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Multimodal platform for continuous monitoring of elderly and disabled

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Abstract—**Health monitoring at home could be an important element of care and support environment for older people. Diversity of diseases and different needs of users require universal design of a home platform. We present our work on a sensor-based multimodal platform that is trained to recognize the activities elderly person on their home. Two specific problems were investigated: configuration and functionality of central workstation as a module for data acquisition and analysis and second problem is devoted to user's home environment monitoring.**

I. Introduction

HEALTH personalization and support for older and immobilized people is actually very important target of many national and international initiatives (e.g. Framework Program 7, Hong Kong "Care for the Elderly 2007 - Active Mind"). Different research areas are connected with those initiatives including "Wearable Sensors (WS)" [1], "Body Area Sensors (BAS)" [2], "Wireless Sensor Networks (WSN)" [3] and telemedicine methods [4]. As a result of this research different sensors and integrated solutions were proposed, usually dedicated for a particular goal. Designing a home platform for support of older or immobilized people different categories of existing and possible components should be considered from particular sensors to central computer stations.

In case of systems with integrated sensors many solutions were proposed like Crossbow IRIS [5], Sun SPOT [6], eWatch [7], Smart-Its [8] or other [9]. Many motes are currently under constructions, however they are usually equipped with embedded sensors (e.g. temperature, light, and location), expending slots (e.g. sandwich model) and communication modules (Bluetooth or based on IEEE 802.15). Dedicated, medical extensions are often proposed like results of CodeBlue project [10], MobiHealth project [11] or UbiMon (Ubiquitous Monitoring Environment for Wearable and Implantable Sensors) project [12]. Typical solutions used for such extensions (or standalone systems) are universal medical diagnostic devices, including ECG, pulsoxymeter, blood pressure/pulse monitors, etc.

Communication interfaces allow data acquisition (especially at home) from motes to a one central station (or a middleware). The central station may be used to process data to assess user state based on many parameters and inform a user relatives or healthcare professional (a nurse, general practitioner) about the patient condition. The central station is often required to limit data processing at sensor node and to build an integrated view on the patient (including ontology based context models [13]).

Recent advances in sensor technology, cellular networks and information technology allow to improve the well-being of the elderly by assisting them in their everyday activities, monitoring their health status and environment conditions. There is more and more projects concerning the "smart" or "intelligent" homes with prototyping information-sensor systems recognizing habitant activities and abnormalities of them [14][15][16][17]. It is possible to develop systems that recognize an individual's everyday activities and automatically detect changes in the behavioral patterns of people at home that indicate declining health [18].

Human-computer interface (HCI) for older citizens or immobilized people/patients is also very important aspect of the home-based system. Specially designed user-interfaces and interaction devices are often required.

The main goal of this paper is to present a design of the multimodal, integrated platform for communication, training and health and environment monitoring at home. Communication includes technical and functional methods of a user communication with his/her environment as well as processing of alerts from a home/user sensor network. The training is mainly related to promote mental activity of a group of patients in danger (e.g. patients with dementia). Home monitoring is devoted to collect patient-related data and home environment data (e.g. fire detection). The very important aspect of the presented platform, is designing of a central computer station to collect data, process events/alerts, supply a proper human-computer interface, etc. In section II

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and III the design of the proposed system is presented. Next results of first module implementations are shown, including human-computer interface for immobilized patient and a module for home environment monitoring.

II. Platform Structure

The aim of our work is to create a smart system that will be adaptable to individuals, will be able to recognize their activities and will help their well being by raising alarms when a potential departure from routine or desirable behavior is detected (for example, the individual did not eat lunch or appears to not take their medication at prescribed times).

Home monitoring of people/patients is a wide term and different applications are possible. Some users are highly immobilized (only basic head/eyes communications) others are free to move but suffer dementia. The platform design requires creating a multi-modular system. The most important features of the platform are human-computer interface (or human-platform interface), middleware (e.g. used for data processing) and sensor/communication nodes.

