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An AmI Environment Implementation: Embedding TurtleBot into a novel Robotic Service Wall

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Abstract

Daily living becomes an important quality factor especially in the ageing society. Elderly people are facing limitations in most of their daily living activities. Novel approaches need to be followed when trying to service the ageing society needs. Various research fields deal with Activities of Daily Living (ADLs), fusing different technologies, to enable mechanisms that could efficiently assist, by enhancing the everyday living quality in the ageing society. In this paper, the implementation of a novel Robotic Service Wall supporting ADLs is proposed. The proposed system follows a modular approach, whereas all system elements provide plug-n-play characteristics. Such an approach enables an efficient system, which can be arranged in various configurations, and can be easily installed in any residence without requiring specific space dimensions. An Ambient Intelligence (AmI) environment is proposed, by interfacing a TurtleBot with the robotic service wall. TurtleBot is utilized as an assistant to the user, controlled by the use of voice commands. The various elements and actuators of the robotic service wall are controlled using a human-machine communication scheme. The user provides the necessary commands to TurtleBot, which then controls the actuators and sensors of the robotic service wall. A variety of services can be addressed by the proposed system, contributing to a higher level of quality in ADLs.

Keywords: Robotic Service Wall, AmI, Autonomous vehicle, Ageing Society

1 Introduction

Ageing Society requires novel approaches for placing mechatronics and robotic service technologies in living environments and for weaving them, according to Marc Weiser [1], into daily activities. Already in early development phases, knowledge at least from the architectural, medical and robotic field is necessary, and subsequent product development, even it requires further fields (e.g. care providers and insurances) also to be involved.

1.1 Related Work

Some researchers already proposed integrated solutions as e.g. Robotic Rooms [2], Wabot House [3], or Robot Town [4]. The aim of those approaches was to distribute sensors and actuators in the environment which can communicate with the intended robot system allowing simpler and robust robot designs. However, those approaches integrate mainly sensors, actuators and robots on an informational level. Furthermore, they are presenting implementations that are realized in a controlled experimental environment.

The proposed robotic service wall was designed and implemented in order to be straightforwardly installed into a regular home environment. The involved industry partners, currently implementing the end-product, are going to install the proposed system into a regular flat, to undergo into a 2-week extensive evaluation process by individuals. Additionally, the proposed integration aims to provide a hardware basis for the delivery of customized 3rd party services, i.e. to become a service channel. In order to integrate those services on basis of technologies seamlessly and connect them to ADLs [5], a fusion scheme of robotic technology physically and informational with architectural elements as e.g. walls and barrier-free design [6] is proposed.

2 Robotic Service Wall System Configuration

The development of the robotic service wall was a systemic and stepwise process. First, the general strategy was defined (**Figure 1**), and then the system modules and functions were designed (**Figure 2**). After an early design phase two 1:1 prototypes (each representing a system variation) were evaluated using an Age Simulation Suite (**Figure 3**).

2.1 Terminal Approach

The advantage of the Terminal approach is that existing walls do not have to be replaced. Analysis showed that service wall which would replace existing walls would become too complex and too expensive to install. Thus, a terminal approach was proposed: A compact element (terminal) will be developed for each life centre (six life centres have been identified: entrance, relax, living, working, food, body care). In order to keep cost and effort low enough for equipping a flat with smart technology, it was proposed to concentrate assistive technology on terminals for each life centre instead of developing a smart wall. Each terminal can be deployed in front of an existing wall as a pre-fabricated kit. A terminal concentrates assistive functions and technologies that have to be brought into a room on a compact element. Thus, in case a room has to be equipped with assistive technology, not the whole room has to be rearranged or renovated, but only one of

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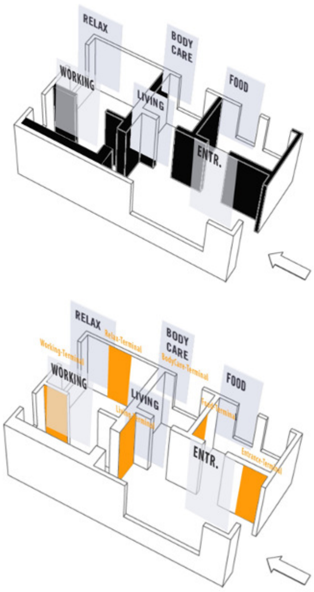

Figure 1 Terminal versus Smart Wall Approach: (Up: Smart Wall Approach, Down: Terminal Approach)

the proposed compact elements has to be installed in this room. The overall aim is to develop terminals for all six life centres. The life centres have been ranked according to their complexity (1=less complex, 6= most complex): 1) Entrance, 2) Relax, 3) Living, 4) Working, 5) Food, 6) Body Care. The complexity was determined through evaluation parameters as installation complexity (number of pipes and cables to be integrated, number of subsystems needed and design complexity). In order to be able to exploit learning effects, the project consortium decided to develop the terminals subsequently starting with the less complex element. Nevertheless, the analysis of the project team showed that the entrance area is crucial in assuring self-sufficiency of elderly people. By supporting activities in this area leaving and approaching the flat could be made easier and safer. Especially for elderly people mobility and communication with the outside world is accounted as important in order to assure physical and psychological health and well being.

