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IMPEDANCE CONTROLLER DEVELOPMENT FOR HAPTIC INTERFACEING USING A HIL EXPERIMENTAL SETUP

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ABSTRACT

Haptic interfacing provides the means through which human operators can interact with virtual environments. A haptic interface contains software simulated virtual environments, controllers and haptic devices. Impedance control is investigated in this paper from the viewpoint of suitability for haptic interfacing development. Impedance control parameters proved a particularly suited for defining the interaction between a human operator and a virtual environment. The investigation was carried out on a HIL (Hardware-In-the-Loop) experimental setup, which combines the real hardware and mathematically simulated components and is used as a generic platform for the development and testing haptic interface options before prototypes are available.

KEYWORDS

Impedance Control, Haptic Interface, Hardware-in-the-Loop, Virtual Environment

1. INTRODUCTION

A haptic interface refers to a mechanical system with computer interfacing that allows human operators to interact with virtual environments (simulated with application software) by applying a motion/force input and receiving a force/motion feedback [1,2]. Applications include training medical students using surgery simulations, pilots and astronauts training etc. In these cases, haptic interfaces play a major role in providing the connection between human (trainees) and the virtual environments using visual, tactile and force sensing. A haptic interface system is shown schematically in Fig.1.

Haptic interface development consists in both haptic device and interfacing software development. Haptic device development proposed in this paper is based on a generic multi degree of freedom robot arm capable of both motion and force/torque control and feedback. This facility satisfies haptic interface device requirements: low friction, inertia and backlash, backdriveability, large force range and high mechanical bandwidth as well as suitable working volume [3, 4]. Interfacing software investigated in this paper is based on impedance control, which proved particularly suited to control robot-environment interaction [5], [6]. In this paper we propose a HIL experimental setup and an impedance controller as a general purpose facility for the development and testing various designs of haptic devices.

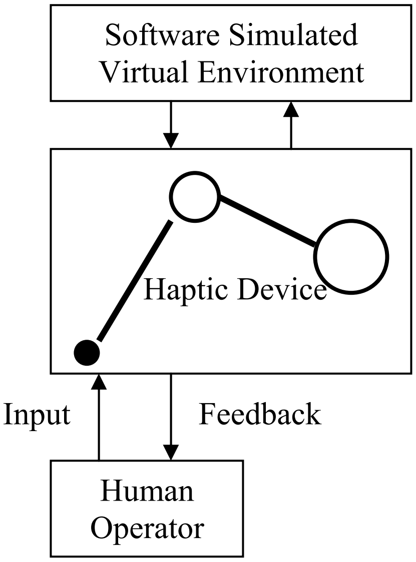

Fig. 1 Haptic interfacing diagram

2. IMPEDANCE CONTROL FOR HAPTIC INTERFACING

The application of impedance control in haptic interfacing is presented in detail in [1]. Both impedance and admittance control were proposed for haptic interfacing [2], [3], [4], [8] and [9]. Impedance control is adopted for the development of the controller for the haptic interface presented in this paper.

Let us consider a planar two degree of freedom robot arm that emulates a haptic device which receives motion commands and generates force feedback. Joint space matrix model contains joint actuators torque, τ, that counterbalances the dynamics of haptic device (i.e. robot arm inertia terms, M and V, gravity generated torque G and friction torque T in robot joints), and applies a feedback force F_{ext} to the human operator through the transposed Jacobian J :

$$\tau = M(\theta)\ddot{\theta} + V(\theta,\dot{\theta}) + G(\theta) + T(\dot{\theta}) + J^T(\theta)F_{ext} \qquad (1)$$

In impedance control approach, the desired interaction is achieved by providing a dynamic relationship between the robot end effecter position and the force it exerts. The force exerted on the environment by the manipulator depends on its position and the locally equivalent desired impedance. A linear second order impedance relation is represented in the Laplace domain as $F(s)=Z(s)X(s) = (Ms^2+Cs+K)\,X(s)$, [2], [6].

Actuator commands are calculated from the desired interaction force using $\tau = J^t F_{ext}$.

