DESIGNING ASSISTIVE TECHNOLOGY FOR DOMOTIC SYSTEMS

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The paper presents a critical analysis of various works in the field of assistive technologies, the ways they are or can be implemented in domotic systems for the aim of improving the lives of elderly or people struggling with disabilities. The achievements and the research done so far in the area is synthetized and design principles are extracted, in order to propose novel ICT-based solutions that increase and facilitate the supply of formal and informal care for older adults.

Keywords: assistive technology, domotics, wearable technology, assistive robotics

1. Introduction

This paper presents the state of the art in assistive domotic systems and extracts the considerations that need to be taken in designing this type of systems.

The main reason in designing assistive technology for domotic systems is aiding elder people or persons with disabilities live a normal life. The indisputable need for this type of systems comes from analysing the numbers of the future beneficiaries.

In a report published by the UN [1], the percentage of population older than 60 years old was 14.3 in 1975, grew to 18.8% in 2000 and is expected to reach 22.6% in 2025 and 34.2% in 2050. The numbers are similar with the prospections made for all the European countries, with an expected 28.8 percent of population aged over 60 in 2025, 36.6% in 2050. The potential support ratio (number of persons aged 15 to 64 per number of persons aged 65 or older) will decrease from 4.6 in 2000 to 3 in 2025 and to 1.9 in 2050 in the European countries. The projected old-age dependency ratio (the projected number of persons aged 65 and over expressed as a percentage of the projected number of persons aged between 15 and 64), as shown in [2] will grow from 27.48% in 2013, in the European Union, 23.92% in Romania to 49.43% in the European Union and 48.49% in Romania by 2050.

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2. Paradigms of Assistive Domotics

2.1. The concept of assistive domotics

The main goal of an assistive domotic system is to help the assisted person live, as much as possible, on his own, minimizing the needed help from other persons. The targeted users may be people with disabilities, like loss or degraded hearing, sight sense, reduced mobility, people suffering from chronicle diseases or simply aging people that have difficulties on living on their own. Also, potential beneficiaries are the caregivers, formal or informal as defined in [3] and the caregiving service providers.

The primary application scenarios for ambient assisted living solutions aim to enhance comfort, improve and monitor health status, save energy costs, prevent and manage hazards such as fires, water leakages, falls or health emergencies, assist users in everyday activities like taking medicine and following doctor's orders, managing the planned activities or, simply, keeping the grocery list.

2.2. Domotics – Home Automation

Assistive domotics derive from building automation. Building automation comprises two main fields: automation of buildings with public destination or offices – referred to as imotics and home automation – domotics.

Imotics comprises the control and monitoring of the following subsystems: Heating, Ventilation and Air Conditioning - HVAC, security (burglary protection and control of access, fire detection and water and gas leakages alarming) and lightning. In the domotic field, all of these systems are integrated, more or less developed, depending on the users' requirements (e.g. the HVAC system is often reduced to a temperature control system). In addition to building automation, domotic systems focus on users' comfort, by automating multimedia devices and other electronic devices in the house (e.g. turning on/off the coffee machine, the washing machine, pulling the drapes, etc.). The notion of "domotic good" is defined, which represents devices whose functioning may be automated. These domotic goods may be used in compensating different problems that the elderly or the people with disabilities have in their day to day lives.

In contrast to the imotic systems, the domotic systems are rarely operated by engineers or technicians, most of the users of these systems having little or no experience in the field. This is why domotic systems need to by easily configurable and used and why they need to support the integration of different common electronic devices that are found in user's homes.

2.3. Ambient intelligence

Ambient intelligence refers to digital environments that are sensitive and responsive to the presence of people, by providing personalized, adaptive and anticipatory services to users [4], [5]. Ambient intelligence has the role of improving a domotic system by adding it properties that derive from artificial intelligence like [4]: context awareness, adaptivity, anticipation, personalization, easy to use interfaces that are integrated in the environment.

There is the field of ambient assisted living, which derives form ambient intelligence and focuses on attending people in their daily lives.

2.4. Main functions of an assistive domotic system

The main functions of an assistive domotic system are: sensing, reasoning, acting, interacting and communicating [6].

Sensing

Sensors used in assistive domotic systems are the ones used in smart homes for implementing the subsystems described in Section 2.1 (e.g. sensors for the HVAC system: temperature, humidity sensors, luminosity sensors for the lighting system, presence detectors, gas detectors and so on).

