Multi-Modal Health and Activity Monitoring Framework for Elderly People at Home

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Abstract - Since the population of elderly people grows absolutely and in relation to the overall population in the world, the improvement of the quality of life of elderly people at home is of a great importance. This can be achieved through the development of generic technologies for managing their domestic ambient environment consisting of medical sensors, entertainment equipment, home automation systems and white goods, increasing their autonomy and safety. In this context, the provision intelligent interactive healthcare services will improve their daily life and allowing at the same time the continuous monitoring of their health and their effective treatment. This paper presents a multi-modal health and activity monitoring framework that enables abnormal event detection and long term evaluation of the health of the elderly people at home. We describe its integration with a Residential Gateway and provide details on the demonstration scenario developed, involving different kinds of sensing modules. This work is supported by the INHOME Project EU IST-045061-STP, http://www.ist-inhome.eu.

Keywords - *Healthcare Services, Elderly, Patient Monitoring, Assited Living at Home, Network Architecture and Design*

I. INTRODUCTION

Europe's ageing population is a challenge for both its social and health systems. By 2020, a quarter of Europe's population will be over 65. Spending on pensions, health and long-term care is expected to increase by 4-8% of GDP in coming decades, with total expenditures tripling by 2050. Similarly, by 2050, elderly people aged between 65-79 years old are expected to make up almost a third of the population which is a rise of 44 per cent compared to the start of the century. As for very elderly people (80+), their share of the total population could grow by 180 per cent over the same period. The majority of older people do not yet enjoy the benefits of the digital age such as low cost communications and online services that could support some of their real needs; only 10% use the internet. Severe vision, hearing or dexterity problems, frustrate many older peoples' efforts to engage in the information society. According to findings of the Center for Disease Control, nearly three quarters of elders over the age of 65 suffer of one or more chronic diseases. The majority of the growing elder population worldwide requires some degree of formal and/or informal care either due to loss of function or failing health as a result of ageing.

The cost and burden of caring for elders is steadily increasing. If given the choice, many elders would prefer to lead an independent way of life in a residential setting with minimum intervention from the caregiver. Ambient Assisted Living (AAL) programs are intended to address the needs of this increasing elderly population, to reduce innovation barriers of forthcoming promising markets for the various target group populations, but also to lower future social security costs on the long run. The major challenges of AAL research programs are to extend the time elderly people can spend in their home environment by ameliorating their level of autonomy and assisting them in carrying out simple or even more complicated everyday activities.

It is a challenging issue for someone to deal with the special needs of elderly people especially in the home healthcare monitoring and treatment. The goal of the INHOME project is to provide the means for improving the quality of life of elderly people at home by developing generic technologies for managing their domestic ambient environment, consisted of white goods, entertainment equipment and home automation systems with the aim to increase their autonomy and safety [1], [2]. Monitoring of different types of chronic diseases of elderly people at an in-home environment relies heavily on patients' self-monitoring of their disease conditions [3]. In recent years, telemonitoring systems, that allow the transmission of patient's data to a hospital's central database and offer immediate access to the data by the care providers, is of a great importance [4], [5].

From the healthcare delivery system point of view, an evolving picture of the patient at any given time will be produced, taking into account diagnoses and treatments, successes and setbacks [6]. The system would assess the current level of functionality and interactively coach the patient to higher levels of functionality. The consistency of continuous monitoring would eliminate much of the inaccuracy from the current random interactions between patients and physicians [7], [8]. Periodically and as determined by medical parameters and health plan factors, this data would be reviewed by trained professionals to such evaluation process.

The User Group is provided by the Health Centre of Vyronas (HCV), which is specialised in the provision of medical services to elderly people at home. The medical personnel are also involved in the requirements specification for aged people. The institute offers some of the houses under surveillance to be used as application testbeds and assist in the evaluation phase of the INHOME technology. This paper presents the overall network architecture, discusses the health and activity monitoring framework, describes the A/V streaming and personal data acquisition by medical devices within the home environment, and finally summarises project's current conclusions.