Impedance control with force feedback, shown in Fig. 2, can be used to simulate dynamic interaction force [2], [8].

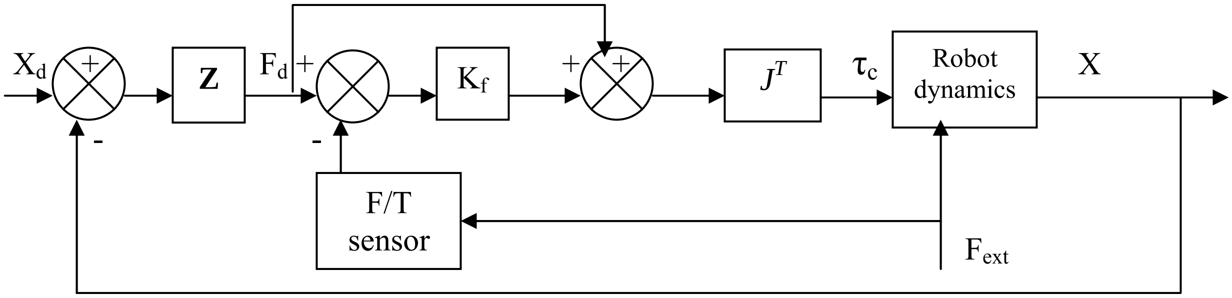

Fig. 2 Block diagram of impedance controller with force feedback

The command torque in Fig. 2 is given by:

$$\tau_c = J^t(F_d + K_f(F_d - F)) \qquad (2)$$

3. HIL EXPERIMENTAL SETUP

In Fig. 3 is shown the HIL experimental setup used in this paper, based on a 2-D planar robot arm [11]. This setup is used to emulate the haptic device while moving an object on a planar surface without friction. A calibration experiment is first carried out to identify the gain K of the relationship, assumed linear and static, between the force exerted on a specimen and the voltage output from the strain gage mounted on the robot arm. This calibration experiment permits to validate the strain gage 2D-force sensor, used to measure the force human operator-robot arm.

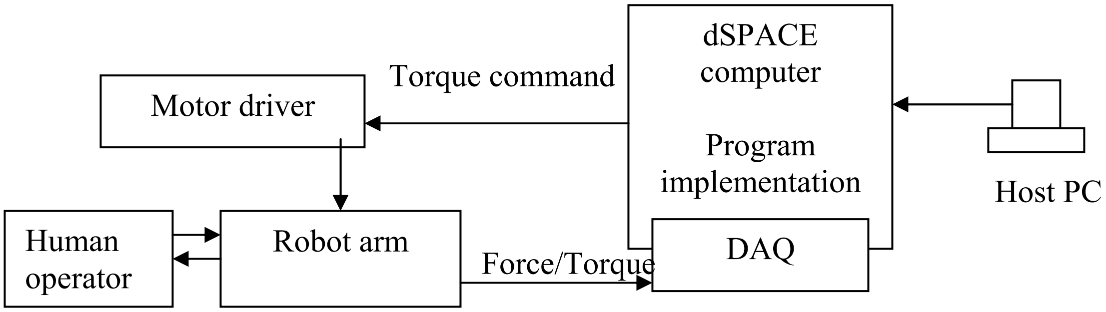

Fig. 3 Block diagram of the HIL experimental setup

Two analog channels of the dSPACE data acquisition board are connected to the two strain gages through two signal conditioning circuits, respectively [11]. The calibration results are shown in Fig. 4. The results show that the 2-D sensor provides, as expected, a linear static relationship within the working range. The K value for channel 1 was identified as 0.0165 V/lb and for channel 2 as 0.0183 V/lb.