2.2 System and sub-system Integration

All terminals follow the same modular approach. The basis for each terminal provide specially designed steel profiles to which cabinets, shelves, seats and other components belonging to the system can be fixed in a plug and play like manner. All elements (e.g. cabinets) offer space for sensors and actuators.

In this paper emphasis is given in the terminal specifically designed for the entrance area of the flat. The basic elements of the terminal for the entrance area are: 1) robotic seat which helps elderly people to sit down and stand up, 2) a module for measuring vital signs, 3) a control interface and 4) a module which houses a TurtleBot [7] that can assist elderly people. The TurtleBot is physically and informational integrated with the terminal and can be seen

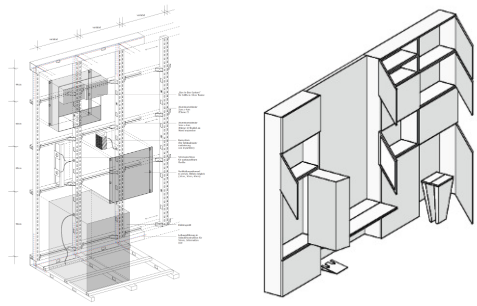

Figure 2 Proposed Robotic Service Wall

as a sub-system of the proposed modular furniture. The modular approach also allows the terminals to be upgraded and adapted to various life circumstances. In **Figure 2** the proposed terminal architecture is depicted.

2.3 Evaluation of Configuration Variation

Although the proposed system employs a modular approach which allows it to be customized to nearly any need, two different configurations of the system were built as 1:1 prototypes and evaluated in terms of ergonomics and usability by using a modified age simulation suite. Leaving and approaching the residence were identified as the two main scenarios. Each scenario was then broken down into sub-activities typical for an entrance area (Reminder/Media Check, Dressing/Un-dressing Shoes, Dressing/Un-dressing Coat, Key and Accessories, Carrying Shopping Bags). Each sub-activity was then evaluated by a) normal person without a disability, b) person with light disabilities (simulated by age simulation suite), c) person using a walking frame, d) person using a wheelchair (**Figure 3**). The evaluation [8] revealed that a mobile system which could relieve elderly people from i.e. carrying shopping bags (**Figure 4**), would substantially improve the usability of the proposed system as elderly people could then focus on more concentrated on basic ADLs as i.e. dressing or undressing activities, making the procedure of leaving or entering the flat, safer and easier.

3 TurtleBot Integration

Vision-based perception of moving people, and analysis of their resulting motion patterns and the understanding of their gestures, comprises one of the active research fields in computer vision [9, 10]. This continuous interest is sustained by the number and importance of potential applications, along with the strong challenges posed by the development of algorithms for robust tracking of people in spite of occlusions and dynamic lighting. While significant efforts have been made in the development of algorithms and architectures, extensive performance evaluation of the resulting systems has not been given proper attention. Monitoring people movements in complex environments, analyzing the resulting motion patterns corresponds to a high level of visual competence that can most

Figure 3 Proposed Evaluation of various configurations of the Robotic Service Wall by Age Simulation Suite

appropriately be identified as ambient intelligence (AmI), [11]. AmI research builds upon advances in sensors and sensor networks, pervasive computing, and artificial intelligence. Because these contributing fields have experienced tremendous growth in the last few years, AmI research has strengthened and expanded, revolutionizing daily human life by making people's surroundings flexible and adaptive. In AmI, technologies are deployed to make computers disappear in the background, while the human moves into the foreground in complete control of the augmented environment. AmI is a user-centric paradigm, supporting a variety of artificial intelligence methods and works pervasively, nonintrusively, and transparently to aid the user. It supports and promotes interdisciplinary research encompassing the technological, scientific and artistic fields creating a virtual support for embedded and distributed intelligence. AmI will eventually become invisible, embedded in our natural surroundings, present whenever we need it, enabled by simple and effortless interactions, attuned to all our senses, adaptive to users and context-sensitive, and autonomous. The basic idea consists of a distributed layered architecture enabling omnipresent communication, and an advanced human–machine communication protocol. The AmI paradigm sets the principles to design a pervasive and transparent infrastructure capable of observing people without interfering into their lives, adapting to the needs of the user.

