Household Objects Pick and Place Task for AR-601M Humanoid Robot

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Abstract. Humanoid robots are created to facilitate many facets of daily life, both in scenarios when humans and robots collaborate and when robot completely replaces human. One of such more important cases is the household assistance for older people. When a robot operates in home environments the needs to interact with various household objects, of different shape and size. A humanoid end-effector is typically modeled to have from two to five configuration of fingers designed specifically for grasping. By making fingers flexible and using dexterous arm one could operate objects in many different configurations. If one chooses to provide a finger control by actuating each of the finger's phalanxes by using separate motor, humanoid hand becomes costly and overall size of the hand will significantly increase to accommodate necessary hardware and wiring. To address this issue, many engineers prefer to employ mimic joints to reduce a cost and size, while keeping acceptable levels of finger's dexterity. This paper presents a study on household objects pick and place task being implemented for AR-601M humanoid robot that is using mimic joints in his fingers. Experiments were conducted in a Gazebo simulation with 5 model objects, which were created to be representations of real typical household items.

Keywords: Grasping · Grasp planning algorithm
Pick and place task · Humanoid robot · Mimic joint
Gazebo simulation · Grasp modelling

1 Introduction

At present, humanoid robotic assistants' development is gaining momentum [22] and the target is to create the most accurate human replica that could perform

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dexterous locomotion and manipulation with the ability to complete some of intellectual tasks. We already seen significant progress that had been already achieved in many areas, including locomotion [5], self-protection at loosing balance [16], collaboration [11], manipulation [17] and others, but in general, modern humanoid robots are yet far away from the functionality that fully conforms to human functionality. Therefore, there is a need for their comprehensive development, including arm movements and vision improvements. Humanoid robots are created to facilitate the work of a human in a variety of environments or to replace a human completely when possible. Humanoids are constructed to operate both in environments without human presence and in social environments when interaction and collaborative activities with multiple humans may be required. One of such environments is a household environment and a humanoid robot is supposed to interact with objects of various shapes, sizes and weights. In addition, environment conditions should be considered. There may appear a high degree of clutter in a grasp scene [10] as well numerous occluding objects [18] that require searching for the target items before they could be picked. Objects may have various qualitative characteristics of their surface material, e.g., the surface of an object may be wet, which may contribute to slipping of an object within the hand grasp. With object that deformed easily (e.g. a sponge for dishwashing) as more force is applied to a gripper during a grasp of such object, the more it will be deformed; therefore, for such objects it is important to find a balance between an applied force and a preservation of the object shape.

A humanoid end-effector is typically constructed to have two to five fingers being designed for grasping household objects. For this reason, it is well suited for grasping household objects, taking into account the above mentioned environmental conditions. Due to the fact that fingers are flexible and dexterous, a robot hand can take a large variety of forms to grasp an object. These advantages have already been taken into account in developing solutions [3], [24] for grasping objects.

The flexibility and dexterity of the fingers of a humanoid robot is achieved by using a large number of joints. They set in motion phalanges of fingers, with combined motion of phalanges representing finger movement. There are two ways to control finger movement: controlling all of its joints or only some of them. When all joints are controlled, fingers can move with a greater accuracy, their movements will be more deterministic and easier to control. But in this case, the humanoid hand may become expensive, and a size of fingers may significantly increase. Increasing the size will affect the success of object grasping: enlarged fingers could either fail to grasp objects, or during a grasp, unintentionally significantly modify a grasp scene while pushing objects as the hand moves toward its target object through the grasp scene. For these reasons, many manufacturers prefer using mimic joints.

The basic idea of a mimic joint is to replace some finger joints with a joint, which movement depends on other joints movement (that are referred as active joints). Thus, only active joints are directly controlled, and a finger is set in motion via these active joints. With this approach, a finger movement accuracy is rather lower and, respectively, it is more difficult to carry out a robust grip. And because of using a significantly smaller number of motors within a finger, this approach results in lower cost and smaller size of a finger.

This article is devoted to pick and place task execution for household objects by humanoid robot AR-601M, which employs mimic joints fingers. The task algorithm verification was performed in Gazebo simulation. The rest of the paper is organized as follows. Section 2 presents a literature review. Section 3 describes kinematics of AR-601M manipulators and the fingers of the robot. Section 4 describes the modelling and simulation. Section 5 presents the results and our future work.

2 Literature Review

This section provides overview of the relevant articles, information from which were used to implement pick and place task execution for robot.

