Home Environment Interaction via Service Robots and the Leap Motion Controller

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Abstract -

Ageing society and individuals with disabilities faces numerous challenges in performing simple tasks in Activities of Daily Living (ADLs), [1]. ADLs represent the everyday tasks people usually need to be able to independently accomplish. Nowadays caring of elderly people becomes more and more important. Performance of ADLs in the long term view can be considered as a serious concern, especially when dealing with individuals who require extreme caregiver assistance. The objective of this paper is to introduce an Ambient Intelligence [2], real-scale home environment implementation, embedded with sensors and actuators, which enhances the independence and autonomy of the individuals upon performing ADLs. A real 1:1 scale experimental flat has been design and developed (Figure 1), in the authors experimental laboratory. A study was made to be able to determine the actual needs, required services, and functionality of the proposed augmented environment. In order to allow a high quality service delivery, a mobile autonomous rover [3] was introduced to act as the main human-machine interface between the user and the distributed robotic systems and actuators. The mobile rover was wirelessly interfaced with the distributed intelligence to allow efficient interaction with the user, either passively, by vocal commands issued by the user, or adaptively, by autonomously navigating into the home environment. Moreover the Leap Motion hand gesture driven controller [4] is used as an intuitive user interface, which allows sub-millimeter accuracy capabilities, interfaced to a Jaco 6-Degrees of freedom robotic arm [5]. Many robotic systems have been designed and produced for assisting ADLs, in order to compensate this loss of mobility. However most of these solution are operated via a keyboard or joystick, which according to the complexity of the robotic system, require a series of configurations and mode selection routines in order to allow a specific trajectory path to be implemented. The authors developed new intuitive interfaces to operate such devices, in order to reduce the involved operation complexity. The user is able with simple gestures to operate and control complex robotic manipulators and mobile robots, without requiring the use of a joystick or a keyboard. The resulting accuracy and evaluated performance of the implemented interfaces, allow error free, continuous, and adaptive interaction between user queries and actuated environment responses.

Keywords-

Robotics and Mechatronics; Sensor Fusion; Ambient Assisted Living; Autonomous Navigation; Leap Motion Controller; Jaco Robotic Arm

1 Introduction

Ambient Intelligence (AmI) is an emerging discipline that incorporates a degree of intelligence into human daily living. AmI is generally associated with systems that are receptive to individuals, reactive to the presence of persons, nonintrusive, ubiquitous, and mainly embedded. AmI is usually identified with intelligent sensors and software embedded in our daily environments [6]. Human-robot interaction and cooperation has become a topic of increasing importance, especially tasks unifying the workspace of humans and robots, which are most common in service applications.

Today, robots and distributed robotic sub-systems start to permeate our every day surrounding, enhancing it with services and additional features. At the same time, this permeation is on the way to transform our perception of what robots are, robot technology, robots' possibilities and the environment they are merged with. This transformation which has to be understood as a natural part of the evolution of robotics, will especially become visible when robots enter the field of service and assistance [7].

Ageing society requires novel approaches for placing mechatronics and robotic service technologies in living environments for assisting in daily activities. Already in early development phases, knowledge at least from the architectural, medical and robotic field is necessary, and subsequent product development even requires further fields (e.g. appropriate groups within the healthcare system) to be also involved. By entering the third stage of life (70 - 85) health problems and limitations occur more frequently. Therefore elderly people face huge difficulties to manage their ADLs independently. In most cases the straightforward solution in an intensive care retirement home. As retirement homes are running out of places (also hospitals) because of the demographic change problem, novel solutions for elderly people that offer independent living in their own home environment by the use of assistive robots should be designed and developed.

In this paper the use of a mobile rover as a communicator between the user and the distributed intelligence as well as novel intuitive interfaces for controlling robotic assistive systems based on human gestures and vocal commands, in a 1:1 scale experimental flat are described. The main idea is the realization of an AmI robotic assisted home environment, in order to increase the independence, autonomy and quality of living of ageing population, upon performing their ADLs.