A. Central Workstation

The role of central workstation combines the middleware functionality and HCI (described later). The following functionalities are requested from the central workstation:

- database management,
- sensor data collection and processing,
- events dispatching and processing (e.g. "take a pill" and "no activity alarm"),
- data integration, classification, rules induction and other activity related to create overall person/patient model including his/her environment,
- communication management (e.g. which interface should be used to send a particular message),
- access control and support for other security mechanisms,
- support for mental training (actually discussed with psychologists/neurologists),
- Human Computer Interface.

TV-set connected to personal computer can be used as central workstation – Fig. 1. Of course it is possible to use standard computer monitor or touchable monitors.

The human-computer interface is one of the most important elements of the platform. The user acceptance of the entire system depends highly on the method how the system can be used by older/immobilized users. Three elementary modes of the HCI were designed:

- interface based on touch screen,
- visually guided interface,
- audio guided interface.

All interfaces require a new design of the graphical user interface. This includes to prepare a platform front end (with selection of services divided into three groups: emergency, medical, and personal activity), GUI of each service and virtual devices (e.g. keyboard, remote control).

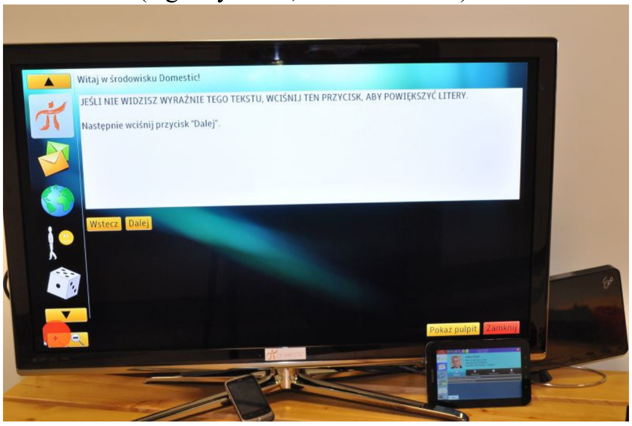


Fig. 1 TV set as a Central Workstation – example of Graphic User Interface also portable tablet with proper software is presented

Visually guided interface is especially designed for this category of patients, which are unable to move. Even in this group there are different subcategories that should be taken into account (patient can use only eyes; patient can move his/her head; patient can move head and a hand, etc.).

We assumed that the platform should also use existing internet services, however, redesigned for the older/immobilized people.

The General Purpose Input Output (GPIO) interface was used to connect different sensors for user's home environment monitoring. Currently, a thermistor-based temperature measurement sensor and an optoelectronic-based movement detector, water leakage and current load detectors were implemented. Humidity, fire and gas detectors are under construction.

The Siemens TC65T module was used as a main controller for home environment monitoring multi-sensor. The module combines GPIO and GSM communication interface. Using Java 2 Micro Edition a set of Midlets was prepared to process GPIO events and communicate with the environment. The module is used as one of the external communication interfaces. Communication between sensors and central station is realized using ZigBEE standard.

The central workstation was build using Java 2 Enterprise Edition, Apache Web server and MySQL database management system. Events from the sensor modules are stored in MySQL tables and can be processed and visualized using dynamically constructed web page. The external access to information services is limited by access lists and is secured by SSL. Additionally, a set of J2ME Midlets was prepared for mobile phones to remotely manage the selected sensor module. Midlets allow to set alarm limits (e.g. smallest and highest acceptable temperatures) which are used to decide about alert generation to a privileged user (e.g. relative, guardian). The module accepts also SMS requests (from the configurable phone numbers) for sending current status data (request-response model).

