Cybi: A smart companion robot for elderly people

Improving teleoperation and telepresence skills by combining Cloud Computing technologies and Fuzzy Logic

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***Abstract*—This paper describes Cybi, an inexpensive smart companion mobile robot for elderly and disabled people. The software architecture that enables users to perform telepresence and teleoperation tasks with Cybi is based on combining Cloud Computing technologies and Fuzzy Logic. On one hand, the robot can be remotely teleoperated from a thin client by executing a specific module of a distributed software component that uses ROS, WebRTC and Google App Engine. On the other hand, Cybi is capable of understanding simple spoken orders that allow it to navigate through an unknown domestic indoor environment. In both cases, a fuzzy reactive navigation software component is used with the aim of making the teleoperation procedure as easy and safe as possible for both elders' caregivers and elderly users themselves. Finally, several real tests are also presented, demonstrating that Cybi could be considered as a suitable robotic companion, since the proposed methods enhance the performance of teleoperation and telepresence tasks.**

Keywords—Smart robot; telepresence; teleoperation; Fuzzy Logic; elderly people; disabled people

I. Introduction

According to the World Health Organization (WHO) predictions [1], the life expectancy at birth is being moderately increased in the world. This growth is even more noticeable in the group of developed countries, where population ageing is a widespread phenomenon whose impact on many fields (mainly economy, family and health care), can be considered as a major issue [2].

Although the physical and psychological conditions of each elderly person could vary, most elderly people suffer from certain diseases related to age, such as cardiovascular troubles, pain, osteoarthritis, deterioration of mental faculties and general distress, among others. Consequently, many senior citizens have special needs and requirements that make leading an independent life difficult. In many cases, the relatives have to take on the responsibility of eldercare, and this situation often complicates balancing work and familiar life.

Technological solutions that combine service robots and Ambient Assisted Living (AAL) systems could help elderly people and their caregivers to improve their daily life. For example, imagine that an elderly person has to stay at home and is unfit for accomplishing certain tasks. The relative that acts as caregiver needs to go out for a period of time, but wants to easily communicate with the elderly person if necessary. A smart companion mobile robot could be the perfect assistant that facilitates such communication. On the other hand, the robot could also be used by elderly people themselves. For example, if they want to carry out certain simple domestic tasks, such as transporting objects (when their physical capabilities are reduced), or to interact with entertainment applications that allow them to improve their physical or mental condition. The robot could also be programmed to automatically remain them some important daily actions, such as taking the medication.

Someone could probably think that there exist enough commercial smart mobile devices designed to meet these goals. However, nowadays, the use of this kind of electronic devices does not look familiar for many potential senior users. Consequently, the companion robot can be considered as a key element that brings technology closer to elderly people, without the need of users having handle complex devices or software programs that could lead them to a frustrating and confusing experience.

According to the aforementioned goals, the companion robot should be capable of:

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- Being remotely teleoperated in a safe manner by users that use typical smart devices (thin clients).
- Being teleoperated by using voice commands and gestures. This is particularly useful for elderly people with reduced mobility.
- Transparently interacting with other electronic components that comprise the AAL ecosystem (if present).
- Being relatively inexpensive. In fact, if it is expected to market this kind of robots, such cost should not excessively exceed the cost of a typical electrical household appliance.
- Being accepted by potential users, from the point of view of usability, accessibility and ergonomics.

Designing an efficient and reliable companion robot involves to take some issues in consideration. In particular, remote teleoperation is a key element for enabling the remote communication between caregivers and elderly people in a natural and easy way; however it is also necessary to ensure the protection of senior users' privacy. In addition, teleoperation tasks require to be carried out in a safe manner, even when the Internet connection fails or other critical situations happen. Then, the robot should be autonomous enough to take proper decisions related to reactive navigation and obstacle avoidance. Finally, it is important to decide which sensors and actuators are needed, and to try to balance performance and safety and economic cost.

Some companies and research groups have presented different approaches for developing Ambient Intelligence based systems for healthcare with the aim of enhancing the daily life of handicapped people [3]. However many of these systems require to automate the home by doing more or less complex (and even expensive), changes in the building.

Other groups have designed companion robots [4], many of them focused on satisfying certain emotional needs of elderly people [5]. In addition, some interesting research works address the impact of using robots in eldercare [6] and try to answer some major questions, such as, how the robot could affect the senior users' life [7] and how they accept robots [8].