The structure of paper is as follows. Related work is presented in section 2. In section 3 the experimental environment and the implemented interfaces for controlling the assistive robotic systems are explained. Conclusions based on the developed application which will serve the need of simple interfaces for human-machine cooperation and their interconnection with robotics and distributed intelligence are presented in section 4.

Figure 1. Interactive Home Environment

2 Literature Review

Some researchers already proposed integrated solutions for intelligent and assistive robotic environments as e.g. Robotic Rooms [8], Wabot House [9], or Robot Town [10]. 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. Since the 1980s several research groups have created environments and prototype buildings for so-called smart buildings. Based on Ken Sakamuras T-Engine Hardware and a complementary operating system, the Tron House 1, 2 and 3 have been built [11]. The US AwareHome [12] and PlaceLab [13] follow a similar approach and MIT's House_n [14] includes even modular intelligent furniture that can be equipped with various sensor systems. Recently designed German prototypes of assistive homes, such as "Haus der Gegenwart" (house of presence) [15] and "Haus der Zukunft" (house of the future) [16], are exemplarily equipped with a variety of networked pervasive technologies integrated by modern design. Similar to our approach Smart Buildings and Robotic Rooms try to integrate sensor-actuator systems with architectonic elements. However, these approaches integrate mainly sensors, actuators and robots on an informational level. Furthermore, they are presenting implementations that are realized in a controlled experimental environment, and cannot be straightforwardly applied into a regular medium sized apartment to serve as an integrated assistive system for ADLs.

In the last few years, different optical sensors have been developed, which allow the mapping and acquisition of 3-D information. Various applications also have been introduced, which exploit the increasing accuracy and robustness, and the decreasing cost over time of 3-D sensors [17]. The applications range from industrial use, object tracking, motion detection and analysis, to 3-D scene reconstruction and gesture-based human-machine interfaces [18]. These applications have different requirements in terms of resolution, frame-rate throughput, and operating distance. Especially for gesture-based user interfaces, the accuracy of the sensor is greatly considered a challenging task [17, 19]. The Leap Motion controller introduces a new novel gesture and position tracking device with sub-millimeter accuracy [20]. The controller operation is based on infrared optics and cameras instead of depth sensors. Its motion sensing precision is unmatched by any depth camera currently available, to the best of the authors knowledge so far. It can track all 10 of the human fingers simultaneously. As stated by the manufacturer, the accuracy in the detection of each fingertip position is approximately 0,01mm, with a frame rate of up to 300 fps.

Speech-based applications primarily require uninterrupted, real-time speech recognition. An intelligent, interactive personal information assistant using natural speech is an example for replacing the slow stylus input and cramped graphical user interface of a PDA. Several recent applications, like voice control of GPS navigation systems and voice-controlled automotive infotainment services [21] crave a stable vocal interface. This certainly means that sophisticated natural language applications like handheld speech-to-speech translation require agile, low complexity, and real-time performance speech recognition algorithms. Various technological problems have interrupted the stationing of vocal applications on embedded devices. The most challenging of these problems is the computational necessities of continuous speech recognition for an application having extensive glossary scheme. The demand to decrease the capacity, size and power consumption for these devices compromises in their hardware and operating system software that restrict their capabilities. The raw CPU speed is one of the underlying compromises. Embedded CPUs generally lack hardware support for floating-point arithmetic functions. Furthermore, embedded devices also have very limited memory, storage capacity and bandwidth [22]. For these consequences, previous research [23, 24], has focused on simple tasks by strictly limiting vocabulary for an application. In the proposed implementation, PocketSphinx [22, 25], an open-source embedded speech recognition system capable of real-time, medium-vocabulary continuous speech recognition, was used by the authors, which was accordingly modified regarding the followed hardware infrastructure.

3 Proposed System architecture

A 1:1 scale experimental home environment was implemented in the authors laboratory in order to allow the implementation, development and testing of the human-machine interaction and robotic assistive systems.

