Experimental Evaluation of the Schunk 5-Finger Gripping Hand for Grasping Tasks

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Experimental Evaluation of the Schunk 5-Finger Gripping Hand for Grasping Tasks

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Abstract— **In order to perform useful tasks, a service robot needs to manipulate objects in its environment. In this paper, we propose a method for experimental evaluation of the suitability of a robotic hand for grasping tasks in service robotics. The method is applied to the Schunk 5-Finger Gripping Hand, which is a mechatronic gripper designed for service robots. During evaluation, it is shown, that it is able to grasp various common household objects and execute the grasps from the well known Cutkosky grasp taxonomy [1]. The result is, that it is a suitable hand for service robot tasks.**

I. Introduction

In contrast to industrial manipulators, service robots operate in unstructured environments with large varieties of different objects. In order to perform useful tasks, a service robot needs to manipulate objects in its environment. For example, in a „clean up the table" task, objects from the size of a toothpick up to a bottle may occur. The robot has to move those objects to a somehow defined place. Handling the complexity and variety of everyday environments is a major challenge for service robotics. The ability to relocate various objects reliably is an important skill required to tackle that challenge.

Grasping depends on the gripper of the robot. In the industrial environment solutions with custom made, object specific gripper fingers may provide perfect form closure with one degree of freedom (DOF) two finger parallel grippers. But this is only feasible for the single object of the specific task. As mentioned, in service robot tasks, objects differ in size, shape and handling constraints. Thus, such solutions are not feasible. Instead, robot grippers with multiple fingers and DOF provide multiple potential contact points, which can be positioned according to the object using grasp control and planning algorithms.

In an environment shared with humans, most objects are designed so they can be manipulated by humans. Thus, in order to create a gripper, which can handle those objects, many approaches mimic the human hand [2]. Anyhow, studying the work of those authors, the design of anthropomorphic hands has to deal with many challenges, such as the actuation within size and mass limits of the gripper, the transmission of forces and moments in the hand, sensor placement and control methods. Thus, optimized kinematics for grasping are not the main focus of many hand designs, and most hand designers have no experience in autonomous grasping.

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Fig. 1. The Schunk 5-Finger Gripping Hand.

This leads to a situation, where different anthropomorphic hands perform very differently in grasping everyday objects due to kinematic properties. In this paper, we present an experimental evaluation of the grasping capabilities of the Schunk 5-Finger Gripping Hand (SVH) as shown in Fig. 1. Different everyday objects with a wide range of sizes are selected. Grasps from the Cutkosky [1] taxonomy are applied to demonstrate the capabilities of the hand.

The paper is structured as follows: Sec. II presents a brief overview over robotic hands and grasping. Sec. III motivates and describes the mechanics and kinematics of the SVH. In Sec. IV we describe our experimental approach, which results are presented in Sec. V. In Sec. VI, we discuss the resulting insights and their relevance for the SVH and the design of hands for service robots in general.

II. Robotic Hands and Grasping

Today, a wide range of different robotic grippers is available. [3] gives an overview over manipulation problems and gripping approaches. In this work, we structure the state of the art of robot hands by the number of fingers and DOFs.

Industrial solutions for gripping are usually one DOF two finger grippers. Robust gripping is archived by either object specific finger design or by applying large forces. Two mechanical principles are common: parallel and angular movement of the fingers. The PR2 robot uses a parallel gripper [4]. [5] presents an angular gripper for manipulation with a six legged walking robot.

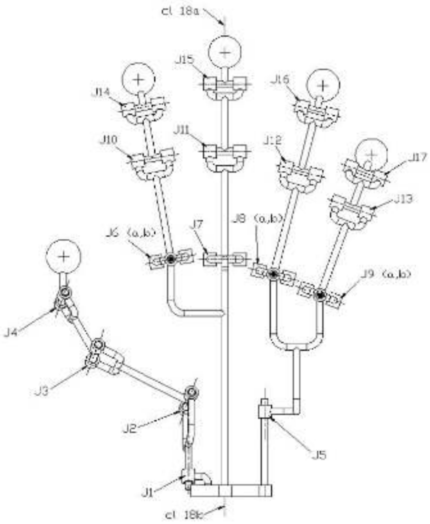


Fig. 2. Kinematic diagram of the SVH, showing all 20 joints, label 18a, 18b refer to the hand centreline.

A more flexible approach are three finger grippers such as the Barrett Hand with 4 DOF [6] or the 7 DOF Schunk Dextrous Hand, which is used by the Care-O-Bot [7] service robot. Those approaches enable robust power grasps for different objects.