The interface of TurtleBot with the proposed robotic service wall can enable such an AmI environment. The communication between TurtleBot and the robotic service wall is achieved by the use of two computers (Master-Slave type of communication model). The first computer (Master), the Mobile Control Unit (MCU), is placed in the robotic service wall. The other elements are interconnected to the MCU host computer via WiFi technology. The second computer (Slave), the Mobile Mechatronic Unit (MMU), is placed on TurtleBot, which is required to provide the necessary commands considering its operation (**Figure 5**). In this proposed architecture, the TurtleBot can actually remotely control the actuators placed within the robotic wall, according to the commands issued

Figure 4 TurtleBot assisting in ADLs

Figure 5 TurtleBot Embedded into the Robotic Service Wall

to it by the user. Thus, it is not required by the user to have a physical contact via a button or a switch in order to actuate an embedded mechanism or device. Voice commands issued to TurtleBot can be interpreted into signals, which are then passed from the MMU to the MCU. The MCU computer can initialize the operation of robotic actuators, initiate processes, retrieve information, and control mechanisms, without requiring the physical presence of the user. The proposed distributed architecture enables an advanced human-machine communication, providing an augmented environment, in which the user becomes a remote user and controller (**Figure 6**).

3.1 Vision

Depth perception is one of the important tasks of a computer vision system. Stereo correspondence, by calculating the distance of various points in a scene relative to the position of a camera allows the performance of complex tasks, such as depth measurements and environment reconstruction [12]. The point-by-point matching between the two images from the stereo setup derives the depth images, or the so called disparity maps [13]. Disparity map extraction of an image is a computationally demanding task. Having extracted the disparity map, problems such as 3D reconstruction, positioning, navigation, obstacle avoidance, etc, can be dealt with in a more efficient way [14, 15].

TurtleBot is able to acquire visual information by using the Kinect Sensor, implemented by Microsoft [16]. The depth sensor consists of an infrared laser projector

Figure 6 Communication scheme

combined with a CMOS sensor, which captures video data in 3D. The sensing range of the depth sensor is adjustable, and the Kinect embedded software is capable of automatically calibrating the sensor based user physical environment, accommodating for the presence of furniture or other obstacles. Due to the fact that Kinect sensor uses an infrared sensor, it can also provide with night vision abilities. Thus, in the proposed architecture, the elderly people can be assisted by TurtleBot, even if the lights are switched off, i.e. during the night. TurtleBot can efficiently navigate with low light conditions or even interfere in case an accident happens, i.e. the user rolls and falls over the bed, while sleeping.

3.2 Voice Commands

TurtleBot operates using the Robotic Operating System (ROS) [17]. ROS is a software framework for robot software development, providing operating system-like functionality on a heterogeneous computer cluster. ROS was originally developed in 2007 under the name switchyard by the Stanford Artificial Intelligence Laboratory in support of the Stanford AI Robot (STAIR [18]) project. TurtleBot can actually provide speech recognition features [19], which are actually utilized by the proposed system. The user can easily create a vocabulary and use specific commands in order to control the various actuators and devices of the robotic wall.
A training procedure was followed in order to create the necessary vocabulary. The vocal commands are acquired utilizing the MMU computer embedded microphone. The training procedure can be repeated to extend or adapt the required functionality according to the user needs. It must be noted that having TurtleBot in the vicinity of the user, the efficiency of the speech recognition performance is enhanced.

3.3 Localization and Mapping

The proposed architecture is applied to an environment whereas dimensions are a priori knowledge. This assumption does apply though to TurtleBot. Once TurtleBot is introduced into this space, the exact space arrangement must be known, in order to enable autonomous operation. A widely known technique which provides this kind of information to autonomous vehicles is the Simultaneous Localization and Mapping (SLAM) [20, 21]. SLAM is a technique used by robots and autonomous vehicles to build up a map within an unknown environment (without a priori knowledge), or to update a map within a known environment (with a priori knowledge from a given map), while at the same time keeping track of their current location. Such a technique is used in the proposed system, in order to get all necessary details concerning the working space of TurtleBot. Once the map of the flat is composed, TurtleBot can efficiently navigate within the flat space.
The working space of TurtleBot comprises a dynamically altered environment, since a flat arrangement changes by items being placed temporarily on different locations, furniture being moved according to the tenant demands, doors left opened or closed, people moving inside the flat, etc. The TurtleBot onboard Kinect sensor can compensate the dynamic adjustments of the working space. Thus, TurtleBot can dynamically avoid obstacles that are detected in its proximity, and update the stored map, according to the detected updated flat configuration.