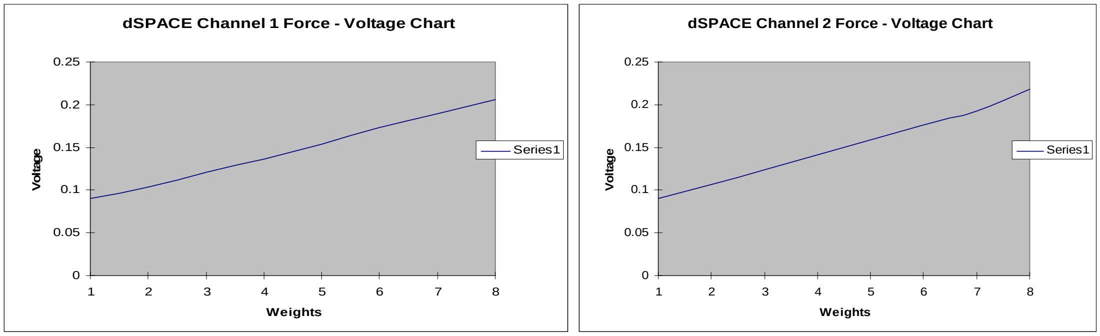

Fig. 4 Calibration results

The virtual environment simulated for this paper, shown in Fig. 5, consists of mass block attached to two identical springs with the same spring coefficients k=10.7mm/lb.

The force vector F, from Eq. 2, can be written in the form

$$Fx = f_{x1} + f_{x2} = F_{mx}\cos(\theta_1 + \theta_2) - F_{my}\sin(\theta_1 + \theta_2) \tag{3}$$

$$F_Y = f_{y1} + f_{y2} = F_{my}\sin(\theta_1 + \theta_2) + F_{my}\cos(\theta_1 + \theta_2) \tag{4}$$

Fx and Fy are forces defined in base frame. F_{mx} and F_{my} are the force measured from the 2-D sensor in end effector frame.

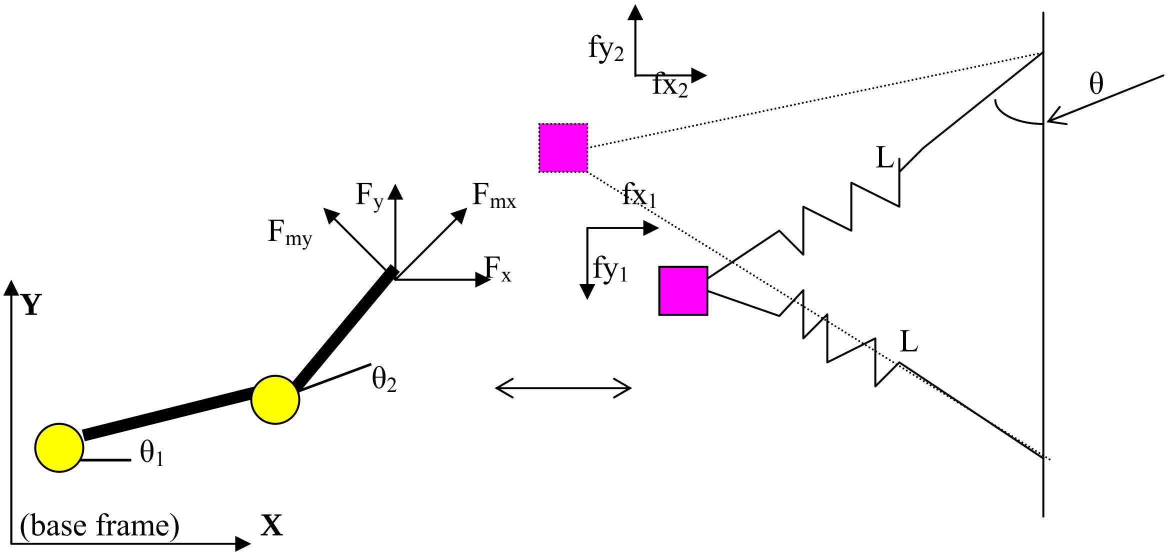

Fig. 4 Schematic diagram of the haptic device (left) and the virtual environment (right)

4. EXPERIMEMTAL RESULTS

The open loop impedance control results for the static case F(s)= K X(s) are shown in Fig. 5.