Hands with 4 or 5 fingers can aim for a anthropomorphic design, which enables them to manipulate objects similar to those, manipulated by humans. Such hands include the Shadow Hand, the Karlsruhe Hand [8] or the DLR/HIT Hand I and II [9], [10] or the hand of DLR's hand arm system [11]. Those hands have to compromise on size, DOFs or the placement of the actuators.

A different view is given from the point of grasping: In [12] a voxelmap-pointshell based approach is presented. Automated grasp planing systems like [13], [14] simulate the closing of the fingers around an object from a preshape pose. Rating functions are used to reduce the resulting set of grasps. Ratings use the grasp wrench space [15], which describes maximal forces which can be applied to the grasped object. More grasp quality ratings can be found in [16]. The quality of grasps might be a measure for comparing grippers, but implicitly includes the quality of the grasp generation.

A method for the task-focused evaluation of parallel jaw gripper design is presented in [17]. The approach is only valid for single objects. [4] applies a purely object based evaluation to the PR2 gripper.

Considering the state of the art, the object centered approach is the only method used for evaluation which covers a sufficient broad range of grasping tasks as required in the service robotic domain. In the following sections, we will extend this approach with a gripper centered evaluation method.

III. The Schunk 5-Finger Gripping Hand

The SCHUNK SVH five finger hand (Fig. 3) is a fully anthropomorphic robot hand. All drives are integrated into

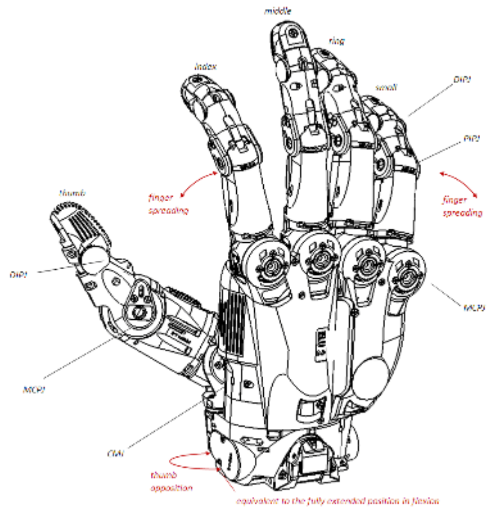


Fig. 3. Sketch of the SVH illustrating the finger movement. Thumb opposition moves Joint 1 and 5, Spread Joint 6b, 8b and 9b.

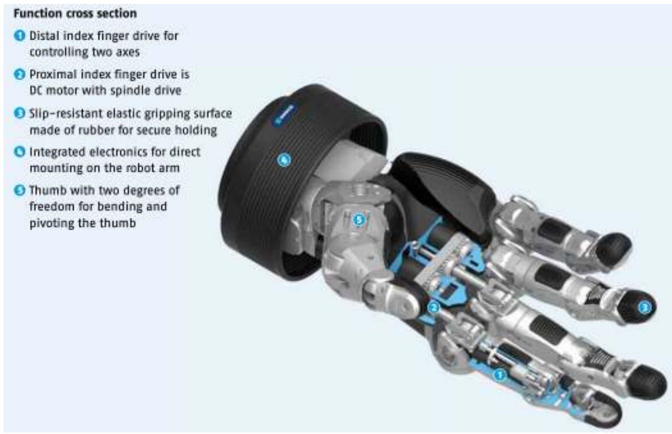


Fig. 4. shows some of the hands functionalities in a cross section. Index 1 shows eg. the drive with the leadscrew mechanism embedded in the index finger controlling J10 and J14. Index 2 shows the drive for controlling J6a integrated in to the palm of the hand. Similarly the spreading mechanism for J6b, J8b and J9b is hidden in the palm.

the hand itself while the motor controllers are completely integrated in to the wrist (Fig. 4). Therefore a very compact solution has been found. Via a standardized interface, the gripper can be easily connected to robot arms. The energy supply of the SVH requires 24 V DC. It is controlled via a serial RS 485 bus. The hand is available as a left and right version. The main design requirement was to resemble its human model in size, shape, and mobility. The hand has an overall length of 242 mm , including the wrist. The palm is 92 mm wide. By means of nine drives, its five fingers can carry out various gripping operations. Moreover, numerous gestures can be constituted.

The hand has 20 joints at all. The majority of the joints of the SVH are actuated through leadscrew mechanisms converting linear movement into rotary movement (Fig. 4). There are 9 DOF in the robot hand, driven by corresponding servo-motors that incrementally turn by control system commands. The discrepancy between the number of joints and

Fig. 5. Selected objects from the KIT ObjectModels Web Database [18].