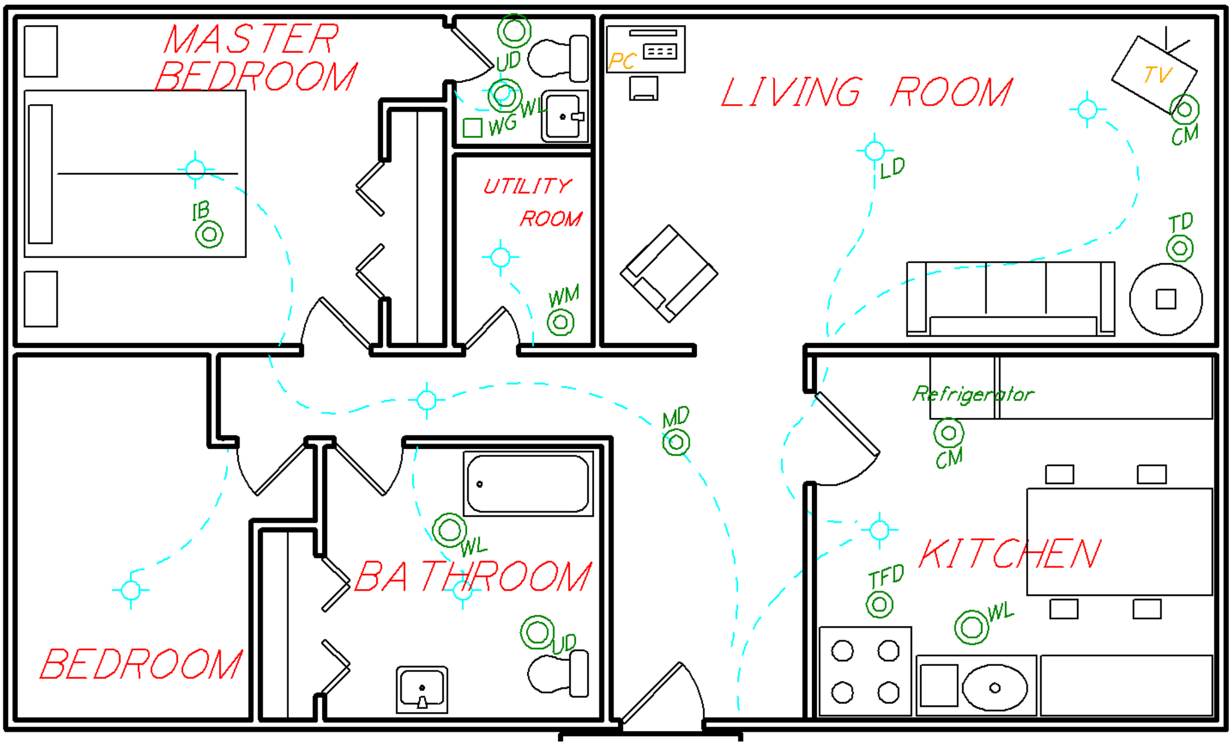


Fig. 2 Floor plan with sensor placement

B. Sensors

To allow digital devices to be treated as 'everyday stuff' we need to open up access to the supporting infrastructure that connects devices and provide users with a simple model that allows them to mange the introduction and arrangement of new interactive devices.

Multimodal platform will use different sensors (or multi sensors) to collect information about person/patient state and his/her environment. Different categories of sensors are currently prepared to measure: heart pulse, temperature, body composition parameters (weight, fat content, etc.), glucose concentration, blood pressure, electric heart activity (ECG), and posture activity (accelerometer). Additionally special multi-sensors are considered to design for a particular group of patients (disease-oriented). Placement of sensors is shown on Fig.2. Appropriate database structure is designed to collect information from each sensor. The one-to-many relationship is used between mother table (directory of sensors) and sensor tables. Each sensor has its own data table (tables). Particular data event is marked using timestamp so it is easy to analyze a set of measurements from many sensors during given period of time. The platform can be easily scaled with a new sensor (multisensory) using plug-in methodology (common interface, XML configuration file, a new data table).

