Intuitive and Adaptive Robotic Arm Manipulation using the Leap Motion Controller

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Abstract

Robotics provide an efficient approach in the development of assistive devices, due to their enhanced functionality. Statistics predict that by 2035, half of the population in Germany is going to be older than fifty, every third person even over 60. These ageing societies face numerous challenges in performing simple tasks in Activities of Daily Living "ADLs". Increasingly, a lot of research is being focused on Ambient Assisted Living "AAL" which presents a new approach that promises to address the needs of elderly people. An important goal of AAL is to contribute to the quality of life of the elderly and handicapped people and help them to maintain an independent lifestyle. The introduction of robotics and technology-supported environments will play a huge role in allowing elderly and physically impaired people to keep living a self-determined, independent life in their familiar surroundings. In this paper, the implementation of a novel intuitive and adaptive manipulation scheme is proposed, by developing a human-machine communication interface between the Leap Motion controller and the 6-DOF Jaco robotic arm. An algorithm is developed to allow an optimum mapping between the user hand movement, tracked by the Leap Motion controller, and the Jaco arm. The system should allow for a more natural human-computer interaction and a smooth manipulation of the robotic arm, by constantly adapting to the user hand tremor or shake. The implementation would specially enhance the quality of living, especially for people with upper limb problems, and would support them in performing some of the essential Activities of Daily Living "ADLs". The applications of this human-robot interaction will be discussed in relation with Ambient Assisted Living, where some use case scenarios will be introduced.

1 Introduction

Impaired or aged individuals require novel approaches for placing mechatronics and robotic assisted services in their living environments. The development of such systems should be focused on cost effectiveness, ease of control, and safe operation, in order to enhance the autonomy and independence of such individuals, minimizing at the same time the necessity for a caregiver. Already in early development phases, knowledge at least from the robotic, medical and ergonomic field is necessary.

Ageing society 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. 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 [2, 3].

Some researchers already evaluated the efficiency of robotic systems and more specifically robotic arms, used by disabled individuals in performing ADLs [4, 5]. 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 [6, 7].

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 [8]. The applications range from industrial use, object tracking, motion detection and analysis, to 3-D scene reconstruction and gesture-based human machine interfaces [9]. 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 [8, 10]. The Leap Motion controller introduces a new novel gesture and position tracking system with sub-millimeter accuracy [11]. 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.

In the proposed paper the authors develop a human-machine interface which offers intuitive and adaptive manipulation in ADLs, using the Leap Motion controller and the Jaco arm.

2 Gesture-based Human-Robot Interaction

Since the introduction of computers to our world, we have been witnessing creative inventions in the science of hu-

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man-computer interaction. For many years, the term "input device" evoked mainly two specific devices: the keyboard and the mouse - the main instruments used to provide user input to a personal computer. Nowadays, with the evolution of computers, and the increasing research on human-computer interaction technologies, we have a large set of input devices that changed the way of interaction. The new approaches of human-computer interfaces will facilitate a more natural, intuitive communication between people and all kinds of sensor-based input devices, thus more closely mimicking the human-human communication [12]. Innovative technologies empower users to be more natural and spontaneous when dealing with them. Also, the systems adopting these technologies show increased efficiency, speed, power, and realism. However, many users feel comfortable with traditional interaction methods like mice and keyboards to the extent that they are often unwilling to embrace new, alternative interfaces. A possible reason for that might be the complexity of these new technologies, where very often users find it disturbing to spend a lot of time learning and adapting to these new devices. Gesture-based human-computer interaction could represent a potential solution for this problem since they are the most primary and expressive form of human communication [12]. Two successful examples of 3-D optical sensors are: the Nintendo Wii and the Microsoft's Xbox Kinect. Each of the two examples have its own operating principle. The Wii operates by means of a remote which the user has to keep holding during the entire operation time. The Kinect was initially developed to allow the user to interact with the Xbox without any controllers, however it was used further as a vision platform in many different applications. An analysis of the Kinect controller showed that it has an approximately 1.5 cm standard deviation in depth accuracy [8].

