Smarthand - Towards a Robust Robot Hand with Increased In-hand Manipulation Workspace

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***Abstract*— The robustness of robotic hands is crucial for hand manipulation in real-world scenarios, as it ensures resilience to uncertainties and disturbances. Robotic hands with intrinsic compliance offer the advantage of optimized contact robustness and reduced reflected inertia, which significantly improves the cycle time for delicate objects. This paper presents Smarthand, a robust, compliant hand with a high force-to-weight ratio based on the DLR CLASH (three fingers) but with optimized kinematics for in-hand manipulation. The modular design allows for different hardware configurations, but also improves maintenance and calibration. The first tests on a two finger and three finger testbed showed new manipulation capabilities in compare to DLR Hand II, with significantly increased robustness and lower system costs.**

I. Introduction

Humanoids with human hands are a trend that can hardly be overlooked. The hope behind this development is that advances in artificial intelligence will make it possible to easily control complex machines and automate tasks that were previously impossible. Prominent examples include Tesla's Optimus [1], Figure 2 [2], Aptronik's Apollo [2] and Engine Ai SE01. These robotic hands were built specifically for humanoids and are not compatible with cobots. Whether the hands are well suited for in-hand manipulation or robust against hard impacts has not yet been determined. The Shadow robotic gripper DEX-EE [3] is designed for in-hand manipulation and is also robust against impacts, although its size, weight and only three fingers severely limit its range of use. The concept of easily and quickly interchangeable finger modules as in DEX-EE will be realised in the new hand. Modular hands such as the Allegro Hand [4] or the Leap Hand [5] pursue interesting concepts with kinematics that differ from the human hand, but the structure of the sequentially arranged actuators limits the achievable forces in relation to finger weight and volume. Our approach combines the modular concept with robust variable stiffness actuation based on N+1 rope actuation of the DLR CLASH [6] (three fingers) but with new kinematics, resulting in the Smarthand.

Name Company / Institution	HAND II DLR	FIVE Fingerhand DLR	CLASH DLR	Shadow DEX-EE	Shadowhand Shadow	Allegro Hand wonikrobotics	SVH Schunk	Smarthand DLR
thumb force	30 N	10 N	20 N	8 N	< 7 N	7 N	ca. 8 N	40 N
fingertip force	30 N	10 N	10 N	8 N	< 7N	7 N	ca. 6 N	20 N
payload	> 10 kg	> 5 kg	3,3 Kg	tbt Kg	5 kg	4 kg	ca. 5kg	> 10 kg
finger length [mm]	150	100	100	140	100	140	100	100
actuated DOF	12	15	6	12	20	16	9	12
Joint velocity [°/s]	360	180	360	180	-	430	-	900
robustness	o	o	++	++	oo	o	++	++
Robust grasps small objects	+	+	++	++	++	++	+	++
power grasps large objects	o	-	++	++	+	+	o	++
In-hand manipulation	+	o	o	+	++	+++	o	+++
Variable stiffness	---	---	+	---	---	---	---	+
Weight [kg]	2	1,5	0,6	2	4,3	1,09	1,3	1,1

Fig. 1: Hand comparsion

II. Design

In table 1 we compare different DLR hands and four commercial available hands. Smarthand should have the contact robustness of DLR AWIWI II [7] or DLR CLASH [6], but also the good in-hand manipulation capabilities of the DLR-Hand II based on the direct torque sensing with improved kinematics. Based on the analysis of the current hands, the requirements for the new robotic hand are as follows:

- The hand should be able to grasp objects with a diameter greater than 130 mm.
- Improved in-hand manipulation workspace.
- The thumb should be 1.5 to 2 times stronger then one of the other fingers.
- Size and weight like the DLR FIVE Finger Hand

A. *Kinematic for improved in-hand manipulation*

In order to find the best kinematics for in-hand manipulation and grasping, we set up a pybullet simulation. Different kinematics for fingers and thumbs were tested to see how well different objects can be grasped and how large the range of motion of a sphere in the hand is [8]. The following

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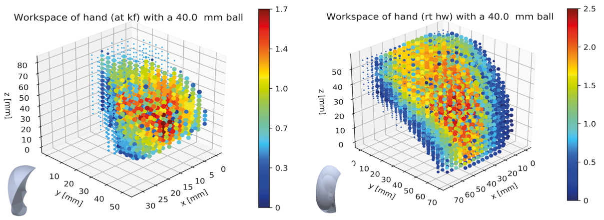

Fig. 2: 3D in-hand manipulation workspace comparison for human like kardan finger(kf) and adduction thumb, in compare to high workspace finger (hw) and rotation thumb (rt).

kinematics proved to be promising for the fingers, in which the abduction occurs after the first buckling axis. This kinematics has a working space of 6× larger than that of a human finger. The thumb has a rotation axis as its first axis, flanked by three bending axes. This combination gives the best result in grasping and in-hand manipulation. The resulting workspace is shown for two example configurations in figure 2.