Another group of sensors consists of those related to monitor user environment parameters. This is especially important for older people deciding to live alone without permanent, personal help. Taking into account the privacy of those persons, different sensors can be required to observe fire and gas dangers, humidity/temperature conditions at home activity of the person, emergency calls (e.g. symptoms of heart attack, ischemia, etc.).

III. SENSORS CONFIGURATION

An exemplary flat plan is shown on Fig.2. Living spaces is consisting of two bedrooms, two bathrooms, kitchen, living room and laundry/utility room. In addition, there will be a shared basement with a home entertainment area with centralized computing services. Different wireless sensors are placed in the habitation area – indicated green on the Fig.2. There are:

- CM – current load meter and switch,
- IB – intelligent bed, with medical diagnostic devices,
- LD – light detector,
- MD – movement detector, sensors that can detect movement over whole flat (indicated blue line),
- TD – room temperature detector,
- TFD – temperature and fire detector,
- UD – urine detector,
- WG – weight meter,
- WL – water leak detector,
- WM – water meter.

Entertainment/main station devices used for acquire and analyze sensors data and for personal rehabilitation and activate purposes:

- TV set – which can be also a central station of the multimodal platform controlled by special designed remote control,

- PC – personal computer – and also central station of the multimodal platform.

System will include human position tracking through ultrasonic sensors or RF technology.

Activities in a smart environment include physical activities as well as interactions (with objects) can be monitored. For example, activities may include walking, resting on a couch and using the coffee machine, refrigerator, etc. An important rule is that these activities are not instantaneous, but have distinct start and end times. In addition, well-defined time relations exist between the events constituting an activity. These temporal relations are important in the determination of the monitored user's indoor activities and can be used for knowledge and pattern discovery in day-to-day activities.

A. Current consumption measurement

Electrical current consumption monitoring can be achieved by means of monitoring of the AC current drawn by the load. This can be achieved assuming that the amplitude of the power network voltage is constant during measurement period. This simplifies significantly measuring circuit. AC current is monitored by means of the current transformer. Current induced in the transformer is converted into voltage, amplified and rectified. This signal is converted to constant value by means of filtration. Voltage that is proportional to amplitude of the current can be directly measured but instead it is integrated and value of the signal is measured with specified and constant acquisition period. This allows to detect even very short current peaks. Results of measurement is stored in internal memory of the microcontroller and transmitted to central system by means of the ZigBEE network. However, we have designed and developed two different power meters. One that is working on a simple principle of AC current monitoring and second more precise – that utilizes readily available integrated circuit (ADE7753 from Analog Devices) for power consumption measurement. The block diagram of first circuit is shown on Fig. 3.

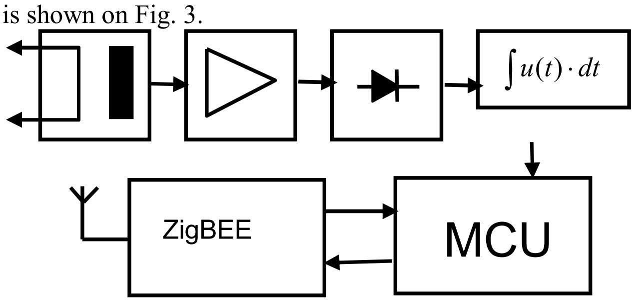
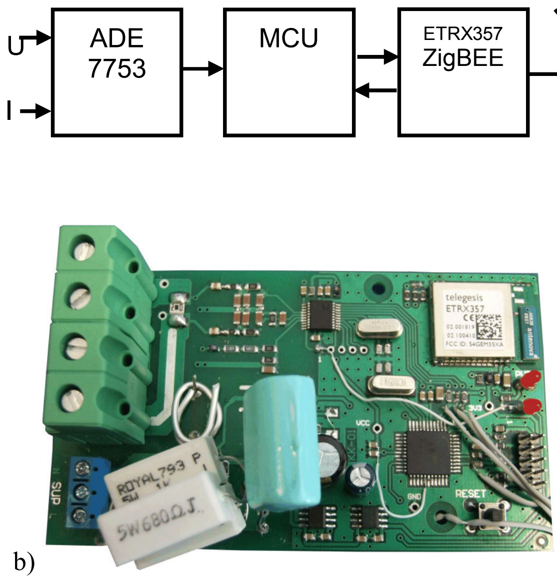