To the above-mentioned sensors, usually used in domotic systems, are added health monitoring sensors and sensor that monitor user's location or posture. Health related information is gathered via body-worn wireless sensors and transmitted to a caregiver via an information gateway. Health sensors have monitoring, as well as diagnostic applications [7].

The concept of Body Area Network – BAN is defined. A BAN represents a network of electronic devices placed in or around the body.

The category comprises sensors for body temperature, blood glucose, blood pressure, blood oxygen saturation, cardiac activity, brain activity, muscle activity, respiration [8] and are designed in the form of wearable technology.

Reasoning

Reasoning consists in analysing the data gathered by sensing devices, transforming it into knowledge and making decisions based on the resulted knowledge. Higher levels of reasoning deal with activity recognition, context modelling, location and identity identification and planning [6], [8], in order to give the system the characteristics of an intelligent environment.

Interacting

Considering that the users experience with software or hardware systems might be little or non-existent, the system must be easily configurable and easy to use. The user interfaces must be integrated in the living spaces, and the way of functioning hidden from the user.

Usually, domotic systems have a Graphical User Interface – GUI that is accessible on a personal computer, or via a web server on different type of smart devices: smart phones, tablets, different kind of devices with internet connectivity. Some of the functions of a domotic systems, e.g. security system control, light control, temperature control have different type of interfaces around the living area, like touch screens, gauges, on/off controls.

When designing assistive domotic systems, the standard type of interfaces must be enriched with easy to use interfaces like voice control or gestures control. This is called multimodality, the seamless combination between different modes of interaction, as defined in [9]. In [10], 74 test persons aged 50 to 75, interviewed about the preferred input and output methods to communicate with a reminder system., stated that the preferred method by the majority was speech for the input and for the output followed by keyboards (for input) and displays (for output).

Acting

Acting represents the actions taken by the system upon the user's environment. Alongside the actuators included in a traditional domotic system (motors for controlling the windows or the windows shutters, different on/off actuators), in an assistive domotic system the environment can be acted on by an assistive robot.

Communicating

Communicating in a domotic system may be implemented through various communication protocols like: KNX, BacNET, LonTalk, X10, Z-Wave, ZigBee and many others. A major problem is that most of them are not interoperable, meaning that devices "speaking" one of them may not communicate to another device using a different protocol directly. This ties the user to using a full integrated solution from one manufacturer. Later improvements of the system are also burdened by the same problem. Also, it has been reported that devices using the same protocol, but produced by different manufacturers are also not able to communicate directly. The problem can be solved by having a residential gateway that "speaks" multiple protocols and makes the translation where needed. Fortunately, there are open source solutions that already solve this problem, like openHAB [11] that supports most of the protocols used in home automation.

Alongside the communication protocols specific to a domotic system, in an assistive solution, there is the problem of communicating the health data gathered by the BAN. As categorized in [8], this communication may be divided in three tiers: Intra-BAN communication - communication between the body sensors which may be achieved through inductive links or intrabody links by using the body tissue as a transmission link; Inter-BAN communication - communication between the BAN and a wireless access point (using wireless communication protocols like ZigBee or Bluetooth) and beyond-BAN communication which covers the data transmission outside the home area network to a tele-healthcare provider (using the Internet).

2.1. Challenges of assistive domotic systems

Privacy

Some of the characteristics of an assistive domotic system, like context awareness, anticipation, and personalization of the offered services rely on the system's access to user's personal data. For example: in order for the system to anticipate user's action, it must have knowledge of the user's daily routines; in order to have a functional voice control interface it must continuously listen to the users speech. Health monitoring is an important part of an assistive domotic system, but it involves tracking personal data, like the medicines the user takes, health status and so on. These limitations can be resolved through a personalization of the system to meet the user's desires (for example not using video cameras, where the user does not want them) and, most important, applying reliable security measures in data usage. By making the user confident that his data is used only in his benefit and that access to personal data is strictly controlled, privacy concerns may be overcome.

Security

As mentioned above, an assistive domotic system must have access to sensitive user data. This is why security is an essential issue when designing such a system. All sensitive data communications must be secured, especially when it is living the perimeter of the house communication network. Also, controlling the system must be restricted to authorized users, so the user interfaces may not be used by malicious persons (e.g. voice control should use voice biometrics or key phrases, gesture control should use a secret sequence of motions and so on).

