

Demonstration of a Large Dissipative Haptic Environment

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Abstract

Herein we describe a hands-on demonstration presented at the 2006 Symposium on Haptic Interfaces. Our device is a dissipative six degree-of-freedom haptic robot with a workspace of 2 cubic meters. By using dissipative actuators we are able to increase user safety. Our demonstration allows subjects to evaluate many of the haptic features that are required for a rich haptic environment.

1. Introduction

General-purpose haptic feedback devices are frequently used for assistance during manual procedures (virtual fixtures in surgery), product design (virtual clay, tactile evaluation), technique training, and rehabilitation. Because of concerns for user safety, most devices limit the power of their energetic actuators (electric motors, hydraulic or pneumatic cylinders) and thus are restricted to low-mass structures and small workspaces. Although large-workspace devices have been built and used (such as MIME [1], WAM [2], PHANTOM [3], and HapticMaster [4]), these machines either carry the risk of user injury caused by a malfunction, or limit their speed, force and/or range-of-motion to levels insufficient for some applications (such as rehabilitation). Our research interest is in exploring the performance capabilities of a device that utilizes passive actuators for motion control. Specifically for our first step, we constructed a six degrees-of-freedom (DOF) haptic environment similar to work previously done by one of the current authors [5]. The device has a workspace of approximately 2 cubic meters, and utilizes dissipative brake actuators for motion control in order to safeguard against user injury. We show through demonstration that even when the device is purely dissipative, many features desired in a general-purpose haptic environment can be realized with orthogonal kinematics, axes alignment and knowledge of human perception and motor control.

2. Mechanical Design

Previous work [5,6] has shown that robots using only non-energetic actuators must have orthogonal kinematics in order to control all the forces in the Cartesian space of the user. Our design (figure 1) implements a six DOF device. The three braked DOF restrict the positioning of the endpoint based on a spherical coordinate system (r, θ, ϕ) , while three free DOF built into the handle assembly allow for roll, pitch, and yaw rotations of the user's hand with respect to the endpoint. The device is intended to accommodate most movements made with a subject's hand and arm while keeping their torso stationary, and has a min/max extension (r) of 0.25/1.0m, with theta and phi travel of $\pm 60^\circ$ (total workspace of approx. 2 cubic meters).

The device is designed to resist a maximum of 134N of force at the endpoint while at full extension ($r = 1.0m$), equivalent to a torque of 134Nm. Instead of using massive particle brakes rated for the full torque load, the design uses smaller, lighter brakes in conjunction with low-mass cable reduction drives. The two-stage cable drives on the theta and phi axes provide an 82:1 reduction in torque, yielding a resultant max torque on the brakes of only 1.63Nm. The reduction in the turret mass substantially reduces the rotational inertia about the vertical axis, creating a device which feels much lighter and more responsive. Because the r -axis of the machine does not

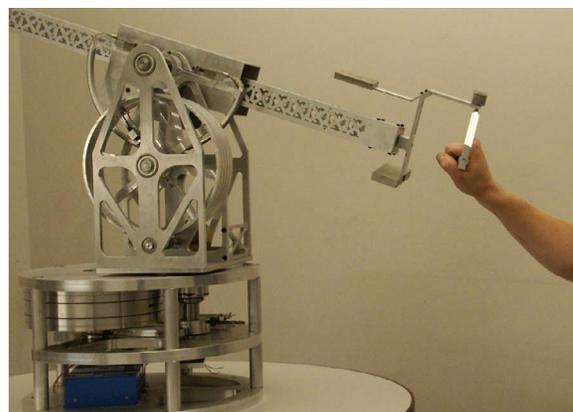


Figure 1: The 6-DOF dissipative haptic device.

have an associated large moment arm, the 134N max force can be resisted with only a simple linear-to-rotational translation stage.

Our three DOF handle was designed to eliminate singularities by using a non-orthogonal gimbal design (figure 2) in which no two axes could align with one another. The yaw axis of the handle is rotated 20° with respect to the roll axis, creating a conical dead zone about the roll axis. Each stage of the handle uses counterweights calculated to keep the assembly dynamically balanced about each of the DOF so that rotations do not produce any off-axis reaction forces. The resulting design provides for pitch rotation of +150°/-180°, yaw of +135°/-180°, and roll of 360°.

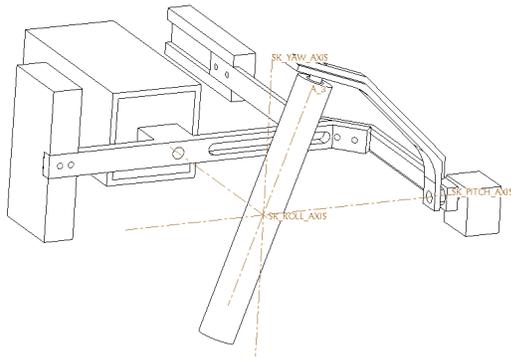


Figure 2. 3-DOF handle design with its rotated yaw axis to prevent gimbal lock.

Because activation of the prismatic stage shifts its center-of-gravity with respect to the pitch axis, we have implemented a variable gravity compensation system to maintain zero net force on the user. The system uses a tensioned spring and cable similar to [7] with the addition of a small DC motor that adjusts the cable endpoint to maintain balance as the prismatic stage shifts. Since the motor moves the endpoint almost perpendicular to the cable, only a small fraction of the motor energy can be conveyed to the user, and user safety is still maintained.

3. Sensing and Control

The device uses optical encoders on each of the three actuated axes, and a six-axis force/torque sensor at the coupling between the device arm and the handle assembly. During development an additional single-axis torque sensor was employed in series with each of the particle brakes in order to calibrate endpoint forces with braking forces. The magnetic particle brakes are activated via linear power amplifiers. Low-level control is achieved by calculating the position, velocity, and acceleration of the endpoint, comparing the values to a map of obstacles, force fields, and dampers, and adjusting the braking levels accordingly.

4. Performance

Our orthogonal kinematics allow for a smooth continuous workspace where the resisted forces can be varied freely. The demonstration depicts virtual geometric objects with both “sticky” and “non-sticky” surfaces [5] in a gravity-free environment.

5. Acknowledgement

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