Although there are several attempts to provide fully autonomous companion robots [4, 9], most current robotic platforms aimed at eldercare are essentially based on teleoperation [10].

Many successfully teleoperated robot can be found for other purposes in literature [11, 12], and teleoperation for telepresence is also an intensive field of research [13]. However, commercial solutions that can cope with certain mandatory requirements in the context of eldercare, such as reliability, usability and relatively low economic cost, among others, are not currently available.

Cybi, the smart companion robot described in this paper, is provided with the skills enumerated before, with the purpose of overcoming some of the aforementioned drawbacks. It is capable of carrying out surveillance and telepresence tasks. In fact, users can directly tele-operate it through spoken commands or by remotely using a simple thin client-based interface. The designed smart teleoperation procedure is safe and reliable since it makes use of a method for automatic obstacle avoidance and reactive navigation based on Fuzzy Logic. In addition, both hardware and software modules could be easily added for extending the capabilities of the robot.

The rest of this paper is organized as follows. Section II describes the hardware and software architectures that allow the robot to carry out the required tasks. Section III explains how a Fuzzy-based obstacle avoidance method enables the autonomous reactive navigation software module to be enhanced, allowing Cybi to navigate, in a safe manner, even if communication fails and it is not possible to properly tele-operate it. Section IV focuses on how the ROS (Robotic Operating System) middleware is extended for improving the communication tasks by using WebRTC and Google App Engine. Thus, Cybi can interchange and eventually store information in the Cloud, transparently. Several tests (performed in real environments), and results are presented in Section V, together with a discussion about the advantages of the proposed system. Finally, Section VI shows the conclusions and addresses some issues related to future work.

II. CYBI: THE INEXPENSIVE SMART COMPANION ROBOT

Cybi is a relatively inexpensive modular robot specifically designed for indoor domestic environments with the aim of being commercially distributed. It is built from commercially available hardware devices controlled by a fully distributed set of software components. Subsections A and B respectively describe the hardware and software architectures that allow the robot to carry out its tasks.

A. Hardware architecture

Cybi is a modular robot based on B.EN.DE.R. (Basic ENvironment for DEveloping Robotic systems), a robotic platform previously developed by the authors and fully described in [14]. As long as B.EN.DE.R is mainly conceived as a research robot, Cybi is expected to be marketed in the near future through a Spanish university spin-off whose main target customers are elderly people and their relatives. Therefore, it is important to take into account several essential aspects such as outward appearance or usability and accessibility degrees. In fact, according to some research works and considering the authors' experience, the appearance should look familiar; then, the typical furniture found in a usual domestic residence has been taken as inspiration during the design process. Fig. 1 shows the evolution undergone from B.EN.DE.R. to the early first real Cybi prototype, which looks like a combination between a piece of furniture and a conventional wheeled mobile robot.

Note that, the electro-mechanical design of the new robot allows the potential users to select the best configuration according to their needs. In particular, the minimum configuration comprises the following components: a differential drive system that consists of two Devantech's EMG49 gear motors with encoders, a Devantech's MD49 serial motor driver specifically designed for such motors, two drive wheels, two castor wheels, two 12 V batteries that supplies 24 V and 10 A/h, a Raspberry Pi B+ board, a RGB-D sensor and a low cost tablet. Several additional sensors could be also included, such as, a Hokuyo URG-04LX 2D laser device and a ring of SRF08 ultrasonic devices, among others.

The approximate cost of the model based on the minimum configuration is about 450 euros. The cost of the more expensive model could be about 1500 euros.

B. Software architecture

The software architecture is organized as a set of software layers, where some modules in the top layer are executed as SaaS (Software as a Service) in the Cloud or in thin clients such as tablets, smartphones or browsers and most software modules in the bottom layer are partially based on ROS components, making the communication between all the modules easier. Fig. 2 shows a diagram that outlines the main relations between software layers and software components in each layer. Note that the modules that directly control the hardware sensors and actuators must be executed in the Raspberry Pi-based controller. However, other components belonging to the intermediate layer could be executed in the Intranet by using a conventional PC (Personal Computer) running Linux and ROS.

