Cognitive and physical stimulation services with a robotic agent in a domestic setting

Mariette Soury[1], Patrick Hède[2], Philippe Morignot[1], Christophe Leroux[1]
(1) *CEA, LIST, Interactive Robotics Laboratory,* 18, route du panorama, B.P.6, Fontenay-aux-Roses, F-92265 France. E-mail: FirstName.LastName@cea.fr
(2) *CEA, LIST, Vision and Content Engineering Laboratory*, 18, route du panorama, B.P. 6, Fontenay-aux-Roses, F-92265 France. E-mail: patrick.hede@cea.fr

Jean-Pierre Savary[3], Joseph Canou[4],
(3) *Siel Bleu*
42, rue de la Krutenau, F-67000 Strasbourg, France.
E-mail: savary.jeanpierre@wanadoo.fr,
(4) *Robosoft*
Technopole d'Izarbel F-64210 Bidart France.
E-mail: joseph.canou@robosoft.fr

***Abstract* — In this paper, we present the service developed for cognitive and physical stimulation of elderly or handicapped people. The services rely on an assistant mobile robot composed of a mobile platform on top of which is set up a manipulator arm. Stimulation relies on scenarios defined together with the partners of ITEA MIDAS project. In order to build the scenarios, we developed object recognition from vision to facilitate object manipulation, as well as to improve the dialog between the end user and the robot. In order to structure the information, we designed and implemented a dedicated ontology about robotics manipulation. The scenarios are defined using an original event robot programming language. In order to be independent from the hardware, we structure our software layers in a web service architecture. These new functions come on top of those existing in the AVISO software, and already assessed by experiments with quadriplegic people. They all contribute to design an assistant robot that can be used and set up by people (end users and care takers) very intuitively in a domestic setting.**

Keywords: Rehabilitation, cognitive stimulation, physical stimulation, assistive robotics, man machine interface, computer vision, object manipulation, ontology, web service.

I. Introduction

Today, the global population is aging faster than ever [30] and worldwide governments are facing the issue of elderly care. They are also trying to integrate as well as they can people who have suffered life accident and are now impaired with physical disabilities.

While most often the answer is a caretaker, either professional or a family member, a caretaker can nevertheless be easily overwhelmed with everyday demands. If some basic daily tasks could be performed automatically, it would free time for the carer, in order for him to spend with their patient for human exchanges.

Automatic assistance via a mobile robot appears as a rapidly growing subfield, as one possible direction for robotic service to persons (e.g., [10] [31] [35] [34]), but current concepts in medical assistance involve mostly remote control of said robotic agent by a nurse.

Figure 1: The mobile robot SAM, composed of a ROBULAB 10 mobile base and a MANUS arm.

A more comfortable solution would be for the robot to be able to grab and carry objects in a domestic environment, without the permanent need for a pilot. With an adapted control interface and a communication system, it would enable the disabled/elderly people to command the robot themselves, thus increasing their autonomy.

The ITEA 2 MIDAS project aims at maintaining elderly people in their home environment as long as possible, by providing them with multiple evolving devices to offer customized support. One of the features of the project, developed by the CEA-LIST, is the robot SAM (Smart Autonomous Majordomo): a mobile robot equipped with a manipulator arm able to recognize and grab objects autonomously (see Figure 1).

The paper is organized as follows: We first present a state of the art in the field of rehabilitation robotics. We then illustrate the robot abilities with physical and cognitive stimulation scenarios. We describe the hardware and software elements of the robot, and we explain the various techniques behind the capabilities of the robot. Finally, we present results of early user tests, a description of future tests, and sum up our contribution.

II. Related Work

A. State of the art

Despite the inner diversity of approaches nowadays, rehabilitation robotics may be structured into the sub-fields of personal autonomy via object manipulation, of transfer (e.g., of the ageing person from a bed to his wheelchair) and of companion robots.

1) Personal autonomy via object manipulation (see a survey in [16]) mainly involves workstation systems (a robotic arm, fixed to a desk, that has access to several elements, see projects RAID [8], DEVAR [35] and Master [6]), standalone manipulators (adding sensor data within the control loop to the previous approach, see Tou [7] and ISAC [22]), wheelchair mounted systems (the robotic arm, most often MANUS or RAPTOR, is fixed onto the wheelchair [1]), and mobile platforms (mounting the robotic arm onto an independent mobile platform, hence leading to the problem of automated guided vehicles, see projects WALKY [27], CARE-O-BOT 2 [13], ARPH [17] and HERMES [4]).

