Versatile Grippers for Multimodal Manipulation

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I. INTRODUCTION

With the emergence of multiple low-cost robots benefiting from learning-from-demonstration approaches such as ALOHA [1], Mobile ALOHA [2], and the universal manipulation interface UMI [3], a clear trend towards simple low-cost robot grippers becomes apparent. But many of the approaches use commercially available grippers or are relatively limited in their sensing capabilities. Commercial grippers can be very expensive which prohibits them from being used effectively in some tasks. Generating large amounts of demonstration data for approaches such as diffusion policies or performing reinforcement learning on the real robots often results in wear and damages to the grippers. Additional risks of damages are introduced while testing and rolling out novel policies which might cause unforeseen collisions or motor overloads. Besides the cost of repairs and replacements, a lot of time is lost waiting for the robot to be usable again. This is especially critical when the device needs to be sent to a manufacturer for repairs.

We aim to approach these issues by introducing our design strategy for versatile self-built grippers using cheap of-the-shelf components and 3D-printing in combination with an array of sensors at the example of two open-source gripper designs.

II. HARDWARE DESIGN

In the following we will outline the key design features in our grippers and explain the decisions made. Afterwards, we outline the specific designs of two different grippers following these principles with different applications in mind.

We use Feetech STS3020/TTL servos as actuators [4]. With a holding force of 20kg, they are strong enough for our applications. At a price of less than 25€ per unit they are cheap to replace and spare parts can be held in stock. The servos provide internal measurements such as their current position and velocity as determined by a 12bit hall effect sensor as well as voltage, current, load, and temperature.

Electronic components are housed in a protective housing close to the base of the gripper with no forces directly acting on them. Cables are strain-relieved to prevent damages to the electric components in the gripper. An Arduino Nano33 IoT is used as control board. It features sufficient processing capabilities for our use cases and provides the (at the moment unused) option of wireless communication. Further, it includes an IMU providing valuable readouts, which can be used for estimating the orientation of the gripper, but also to sense small impacts on the gripper (e. g. making contact with an object).

As sensors additionally to the ones integrated in the motors and control board, we use load cells and have the option of including tactile sensors on the finger tips and other components. Load cells are used for their high robustness, low price, measurement precision, and ease of use. They are integrated into the grippers as essential structural elements HX-711 breakout boards were modified to make use of their 80Hz readout frequency capabilities.

As tactile sensors are very application specific, we optionally use the camera-based DIGIT sensors [5] and a customizable array of force-sensitive resistors (FSR) presented in previous work[6], [7]. The DIGIT sensor is able to capture fine grained detail in materials such as fabric. Its output can be processed by convolutional networks also utilized for image processing. In contrast, the FSR-array sensors feature a significantly lower resolution but are capable of measuring a larger range of forces.

All remaining structural parts are 3D-printed. The key advantage of this approach is that replacement parts can easily be reprinted to fix broken parts with minimal delay and cost. Some of the parts are explicitly designed to break early and thereby protect the servos and other sensible components of the gripper. These sacrificial components can be reprinted within mere minutes. This saves again on cost and downtime of the setup. Additionally, 3D-printing allows for intricate design features where needed, enabling us to accommodate the electronics and sensors within a small build volume.

The grippers mount to the robot arms via an easily removable 3D-printed mounting plate. This allows for quick swapping of the grippers in case of damages or to change the type of gripper.

A. 4-DoF Gripper

As a generalized gripper, we present our 2-finger, 4-DoF gripper featuring four servos and four loadcells. Each finger is connected to the gripper base via two loadcells to measure both the pressure in between the fingers and the pressure exerted by the grippers fingers to the environment. The finger tips are easily exchangeable to allow for quick changes in between no tactile sensors, the DIGIT sensors (and an option not to use them to protect the sensitive gel surface), and our customizable tactile sensor arrays. The feature is highlighted in Figure 1a showing three different types of fingertips. Figure 1b visualizes the tactile sensor measurements taken while performing a pinch-grasp.