II. THE OVERALL NETWORK ARCHITECTURE

The project identified the need for several devices, sensors and terminals to be integrated for enabling the different kinds of identified services for the elderly people. The overall network architecture with all involved device categories and intermediate network entities is shown in Figure 1. The concept of a centralized gateway as communication and interworking entity is utilized. In this scenario, the gateway is the only device directly connected to the Internet and external service providers with the rest of the home devices connected to the gateway. All messages issued by the devices are routed through the gateway and there has not been envisioned direct communication flow between the devices for this project. The residential gateway undertakes the role of coordinating information requests, it establishes the connection to appropriate content servers and forwards the requests of the service applications. The architecture is also enhanced with the introduction and usage of a Multi Service Terminal which acts as a repeater, increasing the limited coverage of the Bluetooth devices and sensors. The gateway processes as well as forwards the information either to WAN and to LAN entities [9].

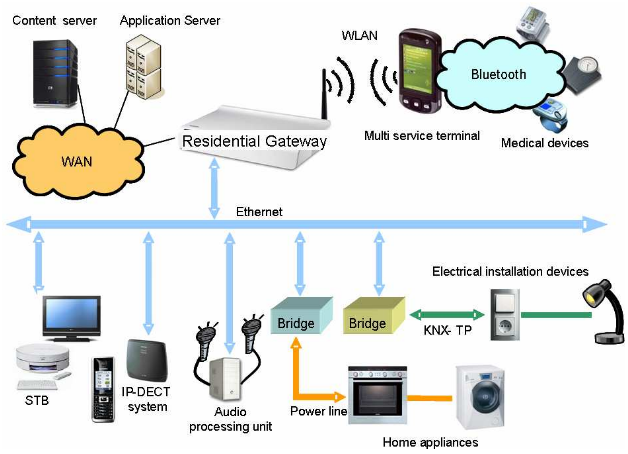

Figure 1. The INHOME Overall Network Architecture

Ethernet, Wireless LAN (WLAN) and Bluetooth are used as communication technologies. Since most devices are equipped with Ethernet sockets and pre-configured cabling is available, the installation procedure becomes rather easy. Also, nearly all the gateways available on the market are equipped with a build-in wireless network interface. The dominating technology for WLAN communication follows the IEEE standards 802.11 a, b, g or n.

The INHOME services are communicating both internally within the home network as well as with the external world. This means that communication must not be limited to in-home data flows only. Depending on the service, communication must be secured to guarantee a level of intimacy. Only user authentication and authorisation can grant access to personalized services. The INHOME residential gateway is the central entity in the home networking environment, deploying the services and facilitating the communication with the external world. The gateway simultaneously functions as both client and server to the other nodes on the network. The peer node functionality is supported by OSGi, which is capable to host both server parts (Web Servers, Custom Servers etc.) and client parts (UPnP, Web Services, custom clients, HTTP clients etc.). Additionally, the residential gateway is hosting data such as related to the user (user profiles, policies etc.), multimedia data (photos, videos etc.), etc.

Services composition involves the user and a service synthesis environment interacting for the production of a personalised service specification. This specification is consistent with the capabilities of the service execution platforms in use and the user profile stored in the identity management module of the residential gateway and will be produced by a Service Synthesis module located on the Residential gateway. The service composition functionality is being used by the application level of the INHOME gateway for providing AAL services to elderly people. Figure 2 depicts the architecture of the INHOME Residential Gateway and the services supported.

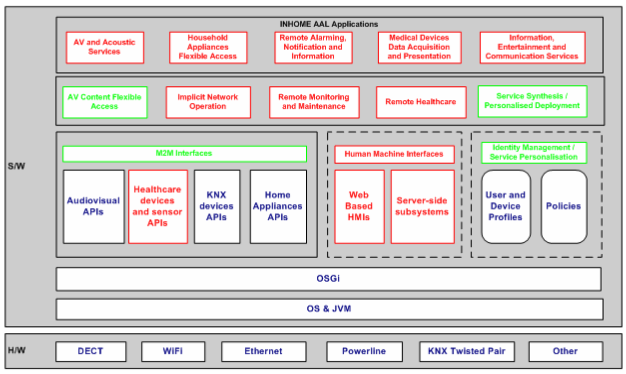

Figure 2. INHOME Residential Gateway and Services

III. HEALTH AND ACTIVITY MONITORING FRAMEWORK

The health and activity monitoring system that we present in this work enables people living in a monitored home to be assisted by a specialist (emergency hospital department or private health security center) in case of abnormal events. This system is adapted to aged, disabled or diseased people. More generally, the idea behind this appliance is to collect all the kinds of data that would help monitoring health of people or that would benefit to other appliances to make smart decision making. Two kinds of monitoring activities are performed by this appliance:

- **Activity monitoring:** By activity, we refer to people physical activity (frequency, duration and intensity of their movements) or to the consequences of their actions on their environment (e.g., temperature in a room, change on the daylight in a room because the curtains have been closed). This information by itself (e.g., a very high temperature in a room) or after combination with other information (e.g., a suddenly closed curtain) can plot abnormal behaviours that could be of interest to record as well as for further investigation on the elderly people's health.
- **Health monitoring:** This monitoring activity includes parameters such as the vital signs which consists in physiological statistics (i.e., body temperature, pulse rate, blood pressure, respiratory rate) often taken by health professionals in order to assess the most basic body functions. This activity could include any other parameter that would be useful to trigger alarms or to monitor on a long term basis.

Concerning specifically the health of people, the proposed monitoring appliance has two main purposes:

- **Abnormal event detection:** A variety of sensing sub-systems are continuously monitoring several parameters such as people physical activity (e.g., motion, ambient light) or health information (e.g., blood pressure, blood glucose level, heartbeats). Abnormal events (i.e., that differs from the average values acquired during a training period) issued by all these sensors are collected and processed by the system in order to take decisions upon the requesting or not of assistance from an external Health Center or from elderly people's relatives. Information received from sensors is validated between each others in order to be more accurate and to reduce false positives. For instance, at night if an abnormal sound activity is detected and a heart beat measurement is that may be abnormal, an alarm will be immediately send to a medical center. To refine further the relevance of the information provided by the system, different level of alarms can be defined (e.g., notice, warning, alarm, emergency) and mapped to different actions.
- **Long term monitoring:** The aforementioned sensing modules will also enable to assess the state of the person based on its behavior and medical parameters. Thus, the Health Center will be able to refer to history data to better choose future prescribed medications.

Whereas such integrated system has already been studied by several projects, INHOME project is to validate the concept of an evolving health and activity monitoring service based on a home gateway. The following section details the multi-modal monitoring system that we have developed in INHOME for that purpose.

IV. FRAMEWORK ARCHITECTURE

This section details the framework that we propose to be used which offers coordinated operation of activity monitoring and medical monitoring for both abnormal event detection and long term evaluation of the health of the elderly people.

A. Overview

Figure 3 depicts the different entities composing the INHOME health and activity monitoring appliance that we have developed. The medical analysis sub-systems in charge of the gathering of the vital health parameters of elderly people is connected to the INHOME gateway. Besides this, a processing unit connects the two different activity sensing modules that we have integrated for our demonstration: the audio sensors and the networked motion sensors.

This processing unit performs high-level analysis of the parameters gathered from the sensing sub-systems and is able to detect abnormal events. It interacts with the INHOME gateway by initiating events and/or receiving queries for measurements from the audio and motion sensors. The INHOME gateway is based on a Residential Gateway (RG) concept, using the Open Service Gateway initiative (OSGi) platform [10].

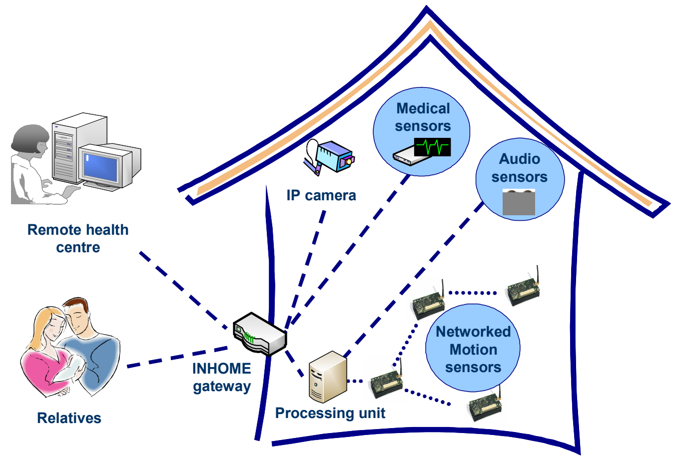

Figure 3. INHOME Health and Activity Monitoring

We propose to use two different sub-systems for activity monitoring function depending on the time of the day: A sensor-network based motion detector using a wrist lace or a necklace that elderly people wears at day time and an audio monitoring system mainly used at night in the bedroom. Both systems trigger alarms which are first processed and then exposed to the rest of the system through the activity monitoring processing unit. These two sub-systems are described with more details in the following sections.