2) Transfer involves (i) physically moving a fragile and/or disoriented ageing person by replacing a four-point cane by a small mobile robot capable of localization, obstacle avoidance and user's health monitoring (see projects SMARTCANE [9] and SMARTWALKER [32]); (ii) helping deambulation and posture transition using a mobile robot (see MOVEMENT project [18] [26], and one use of the TWENDY ONE robot [19]). Recent object manipulation projects, not necessarily dedicated to rehabilitation, involve mobile platforms PR2 from Willow Garage and JUSTIN from DLR.

Companion robotics relies on emotional / affective involvement of the ageing person through interaction with realistic animaloids: the AIBO robotic dog by SONY has been used as robot-mediated pet-therapy for old people with light cognitive deficits [29]. Along the same line, emotional interaction is studied via a robotic baby seal (PARO [38]) or via a Teddy Bear-like companion robot, involving touch [33]. The KOMPAI robot [24] plays a role of secretary with vocal interaction.

B. Discussion

If transfer functions are not covered by the MIDAS project, the remaining two previous sub-fields indeed are: emotions can be detected on the face of the ageing person (e.g., a smile), enabling the system to detect emergency situations regarding the person (e.g., the person's emotional or physical suffering).

MIDAS aims at accompanying the elderly through every stage of aging: our project provides devices to assist every level of dependency. Regarding the sub-field of object manipulation, once the person is not capable of moving by himself any longer, we propose the one arm mobile robotic platform SAM capable of fetching objects, with a grasping procedure not needing a 3D model of the environment [37].

In addition, SAM is also capable of physically exercising the ageing person (training of upper limbs). Cognitive exercising through solving problems using blocks on a table is also proposed (see section III).

III. Assistant Robot in the MIDAS Project

As mentioned above, the role of the robot SAM in the MIDAS project is to propose physical stimulation to the user, as well as object manipulation.

Regular exercise is the surest way for elderly people to keep balance, avoid falls and resulting injuries, prevent joints stiffness and preserve overall health [28].

Consequently, the project includes a physical stimulation program, which goal is to provide soft gymnastics movements for the user to perform at home, when they are not able to join a training group. They are designed as a complement of regular session with a physiotherapist, to keep practicing between visits.

In this context, the CEA-LIST proposed to use SAM, an assistive robot developed in its laboratories, to perform some fitness activities.

With the help of MIDAS partner Siel Bleu (a French health prevention association), we established a set of exercises with the robot, involving upper limbs and joints in particular. The robot's arm is used as a guide, to indicate how far the user must push his movement.

Arm positions can be computed randomly within a given range, avoiding repetitively and therefore weariness of the same exercise, unlike a video. The arm range can be readjusted with the physiotherapist regularly to adapt to the user's fitness level.

The arm gripper can also be used to hold objects and allows additional interactions, such as the use of a guide to work with both hands at a time.

Among elderly population, the MIDAS project targets persons with mild cognitive impairments, such as those in an early stage of the Alzheimer's disease. It has been observed that regular stimulation can strengthen spared cognitive abilities and slow their loss [12]. For this reason, the project also includes various cognitive stimulation exercises.

Orange Labs, one other partner in the MIDAS project, developed a set of exercises in the form of questions displayed on a computer screen. But, instead of typing on the keyboard to answer these questions, the aging person uses a "Majhook table", a sensitive device on which the user moves blocks in the appropriate slot to indicate the answer.

Along the same lines, the CEA-LIST used the opportunity of object recognition to develop a "Memory game". The robot asks the user to memorize two to five objects, and then to put them on a table in front of the robot. It can indicate if the user made any mistake when picking the objects

Another goal of the MIDAS project is to avoid unnecessary motions to the user, who may suffer mobility limitations. One of the issues in this situation is the fetching and carrying of everyday objects around the home.

Here again the use of a robot able to move around the habitation and grab object autonomously is a convenient answer.

Thanks to the navigation functions of the mobile platform provided by Robosoft, another partner in the project, the robot is able to plan his path through the house toward a given room. It is also able to avoid obstacle that could be present on the computed trajectory.

The CEA-LIST previously developed algorithms to control a manipulator arm so as to automate most of its movements to catch small, light objects (less than 10 cm wide and lighter than 1 kg) [31]. With the addition of scene comprehension thanks to image recognition, the complete grasping motion is now automated. Moreover, the object recognition allows the automated research of a know object around the home.