B. Hardware

An important criterion for the hand was to use as many identical parts as possible, which is why it consists of four identical drive modules that can be quickly changed to enable rapid repair in the event of a failure 3. Each drive module consists of four identical RC servos Bluebird A208+, that transmit their power to the finger via tungsten cables. The stall torque of them is 0.95 Nm with a velocity of 1500 degree/s,we use a nominal torque of 0.45 Nm to achieve 20 N fingertip force. The resulting joint velocity of 914 degrees/s in MCP joint could be reduced by higher gear ratio to get stronger fingers. A FAS [9] is integrated the cable path, allowing to measure the cable forces and stiffness. The 8 bit analog encoder from CLASH is replaced by a 14 encoder with a digital interface. The thumb module is identical and is slid over the finger modules from the side. Each module is an Ethercat slave and would allowed to build simple different grippers or hands. A key objective was to enhance the resilience against tendon pretension loss. To this end, each tendon path was analyzed and guiding installations were made where necessary. Furthermore, the tendon terminals were improved to hold the tendon in place at high loads of more than 200 N. This feature plus the higher workspace of the fingers and twice the joint speed improves the crash robustness further than at DLR CLASH shown. Also

III. Experiments

To test the performance of the new finger mechanics, we test them in a two-finger setup for multiple-object grasping, in a three-finger setup for in-hand manipulation and the thumb extra. At that time, the Ethercat electronics were not yet ready, so CLASH electronics were used.

A. Multiple object grasping

The goal of these tests was to grasp multiple objects at once and to verify the sensitivity of the fingers. The results can be found in [10]. The fingers showed new grasp capabilities

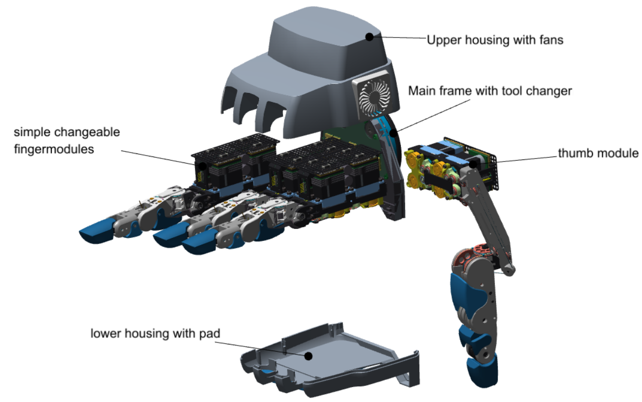

Fig. 3: Mechanical design of Smarthand, with slid out thumb module and disassembled ring finger module. The finger modules are mounted by a single screw and a form fitting the back. The thumb uses two form fits and four screws.

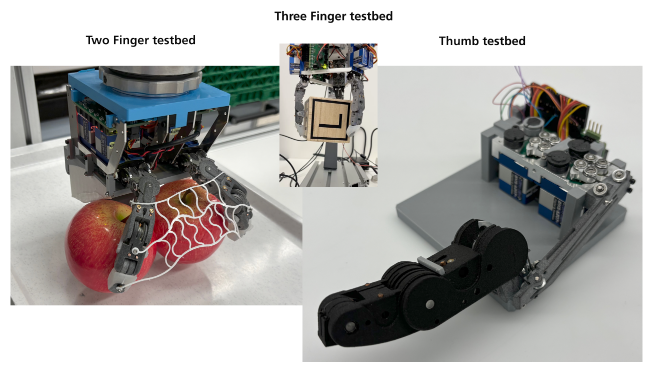

Fig. 4: For the project three different testbeds were built. The objective of the thumb test stand was to evaluate if minimizing the coupling between the first two joints was effective.

as simultaneous grasping two apples or if supported by a net between the two finger good multiple objects grasping.

B. Validation In-hand manipulation

Initial tests with the three-finger test stand showed promising results for in-hand manipulation without re-grasping. In a next step, a four-finger test stand is being built to also evaluate in-hand manipulation of objects with re-grasping.

IV. Conclusion

The paper presents the design of the new DLR Smarthand, a robust, variable stiffness four-finger hand with an increased in-hand manipulation workspace compared to DLR CLASH. Initial testing with the finger and thumb has yielded encouraging results.

Acknowledgment

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