DOFs is caused by mechanical coupling of the joints. The coupling is motivated by the human hand motions, where different joints usually move together, although the are not strictly coupled. A kinematic diagram is displayed in Fig. 2. Joint 1 and 5 are coupled to a thumb opposition DOF (Fig. 3). If the thumb rotates from its zero position aligned with the palm around Joint 1, Joint 5 rotates ring and pinky finger in the opposite direction, leading to a configuration, where the thumb opposes those fingers.

Joint 6b, 8b and 9b are coupled to the spread DOF (Fig. 3). It increases the distance of the fingertip in the extended configuration. The flection of the fingers is implemented as follows: thumb, ring and pinky finger have only one DOF each which controls all their joints. For index and middle finger, the proximal joint (J6a, J7) can be controlled separately. Their distal and medial joint (J10 and J14, J12 and J15) are again mechanically coupled.

IV. Method

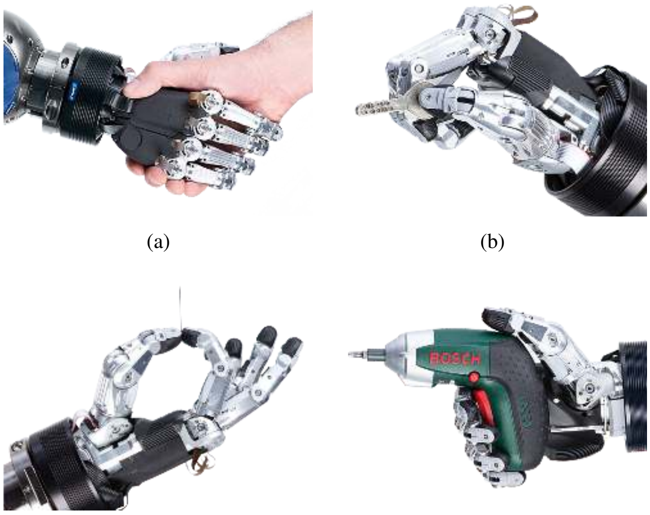
According to [3], three functional requirements for a robotic hand can be distinguished:

1) *manipulative dexterity* is "the capability of the hand to manipulate objects so as to relocate them arbitrarily"
2) *grasp robustness* "is the capability of keeping hold of manipulated objects [...] while maintaining a gentle enough grip not to cause any damage"
3) *human operability* is "the allowance for an easy and friendly interface with the human operator"

Human operability is of no interest for an autonomous service robot. Manipulative dexterity refers to the challenging problem of relocating an object in the hand of the robot. Such manipulation is of interest for very specific tasks such as screwing a light bulb or writing. For general service robot tasks, relocation of objects with respect to fixed coordinate systems is required. This is addressed by grasp robustness.

We propose a two track approach for for the experimental evaluation of a robotic gripper for grasping.

- The first track is gripper / grasp centered. Based on a set of desired grasps, we select suitable objects, to which those grasps can be applied. In order to demonstrate a broad applicability of the hand, a exhaustive set of grasps is desired. Such a set is provided by the Cutkosky grasping hierarchy [1]. We evaluate, which grasps can be executed in a robust way.
- The second track is based on a set of objects. Here, the kind of applied grasps is not in focus, but only the fact, that an object can be grasped. An extensive set of typical household objects is defined by the KIT ObjectModels Web Database[1] [18]. Exemplars of all objects specified in that database are available in our lab. We use a randomly chosen subset of objects from that database with a focus on large objects. The selected objects are displayed in Fig. 5. Beyond that set of objects, three further objects in Fig. 6 demonstrate specific features of the hand kinematic.



(a) (b) (c) (d)

Fig. 6. Specific grasping features of the SVH: (a): Human-like size. (b) and (c): precision and power grasp of very small objects. (d): Ability to grasp tools made for humans.

(a) (b)

Fig. 7. Grasping of large objects. The tin in Fig. (a) has a diameter of 10 cm. The grasp for this object cannot provide form closure.

The resulting grasp taxonomy will reflect the range of object sizes and forms and thus describe how well the hand can perform in an environment with very different objects.

The grasps resulting from these tracks are translated to hand configurations by a human expert. Once the object is grasped, a LWA4P Powerball arm is used to move the hand and especially change its orientation, such that it has to fix the object against gravity. The results of the experiments are described in the next section.