IV. CONTEXT

A. Robot Description

Taking into account all the requirements of the MIDAS project, the robot must provide mobility, object grasping and scene recognition abilities. It is currently composed of a non-holonomic mobile base Robosoft ROBULAB 10, equipped with a 6-DOF MANUS arm with its gripper (see Figure 2).

The base is an indoor mobile platform with 2 propulsive wheels, equipped with various sensors: front- and back-bumpers, sick laser for obstacle avoidance and navigation, as well as ultrasound sensors for proximity detection; A panoramic camera is located on top of the base to provide a large view of the robot environment. The arm is fixed on top of the base.

The arm is also equipped with sensors: 2 webcams located above the gripper on the end section of the arm are used for object recognition, distance stereo-measurement, and visual servoing of the arm movements; An optical barrier located in the gripper allows the detection of objects within the clamps, and pressure sensors on each side of the clamp enable controlled grasp of objects [31].

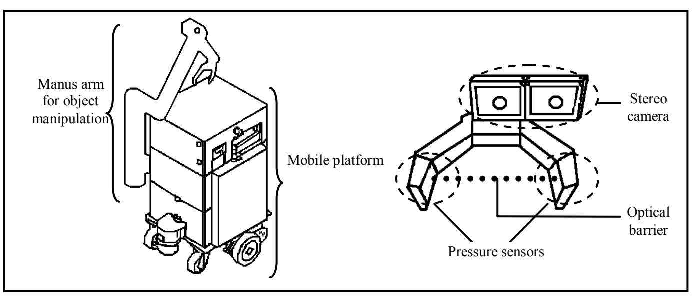


Figure 2: The robot (left) and its gripper (right).

B. Software Architecture

The robot SAM is controlled by a software application called AVISO, which provides a simple graphical user interface. It is built on top of a software platform called Nausicaa. From this GUI, the user can control the arm and check its cameras, locate the mobile on the home map and send it in another room, identify objects in the field of vision of the camera. Since elderly people are targeted by the MIDAS project, the control interface of the robot must be easily accessible.

The application is divided into several modules, implemented as web services to which the global application is a client: One for the mobile platform movements, one for the arm movements, one for the object recognition. Each module can therefore be tested and modified separately, simplifying the maintenance and evolution of the project.

Those web services are based on a DPWS architecture (Device Profile for Web Service), a communication protocol based on SOAP-XML, which homogenizes the exchanges between the various services connected to the same network [21]. This technology allows the “plug and play” of different services available from the network immediately after connection. DPWS is now implemented in C++, C# and Java, so programs written in different languages can communicate easily.

One of the advantages of this compartmentalized architecture is that it allows us to change the hardware part without modifying the global application, only the server side of the module needs to be changed. The mobile platform, formerly a Neobotix MP-M470, is now replaced by a ROBULAB 10 from Robosoft. The control of the mobile platform remains unchanged in AVISO.

V. CAPABILITIES

As explained in section IV.A, the robot must be mobile, and able to grab objects autonomously thanks to visual clues. The navigation part is entirely provided by Robosoft platform; the CEA-LIST offers manipulation skills, presented in this section.

A. Existing object grasping methods

Various methods of grasping for the assistance to people in loss of mobility have been designed in the past.

1) Grasping knowing the place of the object or with controlled environment.

It can be where the position of each object is a priori known (projects RAID [8], Master [6]). Environment can also be equipped with intelligent systems such as intelligent tables [36]. Those tactile tables, covered by a sort of artificial skin, allow localization of objects of more than 5 grams. Those methods need a perfectly controlled and equipped environment which can be costly, difficult to generalize and can reduce freedom of robot’s actions.

2) Grasping with use of 3D geometric model.

A 3D model of object is needed. During the grasping, information from sensors, cameras or lasers is compared with the pre-established model to estimate the position of objects during tracking [5]. This method is used in the project CARE-O-BOT [13]. The development of the 3D model and the information matching during the grasping can be difficult, in particular with the presence of concave and convex regions in the object.

3) Grasping without model or object marking.

The user can select an object on a graphic interface by drawing a bounding rectangle as we previously did [31]. Another example is the selection with a laser cursor for the service robot EL-E [20]. Those methods do not allow an adaptation of the grasp strategy or the later use of the object.

