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Assistance to Older Adults with Comfortable Robot-to-Human Handovers

Jordan Nowak^{1,2}, Philippe Fraisse¹, Andrea Cherubini¹, Jean-Pierre Daures²

Abstract—Today's ageing and increasingly dependent population has strong needs in terms of assistance. In this article, we propose the design of comfortable robot-to-human handovers, guaranteeing manipulability and limiting the effects of gravity forces at the transfer point. Our framework relies on vision and on a bio-mechanical model of the human arms, to obtain a handover area adapted to the person. We validate our developments with the Pepper robot handing over objects to elderly people in a nursing home. The results show that the robot's movements, the distance of the exchange, and the reached zone are all satisfactory, so the person can recover the object in good conditions.

I. INTRODUCTION

A. Motivation

The number of dependent people is increasing as the world's population ages. To maintain at home dependent older adults, and have them regain acceptable comfort in their daily lives, there are many, and increasingly so, specific tools and aids (for example, electric can and bottle openers, grab bar in the toilet or shower, etc.). With the arrival of robotics, health professionals see a possible interest in lightening their work and that of natural caregivers.

Assistive robotics is an opportunity to address this health challenge and help aging populations limit their loss of autonomy and improve their care. It has many advantages, such as simply keeping company, allowing video calls, enabling telepresence, alerting care professionals or the caregiver in case of need, or even bringing objects to the patient. In this study, we focus on physical assistance, and particularly on robot handing over an object to a human subject, in a comfortable zone. Fig. 1 shows a result of a handover during the experimentation.

B. Previous work

Handovers are very complex and humans have a strong capacity for adaptation, and this allows them to perfectly coordinate their actions with each other. To transfer this ability to a robot, it is necessary to fully understand and deconstruct this action. This exchange involves a set of cognitive and physical processes between the two individuals. Despite major advances, object transfer is still a problem studied by researchers around the world [1]. In the context of this research, we are interested in the transfer of objects from a humanoid robot (giver) to a human (receiver). The

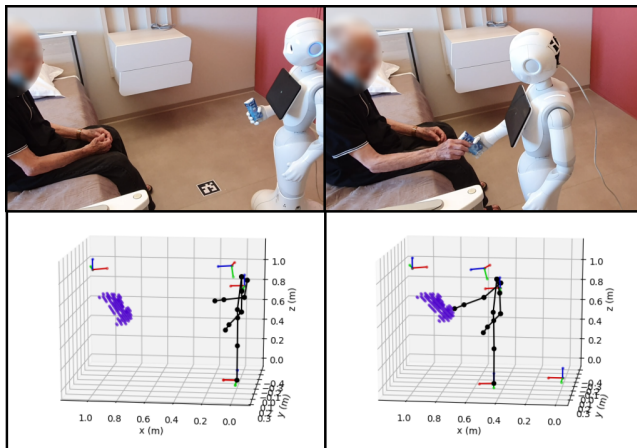


Fig. 1. Two images (with the displays associated below) showing the transfer of an object by the Pepper robot to an older adult sitting. The first column shows the robot initially, with the object held in hand. The second column shows that the point is reached and that the person can recover the object.

exchange can be classified into two distinct phases: the *pre-transfer* and the *physical handover* of the object [2].

Pre-transfer phase concerns the interactions and planning which take place before the physical transfer. The giver analyse the object, grasp it correctly, perceive the receiver's intention to receive it, estimate a transfer area and carry out adequate movement planning.

Communication is important because it coordinates the exchange. and improves the predictions of both partners. Indeed, the movement of the eyes [3] or the direction of the head [4] is sufficient to define the intention. This visual interaction allows for a more natural exchange for the human receiver. Other than the gaze, the spatial and temporal contrasts can improve the fluidity of remittances [5]. It's also necessary to find the best way for grasping an object [6], while also anticipating the way the human would recover it afterwards – by leaving the graspable parts free [7].