The Leap Motion Controller is considered a breakthrough device in the field of hand gesture controlled human-computer interface. The new, consumer-grade controller introduces a new novel gesture and position tracking system with sub-millimeter accuracy. 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 author's 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 [13].

Figure 1 The Leap Motion Controller

The controller is considered to be an optical tracking system based on stereo vision. Within its surface area of 24 cm², the controller has three IR (Infrared Light) emitters and two IR cameras [11]. The field of view of the controller is very wide, up to 150° [13], which gives the user the opportunity to move his hand in 3D, just like in real world.

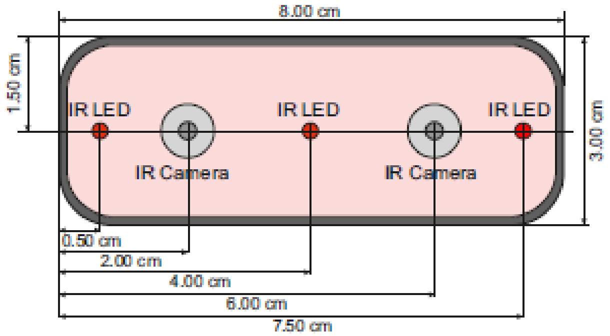

Figure 2 The schematic view of the Leap Motion Controller.

The Software Development Kit (SDK) supplied by the manufacturer delivers information about Cartesian space of predefined objects such as the finger tips, pen tip, hand palm position, etc. Also, information about the rotations of the hand (e.g. Roll, Pitch, and Yaw) are available as well. All delivered positions are relative to the Leap Motion Controller's center point, which lies between the two IR cameras, just above the second IR emitter.

3 Proposed Concept

3.1 Supporting elderly and disabled people in home environments

After discussing about the demographic changes that the world is experiencing and will continue to experience during at least the next few decades, after seeing the challenges that elderly and impaired people face in order to perform simple ADLs, and after recognizing the potential role that robotics could perform in the AAL field, a novel implementation is proposed in this paper.

The most common human-robot interaction is achieved via a keyboard or a 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 an operating mode, or to perform a specific trajectory path. After performing research on new ways of operating such devices, in order to reduce the involved operation complexity, a new human-robot interaction scheme is proposed.

The proposed concept depends on what is so called a more "natural" human-robot interaction. The Leap Motion Controller is used to operate the 6-DOF Jaco Robot to perform ADLs in a more intuitive way. 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. The 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 more realistic imitation 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 commands. The adaptive behaviour of the proposed system is achieved by continuously monitoring the user hand movement patters, and estimating oscillation data readings in real-time, which then according to the detected percentage allows the online reconfiguration of the mapping parameters upon runtime, in order to filter out the unwanted oscillation. The resulting implementation is already applied to different research projects, e.g. the BMBF project USA² (Ubiquitäres und Selbstbestimmtes Arbeiten im Alter).

3.2 Virtual-Operation (Tele-operation)

Another use for such a system could be in Tele-operated applications. Tele-operation is a method to operate a robot, while still being at a distance from it. This technique is specially used in dangerous and risky application areas (e.g. space exploration, surveillance, surgery, nuclear plants, and underwater operations). Nowadays, the use of tele-operation systems is spreading to include non-hazardous environments as well. The systems are widely used all around the world in various applications from space applications to entertainment applications [14]. Also the business sector has been positively affected by the introduction of such systems. The operating costs are being lowered, as the real-operator's share on the control process is reduced, and the virtual-operator's share is increased instead. Moreover, work from home for disabled people is now being possible.