Accessibility

Accessibility concerns the high costs of assistive domotic systems and ease of access to system's functions which implies easy to use interfaces. One of the main reasons that domotic systems are not widely used is the fact that implementing prices are still high, especially for most of the elderly people. Also, most of the already available on the market systems require using products from one sole manufacturer. Interoperability of components from different providers is usually difficult to obtain, requiring trained technicians and this rises the implementing costs once again.

Reliability of the systems is another concern when choosing an assistive domotic system. Such a system aims at replacing care services offered by trained health care personnel, so the system should perform as reliable as a human would, for example, in managing health emergencies, the needed accuracy is a 100%.

Multimodality is the key in raising systems accessibility. The targeted users most often have motion, hearing or other type of impairments. The system must offer interaction methods that take into account the users difficulties.

3. Enabling technologies

3.1. Wearable Technology

Wearable technology may be loosely defined as any kind of technology that is easily worn. It may be designed in the form of wrist computers, bracelets or rings, smart badges or tattoos on the skin (body patches) or they may be integrated in clothing.

Wearable devices can perform the following functions: communicate by integrating wireless communication devices; measure vital signs of the wearer; generate or accumulate energy (from external sources or from the energy from the wearer) for powering integrated devices; stimulate the body with electrical signals; perform mechanical actions such as detecting mechanical traumas, protect against them (e.g. clothing airbags); detect environment factors like temperature, concentration of different substances in the air, radiations and so on.

The medical sensors should be as less disturbing as possible, seamlessly integrated in the users normal look, in order to not make them feel stigmatized [6], [8], so the best options seem to be body patches and intelligent textiles.

Body patches are a proof of what nanotechnology can deliver. For the moment, the most advanced body patches seem to be the ones manufactured by an American company called MC10 that produces flexible adhesive printed integrated circuits for remote biosensing. There are two commercial products available: a body patch for monitoring body temperature designed for babies and a body patch for monitoring hydration level designed for athletes, but there is ongoing research for drug delivery, energy harvesting, monitoring heart rate and muscular activity, detect speech by sensing vibration and many others [12]. The offering costs seem to be low as the hydration sensor is offered at around 10 US dollars. This research sounds very promising and with many implementations in the field of assistive domotic systems, but, although the technology is available from 2010, there is little scientific publishing about it, and the patents for the stretchable electronics technology belong to MC10.

Intelligent textiles can be classified in three categories, based on the degree of integration in the clothing: Side by side textiles – garment level integration: Electronic devices are attached to the clothing through different elements like pockets. Cabling and other elements are sewed into the clothing; Hybrid systems – fabric level integration: Electronic devices are attached permanently to the clothing through sewing or stitching; fully integrated – fibre level integration: The electronic devices are integrated into the fabrics. There is no clear separation between the fabric and the electronic devices. There are many implementations, as described in [7].

3.2. Assistive robotics

There is a multitude of projects that aim at delivering robots to assist the elderly or the disabled in the daily living. Most of these robots concentrate on: reminding the users to perform different activities; - detecting falls and alarming a caregiver or a relative; - providing social interaction through tele-presence and remote communication; - collecting health and location data; coaching the users (e.g. offering mental stimulation or guidance in performing physical routines); offering companionship (displaying conversational abilities); manipulating the environment physically by bringing objects, removing obstacles; lifting and carrying a person from the bed to a chair, sustaining a person in motion; acting as a controller of the smart home: answer the door after informing the user, turn on/off devices, etc.The user interfaces vary from large touchscreens that present a GUI – Graphical User Interface to voice control, facial expressions or physical motions control.

One of the first robots designed for assisted living is Pearl, developed between 1999 and 2002, offering companionship through a voice control interface [13], [14]. A more recent implementation is Florence (Multi Purpose Mobile Robot for Ambient Assisted Living) [15], a Collaborative Project within the 7th Framework Programme that ended in January 2013 (began in February 2010). Florence offers tele-presence communication, fall detection and alarming of relatives or caregivers by video processing, agenda reminders, activity recommendations, health monitoring: only weight and blood pressure. The user interface is a GUI presented on a touchscreen.

Scitos is the name given to a range of robots produced by a German company, MetraLab, with different areas of applicability: exhibition guides, entertainment robots, shopping robots, tray transporters and so on [16]. The most suitable of them for assisted living are A5, G3 and G5 models. The Scitos G3 was used in the FP7 Project CompanionAble for the Hector robot and the A5 robot was used in the Alias project [17]. The G5 is currently used in STRANDS, a Collaborative Project within the 7th Framework Programme that aims to improve the collaboration between men and robots in different areas, including assisted living. There are many different implementations of assistive robots, like: Robocare, Wakamaru, The u-bot, The CareBot, Charlie the Healthbot, Care-O-bot [18], all of them presenting a subset of the functions presented above.

