Design of a Haptic Joystick for Shared Robot Control

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1. INTRODUCTION

Autonomous mobile robots are often equipped with sophisticated sensors designed to provide the system with a model of its surrounding environment. This information can then be used for making task-related decisions and conveying information back to the operator. To date, autonomous systems tend to exceed at well defined tasks such as navigation, planning, and obstacle avoidance, usually in fairly structured environments. However, for many current mobile robotic systems, teleoperated control is still largely favored, in part due to a human operator's sophisticated ability to reason about unstructured environments [6]. Introducing varying levels of autonomy into a teleoperated system allows for a human operator to make high level decisions while leaving other tasks to the autonomy [5]. With this technique, problems can arise when the human operator does not understand why a part of the system they do not have direct control over is behaving in a particular manner (see Figure 1), usually due to poor situation awareness [1]. Attempts have been made to correct these issues by displaying additional sensor and system state information in the operator control unit (e.g., [8]).

An example in which human operators and autonomous control systems successfully work together exists in conventional control yokes found in side-by-side cockpits of modern aircraft. The two control yokes are tied together such that movement of one is mirrored by the other. Additionally, the autopilot system may be tied in such that its control inputs are also reflected by the control yoke. By seeing or feeling the movement of the control yoke, crew members are more aware of the current state of the aircraft's control system [7].

We hypothesize that by having the autonomous system command the robot's velocity with the same control interface used by human operators (i.e., the joystick), human operators will be better able to understand and interact with an autonomous system at varying levels of autonomy (see Figure 2). Specifically, we believe that people will be able to more efficiently teleoperate robots if information about the state of the semi-autonomous system state can be felt as haptic feedback rather than being displayed on a screen.

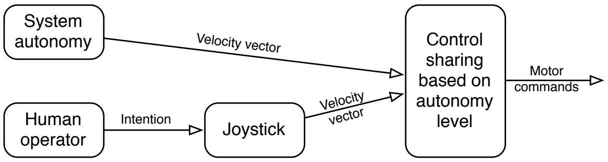

Figure 1: Traditional Shared Autonomy

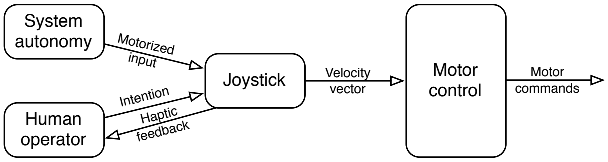

Figure 2: Shared Autonomy With Haptic Feedback

2. DEVICE HARDWARE

Traditional two degree of freedom (DOF) joysticks inherently provide users with some amount of haptic feedback in the form of a constant spring force and hard stops. The spring force is felt as a small amount of constant pressure as springs inside the base of the unit push the handle back towards the center resting point. This pressure provides several important functions. First, feeling any amount of pressure informs the user that the joystick is not centered. Also, the direction of the pressure is inversely related to the direction in which the joystick is pressed. Finally, the joystick will "automatically" center itself when the user relaxes his/her pressure on the unit. The physical layout of the device provides a limited range of motion in which the joystick can move. Thus, the user is informed when the device is at its limit when the device comes to a hard stop. We believe that this kind of feedback should also be present in the haptic joystick. Therefore, interaction with the haptic joystick should feel like a traditional joystick and also have the ability to provide information in a haptic manner. We hypothesize that it will be possible to isolate the effect of enabling various types of haptic feedback.