The article [23] investigated the problem of the implementation of an object manipulation with the participation of only fingers, without hand movements. The urgency of this problem is due to the fact that during the manipulation a situation may arise when the hand may lose the ability to move due to the limits in movement space. In such situation, further manipulation can only be carried out with the fingers of the hand, so the robotic hand must be trained in this type of manipulation. To solve this problem, the authors of the article proposed a set of principles for the design of fingers that allows fingertips to grasp objects and manipulate them. An analytical framework is introduced to accurately assess a dexterous workspace for manipulating objects at the fingertips.

In [7], an algorithm for calculating the optimal configuration for the grasp of a robotic hand was proposed. It can predict the movement of gripping fingers and determine their configuration using information about the size of an object and its position. The metrics used to describe the calculated grasp configuration can be reproduced on a robotic hand.

To solve the problem of obtaining feedback on manipulation while it executes, the authors of article [4] proposed a single model for evaluating the manipulation of the hand and an object. It allows determining the type of grasp and the attributes of an object, with help of which it becomes possible to determine the optimal type of grasp for an object of a certain form, to make their correlation.

The article [12] presents a description of the robot Team Delft that won the competition for the pick and place task. The paper presents information about the robot functionality, its software. The performance of the system and the results of its work in the final competition are discussed.

In [19], a method for planning a powerful grasp for a human-like hand is presented. First, it determines the surface of an object in order to find the best places to perform the opposite grasp with two or three fingers, and then aligns the other fingers to match the local curvature of object surface [15]. The method also creates a database of grasps for the current object that satisfy the force closure condition. Different setting strategies are considered depending on the size of an object in relation to the hand and on the location of the obstacles in the manipulation environment.

To solve the problem of determining a grasp strategy that is capable of ensuring the compatibility of an object determination tasks and carrying out its grasp, a study [21] of analytical and empirical approaches to building a grasp strategy was conducted. As a result, a review of algorithms for synthesizing the grasp of three-dimensional objects was prepared.

The article [20], using the Atlas humanoid robot as an example, demonstrates the use of an object manipulation approach that allows the robot to use any object located in its environment to accomplish manipulation task. The approach allows the robot to understand how to recognize new objects and adapt them for the manipulation task.

In [1], a methodology for teaching humanoid robots to manipulation by demonstration is presented. This approach, according to the authors of the article, will allow humanoid robots to more easily master various techniques of manipulating objects and eventually use and change them at their discretion without human help.

3 Kinematics of an Arm and Fingers

This section presents a description of the AR-601M humanoid robot arms and fingers and the calculation of their working areas. Because of the task in a simulation in the Gazebo simulator, a 3D model of AR-601M humanoid robot manipulator shown in Fig. 1 was used. It is reproduce in details real robot manipulator.

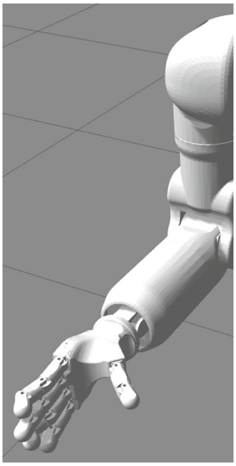


Fig. 1. 3D model manipulator of AR-601M humanoid robot in its default position.

The humanoid robot AR-601M is a Russian development created by the research and production association "Android Technology" [14]. The functionality of the robot allows to manipulate objects, move along a given route, perform local object orientation etc. Each robot arm, including its hand, has 20 DOFs. An arm itself has 7 DOFs, the fingers of each hand have 13 DOFs. To control the movements of the 3D model manipulator, its configuration framework MoveIt! [6] was created and the API of framework was used. For planning motion trajectory of a model, the RRTConnect algorithm was used.

To provide 3D model manipulator ability to move, it was necessary to solve inverse kinematics problem for it. Currently, there are libraries that allow programmatically solving the problem of inverse kinematics. They provide both an analytical solution [9] and a numerical one [2]. Based on them, various plugins are created to solve the inverse kinematics problem for manipulators that use the MoveIt! to control their movements. Therefore, solution of inverse kinematics problem is to select a plugin suitable for 3D model manipulator.

Due to the fact that 3D model manipulator has 7 DOFs, the analytical solution of the inverse kinematics problem is difficult to find for it. Moreover, it may not exist. Therefore, it necessary to find a plugin for the MoveIt! framework that provided a numerical solution of this problem for 3D model manipulator. The plugin "kdl_kinematics_plugin" is a suitable plugin. Figure 2 show the position of 3D model manipulator achieved using this plugin and the MoveIt! framework API.

