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Towards Whole Arm Manipulation for Outpatient Care

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***Abstract*—In nursing, nurses are burdened with many physically demanding tasks. Especially in ambulatory care, nurses are alone with their patients and are under great time pressure. Due to long journeys, no second nurse can be called in. Also, a suitable nursing aid is not always available or at hand for the patient. A flexible robotic solution can help here. In this paper, we consider the positioning of the patient on the side. In particular, the patient mobilized on the side should be held in this position. We analyze how a nurse would perform this activity and how a robot can be used for this. For this, we use Whole Arm Manipulation (WAM). WAM is a suitable means of ensuring that a manipulator can apply the necessary forces and reduce the risk of injury to the patient. We developed an algorithm for WAM based on the kinematics of the manipulator and the geometry of the scene. For simplification, an elliptical cylinder is used as a human model. This is derived from the real dimensions of the patient. The results show that the algorithm delivers valid results in different constellations and is robust against small deviations from assumptions made for development.**

***Index Terms*—Cybercare, Manipulators**

I. Introduction

The care sector is facing great challenges. Due to the increasing number of people in need of care and the reduction in qualified personnel, the amount of nurses in Germany is already not sufficient [1]. There are currently 3.4 million people in need of long-term care in Germany, almost 2.6 million of whom are cared for at home [2]. Forecasts show that the number will rise to 4.5 million by 2055 [3]. These developments will gradually lead to an intensification of the work for nurses. This work is already mental [4] and physically [5] stressful. Therefore many skilled workers often leave this profession after a few years [6]. To counteract this development, the use of robots in nursing can play an important role. However, the use of fully autonomous robots is highly controversial, especially in the care sector, and is for now not desirable in Germany [7]. Therefore we consider semi-autonomous robotics, like telemanipulation, which is particularly suitable for outpatient care. For work where a second nurse is helpful, normally no support can be called in for outpatient care since the presence of the personnel still requires a journey of 6 minutes (11 minutes in rural areas) on average [8]. [9] show in a qualitative survey of nursing care professionals on challenges and requirements for robotic assistants that positioning the patient on his side is an activity where nurses desire robotic support.

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Fig. 1. Comparison between how a caregiver holds a patient and how our one-armed manipulator fulfills the same task. The nurse reaches from the front of the patient the shoulder and hip. It can also be seen here that not only the hand is used for the holding process.

Positioning the patient on his side is a very common activity in the care of bedridden patients, as this is a prerequisite for further work, like cleaning tasks, reapply bandages, or change bedsheets. The current regular procedure of the activity is as follows [10]:

1) Patient turns to the side or is turned by the nurse to the side
2) Patient stays on the side or is secured by a nurse or positioning aids on the side
3) Nursing staff carries out the task

Depending on the patient's weight, this procedure can overload the nurse physically [5]. Especially if step 2 is not carried out by a second nurse or, often for time reasons, not with the help of positioning aids. [9] found that nurses can imagine being assisted by a robot in step 2. A nurse performs the holding action by grasping the shoulder and/or hip [10] as shown in Fig. 1. The nurse makes sure that the patient cannot fall in

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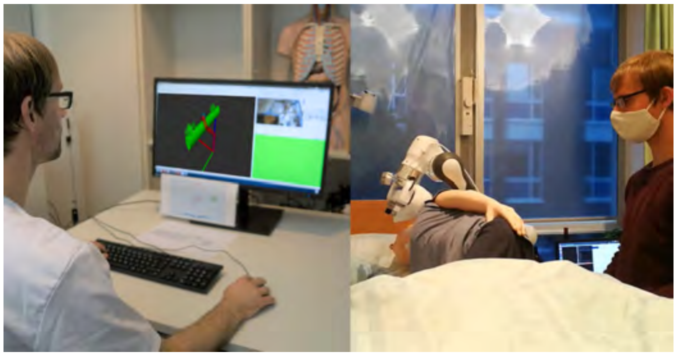

Fig. 2. The system we proposed consists of a remote nurse, who determines the position where the robot is applied to the patient, and an on-site caregiver, who now has both hands free for his work.

one direction or the other. They always stand in front of the patient.