The software component designed for automatically avoiding obstacles (reactive navigation), is a crucial module (located at the intermediate layer), that allows Cybi to navigate in a safe manner even if teleoperation fails or inappropriate commands are given. On the other hand, two elements are key in the communication process: WebRTC and the PaaS (Platform as a Service) Google App Engine. Thus, the communication details are hidden to the final user and data can be eventually stored in the Cloud, if necessary. Both the reactive navigation component and the elements that enhance the communication procedure are fully described in Section III and Section IV, respectively.

III. Enhancing autonomous reactive navigation by using Fuzzy Logic

One of the main problems that a teleoperated robot has to face is when network communication fails or when an inappropriate command that leads it to a collision is received. In a commercial product, this kind of events must be avoided. Therefore, it is necessary to ensure that the teleoperation procedure is safe and reliable even under uncontrolled circumstances. Furthermore, guiding the robot should be easy for both the caregiver (through a thin client), and the elderly person (by using spoken commands).

One solution is to enable the robot with certain skills that allow it to autonomously take decisions from the perceived environmental information. Different sensors (for example, cameras or LIDAR (Laser Imaging Detection and Ranging), devices, among others), could be used for acquiring such information. However, it is necessary to analyze what sensors are more suitable by considering different aspects related to economic cost or computational complexity. In [14], a detailed study about which sensors are necessary for a companion robot is presented. If a laser 2D device is included, the reactive navigation module is more robust and accurate. However, its economic cost is high if compared to cheaper alternative devices, such as ultrasonic devices or RGB-D sensors.

The experiments carried out with Cybi does not use the cheaper configuration, since a Hokuyo URG-04LX 2D laser device has been included; nevertheless the final cost is similar to a pair of conventional electrical appliances; consequently, customers could still acquire it either by buying or by renting it.

The reactive navigation software component implemented in Cybi uses the following elements as inputs: the information acquired by the laser device and the orders given by the caregiver (through a remote thin client), or the elderly person (by using spoken commands). Then, the safest velocity command (including both angular and linear components), is provided as output.

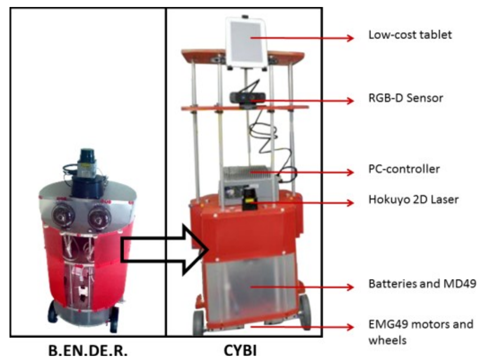

Fig. 1. The evolution from B.EN.DE.R to CYBI.

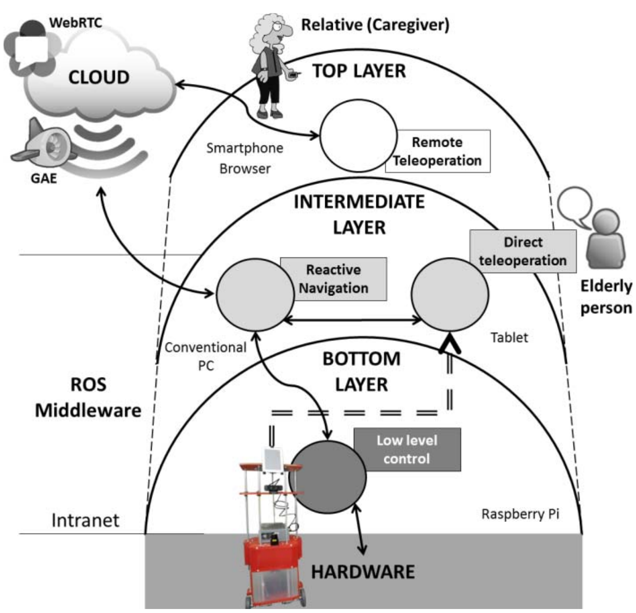

Fig. 2. Layered fully distributed software architecture. Components that belong to the bottom layer are executed in the Raspberry Pi. The reactive navigation component could be executed in a conventional PC in the intermediate layer or in the Raspberry Pi. The interface for teleoperation using spoken commands is carried out by means of an Android tablet and it is also considered as a module located at the intermediate layer. An Android application executed as a module in the top layer allows the relative to remotely teleoperate the robot. Processes in the Intranet communicate to each other by using the ROS middleware. Remote teleoperation makes use of WebRTC and Google App Engine (GAE).