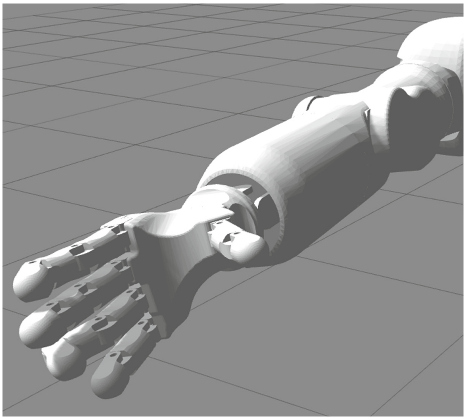


Fig. 2. Applying inverse kinematics plugin to the 3D model of right manipulator.

To prepare the simulation scene, it is necessary to calculate the workspace of manipulator in order to find space on scene for placing an objects, so that the humanoid robot hand could reach and grasp them. To calculate it, is needed to solve the problem of forward kinematics. Then, using obtained solution and taking into account the range of angles of rotation of each joint, a manipulator must be set in motion. During the movement, a manipulator end-effector can reach different points in space. The set of reached points can be accepted as a workspace [13].

To calculate the workspace of 3D model manipulator of the AR-601M robot, according to the above scenario, the Matlab software platform and the software package for performing robotic calculations Robotics Toolbox [8] are suitable. Figure 3 shows calculated workspace for manipulator of AR-601M humanoid robot.

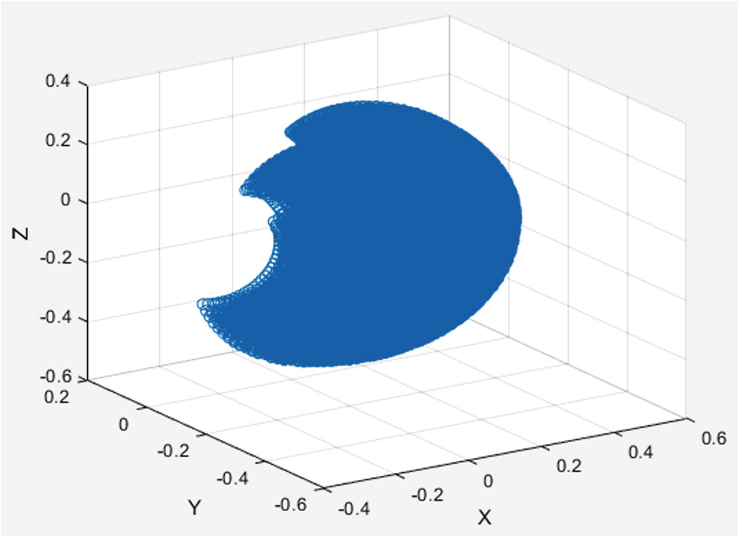


Fig. 3. Workspace of manipulator of AR-601M humanoid robot.

The end-effector of manipulator is represented by a humanoid hand with fingers similar to a human hand. Robot fingers are use mimic joints. For all fingers, the joints closest to the hand's base are the first active joints and are controlled directly. The remaining finger connections are mimic. The principle of movement of mimic joints in each finger is as follows: the angle of rotation of the second joint depends on the angle of rotation of the first joint, and the angle of rotation of the third joint depends on the angle of rotation of the second. The thumb and pinkie have 2 joints. The index, middle and ring have 3 joints.

The fingers workspace calculation is based on the principle similar to calculation of manipulator workspace. Figure 4 shown fingers workspaces calculated using Matlab software package.

4 Simulation in Gazebo

Due to the inability to work with a real robot, pick and place task execution was modelled in a Gazebo simulation. To perform simulation, it is necessary to select 5 real household objects for creating their 3D models and task execution with them further. Figure 5 shown photographs of real household objects.