B. Proposed grasping method

Our approach can be divided into two steps: a first phase of recognition, and then a grasping strategy adapted to the matched object

1) Object recognition using vision without 3D model

Our method does not need any 3D geometric models, even partial. Instead, we use a small group (4 to 8) of 2D images as object model. The acquisition of those images does not require any specific competences as the creation of 3D models does, and it can be semi-automated by putting the object on a motorized turntable and taking pictures of object's views with a nearby camera. This way, new objects can be easily learned to enrich the database. Unlike model-less recognition method such as designation by laser pointer, the object does not have to be within user's view, so that object recognition can take place in another room.

To learn an object, we need pictures corresponding to different points of view on the object. For each picture, the interest points [15] (or keypoints) are extracted using the SIFT method [25].

Once all objects have been captured, a database is created to index all views. This base needs to be loaded in the recognition web service once, during the startup of the AVISO application. A database of 72 images takes 15,5s to load on a PC Intel Core 2 CPU 2,66 GHz 3,50 Go RAM.

During the recognition, ViPR extracts the keypoints from the image and compares their feature vectors with those of the database to find potential object matches. Several objects can be identified in one image, including partially occulted objects, if there are at least 4 keypoints. This recognition is robust to variations of luminosity and can be used in non uniformly lightened places. On the aforementioned database and hardware, our web service takes an average of 450ms to recognize an object.

The CEA-LIST is currently working on its own version of image recognition software, PiRia. It offers the choice of several interest point descriptors including SURF [2], and is now performing as well comparatively to ViPR.

Our application is aimed at people with physical impairments that can prevent them from making precise movements, e.g. click a specific point on a computer screen. Therefore, our previous object selection on screen, where the user had to draw a box around the object by two clicks [31], proved to be an obstacle in some cases.

The software ViPR gives us the coordinates of the recognized keypoints for each object, so we decided to use those points to define a "bounding box": A rectangle enclosing all keypoints found in an image so as to enclose the matched object.

With this method, when the user wants to choose an object in the scene, all recognized objects are shown with their bounding box and the selection is done by a click in the desired box.

In the case of superposition of boxes, we decided to reduce the clickable zone for this selection [37]. Unknown or unrecognized object can still be selected with the previous method. This method can be adapted to other way of selection of known objects, such as the selection from a list.

Currently, we are able to recognize 13 objects from a distance of 30 to 50 cm, even when partially occulted [37].

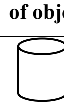
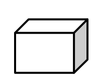
2) Discrete object manipulation

Object recognition gave us the opportunity to adapt the grasping: The arm gripper is 10 cm wide, so although it cannot frontally grasp a box wider than that, it can still catch it from the side, if it is not too thick. Knowing the geometry of an object allows us to catch it from the right angle.

Once an object is identified, the grasping strategy is obtained from an ontology, which also contains information on possible usage and type of objects. Ontology in computer science is a concept used for knowledge representation, i.e. objects and concepts of a domain and the relations between them. It allows a level of abstraction of data models with a more semantic representation [14].

We created an ontology for robotics manipulation with the software XMLSpy, where objects are categorized according to their morphology: symmetric by revolution, cube-like, or more complex shapes. To each category and each point of view on the object, a grasping strategy is associated, describing particularly how to position the gripper opening to the object so as to grab it. (see Table 1)

An ontology is also an effective way to represent more complex concepts regarding objects, such as their fragility (and how much pressure they can bear without breaking), their use (e.g., a cup is a container for liquids, but also a tool for breakfast) or most likely location (e.g., a toothbrush is generally stored in the bathroom). This information can be used for an oriented research of an object, but also for an elaborated manipulation (e.g., a full cup should not be carried upside down). We are currently working on the development of this richer ontology, with the software PROTÉGÉ [23].

Name of strategy	**Geometry of object**	**Possible objects**	**Angle, point of view**	**Grasping strategy**
RevolutionSymetry		Can, bottle, glass	indifferent	Go straight forward.
SideRectCuboid000		Box of cereals, playing cards	0° or 180°	Place gripper opposite to the thinnest side, go straight forward.
SideRectCuboid045			45° or 225°	
TopRectCuboid090		Box of pills	90° or 270°	Place gripper above the box,

TopRectCuboid135			135° or 315°	go straight down.
Cup000		Cup	0°	Place gripper on opposite side of handle, go straight forward.
Cup045			45°	

Table 1 : grasping stategy example

VI. Conclusion

This paper proposed an overview of the robot developed by the CEA-LIST and its implication in the project MIDAS. The project aims at designing solutions for ageing well. First we presented the scenarios created to assist elderly people in their daily life activities. We then described the technical solution (mobile platform with arm manipulator) to implement those scenarios. Finally we presented the capabilities of the robot: Object recognition, manipulation and knowledge representation.