To determine a transfer zone, an estimation of the area where the object should be transferred is implicitly performed. This transfer area must be a compromise and must be easily accessible by both individuals [8].

The work of Sisbot *et al.* [9] and Suay *et al.* [10], have worked on a movement planner specifically designed for the transfer of objects between humans and robots. To this end, they take into account the visibility, safety and physical comfort of human arm movements. To define them, the authors refer to user studies ([11] and [12]), to the theory of proximity [13] and to human ergonomics (in particular on

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[14]). Koay *et al.* [11] and Dautenhahn *et al.* [12] worked on the approach that the robot should have in terms of direction and distance. Like them, we seek to generate an ergonomic transfer space by maximizing the safety and comfort for the human arm. The criteria of distance and direction are not used, but we take into account the manipulability (possibility of movement) and the effect of gravity on the arm joints.

We draw inspiration from Pyo *et al.* [15], which designed a system – relying on a trolley and robot – for handing over objects to patients in hospitals. The particularity in their paper is that it calculates the manipulability index in order to give the object in the best possible condition (by pooling the manipulability map of the robot and patient). Their work ensures maximum manipulability for the human and robot.

Regarding the planning and movement, humans prefer when the movements are natural, fluent and similar to theirs. It allows them to have good legibility [16]. To have this characteristic, it is possible to use control inverse kinematics. Our control strategy is based on this type of inverse kinematics controller based on the Quadratic Programming (QP) architecture [17] to take into account different constraint. Moreover, to limit human stress and improve the user experience, the robot must have low speed motion [18].

The physical handing over of the object begins at the moment of physical contact between the object and the receiver. Here, giver and receiver must analyse the exchange of gripping forces to confirm the correct transfer of the object. Indeed, studies highlights the importance of this haptic perception between a human and a robot [19]. These grip forces tells if the other individual whether s/he intends to let go or take the object and also whether s/he is holding it properly. For this study, the Pepper robot has very limited haptic capabilities. Indeed, it has no force sensor in its hands. Therefore, it cannot detect a human's grip by its means. In future work, it could be envisaged to add sensors to this robot allowing it to take into account grip forces and thus considerably improve the physical interaction during the transfer. For the moment, a tactile interaction on the tablet or a vocal communication allows to signal the good reception of the object by the human.

C. Object transmission objective

In this work, we assume that if humans have more ease in moving their upper limbs and if they spend less energy to keep them in a certain configuration during transfer, this will lead to safer and more comfortable transfers. Moreover, it is necessary to adapt to the person – who may present joint disorders – by taking into consideration his/her joint limits to define the handover points used by the robot.

First (Sect. II), we generate an ergonomic transfer space adapted to the person, for the transfer of an object from robot to human. This space introduces our main contribution in this paper which is the *calculation and consideration of the severity index and potential energy minimizing the efforts on the human upper limbs*. We couple it with the manipulability index, to adjust the generated zones and obtain a satisfactory object transfer space. It is explain later how the robot can

estimate the human posture (Sect. III-B) in front of it, and thus determine the transfer point to be reached (Sect. III). Finally, The results obtained in an experiment with real users in a nursing home are presented Sect. IV. Another contribution is the feedback from these experiments.

II. HANDOVER WORKSPACE

The objective is to create a handover workspace around the person to give an object in a comfortable position. The first goal is to generate a set containing all points attainable by a person. Then, the sort of this point cloud allow to highlight the most comfortable points for object transfer.

A. Reachable workspace

First, a biomechanical model of the human is used to determine the position of his/her hand for each possible configuration. For this, only the upper limbs are used (arms and hands) motricity. We consider the biomechanical model of Kapandji [20] and simplify it, by considering only 3 rotations for the shoulder and 1 for the elbow (see Fig. 2). In case of joint disorders, it is necessary to know the maximum joint limits which the human can reach.