A Fuzzy Logic-based technique is used for solving the problem. The stages of the method are described as follows:

- First, a semantically labelled polygonal representation of the environment is obtained after executing the algorithms described in [15]. The semantic labels describe low level common features found in indoor environments such as, inside and outside angle corners (IAC and OAC), occlusions (OC), saturated areas (SP) and lateral and frontal points (LW and FW) that represent walls, see Fig. 3.
- Next, other algorithms calculate a set of convex sub-polygons (whose edges are semantically labelled), by taking the semantic description of the scenario as input. The collection of sub-polygons provides both metric and semantic information about the distribution of the local free space. In addition, a hierarchical structure is defined, since each sub-polygon is connected to others through common edges, see Fig. 4. Such structure allows exploration and closed areas to be easily detected.
- Next, a fuzzy system uses the semantically labelled polygonal representation as input to calculate the appropriate linear velocity command that should be sent to the drive system, according to the order given by the user and the environment. This order has two components: the linear velocity and the angular velocity (which is transformed into a goal point used as input by a classical path tracking algorithm). The fuzzy system (implemented with the XFuzzy 3.0 tool [16]), is hierarchical and comprises two fuzzy subsystems:
    - The first subsystem calculates a suitable linear velocity by considering the inputs COLLISION and TARGET. COLLISION is the angle defined by the line that joins the closest labelled point of a polyline with the robot and the Y axis of the robot reference system. On the other hand, TARGET is the angle defined by the line that joins the goal point with the robot and the Y axis of the robot reference system, see Fig. 5.
    - The second subsystem improves the previous procedure by modifying the obtained velocity according to how long is the distance between the robot position and the closest labelled point calculated before. Thus, if the distance is long, the linear velocity could be increased, but if the distance is very short, the linear velocity could be newly reduced if necessary, see Fig. 6.

      A minimum distance is used as a threshold (0.5 meters in the experiments). If the robot is in the very close surroundings of the closest polygonal feature and its current direction could lead to a collision, an emergency algorithm is triggered, allowing the robot to properly turn around in the correct direction by using a very low velocity.
- Finally, the semantic representation of the free space based on labelled sub-polygons is used with the purpose of calculating what routes or local paths could be considered as a target, see Fig. 7. This information is sent to help the user during the teleoperation procedure.

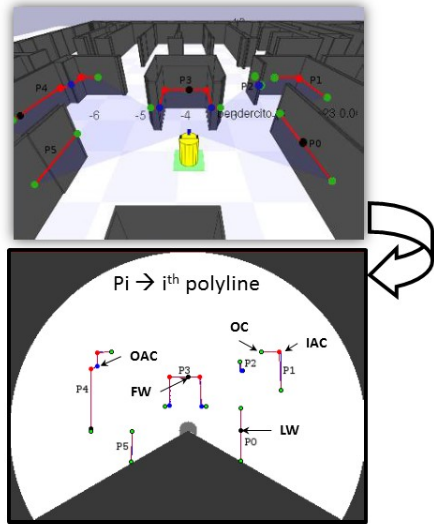

Fig. 3. Example of semantically labelled polygonal representation obtained from data laser.

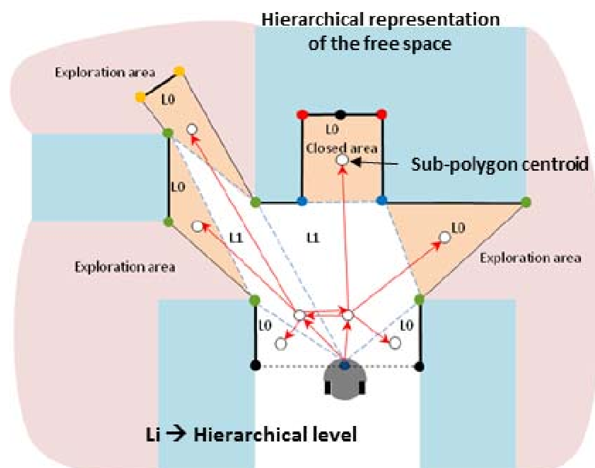

Fig. 4. Example of free space representation by using a set of semantically labelled convex sub-polygons hierarchically related.

