EXTENDING AN ASSISTANCE ROBOT WITH THE ABILITY TO PLAY BOARD GAMES

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ABSTRACT

This paper presents an interactive game system integrated in a mobile robot. Our proposal enables assistant robots to provide cognitive and entertainment games to elders with the aim of improving skills like memory, reflexes, or hand-eye coordination, which are jeopardised in aged people. To gain in user acceptance, the game is virtually recreated by projecting the game board over a table by means of a small projector mounted on the robot. The user can naturally interact with the projected board while him/her movements are detected by the perception system of the robot. To validate the proposed system, a practical case is presented in a laboratory environment.

CCS CONCEPTS

• **Human-centered computing → Displays and imagers**; • **Computing methodologies → Vision for robotics**; *Robotic planning*; • **Applied computing → Computer games**; • **Software and its engineering → Interactive games**;

KEYWORDS

Human-Robot Interaction, HRI, Assistance Robots, Board Games, Computer Vision, Robot Navigation

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1 INTRODUCTION

During the last years, the increase in the life expectancy has compelled us to be concerned about the issues related to the ageing, like the need of continuous assistance for daily activities and the cognitive decline led by senescence. Being aware of this reality, assistant robots have been proposed as a possible solution to provide self-sufficiency to elder people in their homes. In this sense, a number of European projects have been developed, like Excite [9], Teresa [11], or GiraffPlus [3]. These, and other related projects, propose to merge domotic environments with mobile robots to offer assistance and a variety of services to the users [5, 8].

A significant concern related to the elderly is the cognitive decline that can be palliated through different treatments and approaches [4, 6, 7]. Ludiman's survey [1] concludes that classic board games can be used as a tool to prevent the cognitive decline produced by ageing. These games help to maintain cognitive abilities like agility and movement -since they require muscle coordination-, attention or sensory perception. Furthermore, the need to remember the game rules contributes to exercise the memory.

However, some practical limitations might turn classic board games unsuitable for elders. On the one hand, multiplayer games obviously require, at least, another person to play with, which becomes a serious hurdle for elder people living alone. On the other hand, board games requires physical elements, like pieces or cards, which require special attention by the user to conveniently manage and store them, reducing also the diversity of games the person can play. Video games overcome these disadvantages and offer games through computers, tablets, or smartphones. Nevertheless, the limited technological skills of most elders suppose an impediment for this alternative.

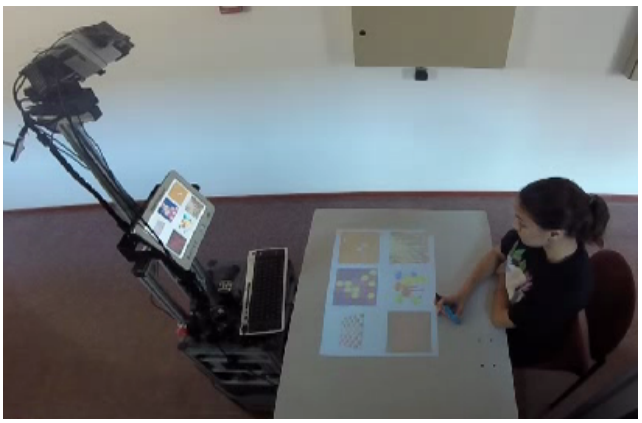

Figure 1: Game session scenario. A small projector embedded in the robot recreates the game over the table surface while the vision perception system estimates the user's movements.