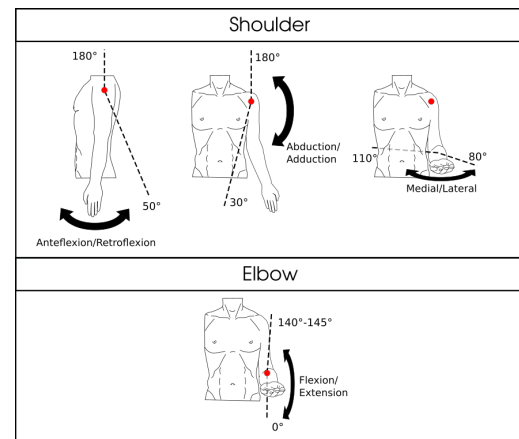


Fig. 2. Articular movements and their limits for each articulation of the 3 shoulder rotations and the elbow flexion.

The objective is to establish a personalized model so that the generated workspace is adapted to the abilities and physical characteristics of the person. We first need to know the height and weight of the person. Indeed, this allows us, according to anthropometric tables [21] [22], to approximate the size of his/her upper limbs. The weight is needed to calculate the potential energy and the severity index in a given position (see Sect. II-B.2). Having defined the model, we can compute the pose of the hand frame in the main reference frame (between the two shoulders, noted R_0 , see Fig. 3). All the point clouds will be defined in this frame.

It is possible now to generate all points accessible by the hand, by rotating each of the four articulations. For this, the joint values are sampled from the minimum to the maximum values. Then, the Cartesian position of the hand can be determined. The 4 joint values which have generated it are recorded. All these coordinates are discretized in voxels, to approximate each point in a voxel at its center.

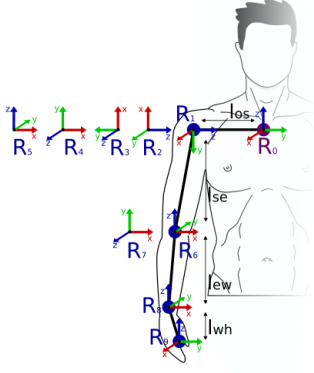


Fig. 3. Human body model with the right arm kinematic chain, right arm frames and the main reference frame (R_0).

B. Ergonomic workspace

1) *Manipulability indices*: To transfer an object to the person, the robot must guarantee the best conditions. Among these, we first focus on manipulability [15], [23], [24]. The manipulability index is a metric of the ease to change pose. Note that for an upper limb, there is redundancy for one hand position (many possible joint angles yield that hand position). But these different configurations do not allow the individual to have the same reactivity. Higher manipulability makes the person more comfortable when grasping objects. The Jacobian matrix \mathbf{J} (which relates the hand speed $\dot{\mathbf{x}}$ to the joint angular velocities $\dot{\mathbf{q}}$ via $\dot{\mathbf{x}} = \mathbf{J}(\mathbf{q})\dot{\mathbf{q}}$) is used to define the manipulability index:

$$m(\mathbf{q}) = \sqrt{\det(\mathbf{J}(\mathbf{q})\mathbf{J}^T(\mathbf{q}))} \in \mathfrak{R}^+ \quad (1)$$

If a point has m higher than a certain value (e.g. 90% of that of the maximal m), it is considered sufficiently manipulable. These points are shown in Figure 4.

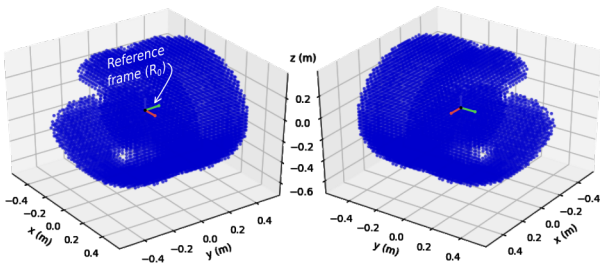


Fig. 4. Two view of the set of points with high manipulability index (greater than 90% of the maximum value) in relation to the upper limbs.