3.3 Tremor Detection

The enhanced precision of the of the Leap Motion controller, is considered a disadvantage for the robotic arm manipulation on the one hand, due to the fact that any hand tremor patterns are directly translated to unwanted oscillation on the robotic arm side, i.e. when operated by a patient with Parkinson disease. On the other hand, the sub-millimeter accuracy of the controller could be seen as an opportunity for detecting symptoms related to hand tremor, which can indicate an abnormal disorder. A special part in the proposed algorithm is designed to take care of this problem. The system can detect and process the user palm displacements according to the user hand tremor patterns, adapting in run-time the output data sent to the robotic arm, in order to filter out unwanted oscillation and to enable smooth operation to allow for grab, pick and place tasks.

In Parkinson disease cases, people suffer apart from the tremor, also from rigidity and bradykinesia [15], mostly essential, but also posture [16]. There are already previous studies on how to measure tremor and bradykinesia in the home environment [17, 18], by using acceleration sensors (accelerometers) and gyroscopes. The Leap Motion Controller can be used in the same sense to validate and quantify the tremor and bradykinesia, once it is possible to calculate acceleration in all axes. Also studies were made on quantifying tremor according to displacements using laser [19], which required a specific laser grid arrangement infrastructure. The authors believe that Leap Motion Controller can be efficiently used as an alternative to devices such as accelerometers, gyroscopes, laser grids, etc, for measuring tremor and bradykinesia, in a much more discreet and robust way, due to its compact size, which enables it to be easier introduced to the user vicinity.

4 Implementation

4.1 Steps of Development

4.1.1 Coordinate system transformation

The Leap Motion Controller and the Jaco arm operate on two different coordinate systems. It was very important at the very beginning to relate the two systems together, by performing some rotations. As illustrated in Figure 3, the transformation from the Leap Motion Controller reference system to the Jaco arm reference system resulted in a 90 degrees rotation about the x-axis, followed by 180 degrees rotation about the z-axis.

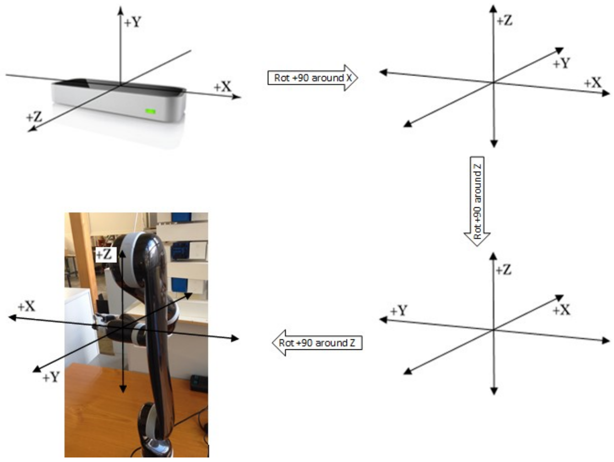

Figure 3 Coordinate system transformation

4.1.2 The Mapping Algorithm

The algorithm represented in Figure 4 is developed to control each motion type of the Jaco arm i.e. Cartesian motion (X, Y, and Z), and Angular motion (roll, pitch, and yaw). Every time a new frame is received from the Leap Motion controller, the algorithm compares the reading with the previous one (which is saved from the previous frame), and accordingly decides on the next steps that need to be followed. If the absolute difference between the two readings is higher than a threshold value (calculated in advance for each user during the calibration process), this means that the arm will react moving either in the positive or negative direction according to the value of the readings. In case of having an absolute difference that is less than the threshold value, the arm will neglect this motion. Different delay times were tested in order to find the optimum delay that allows the Jaco arm to react to the commands received from the algorithm. This process keeps going on with a high frequency rate allowing an optimum imitation of the user's hand. To efficiently neglect hand tremor patterns caused by health problems (e.g. Parkinson's disease), a threshold value for each motion type is extracted during a calibration process.

