Robot Factors: An Alternative Approach for Closing the Gap in Human versus Robot Manipulation

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I. INTRODUCTION

Manipulating human tools reliably would allow robots to perform a diverse set of useful tasks in human environments. However, human tools are often difficult to manipulate with simple robot grippers, particularly given the force requirements for applying the tool. This is often due to the mismatch between the gripper and the tool handle designed based on *human factors*. Our approach argues for modifying human environments based on *robot factors* so as to expand the robot's capabilities or improve the robustness of its existing capabilities. In this paper, we present a case study for applying this approach to robotic tool manipulation. We describe the design of a low-cost universal tool attachment that makes the tool *gripper-friendly* and demonstrate its utility in *grasping*, *applying*, and *placing* common cleaning tools.

II. ROBOT FACTORS

Structured environments, such as factories, enable robots to do impressive, high-precision tasks with high reliability. These environments are explicitly designed around the robot to simplify perception and manipulation problems. As robots move into unstructured environments designed for humans, they are faced with significantly more challenging versions of these problems. Although robotics research is making great strides in dealing with these problems, the state-of-the-art is far from being practical.

This indicates a trade-off: the more structure we can add to the environment to make it robot-friendly, the more complex, reliable, and robust the tasks achievable in that environment are. Our approach is to modify human environments so as to induce additional structure that simplifies the robot's task. We refer to principles that govern such modifications as *robot factors*, akin to *human factors*. Robotics researchers employ this approach in an adhoc way on a regular basis; either to isolate smaller research problems (*e.g.* using fiducials or motion capture systems to avoid the perception problem), or to make large-scale demos work in a particular environment. Some commercial successes in robotics rely on this approach (*e.g.* virtual walls for a robotic vacuum cleaner or ceiling markers for a hospital delivery robot). Our work aims to establish user-centric principles for employing this approach.

We believe that users are willing to modify their environment if they feel that the benefits exceed the costs. For instance, persons with mobility impairments modify their environments to allow a service dog to help with various tasks that would increase their independence. Nguyen et al. developed robotic capabilities that can exploit such modifications, *e.g.* red towels tied around drawers to make opening them easier [2].

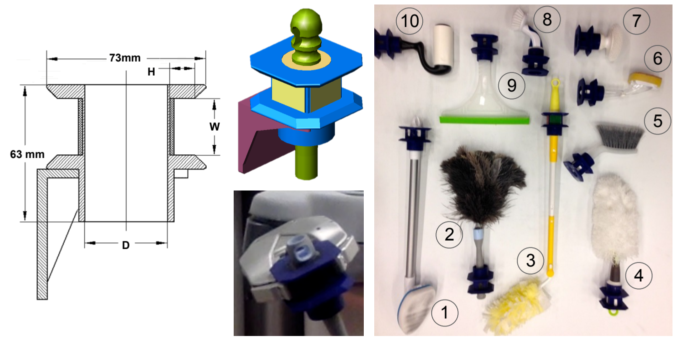

Fig. 1. (Left) Drawing, rendering and picture of the *Griple* (with the PR2 gripper). (Right) Cleaning tools modified with the *Griple* used in our experiments.

More generally, we argue that the practicality of a modification depends on it being (i) low-cost, (ii) easy to install, and (iii) not disruptive to human workflow.

III. THE GRIPLE

In this paper we focus on robot factors for manipulation. In particular, we are motivated by the difficulty of manipulating human tools with handles that are ergonomically designed to fit human hands.

A. Design

We present the design of a universal tool attachment, named *Griple* (*Grip*per Hand*le*), designed to fit the PR2 (Personal Robot 2) gripper (Fig. 1). It aims to improve the stability of the PR2's grasp of human tools and its ability to apply force using the grasped tool. Tool use involves applying a force in the environment through the *tool tip* or *tool application surface*. This force is transferred from the robot to the tool though the grasp point, which requires countering a torque generated at this point due to the extent of the tool (*i.e.* the moment arm). The PR2 gripper has two parallel fingertips allowing a stable precision grasp on objects that have two parallel surfaces within a certain size range. Grasping *cylindrical* objects, such as handles, results in very small contact points. As a result, the torque that can be countered by the friction on these contact points is limited. Griple addresses this problem in two ways: (i) the rectangular cross-section allows for maximal friction between the parallel fingertips and the Griple surface, and (ii) the collars around the fingertips provide additional support to counter the torques from the sides of the fingertip.