3.3. Multimodality

Voice Control Interfaces

This is the most intuitive interface and, as stated above, the preferred method of input and output by the potential users.

Voice control solutions are based on a microphone or an array of microphones receiving the input from the users and sending it to a processing unit. There, the sound is translated to text and matched against the commands known by the processing unit.

The microphone/microphones may be placed on the user or in different places of the living area. The performance of successfully recognizing user's speech is higher with the microphones on the user [19] reaching up to 99% accuracy [9]. Even lower accuracy systems may be used in command and control interface, where the system must recognize predetermined phrases, higher degree of accuracy being needed for systems which present conversational skills.

Gesture Control Interfaces

Gesture control solutions are based on recognition of gestures that are then matched to a corresponding command. In order to get the users gestures, there are three main ways.

The first method is based on image processing. This implies that the living space has enough cameras positioned to perceive human motion, whenever necessary. The cameras send the recordings to a processing unit that interprets users gestures according to the commands assigned to them. There are two ways of getting the input data: using at least two stereo cameras with known position relative to one another to get a 3D representation of the captured images or by using a depth aware camera. Image processing has the advantage that it collects a great amount of information so that gestures can be successfully recognized, but there is a great difficulty in having users accept the lack of intimacy that having video cameras in the living area imposes and there are still several challenges to be addressed like illumination change, partial occlusion, background clutter.

The second method of recognizing human gestures is by having sensors placed on the user’s body and then tracking their position. The sensors can be accelerometers, used for ample gestures recognition, or different sensors that can measure joint angle for different points of the hand as described in [20]. The sensors transmit their position to a processing unit that interprets the gestures. An advantage is the high degree of successful gesture recognition that can be achieved. The main disadvantage is that the user must wear the sensors so that the system can work. Early implementations of this kind of devices date back in the 1980s with the development of the first commercial “Data Gloves” in 1987. Since then, many implementations were continuously developed to include the progress made in sensor technology and in communication methods.

The third way is based on placing wireless signal generators and receivers in the living space. This is a novel technique, or better said a new application of wireless signal processing. The position of the user’s hands is computed by measuring the differences in frequencies between the sent and received waves. Such an example is WiSee [21]. The system is based on a few wireless sources and can recognize a set of nine ample gestures. This is the most user friendly method of the ones described above, it allows one wireless source to monitor multiple rooms, considering that wireless signals do not require line of sight and traverse through walls. The average accuracy of the gesture recognition is 94% in [21], but only for a set of 9 ample gestures and the user must perform a specific gesture pattern in order to start the conversation.

4. Proposed solutions for designing an assistive domotic system

Considering the information presented, the proposed system architecture is synthesised in the following figure:

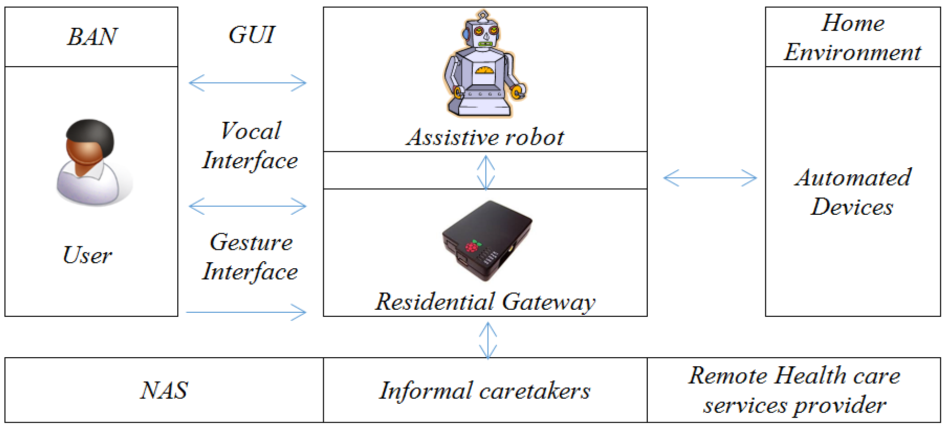

Fig. 1. Proposed system architecture

The classical architecture of a domotic system is a hierarchical one, structured on three levels (the field equipment level, local control level and home control level) with an optional forth, which connects multiple domotic systems to a higher level of supervision for different purposes like energy management, emergency management, usage trends recognition and so on.