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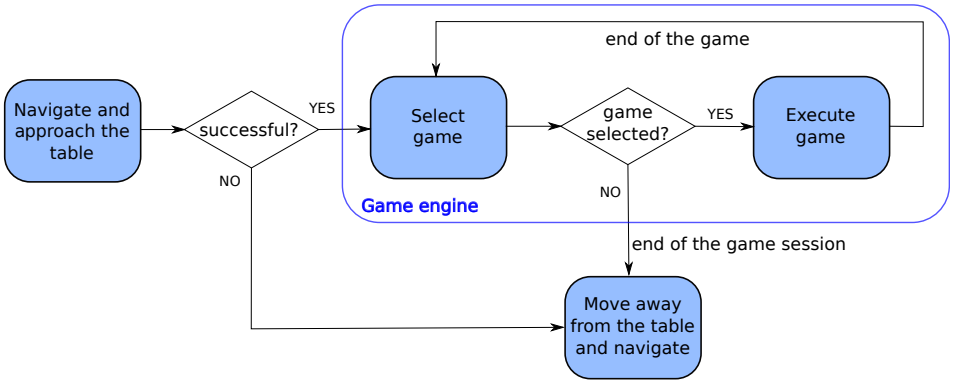

Figure 2: Sequence of tasks carried out by the robot during a game session. The game engine allows the user to terminate the game session at any time.

The proposed solution is to enable assistant robots to play with elder people in a natural way. We claim that, provided that the senior person is already assisted by a companion robot, it could be able to offer her/him games resembling, as much as possible, the normal interaction with people. Interestingly, the robot brings advantages like being available for playing 24/7, offer a wide variety of games, have time control of the game sessions, resume a match at any time or hint alternative moves among others. Furthermore, to achieve a natural performance, the robot is supposed to be also endowed with skills for human interaction, like voice communication or autonomous navigation.

This paper describes a complete interactive game system, which allows a mobile service robot to offer and participate in board games. Our work is designed to offer a variety of games to elder people in a natural and user-friendly way. Concretely, the proposed solution is composed of a projector, which recreates the game board, and a webcam that captures the user's movements related to the game. Figure 1 depicts the proposed interactive game system, where the person (player 1) is placed in front of the robot (player 2), keeping the usual players distribution during board games.

Our proposal successfully addresses the number of challenges arisen during a game session. First, the projector produces a distorted image that must be corrected according to the relative position of the surface with respect to the projector location on the robot. Moreover, the user interaction with the projected board must be conveniently captured, interpreted, and coordinated with the game engine for an optimal user experience. Finally, but not less important, the robot has to safely navigate and approach both, the user and the table, during each game session.

Our contribution to this work includes (i) the hardware calibration, for both the projector and the perception system, (ii) the development of the human-robot interaction during the game, (iii) a fully operational video game engine, including an intuitive menu to select among different games, and (iv) a vision-based algorithm to safely navigate around the table. Moreover, the system has been successfully tested in a laboratory environment.

2 SYSTEM OVERVIEW

Due to the heterogeneity of the present application, the proposed interactive game system has been split into four principal subsystems, namely, hardware calibration, human-robot interaction (HRI), game engine and robot navigation. These subsystems, which are described in detail in the following sections, depict a logical division of the multiple tasks involved in the proposed system. Yet, to illustrate the work flow of a game session, a more convenient division results from considering the chain of successive actions (see Figure 2) that occur over time, leading to the following stages:

(1) The robot safely navigates and approaches the table where the game takes place.
(2) The game engine starts by projecting information about the different available games. Once a game is selected, the game engine starts recreating the board over the table by means of the projector and detecting the users movements, through a webcam.
(3) When the ongoing game ends, the game engine offers the available games to the user again, allowing he/she to play another game. If the user decides to terminate the game session, the board projection and the movements detection are switched off and the robot proceeds to move away from the table.

3 CALIBRATION

The particular position of the projector and the webcam with respect to the surface where the game is taking place generates distortions that have to be corrected to ensure a successful user experience. Regarding to the projector, its relative position produces that the projected image suffers from a trapezoidal distortion. Also, the images captured by the webcam have to be corrected to properly identify and interpret the user movements. Figure 3 illustrates the above-mentioned hardware positions on the robot and the angular differences between planes which generates the distortions.