Fig. 3 Energy meter 1 block diagram

The circuit is detecting AC current by means of the current transformer. Signal is then amplified, rectified and filtered by means of low-pass filter. DC value of voltage is then equivalent to the momentary current drawn by the load – and assuming constant amplitude of the AC voltage – to the power delivered to the load. Momentary values are then integrated to avoid loosing of the short power peaks that might occur. After read-out, the integrator is zeroed and is scoring the energy until the next read-out. Cyclic read-outs are collected and transmitted to the host system by means of the wireless connection using the ZigBEE standard.

Another project utilizes the integrated power meter. The idea of operation is very similar, but now we can measure energy more accurately. The simplified block diagram of the circuit is shown on Fig. 4a) where the photograph of the prototype is shown on Fig. 4b).



a)

b)

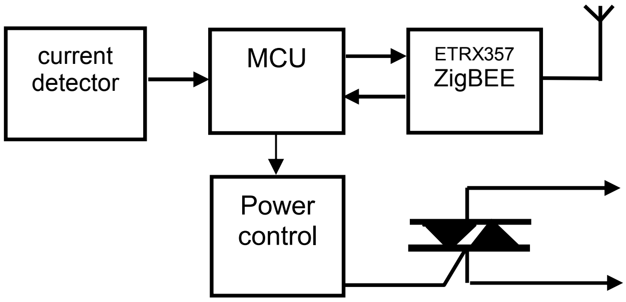
Fig. 4 Energy meter 2 a) block diagram; b) the prototype

B. Intelligent wall-socket

We also have developed the electronic circuit for electric wall socket - Fig. 5. The main task of the circuit is detection of the electrical current flowing to the load and possibility of remote power off of the socket e.g. in the case that supervised person leave the place leaving e.g. iron switched on. The power consumption is measured also by means of the current monitoring. The power delivery is controlled by means of triac with zero-crossing switch on ability. The communication with the system is also realized by means of ZigBEE

C. Intelligent wall-switch

Intelligent wall-switch (Fig. 6) circuit was developed to support classical wall-switch by option of the light measurement and detection of the switch state. Information about current state of the switch and ambient light intensity is available by means of the ZigBEE communication standard.



a)

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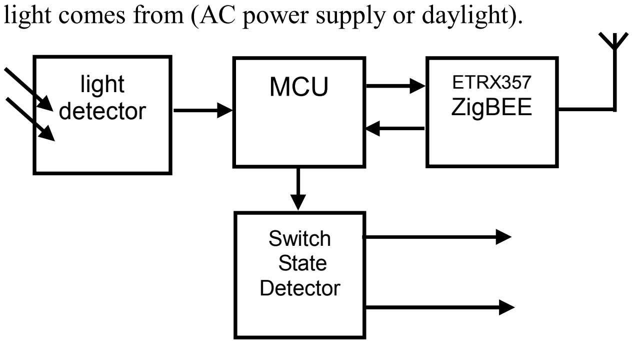
Fig. 5 Wall socket module a) block diagram; b) the prototype – CM (current meter)

Additionally it is possible to detect, whether the ambient light comes from (AC power supply or daylight).