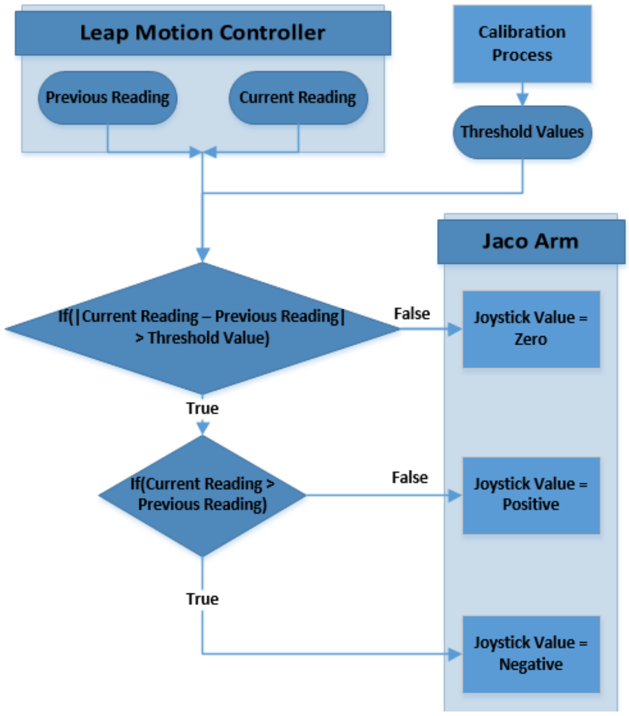

Figure 4 The mapping Algorithm

4.1.3 The Calibration procedure

Before starting the operation, the user perform a specific gesture with his hand or fingers (a clockwise circular gesture) which triggers the calibration process. During this process the user is prompted to fix his hand for a short period of time (10-15 secs). During this period all readings from the Leap Motion controller are stored in data arrays, to be later processed by the calibration algorithm. By applying a conventional filtering technique (the moving average filter) to the readings, the extreme noisy signals are filtered out, hand tremor patterns can be recognized and threshold values can be set accordingly. Threshold values ensure that hand tremor is not reflected to the robotic arm movement.

4.1.4 Palm Cartesian operation

In the first phase of development, all information regarding the user's Palm Cartesian positions (X, Y, and Z) were retrieved from the Leap Motion Controller and fed to the mapping algorithm, implemented using the Jaco API and the Leap Motion Controller SDK files. The algorithm uses the current and previous information supplied by the Leap Controller and achieves an optimum realistic mapping between the user's real palm position and Jaco's palm position. Figure 5 illustrates the operation of the algorithm in the Z-direction of the Jaco arm.

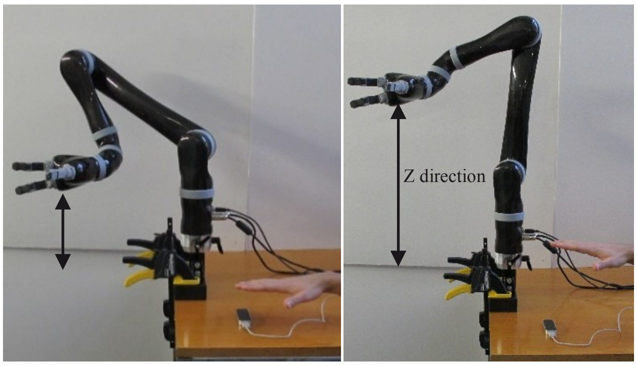

Figure 5 Operation in the arm's Z-direction

4.1.5 Grasp and Release operations

In the second phase of development, the three fingers of Jaco were programmed to follow all grasp and release operations performed by the user. Figure 6 depicts a demonstration of a grasp and release routine. After that, the hand's angular characteristics such as roll, pitch, and yaw angles were considered in the mapping procedure, enabling a more realistic imitation of the human arm.