3.1 Turtlebot Autonomous Navigation and Tele-operation

The Turtlebot mobile rover platform was used [3] to act as the human-machine communication interface (Figure 2). TurtleBot is able to acquire visual information using the Microsoft Kinect Sensor [18]. The depth sensor consists of an infrared laser projector combined with a CMOS sensor, which capture 3-D real-time data. The sensing range of the depth sensor is adjustable, and the Kinect embedded software is capable of automatically calibrating the sensor based on the user physical environment arrangement, 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, elderly people can be assisted by TurtleBot, in low lighting conditions and even if lights are switched off, i.e. during the night. Once TurtleBot is introduced into the home environment, the exact interior configuration 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) [26, 27]. 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 exact current location and orientation within the environment. 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, the mobile rover can efficiently autonomously navigate within the environement space. Figure 3 depicts the recorded interior mapping.

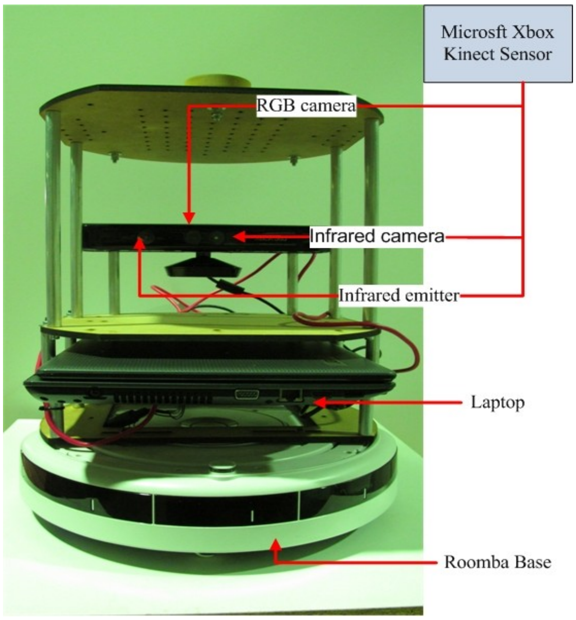

Figure 2. Turtlebot Mobile Platform

The Turtlebot tele-operation is based on ROS open source software [28]. ROS is an operating system that allows for real-time processing of multiple algorithm instances across a network of computers, to guide a robot or group of robots autonomously, in a Master-Slave communication scheme. The ROS master computer, in the proposed research project is comprised by the Turtlebot onboard laptop computer. Therefore all messages that are sent across the network are passing through the onboard laptop. The ROS slave workstation was placed inside the experimental flat. The slave workstation mainly provides the Turtlebot with navigation and localization related information.

Additionally the slave workstation enables the user to tele-operate the robot using any user input device connected to it. Additionally a communication interface was implemented to be able to tele-operate the Turtlebot using a standard Android/based phone or tablet device. The ICT connectivity is depicted in Figure 4.