3.4 Approach Scenarios in ADL Assistance

A series of test and experiments were conducted in order to define the behavior and communication scheme between MCU, MMU and human operator. These comprise only a small set of applications and services, which were included in the current implementation state of the system, in order to get an estimate of the capabilities and provide an estimate of the performance of the proposed system. Additional services and applications can be later added to the system, according to the user needs, arrangement of the flat, and requirements and specifications of the end product. A representation of each of the tested scenarios is depicted below.
In **Figure 7**, the ambient temperature of the flat is controlled using an interaction scheme between the outside-inside temperature sensors, and the user demands. A monitor, embedded to the robotic wall module, provides information to the user about the ambient temperature of flat, as well as humidity, air quality, etc. The user is able to issue a command to TurtleBot (MMU), according to his preferred temperature conditions. The vocal command, after being interpreted by TurtleBot, is wirelessly transmitted to the robotic service wall computer (MCU). The MCU then checks the temperature sensors located outside and inside the flat, and controls the heating/cooling system of the flat to the required temperature.
In **Figure 8,** the situation where the user enters the flat entrance is examined, returning home after shopping. It is assumed that the user usually carries shopping bags, facing difficulties to close the door. Although this situation imposes no major concerns to healthy individuals, it comprises a main problem to the ageing society, due to stiffness and disabilities, difficulty to move, etc. The

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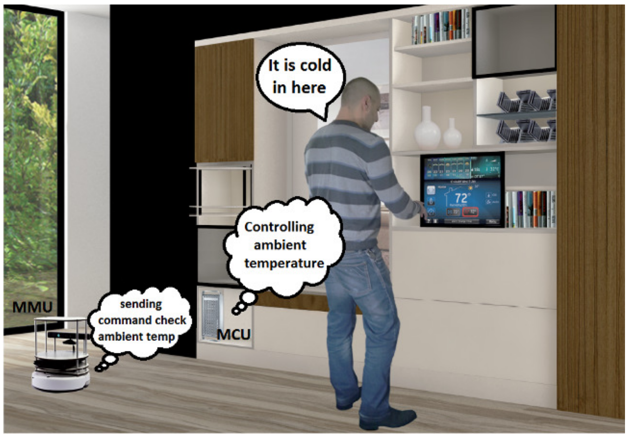

Figure 7 Controlling ambient temperature

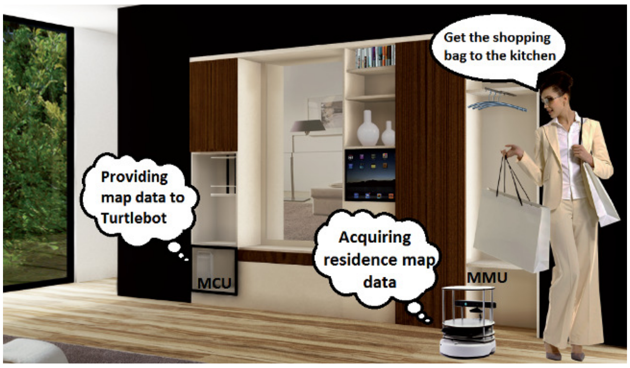

Figure 8 Aiding in ADLs

evaluation depicted in **Figure 3,** which was conducted using an age simulation suit, identified all the difficulties and limitation the elderly people face, while performing simple tasks in ADLs. In this situation the TurtleBot aids in a great degree, allowing ageing society people to be relieved from heavy loads such as shopping bags, while entering the flat entrance. The user issues a vocal command, stating the preferred location where the TurtleBot should deliver their groceries. The MMU then issues a command to MCU, in order to initiate the autonomous navigation within the flat, by acquiring the previously stored map data.
Another feature of the proposed system is the monitoring of the user vital signs and health status. The implementation currently integrates a Diagnostic scale, which provides a bioelectric impedance analysis (B.I.A.), measuring body fat, body water, and muscle mass, and a wearable wrist measurement device for heart rate and body temperature monitoring. These sensors are wirelessly interfaced to the MCU computer. Once the user senses a feeling of discomfort, can issue a vocal command to the MMU. The MMU then triggers a command to the MCU, to get the vital sign sensors readings from the individual. The readings are then displayed in the monitor of the robotic service wall (**Figure 9**).
The main idea behind the implementation of the robotic