We selected for our base system a C.H. Products Flightstick, as it is a common and inexpensive joystick with a simple design. The SensAble PHANToM Omni [4] haptic device

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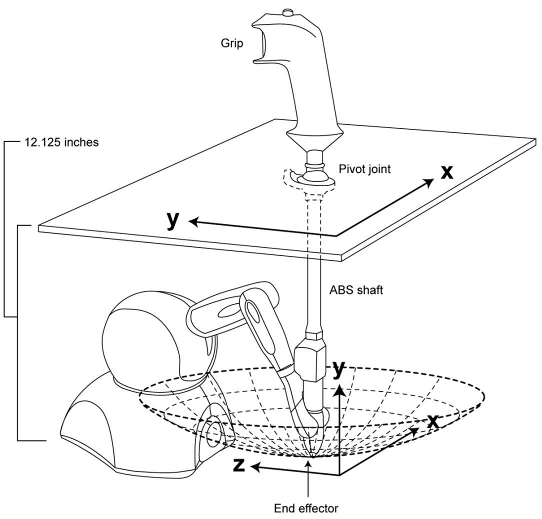

Figure 3: Haptic Joystick Assembly

was selected for the haptic engine as it is widely used in research and comes with a well documented software API[3]. The PHANToM Omni is a 6 DOF haptic device capable of providing haptic feedback in 3 dimensions (x, y, and z axis).

We calculated a configuration in which the PHANToM Omni would have a maximum range of motion, while simultaneously matching the range of motion of the C. H. Products joystick. By maximizing the range of motion of the haptic device, the precision and mechanical advantage of the haptic feedback was also maximized. This configuration required the PHANToM Omni to be positioned below the joystick grip, pivoting about an imaginary point located 12.125 inches above the surface on which the haptic was positioned. We removed the PHANToM Omni's stylus and replaced it with a custom acrylonitrile butadiene styrene (ABS) plastic shaft connected to a joystick grip. A 1/8" hardened metal rod running down the center of the shaft was added to increase rigidity. A physical pivot joint was added to connect the shaft to the mounting surface to complete the assembly (see Figure 3).

3. SOFTWARE

Frequently, the input from a joystick is interpreted as the forward and angular velocity at which a mobile robot should move. Because of the added pivot point on our haptic joystick assembly, the path along which the PHANToM Omni End Effector (OEE) moves is on the surface an invisible sphere (see Figure 3). This path is defined as the minor arc of the great circle passing between two points on the sphere's surface. Therefore, the a mapping between the 2D velocity information and 3D position of the OEE can be defined as a ratio of the maximum distance the end-point can move along the minor arc of the great circle in any given direction, to the associated maximum velocity that the position describes. The robot's internal state can be reflected though haptic feedback to the user by commanding the OEE to travel along the this same arc. This feedback can be used to reflect sensor information such as the distance to an obstacle (i.e., the greater the force, the closer the obstacle). The force applied to the OEE could also be used to represent the autonomous system's intent, with changes in the amount of force indicating decisiveness or sense of urgency.

The complexity of our haptic joystick made it a natural fit for being organized into smaller subsystems (or modules) which could communicate with each other using ROS [2]. For example, the haptic device hardware API was separated such that other modules could subscribe to the two dimensional input information it provides or publish force commands for pushing the OEE and thus creating haptic feedback. Another module has been designed to listen for velocity commands being sent to the motors while publishing sensor information such as laser and video data. Other modules representing various autonomous behaviors are used to interpret this sensor information along with user input and generate haptic feedback commands. By loosely coupling the various pieces of the system, different types of autonomous behavior and haptic effects can be easily swapped in and out of the system for testing.

4. FUTURE WORK

We are planning to conduct an experimental analysis to characterize how haptic feedback can be effectively implemented for various modes of autonomy and the impact each implementation has on the operator's performance. Specifically, we will evaluate the operators' understanding of the remote system state (for all modes of autonomy) and the overall effectiveness of teleoperation during shared control modes. In addition, we would like to investigate how changing the strength and persistence of feedback can be used to manipulate a user's perception of the system state. We will first test scenarios in which the operator and autonomy have an equal share in control with respect to duration and magnitude of the force being applied to the system. Then we will manipulate the share of control that each has. We will also investigate how a user's experience (i.e., the perceived benefit) changes with the amount of previous experience in using classical teleoperated controls.

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