2) *Severity index*: A second index is used to establish the best transfer space: this is the severity index, which informs about the forces exerted on the whole arm at a given pose. It is necessary to recall the dynamics of the arm:

$$\mathbf{M}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{N}(\mathbf{q}, \dot{\mathbf{q}})\dot{\mathbf{q}} + \mathbf{g}(\mathbf{q}) = \mathbf{B}\mathbf{u}. \quad (2)$$

This equation gives the set of forces exerted on a joint during motion. It relates the inertia matrix \mathbf{M} , the matrix of centripetal and Coriolis forces \mathbf{N} , the gravity vector \mathbf{g} ,

the joint torques \mathbf{u} and the matrix \mathbf{B} defining the action of the motors on the actuators. From the expression of the Lagrangian L , i.e.:

$$L = E_c - E_p \quad (3)$$

$$\frac{d}{dt} \frac{\delta L}{\delta \dot{\mathbf{q}}} - \frac{\delta L}{\delta \mathbf{q}} = \mathbf{B}\mathbf{u}, \quad (4)$$

\mathbf{u} and \mathbf{B} are function of potential energy E_p and of kinetic energy E_c . We intend point cloud to be only a function of statically defined parameters. Therefore, the elements related to motion (inertial matrix \mathbf{M} , matrix of centripetal and Coriolis forces \mathbf{N} , and kinetic energies E_c) are irrelevant. Setting $E_c = \dot{\mathbf{q}} = \ddot{\mathbf{q}} = 0$ yields:

$$\mathbf{g}(\mathbf{q}) = \frac{\delta E_p}{\delta \mathbf{q}} = \nabla_{\mathbf{q}} E_p \quad (5)$$

The potential energy can be expressed as:

$$E_p = g * (m_1 * Z_1(\mathbf{q}) + m_2 * Z_2(\mathbf{q})), \quad (6)$$

with g the gravity, m_1 and m_2 the masses of the arm and forearm+hand, Z_1 and Z_2 the heights of the centers of mass of the segments. The masses and centers of mass are established from Winter's model [25]. The geometric model is used to know the coordinates of the center of mass and to express it as a function of the four joint values.

To obtain the minimal potential energy, the two-norm of the gravity vector is computed:

$$s(\mathbf{q}) = \|\mathbf{g}(\mathbf{q})\|_2 = \sqrt{\sum_{i=1}^4 |\mathbf{g}(\mathbf{q}_i)|^2}. \quad (7)$$

Yet, it is also important to know the sign of the potential energy. To minimize it, only the negative values obtained by equation (6) are kept. Practically, the values of $s(\mathbf{q})$ at configurations with negative E_p are minimized. This allows to remove points where the arm configuration would be too high (centre of mass of the arms above shoulder level). These points are uncomfortable to reach. Unlike the manipulability index, the severity index must be minimized. Taking all points with severity index below 25% of the maximum value yields the point cloud shown in Fig. 5.

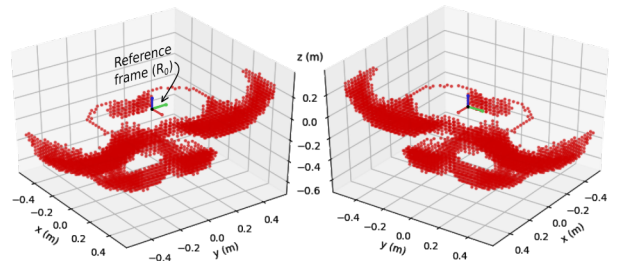


Fig. 5. Two view of the set of points obtained by minimizing the severity index (less than 25% of the maximum value) in relation to the upper limbs.

3) *Pooling*: The main purpose of this point cloud is to determine the optimal zone for object transfer. The points that define the desired zone and that suit our expectations are obtained by keeping only the points in common previously represented in Fig. 4 and Fig. 5. It is possible to generate the transfer zone according to the human's preferred arm. Fig. 6 presents the points in blue for the right arm and the red for the left arm.