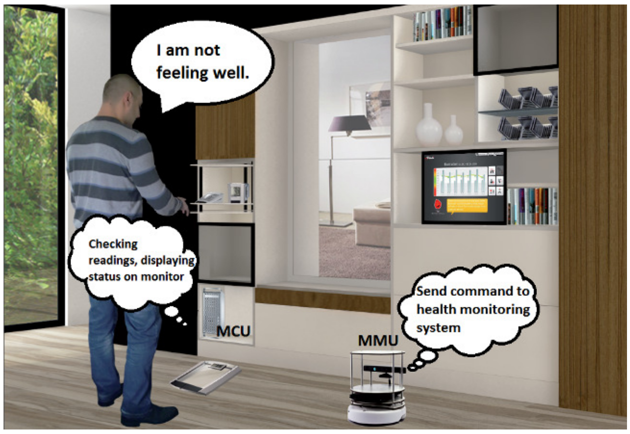

Figure 9 Checking user vital signs

service wall is to utilize as much as possible less space, and on the same time being able to provide a series of services and applications to the user. Thus, the whole design procedure was focused into movable mechanisms and elements that can be deployed on demand, whereas retracted into the structure once they are not needed. Additionally the monitor and input terminal (keyboard/touch screen) of the proposed architecture are deployed along either side of the user to form a cockpit type arrangement, or a gateway, in order to utilize less space and at the same time provide improved ergonomy.

3.5 Service Concepts

The concept behind developing the robotic service wall, equipped with micro system technology, aims at creating the basis for a product service system in the field of prevention, and wellness. Still, the system can be seen as an intermediate stage towards integrating tele-medical services and tele-consultation in the living environment. Furthermore, objects, equipped with micro system technology, provide an ideal user interface for initializing these services.
Principally, the initializing of services can take place in three different ways:

- Manual activation of the service (television, remote control, tablet…)
- Autonomous or semi-autonomous initializing by sensor technology (motion sensor, vital data gathering…)
- Initializing based on algorithms and fusion of information from different systems (e.g. Ambient Intelligence)

Micro systems and data acquisition platforms are increasingly established in the living environment. The robotic service wall can make an important contribution, so that the micro system technology, necessary for development, will be situated inconspicuously in the living environment. Furthermore, the integration of the robotic service wall with TurtelBot is considered as an intermediate step for the delivery of customized 3rd party services. Through modularity on environmental level (Customized Environment Configuration), functional level (Customized Functions/Tools) and service level (Customized Services) completely customizable high-tech service environments are proposed (**Figure 10**).

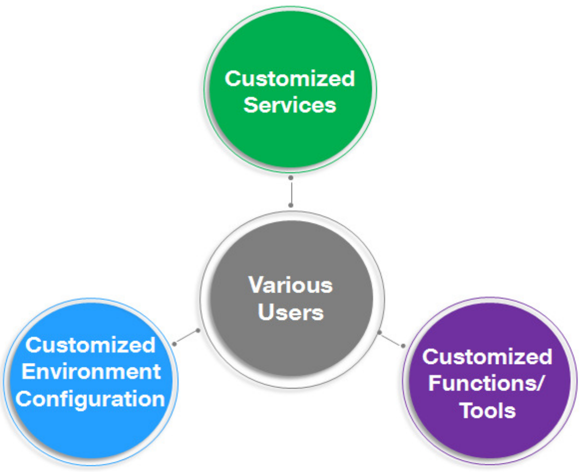

Figure 10 Customized Service Delivery

4 Conclusions and future development

A novel AmI robotic environment oriented towards the ageing society has been proposed and implemented. It employs a novel robotic service wall which can be installed into various locations within a residence, as well as a TurtleBot to enable advanced assistance service delivery. Both from qualitative and quantitative terms, concerning the accuracy and response rate of the embedded actuators and sensors and the various robotic elements, an efficient method dealing with ADLs has been proposed. As a result, it could be applied to enable an AmI robotic environment featuring high-speed tracking and mobile robots, object recognition and navigation, biometrics, speech recognition, and many more.

The proposed architecture is currently in its final stage of development. The robotic service wall is at present under its final manufacturing and implementation stage. Once finalized the corresponding specifications are going to be selected according to further experimentation and evaluation stages, to conclude the final features of the end product. The TurtleBot interfacing accordingly follows a similar approach, since the interaction and communication with the robotic service must achieve optimum compatibility, error free operation, and real-time response.

Customization of the services delivery is promoted by the proposed implementation, since the behaviour, role, arrangement, can be defined according to the individual user needs and preferences. The proposed robotic service wall offers adaptation, expandability, and application oriented functionality.

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