We are now preparing experiments to validate our approach with end-users in a realistic daily life environment.

We were able to assess the acceptability of the robot SAM, by quadriplegic people, and its efficiency to grasp objects via a dedicated interface, with evaluations in rehabilitation centers of Berck (Centre Jacques Calvé) and Kerpape (CMRRF), in France. The conclusion was positive, as the robot was perceived as both useful and easily maneuverable [3].

In the context of the MIDAS project, experiments will be conducted in February 2011 with elderly people suffering from mild cognitive deficiencies. The evaluation protocol within the MIDAS project is being defined by the LI2G, of Grenoble CHU. The tests will be supervised by occupational therapist of the Siel Bleu association. During those tests, we will try to assess the interest of using our assistant robot for physical and cognitive stimulation exercises.

Acknowledgment

This work is funded by the DGE of the French Ministry of Economy, Finance and Industry through contract ITEA 2 MIDAS, as part of a EUREKA European project.

References

[1] Alqasemi R., Mccaffrey E., Edwards K., Dubey R., “Wheelchair-mounted robotic arms : analysis, evaluation and development”. In IEEE ICAIM, pages 1164-1169, Monterey, CA, July 2005.

[2] Bay H., Ess A., Tuytelaars T., Van Gool L., "SURF: Speeded Up Robust Features", Computer Vision and Image Understanding (CVIU), Vol. 110, No. 3, pp. 346--359, 2008

[3] Biard N., Laffont I., Bouteille J., Schmutz S., Desert J. – F., Leroux C., Chalubert G., Busnel M., "Validation d’une interface graphique de pilotage du bras robotisé manus", in Sofmer 2007, 22e congrès de la société française de médecine physique et de réhadaptation, saintMalo, Frnace (4-6 octobre 2007)

[4] Bischoff R., Graefe V., “Machine vision for intelligent robots”. In IAPR Works. On Machine Vision Applications, pages 167-176, Tokyo, Japan, Nov. 1998.

[5] Bourgeois, S., Naudet-Collette, S., Dhome, M., “Recalage d'un modèle CAO à partir de descripteurs locaux de contours ». In: RFIA. Tours, France, (2006)

[6] Busnel, M., et al. “The robotized workstation MASTER for users with tetraplegia: Description and evaluation”. Journ. of Rehabilitation Reseach &Development, 36(3) (1999)

[7] Casals A., Villa R., Casals D. “A soft assistance arm for tetraplegics”. In TIDE Congress, pages 103-107, Bruxelles, Belgium, April 1993.

[8] Dallaway, J., Robin, S., “Raid – a vocational robotic workstation”. In IEEE ICORR, Keel, U.K., September 1992.

[9] Dubowsky S., Genot F., Godding S., Kozono H., Skwersky A., et al.,. “PAMM – a robotic aid to the elderly for mobility assistance and monitoring: a helping-hand for the elderly”. IEEE International Conference on Robotics and Automation. ICRA ’00, (2000).

[10] Dumora J.. “Design of behaviors for a robot assisting handicapped persons” (“Conception de comportements pour un robot d’assistance aux personnes handicapées”). Technical Report, CEA, LIST, DTSI/SRI/08-XXX, August 2008, unpublished

[11] Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955. *(references)*

[12] Flynn, B., Rigney, E. O’Connor, E., Fitzgerald, L., Murray, C., Dunleavy, C.,McDonald, M., Delaney, D., Cunningham, C., Pender, N., Merriman, N., Edgeworth, J.,Coen. R.F. "Efficacy Of A Cognitive Stimulation Therapy Programme For People With Dementia."Irish Journal of Medical Science (2008) Vol:177(Suppl 9), S310

[13] Graf, B., Hans, M., Schraft, R., “Care-o-bot II development of a next generation robotic home assistant”. Auton. Robots, 16(2), pp, 193-205 (2004)

[14] Gruber, T.: Ontology. Encyclopedia of Database Systems, Ling Liu and M. Tamer Özsu (eds.), Springer- Verlag (2009)

[15] Harris C., Stephens M., "A combined corner and edge detector", Proc.of 4th Alvey Vision Conf., 1988, pp 147-151.

[16] Hillman M.. “Rehabilitation robotics from past to present, a historical perspective”. In IEEE ICORR, Daejeon, South Korea, April 2003.

[17] Hoppenot P., Colle E., “Localization and control of a rehabilitation mobile robot by close human-machine cooperation”. IEEE Trans. On Rehabilitation Engineering, 9(2):181-190, June 2001.