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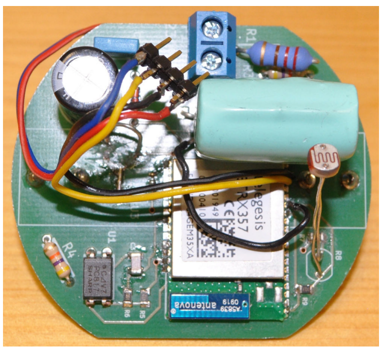

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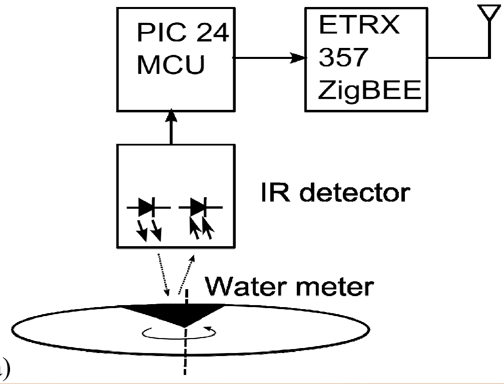
Fig. 6 An intelligent wall switch a) block diagram; b) the prototype

D. Water consumption measurement

We have developed two different water measurement meters working based on two different principles. First circuit is scoring pulses from mechanical water consumption meter. It requires no modification from the casual water meter as most of modern devices have rotating indicator. Thus, we are scoring the revolutions of the meter internal rotor by means of reflection of the IR light. Block diagram of the module is shown on Fig. 7a) where the working prototype is shown on Fig 7b).



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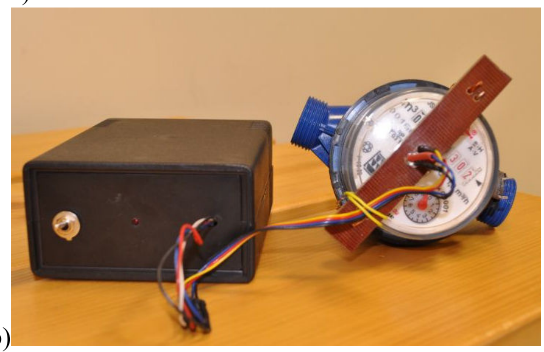

b)

Fig. 7 Automatic detection of water leaking – WD, a) block diagram; b) the prototype

Unfortunately we are not always allowed to gain access to the water flow meter, for many reasons, but happily we are not interested in accurate water measurement, rather water flow information Thus we developed also a water flow sensor, that can report binary information about state of the water in the pipe – is it flowing or not. Water flowing in the pipe makes the noise that can be picked up by means of the microphone. The amplified acoustic signal is then filtered and processed by means of the microcontroller. The microcontroller (Atmega8 by Atmel) is also communicating with the central system by means of the ZigBEE standard. The block diagram of the detector is shown on Fig.8a where on Fig. 8b) the working prototype can be seen.

E. Water leak detector

The water leak detector is a module that detects water leakage on the floor. Device is build on the basis of the ZigBEE module, microcontroller and resistance meter that is detecting unit.

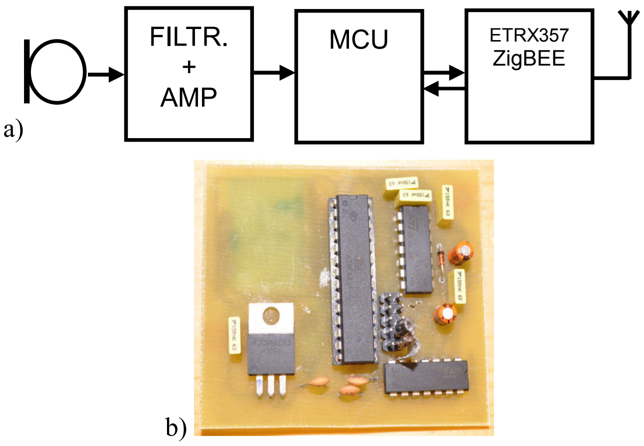

Fig. 8 Water flow sonic detector diagram and prototype

Device is battery powered and thus it can be placed anywhere, where is a risk of water leakage. The block diagram of the device is shown on Fig. 9a) where on Fig 9b) the prototype is shown.