The diameter of the inner cylindrical hole of the Griple is chosen to fit tool handles designed based on human factors

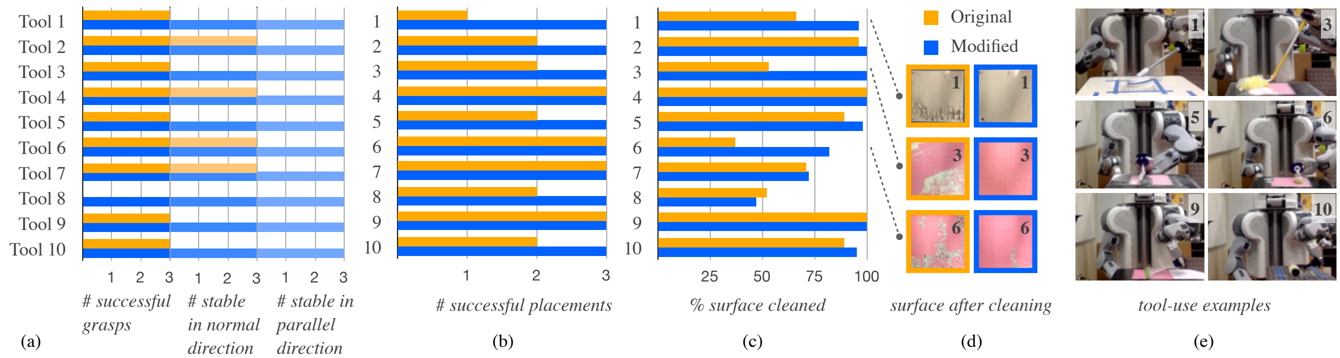

Fig. 2. Sample results from the evaluation of the Griple. (a) Success and stability (in directions normal and parallel to the gripper fingertip surfaces) of grasps out of 3 trials, when objects are hanging vertically. (b) Success out of 3 trials in placing objects vertically. (c) Percentage of the surface that is successfully cleaned in tool-specific cleaning tests. (d) Example surface states after cleaning. (e) Snapshots from the cleaning tests with different tool types.

guidelines [1]. We use Sugru silicone rubber for permanently securing the position of the Griple onto the tool.

B. Evaluation

We demonstrate the performance gain provided by the Griple for 10 representative tools (Fig. 1 (Right)) in three separate experiments addressing the different stages of tool use: (1) *grasping* the tool, (2) *applying* the tool, and (3) *placing* the tool. In each experiment, we compare the robot's performance in two conditions: (a) using *original* tools, versus (b) using *modified* tools fitted with a Griple. The tool set involves a sponge, different dusters, a sweeper, different scrubbers, a squeegee and a lint remover.

All test actions on the robot were programmed using an open source Programming by Demonstration software[1]. Grasping actions involved the robot opening its gripper, moving it to a pre-grasp pose near the tool, approaching the tool, closing the gripper, and moving the tool away from its initial position. For original tools the grasp point was manually around the handle of each tool. Placing actions involved the inverse of grasping sequence. Both grasping and placing actions were tested in two situations where the tool is (i) hanging vertically or (ii) lying on a flat surface.

Tool application actions involved replicating tool trajectories tested by an experimenter prior to programming the robot. A different tool application action was programmed for each tool. All tool application actions started with the tool being handed to the robot by an experimenter. The success of each cleaning tool was measured in terms of the percentage of the target surface on which the tool is successfully applied. Successful application depends on the tool type; therefore, we created a different test for each tool type. For example, the sponge was required to remove marker stains on a whiteboard surface while the dusters were required to dust off talc powder off of a paper surface.

C. Findings

Fig. 2 presents sample results from our evaluation. We observed that the robot was able to grasp tools that have a Griple with 100% success rate both when they were hanging vertically and lying horizontally on a surface. For original tools a high success rate was achieved in the *vertical* grasping tests. This was because the friction at the grasp points and gravitational forces were aligned in this setting, hence generating less torque disturbances on the grasped tool. In the *horizontal* tests, the success rate for grasping original tools was much lower. Although the robot could successfully close the gripper on the tool handle, it was unable to lift the tool up unless the tool was very light (Tools 6 and 7). In both vertical and horizontal tests the Griple resulted in 100% stable grasps. In contrast, none of the original tools were stable in the direction parallel to the grasping surface. Some grasps were stable in the direction normal to the grasping surface. These were mainly the shorter tools (Tools 2, 4, 6, 7, and 8) that had a smaller moment arm for forces applied near the tool's application surface.

We observed close to perfect placement of tools with a Griple. For original tools, placement onto a horizontal surface was more challenging than hanging the tool vertically onto a jig. Failures with original tools were often caused by the tool rotating around the grasp point due to gravitational forces and, in some cases, slipping before being released.

In the cleaning tests, we also observe a better performance when using tools with a Griple, particularly for longer tools (Tools 1 and 3). Original tools with short handles were also effective; however, this was partially due to the experimenter's assistance in handing the tool to provide the most stable possible grasp.

Overall our evaluation demonstrates clear benefits of the Griple in allowing a robot to manipulate human tools.

References

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[1] http://wiki.ros.org/pr2_pbd