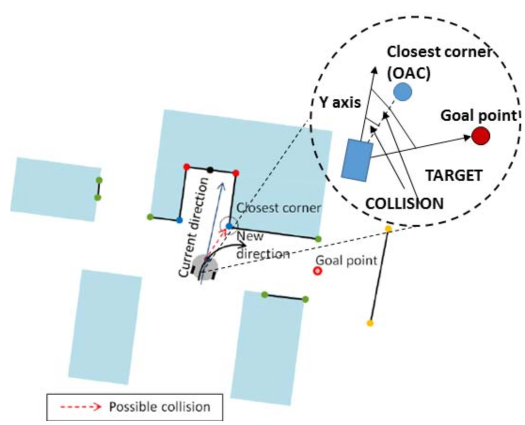

Fig. 5. Example that illustrates a situation where a collision is feasible.

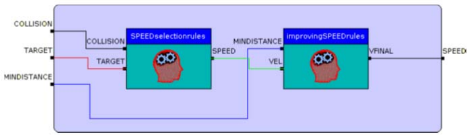

Fig. 6. Hierarchical fuzzy system (in XFuzzy 3.0), used for calculating the suitable linear velocity.

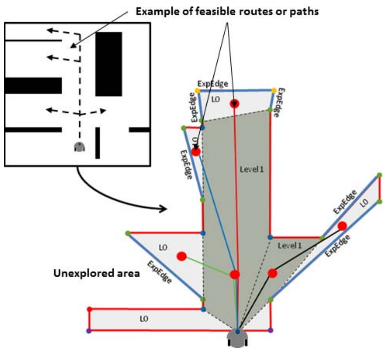

Fig. 7. Example of calculation of feasible paths from the set of semantically labelled sub-polygons. Note that edges with the semantic label "ExpEdge" would lead the robot to unexplored areas from a local point of view.

One of the main advantages of the proposed technique is its low computational cost, since the semantic representation comprises only a few float data that can be processed very fast even if the Raspberry Pi is used for this purpose. In addition, sending visual information about the feasible local paths to the user, who is remotely tele-operating the robot, requires a minimum bandwidth. On the other hand, if a laser device is not available (because the customer want to acquire a cheaper model of the robot), it is possible to use the data acquired by the RGB-D sensor. In this case, the depth image is transformed into a vector of distances (similar to that provided by a laser device), by selecting a specific row. The main limitation of this solution is that the RGB-D sensor only provides an approximately 60 degrees field of view, see Fig. 8.

IV. Extending ROS to WebRTC for improving communication tasks

When the robot is being remotely teleoperated, the caregiver must control the robot through Internet. This fact could pose a problem if the robot is behind a router where the DHCP (Dynamic Host Configuration Protocol) is enabled or where there exist firewalls or proxies. Then, it could be necessary to use a NAT (Network Address Translation) configuration and/or to open certain ports (in the router itself), to allow the robot to act as a server when only the ROS middleware is used. Several attempts of providing a Web access to ROS has been recently made through Rosbridge [17]. However, in this case it is also necessary to know the IP address of the robot controller or of any other PC in the Intranet acting as a bridge, where the Rosbridge server should be executed. In order to make the communication as transparent as possible, some researches propose to use Cloud Computing-based solutions [18, 19]. Nevertheless, many of these solutions require an own server to be available.

In this work, the communication problem is solved by using a combination of ROS middleware, WebRTC technology and Google App Engine, see Fig. 9. Processes in the intranet interchange data through ROS. When the information is interchanged between the top and the intermediate layers, a P2P (peer to peer), connection is used by means of the WebRTC protocol [20], and all the ROS messages are transformed into JSON messages in order to allow them to be sent and received through Internet.

The process (known as "signaling"), for discovering the IPs and for establishing the P2P communication is carried out by using the "datachannels" provided by the Google App Engine API; consequently, sender and receiver are seen as clients and they do not need to explicitly know the IP of each other.