II. Related Work

In this section, we briefly summarize where *whole arm manipulation* (WAM) is used to manipulate or hold objects and then we look at other approaches to similar problems.

The classical approach for WAM is to model the overall system and to control the contact forces between object and manipulator [11], [12]. In particular humanoid robots are used for this purpose. [13], for example, models and controls the system consisting of a two-armed, humanoid robot that is supposed to have a large cylinder in its arms. This is done similarly by [14], who also models such a complete system to transfer a cylinder from WAM to the manipulation with the end effectors. The contact forces between humans and robots differ from person to person, so modeling is difficult. In contrast, we use body geometry, which has the benefit of being able to be measured from the outside and without contact.

We also prefer an analytical solution to the problem over one generated by reinforcement learning, because it is repeatable and transferable to other robots.

Yuan et al. [15] also use the human form to hold and carry a humanoid robot. Yuan et al. [15] use reinforcement learning to generate the robot movement. The sequences are learned on three human models and transferred to a real robot and tested on a person. In our work, on the other hand, we deliberately refrain from machine learning, since this would require re-learning on a real patient to achieve performance in the quality required for use in nursing, which could bring unforeseeable dangers for the patient. In addition, deterministic behavior is required for certification according to the Medical Device Directive. Furthermore, a requirement for our system is that the gripping position can be remotely controlled.

The holding of a person described in this work can be assigned to the Envelop Family. Harada et al. [16] have investigated various types of such manipulation. These include legged robots, humanoid robots, and robot hands. They also found a sufficient condition to reduce the possible solution space for locally manipulating objects with multi contacts. In this way, Harada et al. [16] can provide a fast solution finding.

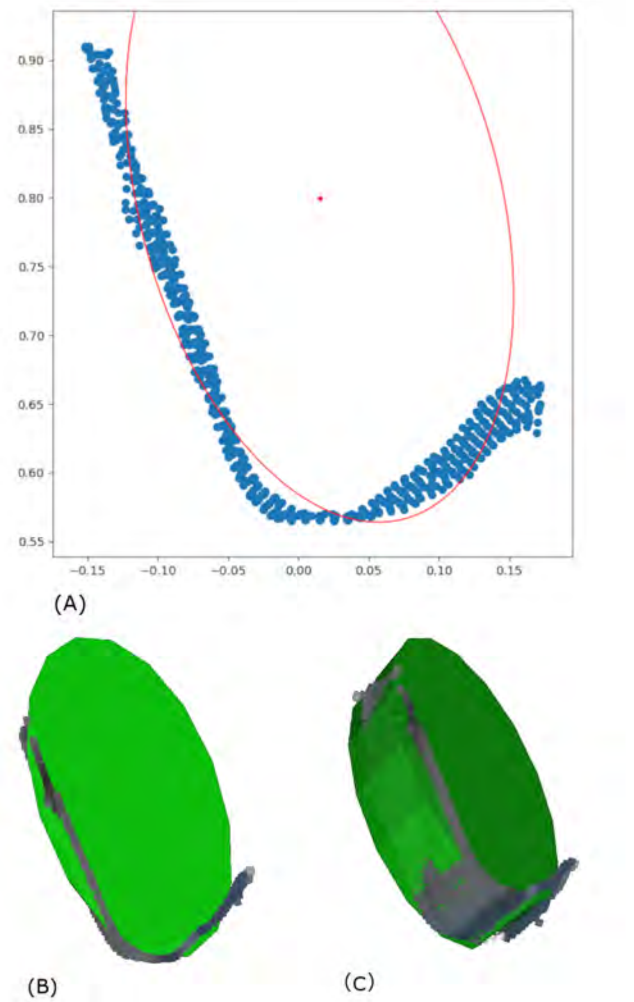

Fig. 3. The elliptical cylinder is generated from a segmented 3D point cloud. For this purpose, the points have extracted that lie in the area where the manipulator is to be applied. (A) These points are projected onto a 2D plane. An ellipse is fitted into this plane. Its ellipse parameters are used to generate an elliptical cylinder, which is used as a model of the human body. In (B), (C) this is fitted into the segmented and cropped point cloud.