Considering the advances in computing power integrated in small devise, the proposed architecture is shown in Fig. 1.

Levels one and two of the classical architecture are merged into one level. The central controller is represented by the residential gateway. It is responsible with commanding and controlling the subsystems of the residence, using the information gathered from all the sensors that are connected to it and the input from the user.

A new addition to the classical domotic system is the existence of the BAN, which collects data about the user's state (location, health state: pulse, temperature, stress level) using wearables as described in section 3.1 - Wearable Technology. The BAN monitors user's health and makes this data available to the default gateway for logging and centralized decision through the use of wireless protocols as described in section 2.4 – Communicating.

The other new addition to the classical domotic system is the existence of the assistive robot. According to the needs of the user, it can help the user move, train his memory, keep companion, remind of daily schedules. More details are provided in section 3.2. - Assistive robotics.

As presented in Fig. 1, the system should implement multimodality through voice and gestures control interfaces enriching the classical GUI interface. A variety of open-source software is available for automatic speech recognition, like CMU Sphinx, Hidden Markov Toolkit, Julius, Simon and MARF, many others being described in [9]. The ones stated above are toolkits, meaning that, above the ready to use solutions for different languages, they also offer libraries that aid developing new voice recognition software. Unfortunately, for Romanian language there is no good open source solution readily available, so one must be created. The first step is creating an acoustic language model and then train it using algorithms based on Hidden Markov Models – HMMs, as this is the most used speech recognition technique. HMMs are also suitable for voice biometrics.

Gesture recognition may be implemented by using open source software like OpenCV for computer vision, the Gesture Recognition Toolkit [22] which processes different type of sensor input or openKinect for the Kinect hardware, all of them running both on Linux and Windows platforms.

The voice and gesture recognition algorithms will be implemented on the residential gateway as well as on the assistive robot for the easy interaction between the user and the environment.

As stated above, the main focus is on the residential gateway which is responsible for intermediating most of the communication in the system and with the outside world, acquiring the health and environment data, processing and logging the data. Depending on the computing requirement (the complexity of the algorithms used), the residential gateway may be represented by a cheap controller as Raspberry Pi, or it can be a more powerful and costly computer. For the software part, a readily available domotic system may be used. It may command and control hardware from different manufacturers, as the lack of interoperability problem is solved by the residential gateway. It will be able to translate the conversations between different devices by using openHAB – the open Home Automation Bus software. This is an open source project written in Java. It is based on OSGi – Open Service Gateway Initiative and it contains packages called bindings for over 70 communication protocols, including KNX, ModBus, Z-Wave, Insteon and digitalSTROM. It also provides GUIs available on desktop web browsers and on mobile operating systems: Android and iOS. OpenHAB also presents a rule engine, offering the possibility of creating scripts. The residential gateway will also be in charge with logging the data on a network attached storage – NAS.

Although it is not the purpose of the currnet study, the default gateway may also communicate with a remote care service provider, so that the user benefits from real time health care from trained personnel.

5. Conclusions

In this paper an overview of current challenges and demands for assistive domotic systems was presented. The need for implementing this type of systems is clear from analysing the statistics on the potential users and proved by the large number of existing research on the subject.

Given that there are numerous acceptable offers of domotic systems on the market, it seems like a viable solution to use one of them for the base of an assistive domotic system and then integrate the assistive technologies in it.

The evolution of wearable technologies may also improve the current solutions of health monitoring, considering that small body patches of the size of regular bandages can offer sensing and communication capabilities at low prices.

An import role is played by multimodality, which rises the accessibility of the system for the intended users. Voice control seems to be the favourite input and output method to communicate with the system, but gesture interfaces and traditional GUIs should aid the interaction with the system.

Assistive robotics also plays an important role, as the "caring bots" may replace the need of human care personnel and it can accomplish many of the functions an assistive system need to perform: monitor the user, provide socialization skills, manage health emergencies, offer mobility aid and assist the user in performing daily tasks.

Privacy and security of the personal data used in an assistive domotic system should represent main concerns in designing such systems as the acceptance of the system may depend on them.

Acknowledgment

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132397.