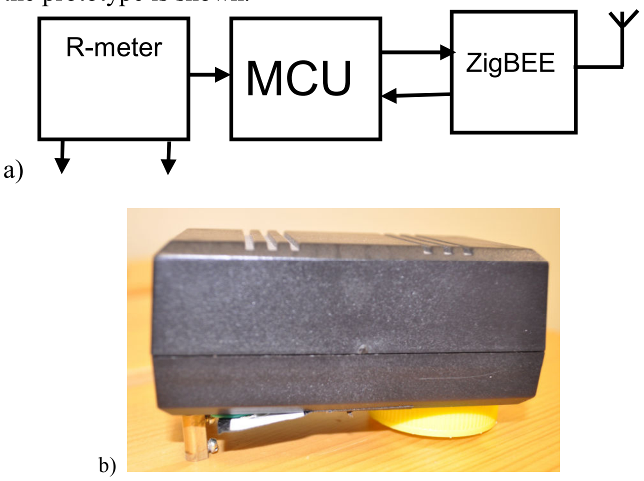

Fig. 9 Water leakage detector a) the block diagram; b) the prototype

F. Sound detector module

Sound detection module is a device that can be placed anywhere in the room. Its task is to detect and classify all surrounding sounds and perform its classification .The classification is performed within device by means of the embedded digital signal microcontroller (dsPIC30f6014 from Microchip). The device can distinguish between groan, fall, door closing and several others. Recognized sound is classified and reported to the central system, which will take adequate action. The block diagram of the device is shown on Fig. 10a) where the photo of the prototype can be found on Fig. 10b.

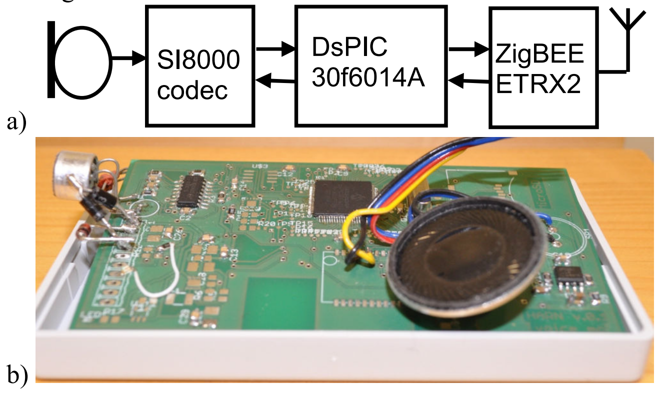

Fig. 10 Ambient sound detection module a) block diagram; b) working prototype

IV. ALERTS

Alerts are messages generated by the person aided, sensor network nodes, medical devices or the central station (as a result of processing of measurement data) to inform the people supported (internal alerts) and individuals (relatives, guardians, doctors – external alerts) of the occurrence of a particular situation. Alerts are divided into internal and external alerts. Table 1 presents the mutual relationship between the types of alerts and typical actors of the support system. Particular situations have been classified into the following priorities:

0 (emergency) - critical situation concerning the danger to life or of injury / incident (including a call for rescue of persons assisted), etc. This level is an "emergency" that requires call the appropriate emergency services.

1 (alarm) - alarm situation concerning the health status of the monitored person or his environment (including the request for assistance from the assisted person). Requires immediate action from a relative / guardian / physician. It does not require an automatic emergency call.

2 (warning) - the situation of concern regarding activities assisted person (broken diet, problems with taking medications, applying procedures, rehabilitation, etc.). This requires rapid intervention relative / guardian.

3 (system error) - the situation of concern associated with

TABLE I.
THE MUTUAL RELATIONSHIP BETWEEN THE TYPES OF ALERTS AND TYPICAL ACTORS OF THE SUPPORT SYSTEM

Alert priority/alert recipient	**Emergency teams**	**GP/ Personal doctor**	**Nurse/social service**	**Relatives/guardians**	**Neighbors**	**Assisted person**
0 (emergency)	X	X	X	X	X	X
1 (alarm)		X	X	X	X	X
2 (warning)			X	X		X
3 (system error)				X		X
4 (serious problem)			X	X	X	X
5 (problem)						X

the technical problems with the support system - required the intervention of a relative / guardian and, possibly, maintenance of the system

4 (serious problem) - the occurrence of a failure in the home environment, or request for help / information generated by the person aided - for a person aided and relative / guardian

5 (problem) - the occurrence of a failure in the home environment (or a simple remainder) - for a person assisted.