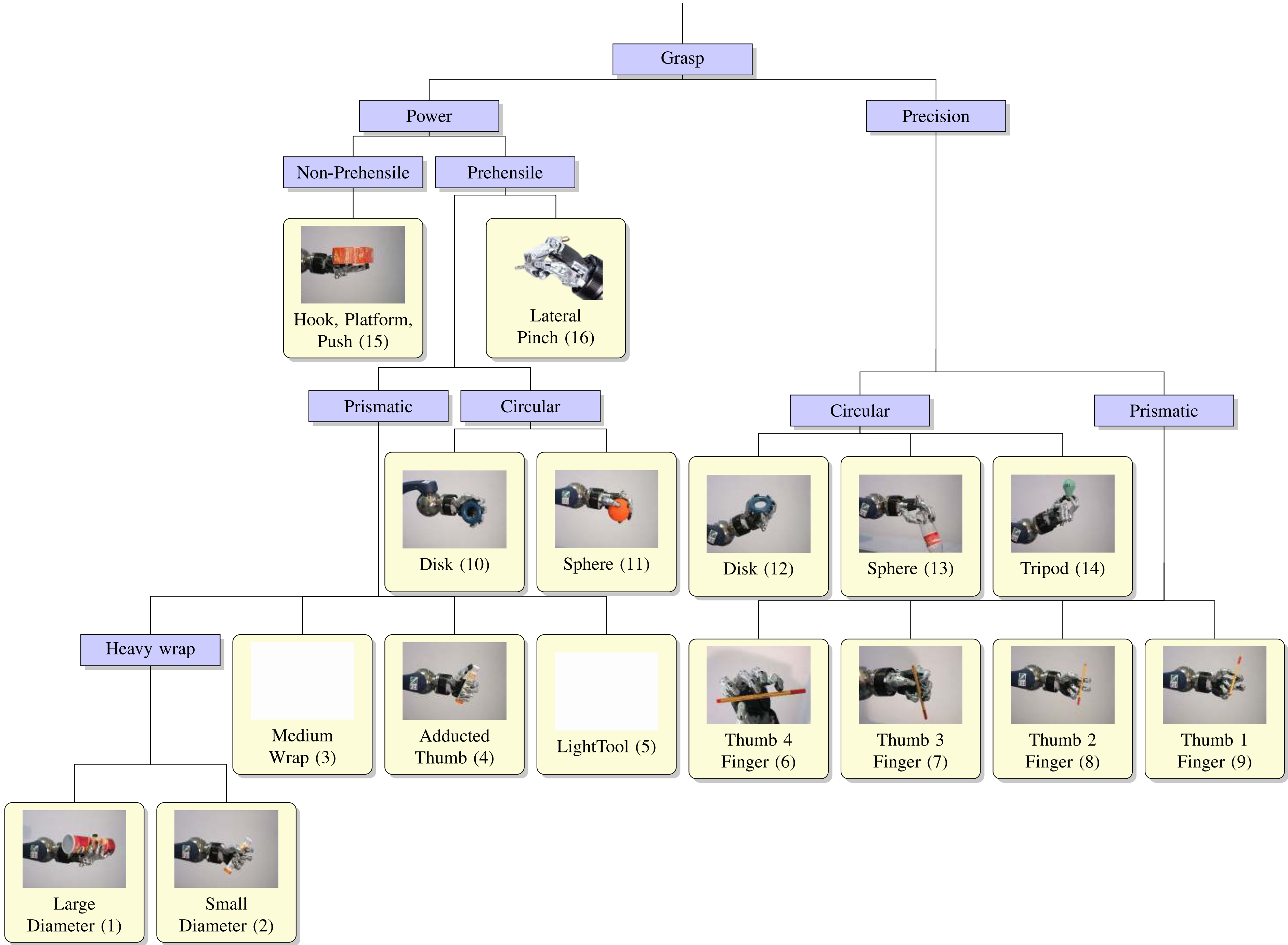


Fig. 8. Experimental result: the SVH reassembling the Cutkosky grasp taxonomy [1]. All but two grasps (3 and 5) can be executed.

V. Experimental Results

The result of the first track of experiments is displayed in Fig. 8. It reassembles the well known Cutkosky taxonomy. In the experiment, 14 of 16 described grasps can be applied by the hand.

Grasp (1) and (2) are power grasps for heavy objects. For the selected objects, the hand achieves form closure for motions perpendicular to thee cylinder's symmetry axis.