R E F E R E N C E S

[1]. *United Nations Department of Economic and Social Affairs,* "World Population Ageing: 1950 – 2050", United Nations Publications, 2001

[2]. *Projected old-age dependency ratio* available at http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&plugin=1&language=en&pcode=tsdde511, Eurostat, 2014

[3]. *Active and Assisted Living Programme*, "Challenge-Led Call for Proposals 2014 AAL 2014", available at http://www.aal-europe.eu/ at 12th May 2014

[4]. *Fariba Sadri,* "Ambient Intelligence: A survey", ACM Computing Surveys, vol. 43, no. 4, pp. 1–66, 2011

[5]. *Ruijiao Li, Mohammadreza, A., Huosheng Hu,* "Towards ROS based Multi-Robot Architecture for Ambient Assisted Living", Proceedings of 2013 IEEE International Conference on Systems, Man, and Cybernetics, 2013, pp. 3458 – 3463

[6]. *Cavallo, F. et al,* "Technological and cognitive roadmaps for Ambient Assisted Living", CEUR Proceedings 4th Workshop HCP Human Centered Processes, February 10-11, 2011, pp. 58-62

[7]. *Patel, S. et al.,* "A review of wearable sensors and systems with application in rehabilitation", Journal of NeuroEngineering and Rehabilitation, 2012, pp. 9 – 21

[8]. *Rashidi, P.*, *Mihailidis, A.*, "A survey on Ambient-Assisted Living Tools for Older Adults", IEEE Journal Of Biomedical And Health Informatics, Vol. 17, No. 3, 2013, pp. 579 – 590

[9]. *Anastasiou, D.,* "Survey on Speech, Machine Translation and Gestures in Ambient Assisted Living", Proceedings of Futures in Technologies for Translation, France, 2011

[10]. *Goetze, S., Moritz, N., Appell, J., E., Meis, M., Bartsh, C., Bitzer, J.,* "Acoustic User Interfaces for Ambient Assisted Living Technologies", Proceedings of Informatics for Health and Social Care, vol. 35(4), 2010, pp. 161–179

[11]. *openHAB,* available at http://www.openhab.org/ at 12th May 2014

[12]. *Son, D. et al.,* "Multifunctional wearable devices for diagnosis and therapy of movement disorders", Nature Nanotechnology, 2014, pp. 397 – 404

[13]. *Pollack, M. E. et al.,* "Pearl: A mobile robotic assistant for the elderly", AAAI Workshop on Automation as Caregiver, 2012

[14]. *Pineau, J. et al.,* "Towards robotic assistants in nursing homes: Challenges and results", Special issue on Socially Interactive Robots, Robotics and Autonomous Systems, Vol. 42, No. 3 - 4, 2003, pp. 271 – 281

[15]. *Garzo, A. et al.,* "User studies of a mobile assistance robot for supporting elderly: methodology and results", Proceedings of the IROS 2012 Workshop "Assistance and Service Robotics in a Human Environment", Portugal, 2012, pp. 71-76

[16]. *Merten, M., Gross, H. M.,* "Highly Adaptable Hardware Architecture for Scientific and Industrial Mobile Robots", Proceedings of the International Conference on Robotics, Automation and Mechatronics, China, 2008, pp 1130 – 1135

[17]. *Rehrl, T. et al.,* "The Ambient Adaptable Living Assistant is Meeting its Users", AAL Forum 2012, 2012

[18]. *Lowet, D. et al.,* "Multi Purpose Mobile Robot for Ambient Assisted Living - Deliverable: D5.1 State of the Art in AAL Robotic Services", 2010, available at http://www.hitech-projects.com/euprojects/florence at 12th May 2014

[19]. *Moritz, N., Goetze, S., Appell, J., E.,* "Ambient Voice Control for a Personal Activity and Household Assistant", Ambient Assisted Living - 4. AAL-Kongress 2011, Berlin, Germany, 2011, pp 63-74

[20]. *Thomas Zimmerman et al.,* "A Hand Gesture Interface Device", CHI '87 Proceedings of the SIGCHI/GI Conference on Human Factors in Computing Systems and Graphics Interface, 1987, pp. 189 - 192

[21]. *Qifan Pu et al.,* "Whole-Home Gesture Recognition Using Wireless Signals", The 19th Annual International Conference on Mobile Computing and Networking (Mobicom'13), 2013, pp. 27 - 38

[22]. *Gillian, N. et al.,* "Gestures Everywhere: A Multimodal Sensor Fusion and Analysis Framework for Pervasive Displays", 3rd International Symposium on Pervasive Displays (PerDis'14), Copenhagen, Denmark, 2014