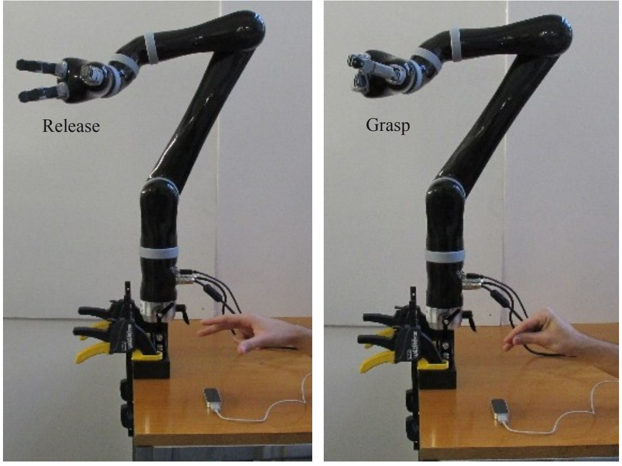

Figure 6 Grasp and Release Operation

4.1.6 Connection with Arduino micro-controller

To enhance the functionality of the system, an interface is established between the developed software and the Arduino Uno micro-controller. This connection allows for the possibility of interfacing any additional sensors, actuators, and display systems (e.g. LEDs, push buttons, display systems, etc.).

4.2 Overall Information Flow Diagram

The diagram below illustrates how information flows between the different entities of the overall system. The user's hand movements are captured by the Leap Motion Controller and sent to the computer. The implemented software algorithm performs all necessary computations, and sends control commands to the Jaco arm. At the same time, information is received-from/sent-to, additional sensors, actuators, and display systems via a microcontroller board.

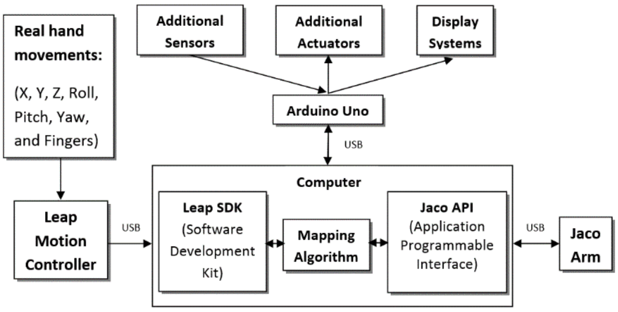

Figure 7 The information flow diagram

5 Application to the USA² Project

5.1 General Overview

The USA² project is focused on decentralized fabrication in modular micro factories, based on the concept of Cloud Manufacturing. The main goal of the project is to offer possibilities for elderly people to work at their home environment and thus contribute to the society. The topic includes research in different areas such as robotics, technology, health, society, and change management. The project aims at offering different work place scenarios (use cases) and a mock-up/demonstrator (to visualize an exemplary working place for testing), Figure 8.

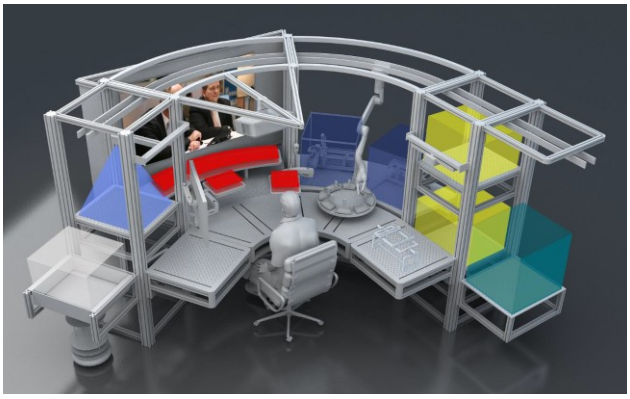

Figure 8 The USA² project demonstrator.