Grasp (3), (4) and (5) are further power grasps, where the fingers wrap around a cylindrical object. For grasp (3) and (5), the thumb base is the limiting link in the kinematic chain; the thumb cannot be placed next to the object as required by grasp (3) or close to the palm as required by grasp (5). Since thumb rotation is coupled with base orientation of the ring and pinky finger to the „thumb opposition" DOF, the thumb cannot be moved to the required configuration without moving ring and pinky away from their configuration. Grasp (4) can be executed, because the opposition in the "thumb up" configuration is directed towards the fingers.

Grasps (6) to (9) continue that class of grasps for small objects and precision grasps. Grasp (9) shows a pinch grasp, where the object is held between index finger and thumb tip. For grasps (8) to (6) more fingers are added. Those grasps are kinematically executable. Anyhow, ring and pinky finger tip make their way to the object, but cannot contribute to the force executed on the object. This is again caused by the thumb, which cannot move far enough towards the pinky to actually oppose those fingers.

The above row in Fig. 8 contains grasps for circular objects. Grasp (10) and (11) provide power grasps with form closure disks and spheres of a diameter up to 9 cm. On the precision side, grasp (12) for the disk can be executed. Although, the object in grasp (13) is not a sphere, its end forms roughly a sphere section. The grasp for precision grasping of a sphere is applied successfully. Grasp (14) is applied to hold a light bulb with a tripod between thumb, index and middle finger.

Grasp (15) shows a flat hand, which carries an object such as a box or a tray. It is not a typical grasp used by robots, but can be executed due to the ability of the hand to align the thumb within the palm plane. In grasp (16) the thumb opposes the side of the index finger to hold a key. Kinematically, it is executable, but it holds the object against a metal element of the index finger. Thus, resulting friction is limited while the grasp is based on force closure.

On the second track of our experiments, the hand was able to grasp all objects of the selected set successfully. From our experiments, the maximum reasonable distance between thumb and finger is around 10 cm. This is the limit for the thickness of grasped boxes and the diameter of grasped cylinders and spheres. It is shown in Fig. 7. While the approximately cylindrical object in Fig. 7(b) is grasped with form closure (except cylinder axis), the 10 cm diameter tin in Fig. 7(a) is held by friction in the fingertips. More grasps are displayed in Fig. 6.

[1] http://i61p109.ira.uka.de/ObjectModelsWebUI

VI. Discussion

The experiments have shown, that the SVH is kinematically able to execute 14 of the 16 grasps of the Cutkosky taxonomy. It was also able robustly grasp 20 different household objects. This indicates, that the hand is able to handle a large variety of objects and thus is a suitable gripper for a service robot in the household domain.

Limitations of the hand results mainly from the mobility of the thumb. While a human thumb can easily touch the tips of all four fingers, the thumb of the SVH can touch the index finger tip and move towards the middle finger.This prevents the opposition of those fingers in precision grasps of cylindrical objects.

The limitation of the motion range of the thumb is caused by its base joint (carpometacarpal joint). This joint has a very high flexibility in the human hand. Other robotic hands known to the authors share this problem. The DLR/HIT Hand II [10] has a completely fixed thumb base joint, which limits executable grasps to a small subset. In its predecessor, the The DLR/HIT Hand [9], this joint is fully implemented, but still with a limited joint range. Also, that hand shows that the additional joints may come at the price of a larger hand.

Although this paper focuses on the kinematic of the hand and the feasibility of grasps, we ensured that the grasps were able to fix the objects when the hand was moved in space.

VII. Outlook

Further investigations should consider acting forces and moments. The obvious question is the mass of objects, which the hand can still support against gravity. First tests indicate, that the fingers can easily support objects up to 500 g and maybe more. Those test were made against the force closed direction of a heavy wrap grasp. If a force is applied in the direction of the cylinder axis, fixture is provided by friction. The SVH is equipped with rubber pads to enhance the friction with grasped objects. Anyhow, tolerated forces will differ from those from form closure.

Another approach would be the evaluation of the ability of dextrous manipulation. We have shown that grasps for precise manipulation are feasible, but it is still an open question, if joint and sensor precision are high enough to exploit the possibility of relocating an object relative to the wrist.

VIII. Summary

We have proposed an experimental evaluation method of robotic hands for service robot tasks with two experimental tracks. The first is hand centered and based on the Cutkosky taxonomy. In the experiment, it is evaluated which grasps can be imitated by the robot hand. The second track is object centered and uses a set of objects from a typical service robot domain. The experiments focus on the hand kinematic. The Schunk 5-Finger Gripping Hand and its kinematics have been introduced. The evaluation was applied. The hand was able to execute 14 of 16 grasps from the first track and grasp all objects from the test set. Thus, the hand is suitable for the application in service robotics.

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