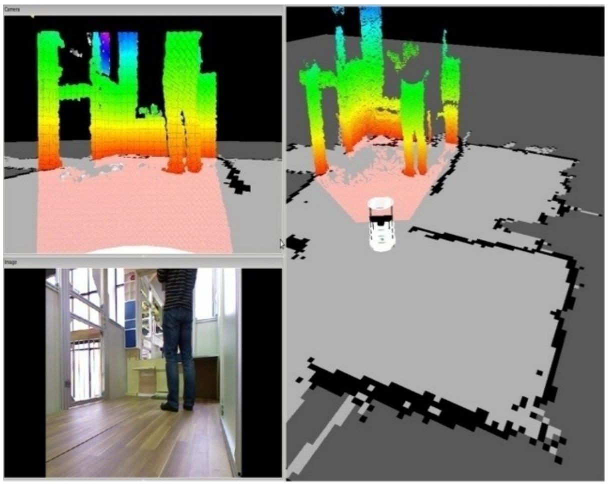

Figure 3. 3-D point cloud of actual interior space arrangement

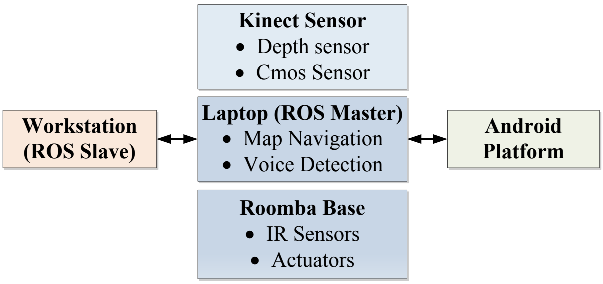

Figure 4. Overview of ROS Connectivity

3.2 Speech-driven Navigation and Tele-operation

As earlier mentioned in section 2, the PocketSphinx speech recognition application was used for the implementation of the vocal command driven human-machine communication interface. A special dictionary was created and vocabulary files were generated. The voice application compares the user vocal queries with the precompiled dictionary words and then publishes a matching word via the recognizer application. This allows the vocal-driven navigation of the Turtlebot throughout different locations in the flat. A set of five keyword phrases were used: “entrance” “kitchen” “bedroom”, “bathroom”, “living room”. When these words are detected by the Turtlebot onboard microphone input device, the requested destination point and orientation of the robot are sent as coordinates to the mobile rover. It operates autonomously dynamically avoiding any obstacles in its path, by reconfiguring in real-time its trajectory. The implemented algorithm flow chart for the speech driven operation is presented in Figure 5.

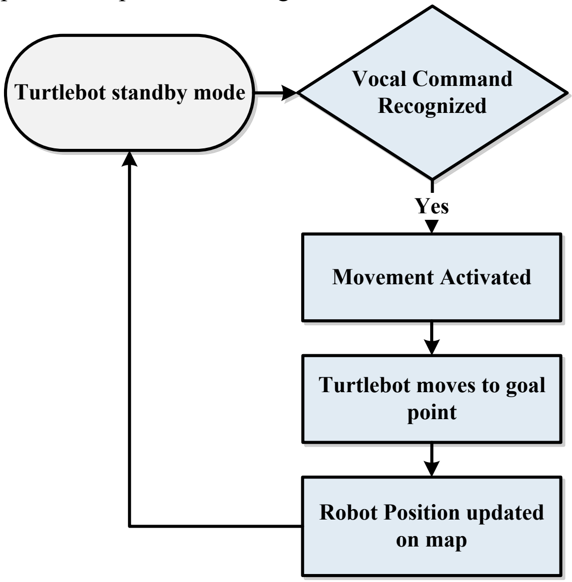

Figure 5. Flow chart of speech-driven autonomous navigation

3.3 Leap Motion controller Navigation and Tele-operation

A new sensor which introduces a novel gesture and position tracking system with sub-millimeter accuracy was used to navigate the mobile rover by user issued hand gesture patterns. The Leap Motion controller, (Figure 6), tracks the user’s palm posture, and all the accompanied “roll”, “pitch” and “yaw” orientation angles, thus all information regarding the user palm Cartesian position and orientation is retrieved from the sensor.

Figure 6. Leap Motion Controller device

Once the user palm is introduced into the operating range of the Leap Motion controller (a hemispherical area of approximately 1 meter radius), the roll and pitch values of the users palm posture are recorded with a rate of up to 300 times per second. Data streams for roll and pitch angles are generated by accordingly rotating the user hand towards the roll and pitch angles (Figure 7). The recorded roll angle values are interpreted into left/right rotation of the Turtlebot, and the recorded pitch angle values into forward and backward movement of it (Figure 8). An efficient algorithm using sequence of checks and conditions was implemented to enable a smooth translation between the recorded user palm posture, and the navigation commands sent to the Turtlebot. An intuitive "virtual joystick" function was thus implemented to navigate the robot using the Leap Motion controller – user palm interaction.