The task we are investigating is similar to that of a robotic finger/hand and caging. Therefore, relevant work from these areas will be reviewed in the following. An overview of robotic grasping is provided by [17]. Grasping is defined as multi-point contact between robot and object. The part of the robot with which the contact is made is called a finger. Bicchi et al. examine different methods for force analysis, contact models, and kinematics of hands. Furthermore, they point out that most literature ignores the kinematics of fingers and geometry of objects. Exceptions to this are found in [18], [19]. Bicchi et al. analyze the kinematics of the hands used and the objects to be gripped. In one case, a hand with two single jointed fingers, in the other case a hand with three double-jointed fingers. These only use hinges. [19] uses the Convex Hull Construction for generating the grasp. [18] consider tiltable

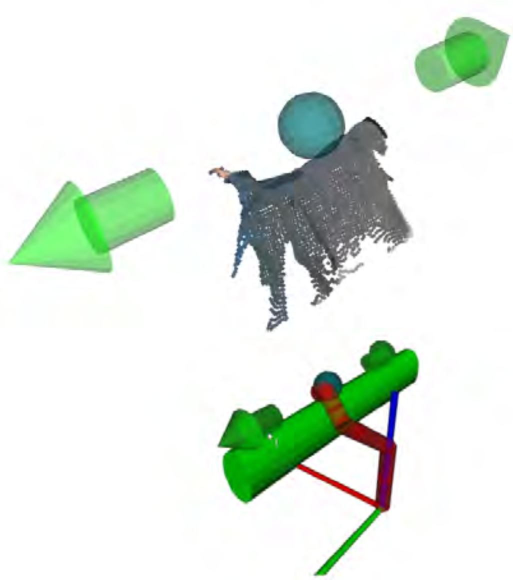

Fig. 4. Example of an interaction element above the segmented point cloud. And an interaction element above the elliptical cylinder derived from the point cloud with a manipulator attached to it. This interaction element can be moved along the longitudinal axis of the cylinder. Thus the target position of the robot is defined. The lower part of the figure also shows a live preview of the expected robot configuration in red.

polygons with known geometry, with which a form fit with the two-finger gripper is algebraically calculated. In this paper, we extend this concept by taking in addition swivel joints into account, which leads to more degrees of freedom. We use the well-known geometry of the object and the finger.

III. Proposed System

We, therefore, propose a telerobotic solution for this task: the use of a collaborative manipulator mounted beside the bed and remotely controlled by an experienced nurse. In this way, on the one hand, the nurse can be relieved on-site, but on the other hand, the nursing service can also benefit from the experience of nursing staff who are no longer able to work at the bed themselves due to physical limitations. The robot has to hold the patient similarly as a nursing force would do, see Fig. 2.

We decided to realize the enclosing grasp for WAM. Since, if large or heavy objects are to be manipulated, WAM is usually used [13], [15], [20]. In the WAM, the load is not only applied to the end effector but is distributed over the links of the manipulator. This brings the load closer to the base and also increases the contact area that can be used for manipulation. Therefore, it allows heavy and large objects to be manipulated, which can also be observed with nurses holding a patient, as in Fig. 1. A robot that is strong enough to manipulate a human being can easily injure him. The distribution of the forces over several contact points also reduces the risk of injury to the patient, as high punctual pressure forces are avoided. Unlike most other works that use WAM, we only use a manipulator and not a humanoid robot.

Fig. 5. View of the complete proof-of-concept setup: bed, dummy, robot arm.

We do not generate the movement via a special control, like [13], [17], [20], [21], or via machine learning [15], because we need predictable behavior of the machine [22]. To achieve this we use the kinematics of the robot and the geometry of the patient. The cross-section of the human body can be approximated well with an ellipse at the shoulder and hip, as shown in Fig. 3. As a result, we choose an elliptical cylinder as a geometric model for the patient's torso.

The robot must hold the patient in suitable places. This can be patient-specific and is, therefore, best decided by a nurse. Since shoulder and hip cannot be recognized so well by a technical system we choose the approach of telemanipulation.