B. Sensor-network based motion detector

We propose an activity monitoring service running on Crossbow MICAz [11] sensors equipped with a MTS310 sensor board attached to their serial port which offers a variety of sensing modalities such as light, pressure, acceleration, temperature and acoustic. MICAz nodes have very limited capacity in memory and processing power as they only embed an Atmel ATmega128L microcontroller with 4KB of RAM and have 128KB of programmable flash ROM.

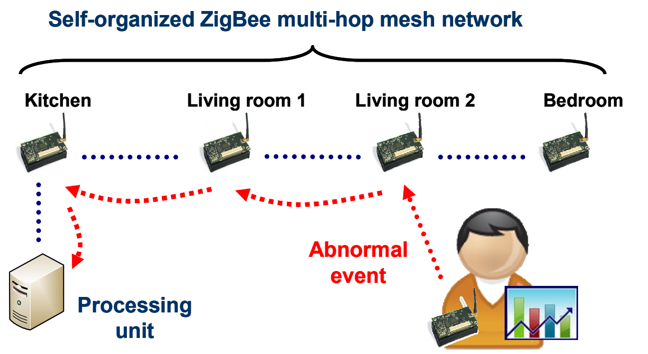

Figure 4. Sensor Network Based Monitoring Service

As shown by Figure 4, sensor nodes are divided in two categories: infrastructure nodes which form the ZibBee-based mesh communication network and sensing nodes which are worn at day time by people. Infrastructure nodes run a routing protocol to enable multi-hop communications. Such network organization allows auto-configuration and eases the extension of the network as users would just have to deploy a new relay to cover a new room or to adapt to new room layout. On sensing nodes, the sensing service is related to the accelerometer. It offers the possibility: (1) to get the latest values of the accelerations over the z and x axis, (2) to be notified periodically of these values and (3) to be notified of these values whenever an abnormal event occur.

The fact that infrastructure nodes are static after deployment provides a very simple positioning system which allows adding location information to alarms: the data packets issued by the sensors are tagged with the id of the first node of the infrastructure. A simple mapping between sensor's identifier and rooms helps to locate where the elderly person was when the alarm occurred. The monitoring service stack implemented in TinyOS [12] rests upon the IEEE 802.15.4 interface, also known as ZigBee, and a queuing management module which has been implemented to handle incoming and outgoing packets.

C. Audio monitoring system

The purpose of this application is to detect any audio event which does not belong to the audio background related to non activity ambiance. Figure 5 shows the sound processing chain required by our audio monitoring system. A microphone network, associated with a pre-amplifier and a sound-board, is used to measure the audio activity of each monitored room in real time. In its first version, the system does not intend to model abnormal audio event but just to analyse current audio energy level and the difference form the previously trained model. Yet, the audio analysis algorithms implemented on the processing unit could later be enhanced to enable more elaborate capabilities. If significantly different from the average values usually experienced (the threshold can be defined) an alarm is raised by the processing unit. A home sound cartography is also computed by the processing unit and possibly provided on demand to the Health Center through the residential gateway.

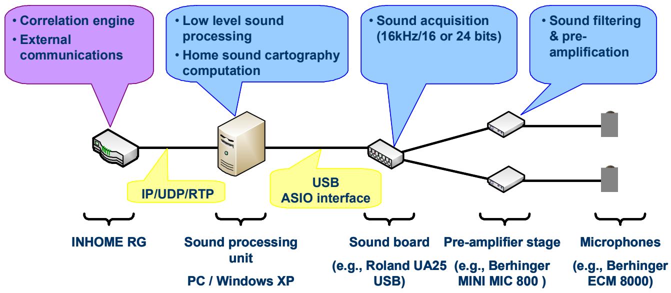

Figure 5. Sound Processing Chain

D. Health monitoring subsystem

The health monitoring subsystem develops a real time, interactive, home health care service based on the wireless or wireline acquisition of medical data from devices operating at the user's home environment. Interconnecting the health monitoring subsystem with the activity monitoring subsystem at the home gateway, the overall system becomes an integrated, adaptive, reactive, customisable, with extendable intelligence health care system