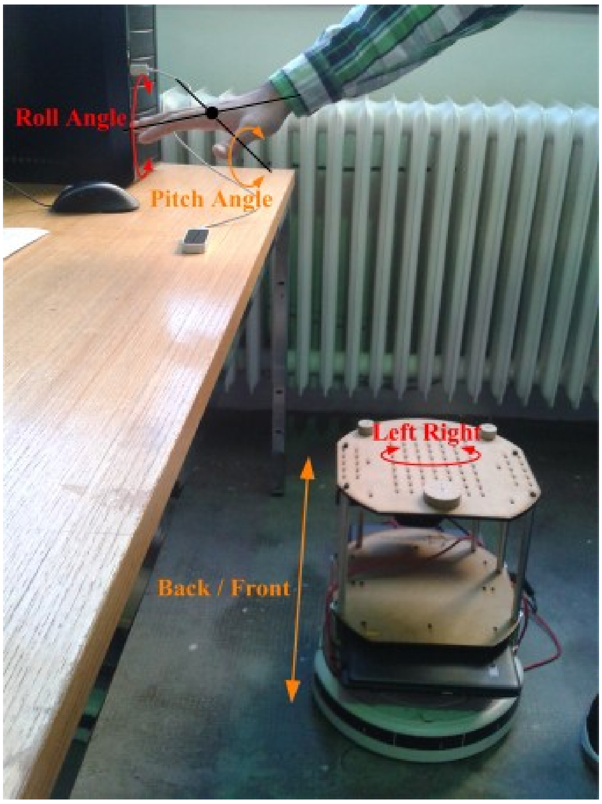

Figure 7. Roll/Pitch - Rotate/Move translation scheme

The proposed tele-operation of Turtlebot using the Leap Motion controller enables an intuitive manipulation considering the mobile robot navigation within the home environment, due to the fact that the controller comprises a compact size sensor, which can be discretely placed in the vicinity of the user, efficiently replacing bulky input devices such as keyboards and joystics.

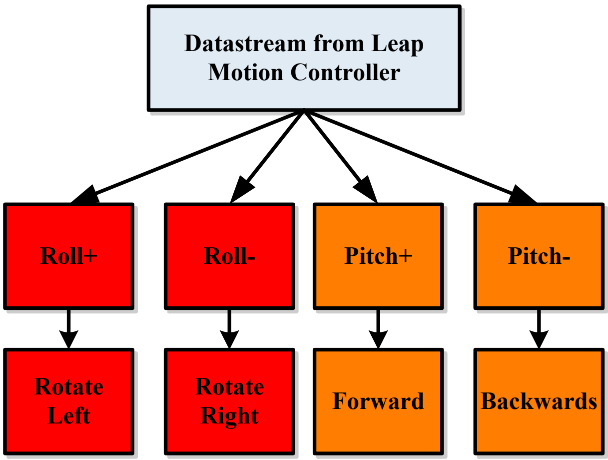

Figure 8. Leap Motion Controller data stream interpretation

3.4 Leap Motion controller – Jaco Robotic arm interface implementation

In the proposed implementation the authors introduce a novel human-machine interface which offers intuitive and adaptive manipulation in ADLs, using the Leap Motion controller and the Jaco arm [29].Some researchers already evaluated the efficiency of robotic systems, specifically robotic arms, used by disabled individuals in performing ADLs [30, 31]. An important parameter when concerning the efficiency of assistive devices for disabled individuals is the economic benefit in terms of comparing the robotic system cost with the total cost required for a caregiver, in a long term scheme. The Jaco robotic arm, can efficiently substitute caregivers as a cost saving alternative [5, 32].