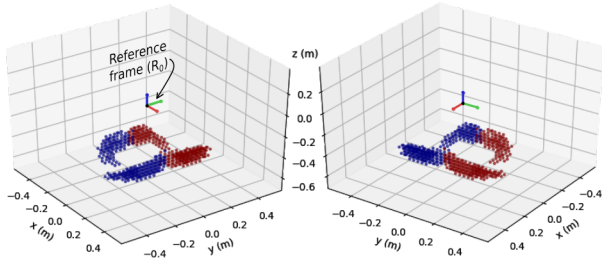


Fig. 6. Two view of the set of points obtained by increasing the manipulability index and minimizing the severity index (respectively greater than 90% and less than 25% of the maximum value) in relation to the left arm in red and to the right arm in blue.

III. HANDOVER APPLICATION

In order to realize this object transfer application, we still have a few points to address. The first one concerns the robotic grasping of the object. Then, the estimation of the human pose and the adjustment of the transfer space. Finally, the determination the transfer point and control the robot to reach this point.

A. The robotic grasp

The Pepper robot has fairly simple hands, which are not adapted to grasping. Each hand has a single motor that operates all the fingers at the same time and this does not allow it to realize precise gripping and a holding force important. For this reason, we have chosen simple objects for transfers, such as a packet of tissues or a small bottle of hydroalcoholic gel. These object can be held securely during the transfer (plastic fits well in Pepper's hands) and the robot can easily lift it. At the start of each experiment, an operator correctly places the object in the robot's hand during the retrieval phase. The robot extends its arm, opens its hand, then closes the hand to hold the object firmly, while the arm returns to the side of the body. This grasp phase is important and improving it will be addressed as future work.

B. Pose estimation

An RGB and a depth images taken at the same time are retrieved. Then, an algorithm allow to matching this two images and to obtain the colored depth image. This colored depth image is analyzed with OpenPose [26] which is a library which allows to detect in real-time multi-person human body, hand, facial, and foot keypoints on images RGB. Therefore, it is possible to easily have the position of the shoulders and the reference point in the image. The depth information give the position of this point.

C. Workspace adjustment

The point cloud generated in Sect. II-B defines a zone that is comfortable for an object-to-human transfer. However, we still need to make some adjustments depending on the situation to define a consistent transfer point.

1) *Pepper handover workspace* : The robot has to transmit an object to a human in front of it. This human can be in different positions. Depending on the position of the human, the generated point cloud will be at different heights. We need to make sure that the robot can reach the targeted transfer point. As in Sect. II-A, the resulting point cloud is generated with the geometric model of the robot and a reference frame between the two shoulders. Then, the manipulability and severity index are calculated as in Sect. II-B. This will allow to adjust the reach zone of the robot by maximizing the manipulability and minimizing the severity index. In order to have a sufficiently large zone, we choose to keep the points whose manipulability index is higher than 25% and whose severity index is lower than 75% of their maximum value. The resulting cloud of points is represented in Fig. 7. This new space seems to be more appropriate for the robot and therefore defines two new limits. Indeed, the points of the so-called comfortable zone of the human between these height limits are kept.

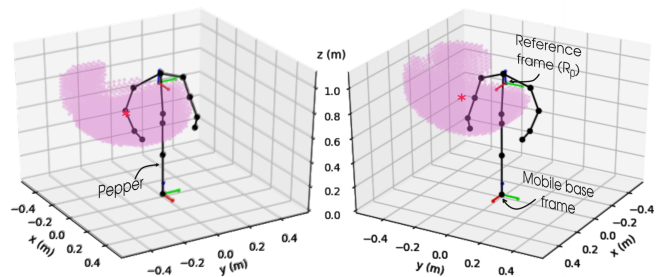


Fig. 7. Set of points (transparent purple) generated for Pepper's right arm by minimizing the severity index (at 75% of its maximum value) and maximizing the manipulability index (at 25% of its maximum value). The barycenter of this point cloud is shown as a red star. Pepper is represented here in wireframe for a better visualization (black points and segments).