[18] Huntemann A., Mayer P., Gelderblom G.J., Pisetta A., Kronreif G., et al., (2007). “MOVEMENT use in progress”. IEEE 10th International Conference on.Rehabilitation Robotics, 2007.

[19] Iwata H., Sugano S. “Whole-body Coordinated Control for Task Execution and Human Following,” Proc. of CISM-IFToMM Symp. on the Theory and Practice of Robots and Manipulators (ROMANSY’08), pp.209-216, Jul. 2008

[20] Jain, A., Kemp, C. C., “EL-E: An Assistive Mobile Manipulator that Autonomously Fetches Objects from Flat Surfaces”. In: Autonomous Robots, Special Issue (2009).

[21] Jammes F., Mensch A., Smit H.. “Service-oriented device communications using the devices profile for web services”, IEEE Intern. Conf. on Advanced Information Networking and Applications Workshops, vol. 1, pp. 947-955, Niagara Falls, ON, Canada, May 2007.

[22] Kawamura K., Bagchi S., Iskarous M., Bishay M. “Intelligent Robotic Systems in service of the disabled”. IEEE Trans. on Rehabilitation Engineering. 3(1°:14-21, March 1995.

[23] Knublauch H., Fergerson R. W., Noy N. F., Musen M. A., "The Protégé OWL Plugin: An Open Development Environment for Semantic Web Applications", http://protege.stanford.edu/doc/users.html#papers

[24] KOMPAI: http://robosoftnews.wordpress.com/category/kompai/

[25] Lowe, D. G. “Object recognition from local scaleinvariant features”. International Conference on Computer Vision. pp, 1150—1157. Corfu, Greece (1999).

[26] Mayer P., Edelmayer G., Gelderblom G.J., Vincze M., Einramhof P., et al.,. “MOVEMENT-Modular Versatile Mobility Enhancement System”. IEEE International Conference on Robotics and Automation, 2007.

[27] Neveryd, Bolmsj B., “Walky, an ultrasonic navigating mobile robot for the disabled.” In TIDE Congress, pages 366-370, Paris, France, 1995.

[28] Nied R. J., Franklin B., "Promoting and Prescribing Exercise for the Elderly", in Am Fam Physician. 2002 Feb 1;65(3):419-427. (http://www.aafp.org/afp/2002/0201/p419.html)

[29] Odetti L., Anerdi G., Barbieri M.P., Mazzei D., Rizza E., et al., (2007). “Preliminary experiments on the acceptability of animaloid companion robots by older people with early dementia”. Engineering in Medicine

and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE.

[30] Population Division, DESA, United Nations, "World Population Ageing 1950-2050", http://www.un.org/esa/population/publications/worldageing19502050/

[31] Remazeilles, A., Leroux, C., Chalubert, G.: SAM: a robotic butler for handicapped people. In: IEEE RO-MAN. Munich, Germany (2008)

[32] Spenko M., Yu H.Y., Dubowsky S., "Robotic personal aids for mobility and monitoring for the elderly". IEEE Transactions on Neural Systems and Rehabilitation Engineering 14: 344–51. (2006).

[33] Stiehl W. D., Breazeal C., "A Sensitive Skin for Robotic Companions Featuring Temperature, Force, and Electric Field Sensors". Intelligent Robots and Systems, 2006 IEEE/RSJ International Conference on. (2006)

[34] Takagi M., Takahashi Y., Komeda T., "A Universal Mobile Robot for Assistive Tasks", 2009 IEEE 11th International Conference on Rehabilitation Robotics, Kyoto International Conference Center, Japan, June 23-26, 2009

[35] Van der Loos, H. "Va/Stanford rehabilitation robotics research and development program: Lessons learned in the application of robotics technology to the field of rehabilitation". IEEE Trans. on Neural Systems and Rehabilitation Engineering, pp, 46--55 (1995).

[36] Volosyak, I., Ivlev, O., Gräser, A., "Rehabilitation Robot FRIEND II The General Concept and Current Implementation". In: Proc. of the 2005 IEEE ICORR. Chicago, IL, USA (2005)

[37] Vorobieva H., Soury M., Hède P., Leroux C., Morignot P., "Object recognition and ontology for manipulation with an assistant robot", in ICOST, 2010, Seoul, Korea.

[38] Wada K., Shibata T., Musha T., Kimura S.. "Robot therapy for elders affected by dementia". Engineering in Medicine and Biology Magazine, IEEE 27: 53–60. (2008).