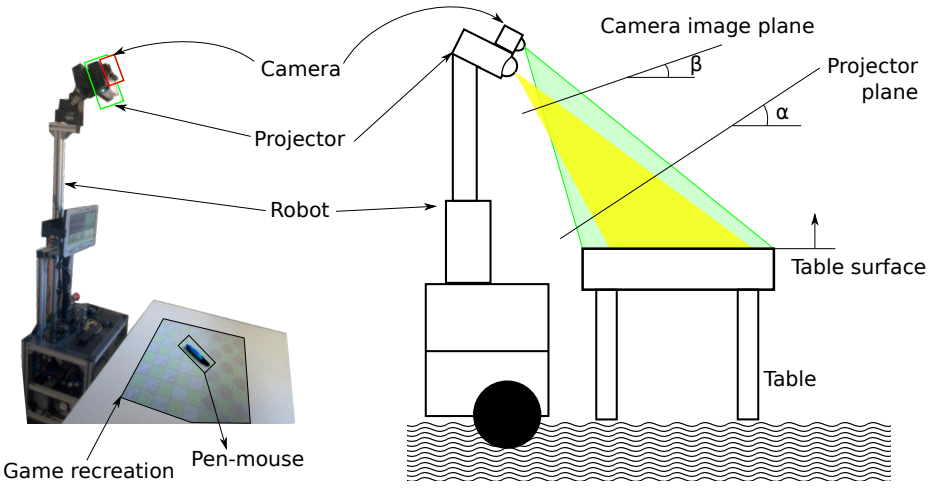

Figure 3: Left: Hardware elements which constitute the interactive game system. Right: Angular differences between the projection plane and the table surface (α) and between the latter and the camera image plane (β). These differences cause image distortions

3.1 Projector Calibration

To correct the trapezoidal distortion caused by the projector, we transform every image recreated by our system through a projective transformation obtained during the system calibration stage.

The challenge of this calibration is the absence of embedded sensors in the projector to measure this distortion. To solve this issue, we use an additional camera placed perpendicular to the table surface to determine the projective transformation by comparing both, the image projected on the table as observed by the camera and the image the system pretends to present to the user. This transformation is usually denoted as a matrix H, which relates pixels from the first image (x, y) with pixels from the second one (x', y'), as shown in Equation (1). Homogeneous constraint is applied, meaning $z' = 1$.

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & H_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \quad (1)$$

The search of correspondences between images is simplified, since the minimum amount required for the calibration process is 4. For that, we create a known and well-defined pattern with 4 white, symmetrically located circles over a black background, which are automatically detected using the *Hough* algorithm after applying standard noise reduction filters. Once the correspondences are determined, the homography matrix H is estimated. It is important to remark that this calibration is carried out only during the setup of the system, being valid as long as the height of the table and the robot-table distance keep invariable at each game session.

Once the matrix H is obtained, the camera used for calibration is not longer used since its location hinders the usability of the system.

In general, the output resulting of the application of this projective transformation is a larger image. This effect is inherent to the own transformation and it is solved by resizing the rectified image to fit the display area of the projector as shown in figure Figure 4.

3.2 Vision Perception System Calibration

The position of the webcam over the robot also generates a distortion in the captured image. We need to correct this deformation in order to correctly interpret the user's movements. Through this calibration, we can map the board presented by the projector -which appears with distortion in the observed image- and the actual game board -without distortion-. For this calibration, we apply the same methodology described in section 3.1. The projector is employed to emit the same pattern used for correcting the projector distortion, and the same procedure to search the pattern in the webcam image is followed to obtain an homography transformation.

4 HUMAN-ROBOT INTERACTION

In this Section, we present the bidirectional communication established between the robot and the human during the game session. Firstly, we tackle the extension of the robot social behaviour through the game recreation and the voice system. Secondly, the vision perception system which allows the human player to interact with the game is addressed.