Most manipulators are operated via a keyboard or joystick, which according to the complexity of the robotic arm, require a series of configurations and mode selection routines by pressing a series of buttons, in order to select the desired operating mode, or to perform a specific trajectory path translation. The authors research on new ways to operate such devices, in order to reduce the involved operation complexity, since elderly people tent to face difficulties upon operating a complex interface, or refrain from further on a daily basis since they consider the interrelated controlling scheme complicated. Instead of using the original joystick "Kinova Joystick" of the Jaco arm and thus having to switch between different modes of control, the joystick is replaced with the Leap Motion controller which allows for an intuitive human-machine interface realization. The Leap Motion controller monitors the user's hand/hands, fingers, and all the accompanied positions and angles. All information regarding the user palm Cartesian position is retrieved from the controller and fed to the algorithm. The algorithm uses the current and previous information supplied by the controller and achieves an optimum realistic mapping between the user's real arm and the Jaco arm. Additionally the arm's angular features such as roll, pitch, and yaw angles are considered to the mapping procedure, enabling a realistic translation of the human arm. The Jaco arm fingers were also programmed to follow all grasp and release operations performed by the user fingers. To address safety requirements between the user and the arm, safe zones were considered according to the operating workspace of the robot, in order to ensure safety in case of unintentional user hand movements within the operating range of the Leap Motion controller.

The Leap Motion - Jaco arm operation was adapted into various locations of the home environment, i.e. the bed, entrance, and also to a wheelchair within the flat (Figure 9). The main contribution of developing such interfaces is to introduce the assistive services and functions that the Jaco arm offers in performing ADLs. Ageing society faces numerous challenges in performing simple tasks in ADLs. Nowadays caring of elderly people becomes more and more important. Individuals with upper limb impairments, also face difficulties to perform ADLs, especially in cases where the impairments have resulted from spinal cord injuries, neuromuscular diseases, etc. Many technical aids have been developed to assist in impairments in the home environment. However these assistive devices provide limited functionality and cannot address in an efficient way independence and autonomy [33, 34]. By introducing the Jaco arm within the proposed interactive home environment, and by focusing on assisting the user on various daily living activities by an intuitive, easy to operate, gesture driven compact size sensor, a new human-machine communication scheme can be established.

3.5 Overall system architecture

The proposed system architecture is presented in Figure 10. The Leap Motion controller is connected via USB to the ROS Master PC, which is comprised by the TurtleBot onboard laptop. Additionally the Android-based mobile device is wirelessly connected to the ROS Master PC. Both the Leap Motion controller and the Android-based platform comprise the user "Input Level". The related user input queries are:

a) "roll" and "pitch" angles of the user palm recorded data required to navigate the mobile platform (Leap Motion controller),
b) user palm posture in terms of position and orientation required for the manipulation of the Jaco arm trajectory planning and Jaco arm fingers grasp-release operations (Leap Motion controller),
c) key-based graphical user interface to navigate the Turtlebot in the proposed home environment (Android-based device).

The remaining of the system architecture comprises the Jaco arm operation ("Output Level"), where a dedicated miniPC according to the home environment setting (bedroom miniPC, Entrance miniPC, Wheelchair miniPC) is used to provide the recorded input data from the Leap Motion controller. The data exchange communication between to the Turtlebot Master PC and the dedicated miniPCs is implemented using standard TCP/IP sockets, where raw data recorded from the Leap Motion controller are wirelessly, via a WiFi local area network, transferred to the Jaco arm, which is connected via USB to the dedicated miniPCs. For the experiments conducted under the proposed work, a single Jaco robotic arm was used, manually exchanged between the bedroom, entrance and wheelchair settings.

Figure 9. Leap Motion Controller Jaco Robotic arm operation under various arrangements

