Toward Haptic Interfaces with Higher Impedance Range: A Hybrid Actuator with Controllable Mechanical Damping

This paper presents a novel hybrid actuator with controllable mechanical damping. It provides the actuation means for haptic interfaces that can render higher impedance contacts through intrinsic passivity. The overall actuator is a dual actuation system where the primary actuator is responsible for generating the joint motion while the secondary actuator regulates the applied damping through a semi-active friction mechanism. This semi active friction mechanism applies a purely dissipative torque on the joint which can be continuously controlled to produce levels of damping ranging from a completely free system to heavily damped or completely locked joint. The present work mainly focuses on the mechatronic details of the actuator design and in particular the modelling and control of the damper. The proposed variable damper mechanism is evaluated on a simple 1-DOF joint. Experimental results are presented to demonstrate that the unit is capable of replicating physical damping with adequate performance

Keywords: Variable damping actuators, force feedback, haptic interfaces, controllable brakes

Introduction

High impedance interactions in VR and teleoperation with force feedback can create instabilities in the haptic devices as virtual springs and dampers can appear active, in contrast to their real counterparts, which are always passive. These instabilities may be triggered by the actions of the operator or by intrinsic actuation, sensing or control issues. Such as sensors resolution and quantization noise [1], structural elasticity, sampling rate, processing and communication delays. The analysis in [2],[3],[4] represents one of the studies in the literature towards a common stability condition for haptic displays. It has been shown experimentally that the stable region can be increased if the haptic device is physically damped [3],[4]. The approaches introduced in [5],[6],[7],[8] also suggest that an actuator with integrated variable physical damping may significantly improve the performance of a force feedback device when rendering hard contacts by intrinsically ensuring the device stability.

This work presents the design and development of a hybrid actuator incorporating a semi-active variable damper. The implemented damper is a fast and strong friction mechanism with high dissipative capacity which can be controlled to modulate the apparent damping of the joint over a wide range. This paper presents the overall mechatronic design and the system architecture it describes in detail the methods for designing the friction interface and produces a model of the system. The employed control scheme for regulating the damping is described followed by experimental results which validate the actuator functionality.

System description

The developed hybrid actuator consists of the main motor driving the joint and a damper mechanism controlled by a secondary actuator. A conceptual diagram of the system is presented in Figure 2. The joint motor drives the output link without gearing, while the damper assembly provides damping to the link in the form of a controlled friction brake acting on the rare side of the main motor shaft. In this arrangement the damper is effectively connected in parallel to the output link with respect to ground (i.e. the actuator casing). The developed actuator is presented in Figure 1.

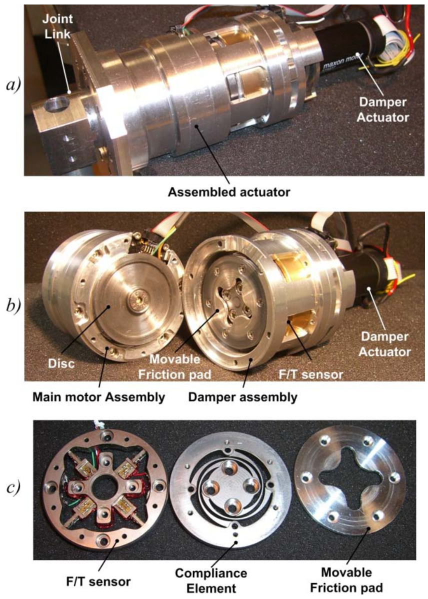

Figure 1 The developed variable damping actuator a) Complete assembly b) Main motor and damper assemblies exposing the brake disk, c) The F/T sensor, compliance element and movable friction pad.

Damper Design, Model and Control

The torque of the damper motor τ_D (Figure 2) is converted by the ball screw assembly into a normal force F which acts through the movable brake pad on the brake disc to produce the damping torque τ_{fr}. The aim of the damper control system is to control damping by modulating the torque applied to the output link according to the velocity of the output link. In this work this is performed by regulating the position of the damper motor using a compliant element, and models of the stiffness and of the conversion of braking force into friction torque at the friction interface.

Experimental results

To evaluate the performance of the damper mechanism it has been evaluated on a simple 1-DOF joint through a damped pendulum experiment. The output shaft was connected through a rigid link to a 1kg mass and the mass was allowed to oscillate from a high potential vertical position (180°) and until it rested at the minimum of 0°. Since the main actuator is not the focus of this work it was kept inactive during the course of these experiments. Data for two damping coefficients, namely C_2 and C_3 are presented in Figure 3. It can be noticed that position tracking is very accurate while the measured force follows closely the computed force from the stiffness model. The measured friction torque also corresponds well to the damping torque reference. Finally the ability of the system to achieve the commanded damping coefficients C_1=0.01, C_2=0.05 and C_3=0.1 Nm-s/rad is shown in Figure 4.

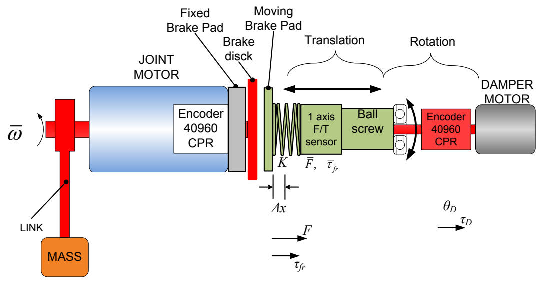

Figure 2 Conceptual schematic of the actuator and damper

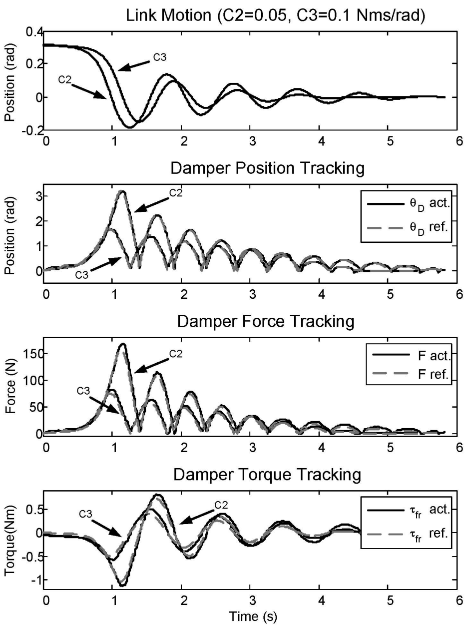

Figure 3 Damper plots for a pendulum mass=1kg at 0.2m subjected to damping C2=0.05Nms/rad and C3=0.1Nms/rad.

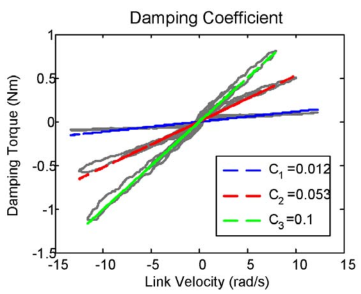

Figure 4 Damping coefficients obtained from the pendulum experiment.

Conclusion

The experimental results verified the design method since the measured characteristics of the damper match to a large extent the design calculations. Furthermore the results demonstrated that the unit is fast and powerful enough to achieve the required damping with good accuracy.

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