4.1 Game Recreation

By recreating the game over the table surface, we allow the user to visualise and play a game which is indeed being natively executed in the robot embedded computer. This recreation increments the user acceptance of our work, since it enables her/him to play typical games in a natural and friendly way. Likewise, locating the robot in front of the human player maintain the established and classic distribution during board games. To achieve a reliable recreation, the following technical attributes are deemed:

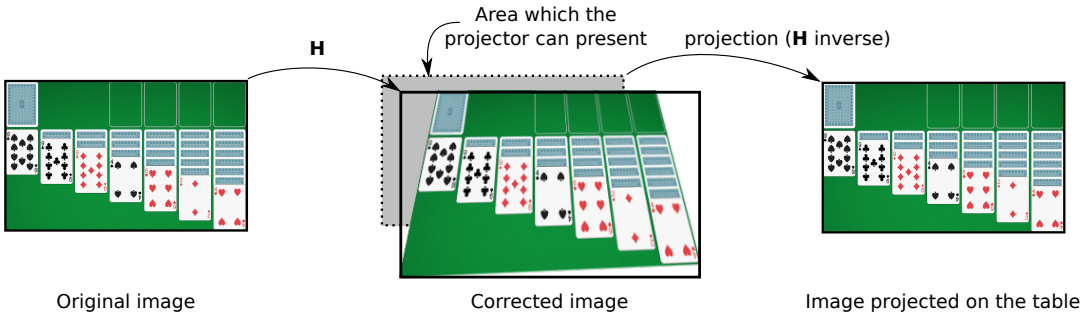

Figure 4: Correction of the original image by applying the projective transformation H. The output image is larger than the original, effect produced by the own transformation.

- **Projective Transformation**: Which allows the system to correctly project the board on the table, recreating the game as if the real board were placed on top.
- **Image Rotation**: Since the human player is sitting in front of the robot, the projected board is rotated by 180°.
- **Exit Button**: We provide the user with an exit button in red, located at the bottom right corner of the projected board. This button allows the user to conclude the ongoing game at any time.
- **Cursor**: In order to help the user to realise where his/her movements have been detected, the cursor is replicated, represented as a small blue circle.

The robot is also provided with the ability to speak to the user during the game session, improving its social behaviour. The voice communication implemented in this work is limited and not voice recognition skills are considered.

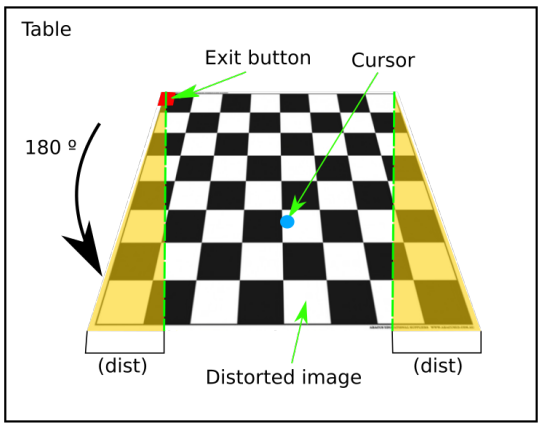

Figure 5: Projected images over the table are seen as parallelograms. These images have to be modified to correct the distortion (dist) and rotated 180°. An exit button and the cursor are recreated for the human player.

4.2 Human Movements Detection

The vision perception system of the robot captures the human player movements by means of a webcam, which are subsequently interpreted and coordinated with the game engine in order to offer an optimal user experience.

The user is provided with a *pen-mouse*, device which allows him/her to interact with the different pieces of the game. Usually these devices provide buttons and a pointer. Nevertheless, while the buttons are useful and used during the games, the pointer is deactivated, given it only provides a relative position but not the global position within the board. Thus, the proposed system conveniently tracks the pen-mouse and relates its position with respect to the projected board.

In order to register and estimate the *pen-mouse* motion within the projected board, we implement a tracking system by means of the *Camshift* [2] algorithm, taking advantage of the device shape and colour. To strengthen it, the input images are processed by firstly, restricting the device detection into the board game, avoiding false positives outside the target area, and secondly by applying noise reduction filters. Finally, constraints related to the colour and shape of the device are included, preserving just those elements with high probability of being the target *pen-mouse*.

A rotated rectangle defined in the image plane is obtained after running the detection algorithm. This rectangle is determined by its position, size, and orientation. Inside this parallelogram we adjust an ellipse which represents the basic geometry of the *pen-mouse*. One of the vertices of this ellipse represents the tip of the device which is in contact with the table surface. Which vertex defines this tip depends on how the user holds the *pen-mouse*. If the user is left-handed, the tip is defined by the green circle (left image), meanwhile the right image shows a right-handed user, configuration in which the tip is represented by the red circle. We integrate a configurable parameter in the interactive game system to specify if the user is left-handed or right-handed.

