S.I. DISCUSSION ON THE FRAMEWORK FOR CHARACTERIZING INPUT METHODS

In this section, we discuss some extensions of Section III and expand on the limitations mentioned in Section VI of the main article.

A. Expanding the feature set

As mentioned in Section VI, new features will emerge from considering more complex scenarios than the ones considered in our work. We discussed transferability as a possible feature, where the same demonstrations may need to be retargeted between different types of end-effectors or robots with different form factors. Another feature could be resumability, which would be important in scenarios where demonstrations need to be paused and resumed often. Input methods that provide support for this feature would benefit Incremental Learning from Demonstration (ILfD) scenarios. A feature that would belong to the feature group of Practical Qualities would be the range of object types (e.g., based on size, weight) the input method can handle.

B. Relative weightings of features

In Section III-C, we mention that we consider binary weightings of features in our work, that is whether a feature is prioritized or not. Ideally, these features could be better weighted depending on the design goals. For instance, in Lee et al. [1] the authors describe the difficulty in generating demonstrations with the right force profiles (Feature 3: Desired demonstrations) and accurately capturing precise force-based demonstrations (Feature 12: Instrumentable). There is an interesting trade-off between these two features beyond just their presence or absence. The extent to which input methods serve these features would be measured by using measurement tools similar to those used in our work. Understanding how each individual feature can be measured and weighted is a promising direction for the extension of this work.

S.II. ADDITIONAL DESIGN DETAILS OF INSTRUMENTED TONGS

We mention in Section IV that tongs serve as a metaphor for the limitations of a robot gripper. We have used the tongs metaphor to explain the limitations of robot grippers to manufacturing engineers, suggesting they try to perform a task with salad tongs to assess its appropriateness for automation.

A. Past iterations of the design of instrumented tongs

Our initial designs shown in Figure S1.A used the kitchen tongs metaphor literally; we adapted standard kitchen tongs by attaching force sensors in the tips and an inertial measurement unit (IMU) near the hinge. Kinematic data (position and orientation) was approximated using algorithms from VR tracking applications [2]. The prototype showed the need for an improved design that rigidly mounted high quality sensors. The next iteration as shown in Figure S1.B used better force sensors and an HTC Vive controller to track position and orientation. This was accompanied by an encoder which directly recorded the angle between the two arms.

Fig. S1. Design of previous iterations of instrumented tongs.
Our current design uses 3D printed plastic pieces connected with a spring-loaded hinge to provide the same mechanism as simple kitchen tongs, but with a shape that more readily allows for high-precision force-torque sensors to be attached.

B. Additional design details of the current prototype

1) Objects are directly in contact with the tool side of the force-torque sensors through the soft padding. Manipulating objects with other parts of the tongs will result in incorrect measurements.

2) The base of the prongs that are used to attach motion capture markers are filleted to relieve stress and the ends are threaded to screw markers on.

3) The choice of the type of sensors depends on the application. Sensors such as the SynTouch BioTac sensor (temperature, pressure, vibration), Optoforce force sensors (3-axis force), the Tekscan pressure sensor array (2D pressure images) provide different sensing capabilities and may be preferred over traditional force-torque sensors.

C. Variations of the tongs design

There are several variations of the design that we have not explored in the current work. For example, a more complex mechanical design similar to parallel jaw pliers may better approximate a robot gripper, or attaching the gripping surfaces more directly to the user’s fingers like castanets. Directly integrating the force-torque sensors into the device instead of using an off-the-shelf sensor can make the device less bulky and better suited for a broader range of scenarios. These designs share the strategy of our current design, and future work could use our framework to compare tongs against such related devices.

S.III. ADDITIONAL EXPERIMENTAL DETAILS

A. Study setup

The four methods of demonstration that we characterize in the user study are shown in Figure S3. Participants demonstrate using two input methods, hand and tongs on one side of the workspace. The robot is placed on the opposite side of the workspace, where participants demonstrate using the two other input methods, kinesthetic and teleoperation. The layout of the task-space as shown in Figure S2 is symmetric for both sides of the workspace.

B. Methods of demonstration

Position and orientation of free-hand demonstrations are tracked using a glove with a set of markers attached to the back of the glove as shown in Figure S4.A. Although all joint angles of the current state can be recorded by the robot, to allow for direct comparison with other methods, we track the end-effector using motion capture markers on the robot as shown in Figure S4.B.

For kinesthetic guidance, while the robot is in the “freedrive” mode, it is possible to physically move the robot arm to the desired position. The native implementation of the freedrive mode on the UR5 robot requires the user to keep a button on the back of the teach pendant pressed. To allow users to be able to use both hands to move the robot arm during the demonstration, the robot arm is set to the freedrive mode by the experimenter through a command via network connection. Buttons on a Logitech R800 Wireless Remote are reprogrammed to allow the user to control the gripper.
REFERENCES

[1] A. X. Lee, H. Lu, A. Gupta, S. Levine, and P. Abbeel, “Learning force-based manipulation of deformable objects from multiple demonstrations,” in *2015 IEEE International Conference on Robotics and Automation*, pp. 177–184, May 2015.

[2] S. M. LaValle, A. Yershova, M. Katsev, and M. Antonov, “Head tracking for the Oculus Rift,” in *2014 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 187–194, IEEE, May 2014.