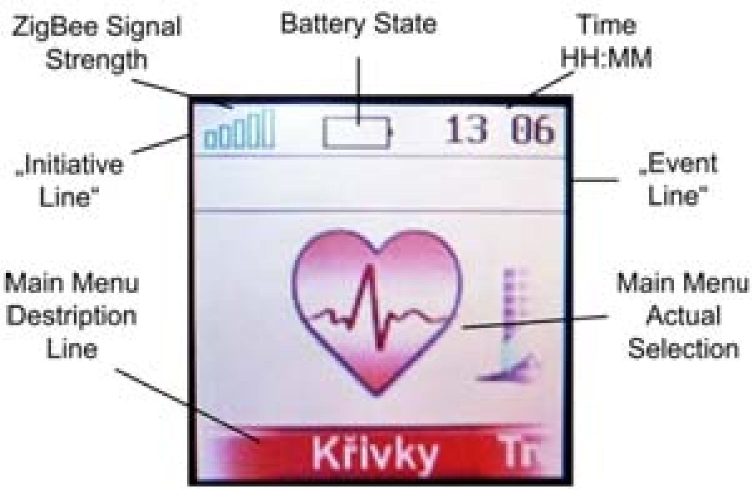

Fig. 5. Top menu area

Fig. 6. Two channel ECG and PPG

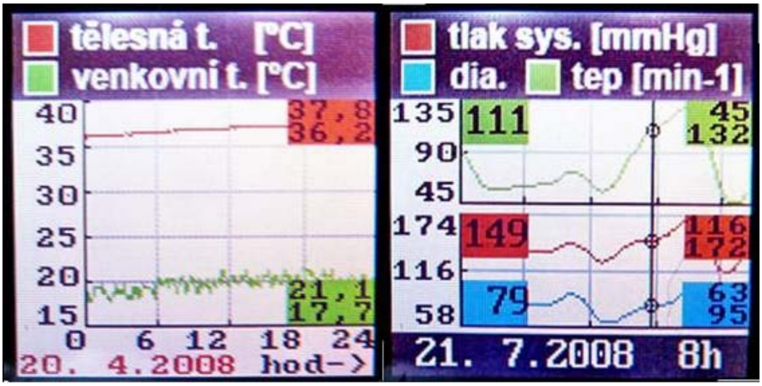

Fig. 7. Body and ambient temperatures, blood pressure

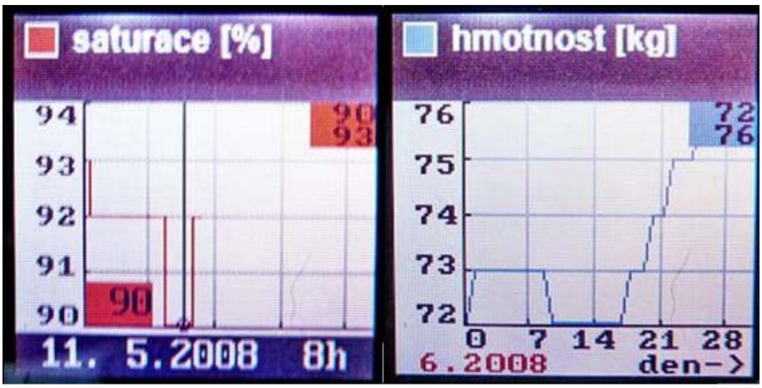

Fig. 8. Blood oxygen saturation and body weight

5 Outer Part of Architecture

Demarcation points between particular instances of inner block and outer block are base units. Fundamental task of entire outer block is to evaluate and archive data measured in instances of inner block. This functionality is implemented by supervision centre as can be seen in Fig. 9.

Measured values are archived by supervision centre in database of measure values. Each instance of inner block performing monitoring of one user is identified by locally unique PAN ID. This PAN ID serves as primary key identifying data of particular user in database. Supervision centre has set of ranges defined for every user. These ranges determine desirable values for each measured data type. Operator of supervision centre informed in case of exceeding of given range. Another element in outer part of architecture is management server. Purpose of management server is to provide auxiliary functionality necessary for

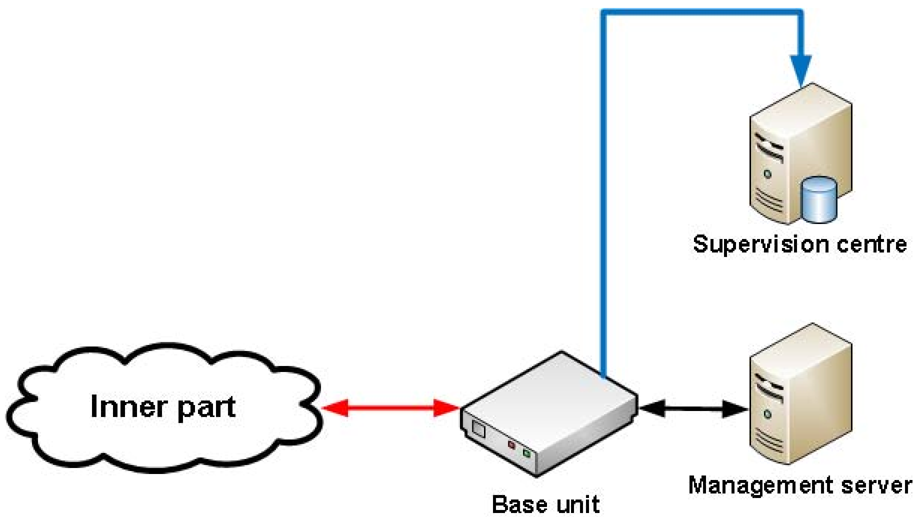

Fig. 9. Outer part of architecture

operation of instances of inner block. Some of the more important examples of this functionality are IP address assignment and remote management.

5.1 Construction of Outer Part of Architecture

Communication in outer part of architecture is at physical and data link layer of network stack implemented by Ethernet technology. Selection of transport media (metallic or optical solution) depends on required distance between given instance of inner block and outer block. It's possible to use suitable WAN technology for tunneling of Ethernet frames in case of greater distance, for example xDSL or DOCSIS. Bandwidth of today's implementations of Ethernet technology is more than suitable for transport of biomedial data. Maximal amount of data genereted by each instance of inner block is limited by bandwidth of ZigBee network to 250 kbps of raw data. It's possible to transport data from thousands instances of inner block if link connecting supervision centre is implemented with 1000 Mbps Ethernet network. Communication is implemented using TCP/IP protocol at network and transport layers. Connection-oriented TCP protocol ensures reliable transport of measured data. Address of ZigBee cluster is used as unambiguous identification of measured data type transported in particular TCP connection. Connectionless UDP protocol is used for implemetation of auxiliary funcionality. Examples of this funcionality is provisioning of instances of inner block, specifically assignment of IP addresses and remote management by SNMP protocol.

6 Conclusions

Described architecture and design of mobile telemetry system for ambient assisted living is result of rigorous testing and evaluation of real solutions. Nevertheless, there is always space for improvements of such system. Described system is primarily aimed at indoor use. Future revisions of system will be designed as outdoor operable including 3G mobile data connection. As mobile unit is battery powered, future development will be aimed at further reduction of power consumption.

Acknowledgment

The work and the contribution were supported by the project Grant Agency of Czech Republic GACR 102/08/1429 "Safety and security of networked embedded system applications". This work was supported by the Ministry of Education of the Czech Republic under Project 1M0567. This work was partially supported by the faculty internal project,"Biomedical engineering systems V".

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