Special circumstance are envisaged, capturing them as exceptions. For instance, the disappearing of the *pen-mouse* from the game board for a long time. In this particular scenario, the embedded buttons in the device are deactivated in order to avoid undesired interactions.

5 GAME ENGINE

An important feature of the proposed interactive video game system is the possibility to offer several games to the user. Once a game session starts a menu is projected on the table where the different available games are represented as icons, facilitating the user selection. The human player can select the desired game by means of the pen-mouse, locating it over the representing game icon. After a game is selected by the user, it is executed in the robot embedded computer and recreated on the table. During the game, the user's movements are detected as commented in Section 4 and input to the game engine. The inclusion of a virtual button easily permits the user to exit the application at any moment. This action stops the game recreation and the user's movements detection.

6 ROBOT MOVEMENT

This section presents the navigation tools that allow the robot to move safely towards the table, avoiding collisions. These tools are based on the ROS (Robotic Operating System [10]) navigation stack, including map localisation, path planning, and dynamic collision avoidance. Additional functionalities have been implemented to allow the robot to approach and move away from the table, since the usual navigation algorithms do not permit the robot to get close to obstacles -a table is considered an obstacle-.

The components from the ROS navigation stack used in this work are the following:

- **gmapping/map_server**: environment mapping using SLAM techniques based on 2D lasers. The occupancy grid mapping, which is used to locate and plan the path, is taken from the package *map_server*.
- **amcl**: probabilistic localisation system based on particles filter.
- **move_base**: global path planning from the start position until the table.

In order to allow the robot to approach towards the table, the webcam is employed to estimate the current robot pose. The key feature to compute this pose is the edge of the table, which appears as a single straight segment in the captured image. In order to detect this edge, the *Hough* algorithm for lines is executed, processing beforehand the input image to remove noise by standard filters. Among all the detected segments, we keep the candidate which best matches the reference position (previously defined in the system).

On the other hand, when the game session concludes, the robot must move away from the table in order to navigate from a safe initial position. For that, the robot moves backwards for a fixed period of time.

7 SYSTEM VALIDATION

Since an accurate user movement detection is indispensable to ensure the performance of the proposed system, a study on the detection errors has been carried out as described in Section 7.1. Also, validations of the whole system are detailed in Section 7.2

7.1 User Movement Detection Errors

In order to quantify the errors in the *pen-mouse* position estimation, we have designed two different experiments (**A** and **B**). The former aims at studying the accuracy of the estimation, while the reliability with respect to the pen tracking is tested in the latter.

- **Experiment A**: The pen is located at six known position (control points) and is detected by our algorithm, computing subsequently the $D4$ distance between the detected location $p_1 = (p_{1x}, p_{1y})$ and the ground-truth $p_2 = (p_{2x}, p_{2y})$, with $D4(p_1, p_2) = |p_{1x} - p_{2x}| + |p_{1y} - p_{2y}|$. Figure 7 depicts the five-numbers summary of the percentage errors for each situation, with an average of 569 images per sequence. We obtained an average percentage error under 3% revealing that the estimated pen position and the true position within an 1024x1024 image differs in average, at most, 30 pixels. In practice, this figure suffices the requirements of typical games.
- **Experiment B**: The pen is freely moved under three different light condition, namely, dark, medium and bright light. Figure 6 shows the percentage of valid detection for each sequence with an average of 634 images per situation. It can be notice that our algorithm is able to detect, estimate and track the pen position independently of the light level, achieving more than 94% of valid detection per sequence.

7.2 Real Environment Validations

To validate the correct behaviour of the proposed interactive game system, we have tested it in real scenarios. In these validations, a mobile robot from the MAPIR[1] laboratory, *Rhodon*, carries out the robot player role. A small projector (YG300 LCD Mini Proyector) and a webcam (Creative Live! Cam Sync HD 720p) have been incorporated on the robot. The user is provided with a pen-mouse (SODIAL(R) 2.4GHz Wireless Pen Shaped Mouse Adjustable) whose position within the projection area is detected and input to the game engine.