2) *Human posture*: The points located on the back of the person are removed because these points have little interest for this application. Then, it is necessary to estimate if the person is standing or sitting and to remove points below the hip if he/she is sitting. Indeed, we could see that when the person was sitting, there was a chance that the points of the generated point cloud would be confused with the position of the legs. There is therefore a risk that the robot gives the object too low (for a seated person) and touches the legs.

D. Transfer point estimation

A selection must be make in point cloud to see which point should be reach for the transfer of the object. The first idea was to take the closest point between this zone and the position of the robot's hand in order to limit the displacements of one towards the other. However, with this solution the point to be reached was generally a little too low.

To adjust this problem, it is necessary to take into account the Pepper’s workspace, and to calculate the barycenter (see Fig. 7). The closest point between the human handover space and the position of this barycenter is estimated. This allows to ensure a more appropriate height for the object transfer.

E. Control to reach the target point

RKCL controller [17] is used to reach the transfer point by controlling the robot’s arm while managing the mobile base. This C++ library allows to quickly set up the controller for the Pepper robot and offers the necessary tools to perform tasks in the Cartesian space. The controller takes into account the kinematic properties and joint constraints imposed by the robot and the intended application. Other parameters affect the control law itself, such as the gain parameters, or the time step of the control loop. We set the latter to *50ms* to give the controller enough time to process the vision data between steps while being sufficiently reactive to perform smooth motions. This library ensure that the joint command does not violate the authorized limits in terms of position and velocity.

IV. EXPERIMENTATION

We set up an experiment which consists to generated different zone and realizing transfers from the robot to the human to evaluate the satisfaction of the receiver. The objective is to find an acceptable threshold combination for the object transfer. Older adult were selected as volunteers. They were requested to sit on a bed during the experiment.

A. Process and survey

First, the thresholds for the severity and manipulability indices are set up. The variation of these parameters may give very different transfer zones. We choose three combinations of thresholds which give the zones shown in Fig. 8 (generated with no joint disorders on its upper limbs).

For a good estimation of the preferences, we performed four transfers per generated zone which results to twelve transfer. Questionnaires are used to determine the most appreciated zone by the volunteer.

First, it is necessary to ask the weight, height and articular amplitudes limits to the volunteers. The algorithm generates the ergonomic transfer zone. The robot will first turn to be in front of the person in turning on its mobile base and lower or raise its head to center the person in the image. Then, the robot estimates the human pose, maps the cloud of points around the human and estimates the point of transfer to reach. The transfer can then begin and the robot looks in the direction of the person during the transfer. When the point is reach, Pepper then announces that the person can take the object. For a better interaction, voice recognition have added in order to warn the robot that the human hold the object. The robot to stop waiting and to open the hand gently.

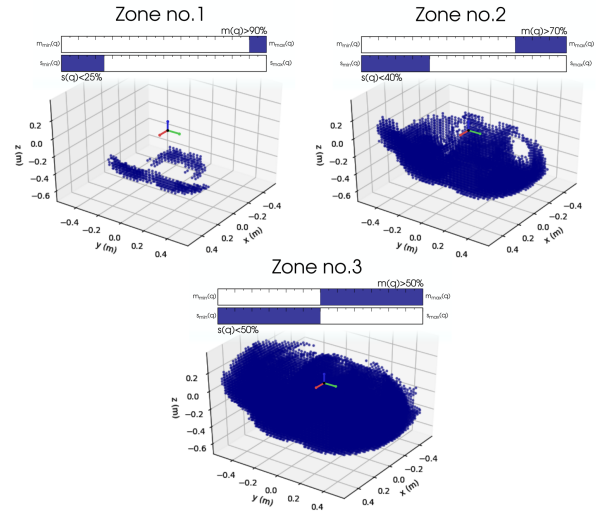


Fig. 8. Set of points obtained for the second experiment by different minimization of the severity index ($s(q)$) and maximization of the manipulability index ($m(q)$). The percentage represents the location of the threshold in relation to the maximum and minimum indexes value. The reference frame R_0 represents the frame located between the two shoulders of the human.