Alert system was implemented in Java and Java FX. Concurrent processing (java.io.concurrent package, e.g. PriorityBlockingQueue) has been used to map N-sources to M-alerts and K-recipients. Each source (e.g. water consumption sensor, ECG sensor, etc.) is related to an observable producer, which delivers XM-based message to the central station. The central station processes particular or combined messages to identify the priority of the situation and send the alert to the consumers. Consumers distribute alerts to particular recipients. It is assumed that at least four communication channels can be used:

- visual and audio messages for the assisted person;
- audio or/and visual messages for neighbors (environment of the assisted person home),
- messages transmitted by GSM module (SMS, audio messages, data alerts),
- messages transmitted by the secondary data channel (e.g. analog phone modem, internet connection, etc.).

When the situation occurs the message is received by central station (internal alert) and is processed to prepare appropriate response. One possible response is audio/visual information to the assisted person (locally) or external recipient (processed message in the dedicated software). In Fig.11 the examples of windows are presented for different priorities of the alerts. All alerts are recorded in the database as well as responses.

Fig. 11 Examples of windows for different priorities of the alerts

A user can get precise localization of the alert source (button “WHERE”) and should confirm the message (the information is stored together with the recipient role). When the “CONFIRM” button is pressed the user can get additionally information (which depends on the alert message), for example in case of “water leakage” the contact data to the appropriate service can appear.

V. CONCLUSION

The design of multimodal platform for communication, training and patient monitoring at home was presented.

In our work we want to solve tree aspects. First, we want to support social connections between elder parents and their adult children or colleagues and friends preventing against digital and social exclusion. These persistent connections will convey activity in the respective homes as well as trends over time. Second, we hope to support "everyday cognition" by augmenting those aspects of memory that decline with age and planning capabilities of elder residents. Third, we also plan to sense and identify potential crisis situations so that appropriate outside services can be contacted as needed.

The presented multimodal platform infrastructure is an excellent chance to obtain general information about a user while at home, and a wearable computer can gather data wherever the user may go outside. The home can contain a large amount of computation and infrastructure for sensing at a distance, while a wearable has the advantage of immediate and intimate contact with the user. The data gathered on the wearable might then be filtered and released to the environmental infrastructure as appropriate. On the other hand, the wearable may draw on the house's data resources to cache important information for the mobile user when away from the house. Thus, an automated wireless collaboration between the platforms seems appropriate, with the user placing limits on the type and level of information transferred between his personal and environmental infrastructure. We will develop such infrastructure interactions and explore some of the technical and social benefits.

The very important aspect (especially for older people on retirement) of the system is the cost. We assumed to build implementations of all platform elements using no expensive solutions. The already implemented modules are using free software and relatively inexpensive hardware elements.

One possibility is to optimize the GUI of applications and design special virtual keyboards (with limited set of key). Different options of HCI are required for different group of patients. The new audio commands processing subsystem is required (modified version of the general purpose system present in Microsoft Vista/7). Finally the combination of visually and audio guided interfaces could be more comfortable for many patients.

Dedicated multi sensors for special group of patients are still under designing. The final goal is the possibility to collect a platform from building blocks according to the given patient needs. That is why the proper system design is so important.

Another open problem is respecting people/patients privacy and creates a highly secure system in a house and in external communications. Some previous works were published [19][20] but this is still an open subject. The system is still under development and up to now we don't have a evaluation results of usage the system by older people. In laboratory condition system works reliably but still with limited functionality. We will plan to evaluate prototyping system in situ in the nursing home and in the home of older person.

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