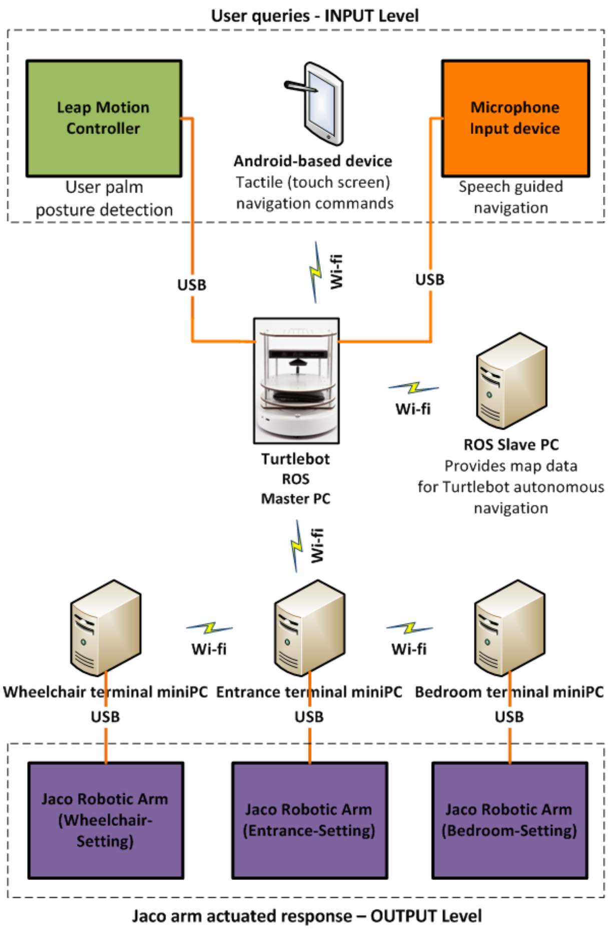

Figure 10. Proposed Human-Machine Communication System Architecture

4 Results and Further Development

The proposed robotic home environment interaction scheme is still under development in order to define final specifications and offered services, and to enhance its functionality and operation towards the user. Currently the vocal user queries for the voice guided navigation are limited to a specified dictionary list of queries. Tests implemented to evaluate the system performance presented a real-time response between user vocal queries and resulting signaling commands to the mobile robot motor drives. The observed real-time response efficiently provides a responsive system with minimal error rate. Errors are currently introduced by the voice recognition module, in case ambient noises are dominant. This error rate can be minimized by an appropriate voice recognition training stage, corresponding to a new set of vocal commands that would allow efficient differentiation of user queries and ambient noises false interpretation.

The Leap Motion controller undoubtedly comprises a very efficient and real-time response module. Due to its enhanced sampling frequency (up to 300 frames per second) and accuracy (submillimiter), it appropriately addresses the need for short time delays between user queries and system response. Fusing such a responsive controller device with the various robotic subsystems (Turtlebot and Jaco Arm), extended functionality can be enabled to the user, once many features and service dealing with navigating the mobile rover and actuating the robotic arm can be dealt with a highly intuitive manner, and more importantly via the same terminal.

Further development of the proposed human machine interface comprises user friendly operation of such complex robotic systems, since elderly people tent to face difficulties upon operating a complex interface, or refrain from further on a daily basis since they consider the interrelated controlling scheme complicated.

5 Conclusions

Performance of ADLs in the long term view can be considered as a serious concern, especially when dealing with individuals who require extreme caregiver assistance. The objective of this paper is to introduce an Ambient Intelligence real-scale home environment implementation, embedded with sensors and actuators, in order to enhance the independence and autonomy of the individuals upon performing ADLs. Thus, a 1:1 scale home environment has been design and developed in the authors' experimental laboratory. The home environment was constructed according to the actual needs, required services, and functionality of the proposed augmented environment. In order to allow a high quality service delivery, a mobile autonomous rover was introduced to act as the main human-machine interface between the user and the distributed robotic systems and actuators. The mobile rover was wirelessly interfaced with the distributed intelligence to allow efficient interaction with the user, by user issued vocal commands and by autonomous navigation into the home environment. Moreover a novel high precision gesture driven 3-D scanning controller is used to develop an intuitive user control interface. By wirelessly interfacing this compact size gesture driven controller with the mobile platform and also a lightweight robotic arm, a novel human-machine control interface is implemented. Mobile rovers and robotic arms, require some standard user input devices, such as keyboards, joysticks, etc. By using this new compact gesture driven controller the authors propose new ways of operating such platforms, in order to reduce the involved operation complexity. Such an approach enables the straightforward incorporation of robotic systems into the proposed home environment, to enhance the independence and autonomy of individuals upon performing ADLs.

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