B. Results and discussion

At first, we carried out this study with seven older adults aged between 86 and 99 (average 91.86 years \pm 4.78 years). Three of this residents had limitations on their joints (mostly shoulders). The points cloud generated is more centred in front of the person and better adapted. For a person with no joint disorders, the values presented in Sect. II-A are kept.

Then, we included younger people to get more data. These new inclusions gave a total of twelve volunteers with age between 21 and 99 (average 68.83 years \pm 30.28 years).

The results to the satisfaction questionnaire give the ranking shown in the histogram of Fig. 9 for the generated transfer zones (Fig. 8). It shows the results obtained for the seven residents of the nursing home (in orange), and the results obtained for all the participants (in blue).

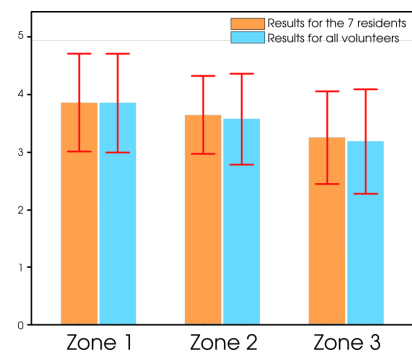


Fig. 9. Histogram showing the scores (out of 5) for each zone generated in the second experiment: orange for the 7 residents of the nursing home and blue for all 12 participants of the experiment.

The subjects prefer that the object is given to them close enough. Indeed, zones 1 and 2 were globally appreciated because they were always easily accessible. For the movement of the robot did not surprise them and seems to suit them

very well. For the distance, there was no surprise either, only some transmissions too far away (third zone). In the context of these demonstrations, this does not surprise them and they seem confident about the proximity of the exchange. Finally, for the question of the relevance of the study, the most concerned people (the residents) remain much more neutral towards this question and sometimes express their fears. For example the fear that the robot replaces the human, and impoverishes the human interactions already considered as too weak. They also fear that the interaction and the understanding of the robotic tool are not so simple on people with degraded cognitive functions. To evaluate or to have an idea of the ability to judge, understand the instructions, but also to memorize and to be attentive it would be interesting to have an evaluation of the cognitive profile beforehand.

Despite the encouraging results, we know that these experiments are carried out on a too small sample of people. It is necessary to carry out a larger number of tests in the near future to validate this work in a more concrete way.

V. CONCLUSION

This work allowed to carry out the handover of an object from robot to human, at a point considered optimal for humans. With two metrics we can establish a cloud of points that would allow us to map the most comfortable and manageable points around the individual. The first is the manipulability index, which allows to know if the person can easily change position in a given configuration of his/her arm. The second is the severity index, which gives the positions for which the human uses the least amount of energy to maintain or change his/her position. This work takes into account the weight, height, and joint limitations.

We had the opportunity to carry out an experiment directly in a nursing home with older adults and we could evaluate their satisfaction with the generated transfer zones. Generally, the object was always reachable. The subjects' answers show a preference for transfers in the zones closest to them. The volunteers with relevant joint limitations were satisfied with the transfer zone adaption.

We plan to continue our experiments with older adults, to obtain more data and more opinion on these transfers. We would also like to improve the algorithm by taking into account the person's field of view, better estimate his/her posture and detect when he/she is lying on the bed.

ACKNOWLEDGMENT

We thank all participants in the user study, and the professionalism of the nursing home staff for the room accessibility and the contact with the residents.

INFORMED CONSENT AND COMMITTEE

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee for the Protection of Persons concerned (CPP SUD méditerranée IV: Ref. 160908 NI ID RCB: 2017A 01898-45) on 19 June 2017.

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