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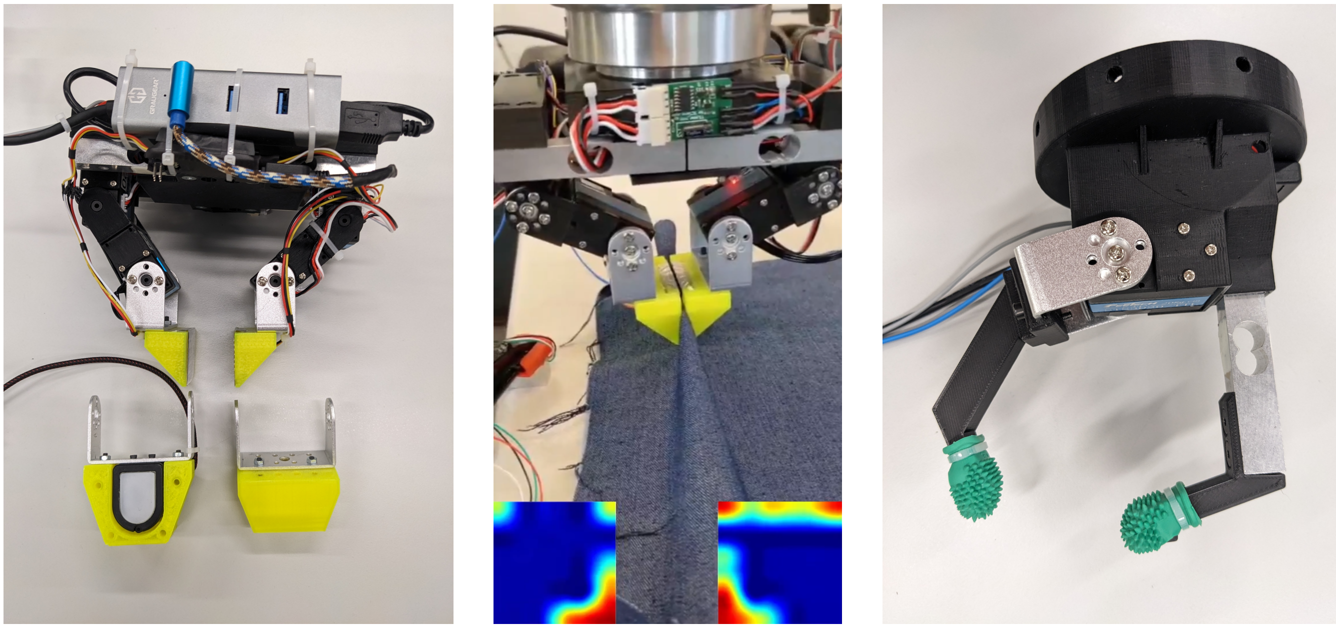

(a) (b) (c)

Fig. 1. Two of our grippers. **(a)** The 4-DoF gripper equipped with tactile sensor array fingertips. Below: alternative fingertips with the DIGIT sensor (**left**) and without any tactile sensors (**right**). **(b)** The 4-DoF gripper grasping a piece of fabric in a pinch configuration. **(c)** The 1-DoF gripper with a single actuator in the palm. The stiff finger (right) predominantly consists of a loadcell and a 3D-printed plastic part designed to break in case of collisions.

The fingers can be either controlled freely or in a parallel mode allowing power grasps (e. g. for grasping a bottle) as well as pinches.

The gripper was utilized in a previous work to grasp fabrics [8]. There we use the motor load readouts and the tactile sensor array to adapt the grasp yielding a lower load on the motors while maintaining a high grasping force compared to static position control. Further, the tactile sensor array is utilized to detect whether the grasped piece is stable in the gripper, slipping out our already lost.

B. 1-DoF Gripper

Our 1 Degree-of-Freedom gripper was primarily designed for the manipulation of garments and fabrics. However, it has shown to be generally useful for precise manipulation tasks. The general hardware design is heavily inspired by the qb robotics SoftClaw [9]. It features two fingers, one of which is actuated while the other one is statically mounted to the base via a loadcell. The loadcell is used to measure the grippers grasping force and was successfully applied to control the force exerted by the fingers onto grasped objects. Both fingertips are covered by rubber thimbles commonly utilized by humans to increase the friction when manipulating paper or counting money. We found that the thimbles significantly improve the grasping reliability and strength of the gripper and do not use additional tactile sensors. The gripper is shown in Figure 1c.

The reliance on a single motor comes with multiple advantages. Controlling the gripper is very simple and predictable reducing possible overhead. But also the mechanical construction is simplified by using only a single actuator and load cell which increases the reliability and lowers the price. At the time of writing, the gripper can be built with a total cost of under 80€ in parts assuming only filament costs for the printed parts.

III. SOFTWARE

Both gripper designs share a very similar firmware and driver as it is designed from the ground up to support a configurable number of actuators, loadcells and additional sensors. It sends sensor data and receives commands in the form of text via a serial interface to and from the host PC. URDF files are available enabling visualization of the gripper in RViz and integration into a MoveIt configuration.

On the host-PC, the communication is handled via a ROS driver offering a convenient interface to control the actuators and sensor data readouts. In addition to the supporting the default ROS interfaces, the driver also provides the option to directly send commands to the firmware. This opens up possibilities such as changing internal parameters of the servos such as PID values via the ROS interface.

The tactile sensor array and DIGIT sensors integrated into the fingertips of the semi-parallel gripper are connected directly to the host PC via a USB-hub mounted to the gripper. They are integrated into our software pipeline using separate ROS drivers.

The gripper firmware, drivers and meshes are available in the following repositories:
`https://github.com/TAMS-Group/q_gripper`
`https://github.com/TAMS-Group/agile_gripper`

References

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