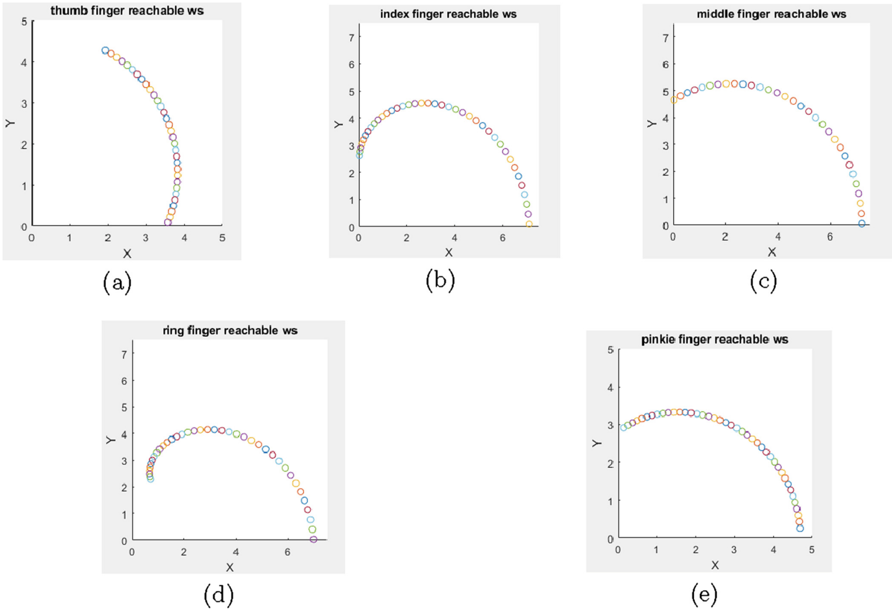


Fig. 4. Reachable workspace for: (a) thumb, (b) index, (c) middle, (d) ring and (e) pinkie. Unit measurements is centimeters (cm).

The 3D models of the selected objects were created using the SketchUp tool. Their dimensions exactly correspond to the real objects dimensions.

To perform simulation, it is necessary to determine the coordinates of the target point for reaching it and grasping object, and the angles of rotation of active finger joints. These values were determined empirically during the experiments according following scenario.

First, it is necessary to determine the height with regard to object that the hand must take to grasp it. Taking into account the height of each object, it is necessary to divide by 5 in order to get 5 points with the same x and y coordinates, but different z coordinates. Getting 5 points due to the need to find out position the fingers take relative to the object when the hand reaches each point in space. Such movements of the manipulator must be carried out in order to avoid situations when the trajectory of movement of only some of the fingers is able to pass through the object. Thus, the z coordinate of the target point is determine.

After that is needed to determine the x and y coordinates of the target point. According to the calculated fingers workspaces, presented in Fig. 4, it becomes clear that the trajectory of the movement of the fingers during their flexion has the direction of movement from the initial, straightened position, in the direction of their attachment to the arm, along a curved line. For this reason, when the hand reaches such a point in space, being in which the ends of fingers can be in the middle of the object, for example, bottles, the fingers can not be able to

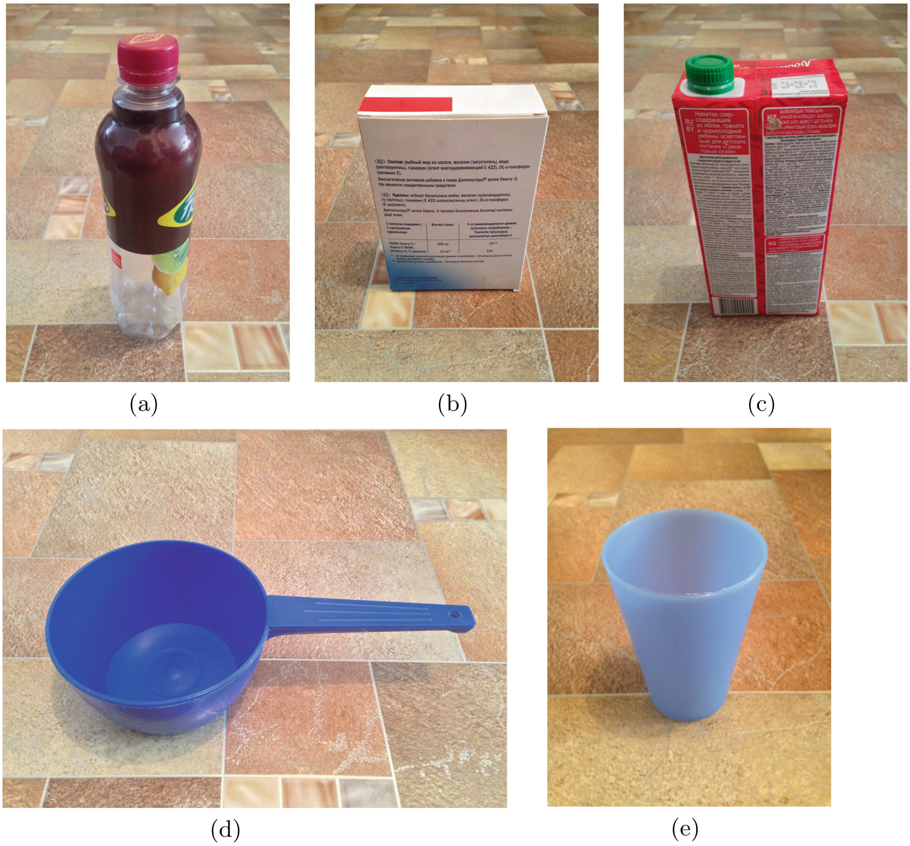
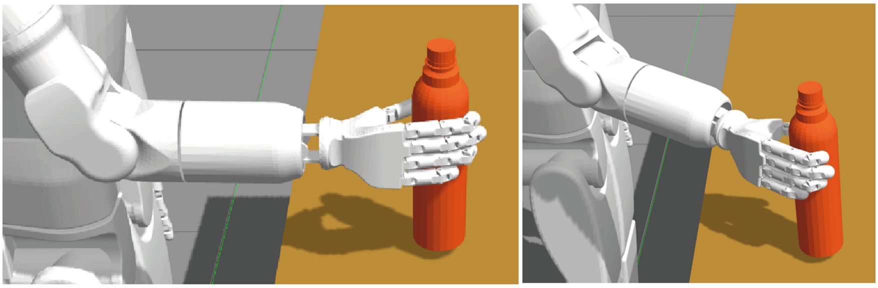