V. Tests and results

Cybi has been tested in a real home where a couple of elderly persons live. Such home is equipped with a conventional router that allows the connection to Internet by using the DHCP protocol. A relative has been acting as caregiver. An Android smartphone has been used as "thin client" to remotely control the robot. Cybi has performed the following tasks: Objects transportation (the elderly person has teleoperated the robot by using spoken commands), and telepresence (the relative has used Cybi with the aim of carrying out both surveillance and videoconference operations), see Fig. 10. The obtained results are promising, since the robot has accomplished its tasks most of the time, and the teleoperation procedure has demonstrated to be robust even when the Internet connection fails or it is slow. Moreover, installation and start-up of the system is fully automatic, and users do not need to carry out additional configuration tasks in their routers to allow the robot and the remote client to be connected through WebRTC.

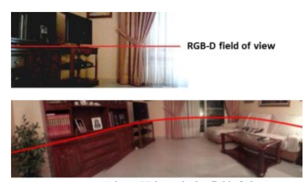

Fig. 8. Comparison of the field of view provided by a RGB-D sensor and a Hokuyo 2D laser device.

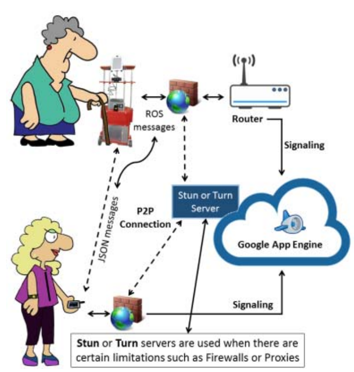

Fig. 9. Communication diagram using Web RTC.

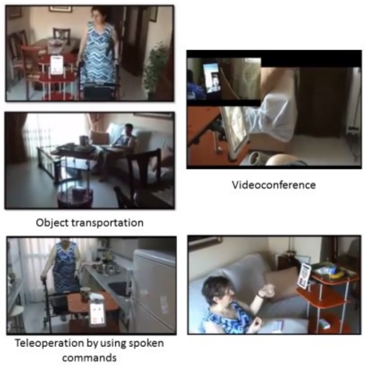

Fig. 10. Several tasks carried out by Cybi in a real home with real users. A demonstrative video is shown in the following link: Cybi Demo.

However, some issues, which have not been considered yet (for example, when Cybi finds a closed door), are expected to be solved by equipping the home with cheap actuators that automate some elements. All these components will be able to communicate with the rest of devices through ROS messages in the Intranet.

VI. Conclusions and future work

In this paper, a companion smart robot named Cybi has been presented. A fully distributed software architecture (based on modules that are connected through a software component that combines the ROS middleware, WebRTC and Google App Engine), allows the user to control the robot in a natural and transparent way. In addition, both hardware and software could be easily extended for adding new capabilities. The designed smart teleoperation procedure is safe and reliable (even if the connection fails or the users send inappropriate commands), since it makes use of a Fuzzy Logic-based method for automatically avoiding obstacles.

Future work is focused on improving the designed algorithms, testing Cybi with a higher number of customers, designing cheap wireless devices that helps the robot to navigate better through the environment and marketing the product during this year through a university spin-off.

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References

[1] World Health Organization, Good health adds life to years, Global brief for World Health Day 2012, Publications of the World Health Organization, WHO Document Production Services, 2012.

[2] D. de la Croix, O. Pierrard and H.R. Sneessens, “Aging and pensions in general equilibrium: Labor market imperfections matter”, Journal of Economic Dynamics and Control. vol. 37(1), pp. 104–124, 2013.

[3] A. Coronato and G. De Pietro, “Pervasive and Smart Technologies for Healthcare: Ubiquitous Methodologies and Tools”, CNR Italy, 408 pages, 2010.

[4] H. M. Gross, Ch. Schroeter, S. Mueller, M. Volkhardt, E. Einhorn, A. Bley, Ch. Martin, T. Langner, M. Merten, ”I’ll keep an Eye on You: Home Robot Companion for Elderly People with Cognitive Impairment”, in Proc. IEEE-SMC’11, October, 2011.

[5] T. Tamura, S. Yonemitsu, A. Itoh, D. Oikawa, A. Kawakami, Y. Higashi, T. Fujimooto, and K. Nakajima, “Is an Entertainment Robot Useful in the Care of Elderly People With Severe Dementia?”, Journal of Gerontology: MEDICAL SCIENCES, Vol. 59A, No. 1, pp. 83–85, 2004.