5.2 The Schematic Diagram of the system

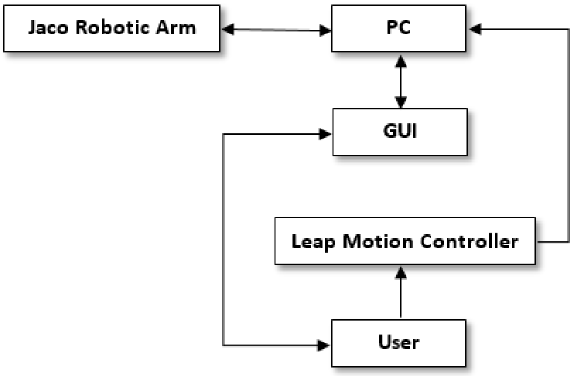

Figure 9 The schematic diagram of the system

As shown in Figure 9, the user directly interacts with the Graphical User Interface (GUI), which is considered the main control unit of the whole system. In case of having the Leap Control active, the Leap Motion Controller tracks the user's hand and fingers, and send this information to the PC. The PC receives information from both the GUI and the Leap Motion Controller and accordingly decides on the suitable information to be sent to the Jaco arm.

5.3 GUI

A GUI was developed in order to control the complex functionality of the Jaco arm in a user friendly way (see Figure 10). The GUI has several push buttons allowing both, automated and manual operation of the arm. Some buttons are responsible for moving the arm to certain fixed positions within the workspace. Additionally, an emergency exit button, stops the arm immediately and closes all running communications. There are two buttons responsible for starting and stopping the Leap control, "Start Leap" enables the control priority to the Leap Motion Controller, while "Stop Leap" disables the Leap control even if the sensor is still tracking the user's hand. Grasp and release operations could be performed by pressing the Grasp and Release buttons respectively. The user is given the option to save a fixed number of temporary positions during operation, thus having the possibility of accessing them later. The interface allows the user to explore all the different functionality of the system with just a series of button presses. This application could run on desktop computers, laptops, or touch screens.

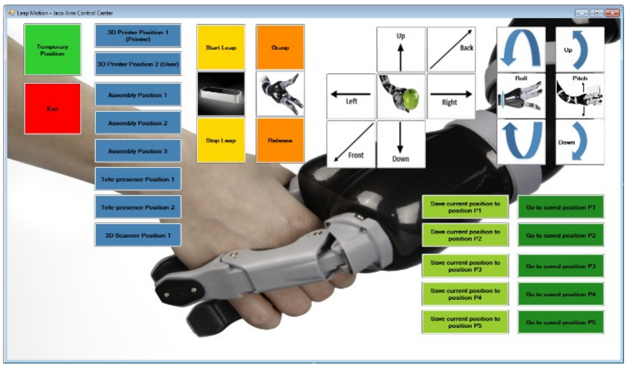

Figure 10 The implemented graphical user interface (GUI)

6 Application to an AAL flat

As mentioned in the earlier in this paper, the main concern of AAL research is to contribute to the quality of living of the ageing society and impaired people, and assist them in maintaining an independent lifestyle in their home environment, as long as possible. The main idea here is to introduce the implemented system of the Jaco arm and the Leap Motion controller to different smart-terminals within the authors experimental AAL flat, and also to mobility aids such as wheelchairs, rollators, etc.

A common problem that elderly people often face when living alone in their home environment is related to medication. Occasionally, they forget to take their medication on time, or maybe face difficulties in preparing it. Some other times, due to mental or sight illnesses, they take the wrong medication at wrong times. These scenarios very often cause serious problems that could risk their lives. Robotic arms could assist in such cases. The Jaco arm could possibly be mounted in the bed terminal, and supply the user with required items. Figure 11 demonstrates such a system concept. The arm could move along the back of the terminal, where it could easily access all the modules of the terminal as well as, the user's personal space.