The mobile robot performs all the tasks involved in this work in order to offer games to the user. Both the projector and the camera have been located on the robot at a height of $0.8m$. This distance is compelled by the limited focal length of the projector.

[1] http://mapir.uma.es

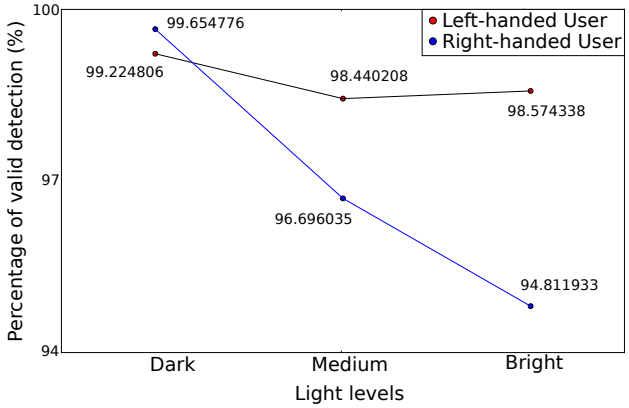

Figure 6: Percentage of successful pen position estimation under three different light conditions.

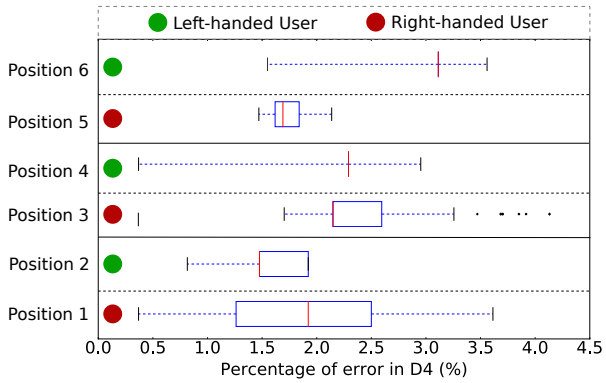

Figure 7: Error in the pen position estimation for six different control positions.

The already built-in sensors and actuators of the robot are employed during the navigation stages. Importantly, the additional hardware which constitutes the interactive game system is affordable, lightweight and non-intrusive, making our work easier to incorporated into assistance robots.

Regarding to the offered games and considering the limitations of the projector, during the validations a total of six games are presented to the user, games which are available in every Linux SO, e.g. checkers or chess.

Figure 8 depicts game sessions in which a human is playing with the mobile robot *Rhodon* in a laboratory environment during the validations of the proposed system.

8 CONCLUSIONS AND FUTURE WORK

With this work we have provided an assistance mobile robot with the ability to offer and play board games with humans. Special importance has been given to simplicity and user acceptance. A small projector and a webcam have been integrated in the robot. The former recreates the game over the table surface, while the latter is used to estimate the user's movements. Distortions related to the relative positions of both constituents in relation with the table surface have been contemplated and corrected by using homography transformations. A game engine which initially offers to the user the available games to subsequently execute the selected game, has been implemented. Navigation modules have been developed, allowing the robot to move safely from its initial pose towards the table. Finally, a number of tests have been carried out with a real mobile robot in a laboratory environment, verifying the correct performance of the proposed interactive game system.

Figure 8: During the experiments, six different games have been played by the users and the robot by means of the proposed interactive game system

As future work, we propose an automatic calibration for the system projector-webcam along with an improvement in the voice communication, providing the user with the ability to speak and control the robot and the game via voice commands.

REFERENCES

[1] José Manuel Cort Bordería, Rakel Poveda Puente, Ricard Barberá i Guillem, Malena Fabregat Cabrera, and María Costa Ferrer. 2004. Juegos de mesa y personas mayores: la importancia de nuevos diseños. *Revista de biomecánica* 42 (2004), 11–12.