IV. Interaction

The application of the manipulator to the patient should be remotely controlled. Especially the position along the longitudinal axis should be determined by a nurse. The nurse can then select exactly the position that is optimal for each patient. Through a live preview of the expected robot configuration, the remote nurse can assess it and, if necessary, readjust it by slightly changing the target position. In consultation with the nurse on-site, the remote nurse can also adjust the patient's position to bring the patient into a position that is easier for the robot to reach.

Our interaction concept provides that the remote nurse can move along the longitudinal axis of the patient with an interactive element and thus determine the position. The interaction element is fixed above the patient in x- and z-direction. The interaction element and patient are displayed in a 3D camera image. In this view, the nurse gets a preview of the robot end pose for the selected position. If a position is not reachable, the last valid one remains selected until a new reachable position is selected. This requires the following components:

- Segmentation of the patient from the 3D camera image
- Placing an interaction element over it
- Determine the ellipse parameters at the selected position

Fig. 6. Demonstration of the working system. Find this as video here: https://youtu.be/EDAIammuRvw

- Calculation and adjustment of the optimal joint positions under consideration of the joint limits

For the segmentation of the 3D camera image, we used the plane model segmentation of the Point Cloud Library (PCL) [23]. The interaction element is realized by using the visualization program RViz from ROS [24]. Fig. 4 shows the segmented point cloud with the interaction element. From the segmented point cloud we extract the points that are located at the position of the interaction element $\pm$ of the radius of the manipulator, see Fig. 3(C). These points are then projected onto a 2D plane. [25] is used to determine the radii, the center, and the tilt of the ellipse. The result is shown in Fig. 3(A). These parameters are then used to generate the elliptical cylinder as a human model. In Fig.3(B) and (C) the cylinder is placed in the point cloud. The evaluation of this procedure using an Intel Realsense D435 and the Laerdal Resusci Anne shows that over 90% of the dots are on the elliptical cylinder. This shows us that an elliptical cylinder is suitable as a simplified human model.

V. Proof of Concept

The overall idea in this project is that a semi-autonomous manipulator, supervised by a nurse, should be available when needed by a nurse, patient, or caring relative. The work presented here aimed at developing a proof-of-concept whole arm telemanipulation system for holding a patient using an off-the-shelf manipulator. This was considered to keep the cost low. An early proof-of-concept was therefore implemented to test the algorithm, keeping the requirements in mind. The overall design consisted of a robotic manipulator, with a depth-camera mounted on it, placed next to a patient's bed. For testing purposes we choose the mounting to be next to the head area of the bed so that the shoulder of the dummy can be reached with the manipulator. The setup is shown in Fig. 5. The aim was here to be able to place the manipulator in the desired way around the patient dummy. Initial tests show successful caging of the dummy under different positions of it.

A. Robot arm

The robot used for this system is the Franka Emika Panda (Fig. 5). This robot is a 7 degrees-of-freedom (DOF) manipulator, which can act in a large motion space to perform different tasks. The Panda also has more than one hundred sensors that make it very accurate and stable and allow a soft performance [26]. A cushion was added at the given contact point between the manipulator and patient simulator.

B. Test Insights

We show in an example the functionality of the system we propose.

A patient dummy is lying in the nursing bed, beside which a Franka Emika Panda Manipulator is mounted. Via the interaction element, the gripping position for holding the patient is selected. The algorithm calculates the joint angles live. The selected position is then adjusted by the manipulator. As shown in Fig. 6, this leads to a successful holding of the patient dummy.

A demonstration video is available here: https://youtu.be/EDAIammuRvw

VI. Conclusions

In this work, we propose a concept for the relief of nurses through the use of robotics. With the help of WAM, a patient can be held in a lateral position. The location of the caging is determined by a remote nurse. A suitable interaction concept was developed for this purpose. Our simplification of the human being to an elliptical cylinder is appropriate. We have shown in a proof of concept that the proposed system works.

In future work, we will present the algorithm in more detail and develop it further. In particular, more complex geometries will be used as an approximation for the patient. We will look at superquadric functions to generalize the possible geometries and thus better approximate the patient. Furthermore, we plan comparison with other methods for motion generation of WAM. Finally, the system will be evaluated with nurses.

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