The health monitoring subsystem acquires the data from the medical devices, checks for possible alarm conditions, takes action is necessary, relates and/or presents the measurements values, stores the measurements for post-analysis and archiving purposes, The elements participating in this subsystem are illustrated in Figure 6 and highlighted as:

- The medical devices, which are used to perform measurements such as blood pressure, cardiac pulse, body weight etc.
- The INHOME terminal which is responsible to communicate with the devices for acquiring those measurements.
- The residential gateway which is responsible to run services based on the data produced by the medical devices.
- The TV device which is responsible to display the measurements in a user friendly manner.
- The DECT phone which enables the user to contact his/her physician.

There are two different communication interfaces utilised, the Bluetooth and 802.11. The Bluetooth communication is used to directly transfer the medical information to the gateway or at the INHOME terminal. The INHOME terminal is used as an intermediate collection point due to the fact that it could be carried by the user and it can be in the proximity of the medical devices. It can be extended with the ZigBee interface, thus becoming also part of the sensor network and a bridge between the activity and health monitoring subsystems.

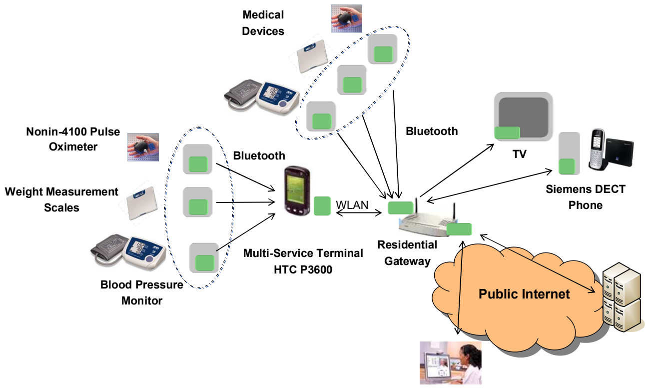

Figure 6. Health Monitoring Subsystem

The INHOME terminal and the 802.11 interface are used as the Bluetooth connectivity would not be always guaranteed, since the medical device could be out of the Bluetooth coverage of the gateway. After having acquired the data from the medical devices, the INHOME terminal sends this data through a WLAN communication to the residential gateway, which in turn processes this data.

Some key processing is related with the identification of alarm values based on the normal range for each type of measurement, the user profile and updates that can exist from the doctor. The service execution in the gateway is also responsible to send the data to the TV, enabling the user to view the values and assisting the elderly people as vision capabilities are reduced. Upon the detection of an alarm condition, the service in the gateway is also responsible to take appropriate action according the medical case and user. For example, it may require additional information from the activity monitoring subsystem, discover the phone number of the relevant physician, which maybe stored locally or at a remote location, send the phone number to the DECT phone allowing the user to avoid the manual dialing of the number or even call directly the doctor, etc.

The implementation at the INHOME terminal is based on J2ME (Java2 MicroEdition) which is capable of communicating with each medical device and acquiring the relevant data over Bluetooth. The alternative approach of direct communication with the residential gateway and alarm/action logic were performed with the development of communication

V. CONCLUSION AND FUTURE WORK

The proposed framework offers coordinated operation of activity monitoring (motion detection & audio in our case) and medical monitoring for both abnormal event detection and long term evaluation of the health of the elderly people.

Continuous interaction, collecting of information, detailed patient status and appropriate user profiling would be the key issues to address the needs of both the elderly users at home as well as the experts at the Health Care centers. In this paper, an interactive healthcare services environment for assisted living at home was presented, identifying the underlying technology employed such as adaptive audio monitoring algorithms, self-organized ZigBee multi-hop mesh networks, OSGi, Java and Web Services.

These technologies have not yet fulfilled their full potential and according to the model presented at this paper, utilising them as integrated and interacting technologies, they may provide solutions and services that would be influencing the way that home networking and home health care architectures are provided in the future.

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