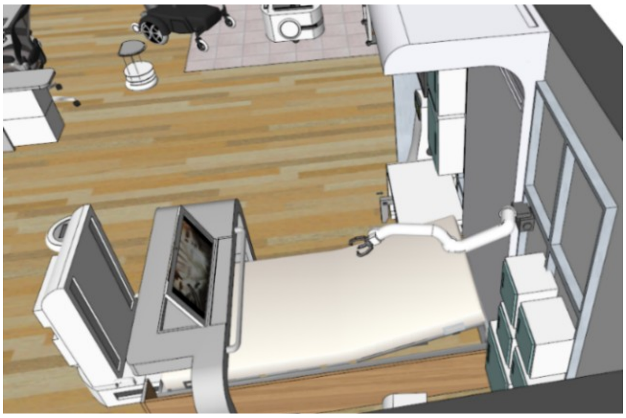
Figure 11 The bedroom terminal

The Lisa Smart Wall comprises a robotic service wall developed under a research project in the area of AAL [20]. The service wall was prefabricated offsite and then delivered as a plug and play terminal. The design is modular and customizable according to the special needs of each user. Different devices and modules could be easily added to or exchanged from the terminal. The Jaco arm could benefit the functionality of the Lisa Smart Wall by offering more assistance to the user. By attaching the Jaco arm and the Leap Motion Controller to the smart wall, the user can intuitively interact via the proposed Jaco arm manipulation algorithm, Figure 12.

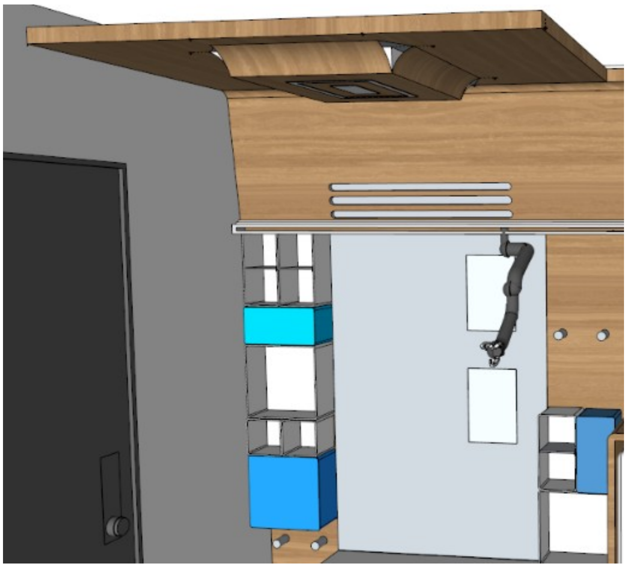
Figure 12 The Lisa Smart Wall


Figure 13 The kitchen terminal

Because of the fact that elderly people spend a large portion of their time in the kitchen, equipping kitchens with assistive mechatronic and robotic systems is essential. The Jaco arm could work along with the user and perform tasks that seem to be difficult for the user to independently accomplish. One very important advantage for the Jaco arm in the kitchen environment is being waterproof according to the IPX2 standard [21], this ensures a safe and efficient operation. Tasks could range from preparing the utensils, raw materials, and the workspace for the user, to a higher level of performing the cooking process itself. A user friendly interface could be designed to allow an easy control of the whole system. A possible scenario for such a kitchen is illustrated in Figure 13.

7 Conclusion

A novel human machine interface is proposed dealing with the intuitive manipulation of a robotic arm for implementing ADLs, using a new gesture and position tracking system with sub-millimeter accuracy. The main objective of this study is to introduce a simple and straightforward robotic arm manipulation scheme, in order to enable the incorporation of robotic systems into the home environment, to enhance the independence and autonomy of individuals with severe mobility impairments, and to allow at the same the monitoring and prevention of abnormal disorders such as hand tremor patterns i.e. Parkinson's disease. The use of the implementation in teleoperated applications has also been discussed. It could serve operations going on in risk environments, as well as a wide variety of non-hazardous applications.

The authors believe that the Leap Motion Controller technology would be undoubtedly benefit and enable the realization of various human-machine interaction application in the field of AAL and ADLs, due to its compact size, enhanced precision, and low purchase cost.

8 Acknowledgements

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