[2] G.R. Bradski. 1998. Real time face and object tracking as a component of a perceptual user interface.. In *IEEE Workshop on Applications of Computer Vision. WACV'98*. https://doi.org/10.1109/ACV.1998.732882

[3] Silvia Coradeschi, Amedeo Cesta, Gabriella Cortellessa, Luca Coraci, Cipriano Galindo, Javier Gonzalez-Jimenez, Lars Karlsson, A. Forsberg, Frennert S., Francesco Furfari, Amy Loufti, Andrea Orlandini, Filippo Palumbo, Federico Pecora, Ales Stimec, Stephen Von Rump, Jonas Ulberg, and B. Otslund. 2014. *GiraffPlus: A System for Monitoring Activities and Physiological Parameters and Promoting Social Interaction for Elderly*. Springer, 261–271.

[4] Martha L Daviglus, Carl C Bell, Wade Berrettini, Phyllis E Bowen, E Sander Connolly, Nancy Jean Cox, Jacqueline M Dunbar-Jacob, Evelyn C Granieri, Gail Hunt, Kathleen McGarry, Dinesh Patel, Arnold L Potosky, Elaine Sanders-Bush, Donald Silberberg, and Maurizio Trevisan. 2010. NIH state-of-the-science conference statement: Preventing Alzheimer's disease and cognitive decline. *NIH consensus and state-of-the-science statements* 27, 4 (April 2010), 1–30. http://europepmc.org/abstract/MED/20445638

[5] H. M. Gross, S. Mueller, C. Schroeter, M. Volkhardt, A. Scheidig, K. Debes, K. Richter, and N. Doering. 2015. Robot companion for domestic health assistance: Implementation, test and case study under everyday conditions in private apartments. (Sept 2015), 5992–5999. https://doi.org/10.1109/IROS.2015.7354230

[6] SK Inouye, ST Bogardus, DI Baker, L Leo-Summers, and LM Cooney. 2000. The Hospital Elder Life Program: a model of care to prevent cognitive and functional decline in older hospitalized patients. Hospital Elder Life Program. *Journal of the American Geriatrics Society* 48, 12 (December 2000), 1697–1706. http://europepmc.org/abstract/MED/11129764

[7] S Kalmijn. 2000. Fatty acid intake and the risk of dementia and cognitive decline: a review of clinical and epidemiological studies. *The journal of nutrition, health & aging* 4, 4 (2000), 202–207. http://europepmc.org/abstract/MED/11115801

[8] Javier Monroy, J. R. Ruiz-Sarmiento, Francisco-Angel Moreno, and Javier Gonzalez-Jimenez. 2018. *Towards a Semantic Gas Source Localization under Uncertainty*. Springer, Cham. https://doi.org/10.1007/978-3-319-91479-4_42

[9] Andrea Orlandini, A. Kristoffersson, Lena Almquist, Patrik BjÃűrkman, Amedeo Cesta, Gabriella Cortellessa, Cipriano Galindo, Javier Gonzalez-Jimenez, Kalle Gustafsson, Andrey Kiselev, Amy Loufti, Francisco Melendez-Fernandez, Malin Nilsson, Lasse Odens Hedman, Eleni Odontidou, J. R. Ruiz-Sarmiento, Marten Scherlund, L. Tiberio, Stephen Von Rump, and Silvia Coradeschi. 2017. ExCITE Project: A Review of Forty-two Months of Robotic Telepresence Technology Evolution. *Presence: Teleoperators and Virtual Environments* (2017). https://doi.org/10.1162/PRES_a_00262

[10] Morgan Quigley, Ken Conley, Brian Gerkey, Josh Faust, Tully Foote, Jeremy Leibs, Rob Wheeler, and Andrew Y Ng. 2009. ROS: an open-source Robot Operating System. In *ICRA workshop on open source software*, Vol. 3. Kobe, Japan, 5.

[11] Compiled by: Giuseppe Riva. 2017. TERESA: Socially Intelligent Robot as Window to the World. *Cyberpsychology, Behavior, and Social Networking* 20, 5 (2017), 343–343.