[6] M. L. Walters, K. L. Koay, D. Sverre Syrdal, A. Campbell and K. Dautenhahn, “Companion Robots for Elderly People: Using Theatre to Investigate Potential Users' Views”, IEEE RO-MAN: The 22nd IEEE International Symposium on Robot and Human Interactive Communication Gyeongju, Korea, pp. 26-29, 2013.

[7] J. Broekens, M. Heerink, H. Rosendal, “Assistive social robots in elderly care: a review”, Gerontechnology, 8(2), pp. 94-103, 2009.

[8] L. Lammer, A. Huber, A. Weiss, M. Vincze: "Mutual Care: How older adults react when they should help their care robot", Third International Symposium on New Frontiers in Human Robot Interaction - AISB 2014, April 3-4, 2014, Goldsmiths, University of London, UK.

[9] H. Van Den Heuvel, C. Huijnen, P. Caleb-Solly, H. H. Nap, M. Nani, E. Lucet, “Mobiserv: A service robot and intelligent home environment for the Provision of health, nutrition and safety services to older adults”, Gerontechnology 2012, 11(2).

[10] S. Coradeschi, A. Cesta, G. Cortellessa, L. Coraci, J. Gonzalez, L. Karlsson, F. Furfari, A. Loutfi, A. Orlandini, F. Palumbo, F. Pecora, S. von Rump, A. Štimec, J. Ullberg and B. Östlund, “GiraffPlus: Combining Social Interaction and Long Term Monitoring for Promoting Independent Living”, In Proceedings of the 6th International Conference on Human System Interaction (HSI 2013), pp. 578-585, Gdansk, Poland, June 2013.

[11] T. Haidegger and Z. Benyó, “Surgical robotic support for long duration space missions”, Acta Astronautica. vol. 63, no. 7, pp. 996–1005, 2008.

[12] T. Haidegger, “The Advancement of Robotic Surgery—Successes, Failures, Challenges (in Hungarian),” Orvosi Hetilap, vol. 151, no. 41, pp. 1690–1696, 2010.

[13] A. Kristoffersson, S. Coradeschi and A., “Loutfi A Review of Mobile Robotic Telepresence”, Hindawi Publishing Corporation Advances in Human-Computer Interaction, vol. 2013, Article ID 902316, 17 pages.

[14] N. Pavón-Pulido, J. A. López-Riquelme, J. Ferruz-Melero, M. A. Vega-Rodríguez and A. J. Barrios-León, “A service robot for monitoring elderly people in the context of Ambient Assisted Living”, Journal of Ambient Intelligence and Smart Environments, vol. 6, Number 6, pp. 595-621, December 2014.

[15] N. Pavón, J. Ferruz, A. Ollero, “Describing the environment using semantic labelled polylines from 2D laser scanned raw data: Application to autonomous navigation”. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2010), Taipei (Taiwan), pp. 3257–3262, September 2010.

[16] I. Baturone, F. Moreno-Velo, S. Sanchez-Solano and A. Ollero, “Automatic design of fuzzy controllers for car-like autonomous robots,” IEEE Transactions on Fuzzy Systems, vol. 12, no. 4, pp. 447- 465, August 2004.

[17] B. Alexander, K. Hsiao, C. Jenkins, B. Suay, and R., “Toris Robot Web Tools”, IEEE Robotics & Automation Magazine, december 2012.

[18] M. Waibel, M. Beetz, J. Civera, R. d’Andrea, J. Elfring, D. Galvez-Lopez, K. Häussermann, R. Janssen, J. M. M. Montiel, A. Perzylo, B. Schiessle, M. Tenorth, O. Zweigle and M. J. G. Van de Molengraft, “RoboEarth – A World Wide Web for Robots”, In Robotics & Automation Magazine, IEEE, vol. 18, no. 2, pp 69-82, June 2011.

[19] B. Kehoe, S. Patil, P. Abbeel and K. Goldberg, “A Survey of Research on Cloud Robotics”, IEEE Transactions on Automation Science and Engineering.

[20] C. Vogt, M. J. Werner, T. C. Schmidt, "Content-centric user networks: WebRTC as a path to name-based publishing," Network Protocols (ICNP), 2013 21st IEEE International Conference on , vol., no., pp.1,3, 7-10 Oct. 2013.