Fig. 5. Household objects selected for creating their 3D models: (a) bottle, (b) box of vitamins, (c) juice box, (d) ladle and (e) plastic cup.

grasp an object in the middle as in the case of performing a simple antipodal grip using parallel grippers. Therefore, it is necessary to determine the distance between an object and the inside of the palm of the hand, suitable for gripping, taking into account the peculiarities of the movement of the fingers described above.

To determine the desired distance, in the XY plane, it is necessary to move the hand to an object so that between the object and the inside of the palm of the hand 4 different distances can be obtained for comparison. In all 4 cases, the beginning of the distance is necessary to establish the inner part of the palm. Its end is determined by the position of the object in which its side, to which the movement of the arm:

– For 1 distance is located on the same line with the beginning of the third, extreme phalanx of the middle finger



(a) (b)

Fig. 6. Pick and place task performing for 3D model of bottle

- For 2 distances it is located on the same straight line with the beginning of the second phalanx of the middle finger
- For 3 distances it is located on the same straight line with the beginning of the first phalanx of the middle finger, which is set in motion by the active joint
- For 4 distances, it is located as close as possible to the inside of the palm, to prevent empty space between the surface of an object and parts of the hand.

To determine the x and y coordinates of the hand target point the middle finger was selected for the following reasons. The end of the middle finger is located farther than the ends of the other fingers. Because of this the end of the hand is determined by the coordinates of the end of the middle finger. Such estimation of the end of hand allows to cover the maximum surface of an object during its grasping, this contributes to a greater fixation of an object in the hand.

After calculating the desired coordinates of the target point, necessary to achieve by hand and grasping an object, it is necessary to determine the angles of rotation of the fingers for the grasp implementation. Due to the use of mimic joints in the fingers of a humanoid hand, this task comes down to finding the angles of rotation of the first joints of each finger located closest to the center of the hand. The angles of rotation of the connections of each finger must be set to their successive increase and choose such values of the angles of rotation at which it becomes possible to implement a reliable grasp an object without slipping it. Figure 6 shows the results of the pick and place task execution for the 3D model of the bottle, obtained by performing the calculations presented above, as well as using the 3D model manipulator of AR-601M humanoid robot. Video about task execution for other objects is available at: https://tinyurl.com/y5mbfhya.

5 Conclusions

This paper described pick and place task that was performed in Gazebo simulation by a 3D model of AR-601M humanoid robot right arm. Five 3D models of typical household objects were used for the task verification. We presented kinematics of the manipulator and its fingers, including their characteristics and workspace calculation. Virtual experiments were performed in order to obtain coordinates of target points and angles of finger rotations, which were necessary for pick and place tasks. As a part of our future work we plan to provide an automatic calculation of target points for object grasping employing robot on-board cameras, and to validate our approach via experiments with the real robot.

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