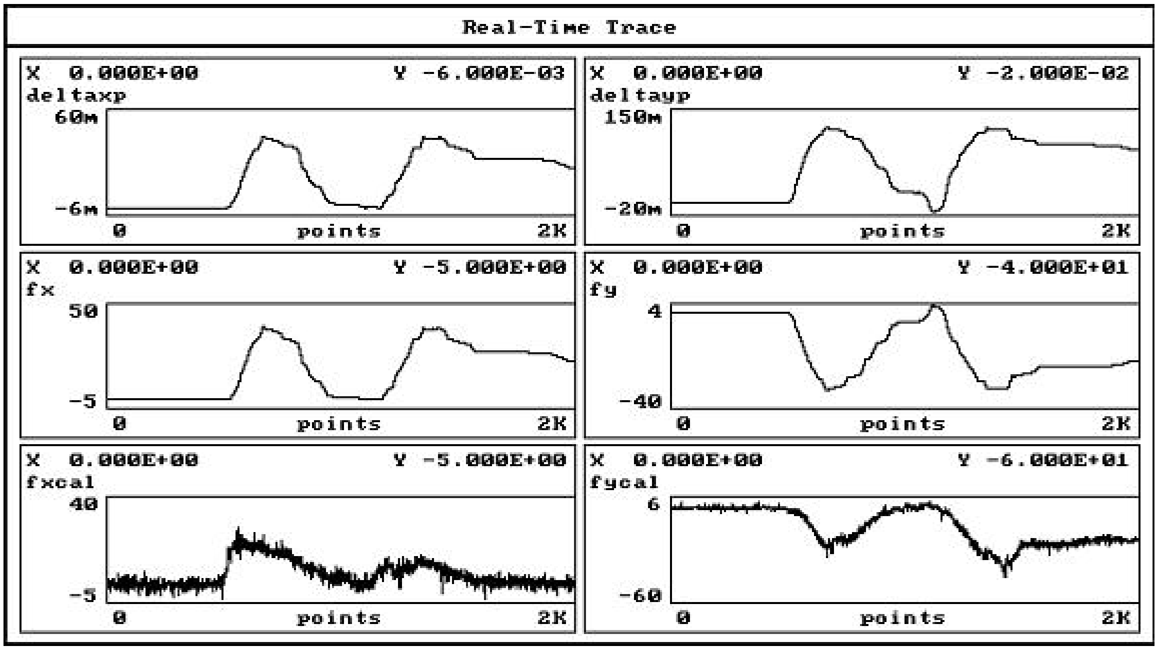

Fig. 5. HIL experimental results

In Fig. 5, "deltaxp" and "deltayp" refer to the motion input to robot arm, "fx" and "fy" refer to the force command sent to actuator and are also to the theoretical values, while "fxcal" and "fycal" refer to the measured force from sensor. Experimental versus theoretical results are displayed in Fig. 6 for various planar positions of the haptic device.

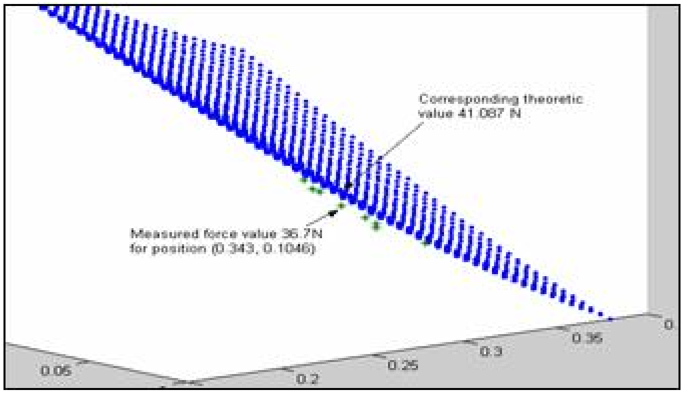

Fig. 6 Measured and theoretical values of the interaction force

Experimental results from Fig. 5 confirm that the measured force outputs values of the proposed HIL setup follow closely the force commands given an arbitrary motion applied by the human operator to the haptic device. The measured force values shown in Fig. 6 are close to the corresponding theoretical values, confirming the ability of the proposed HIL experimental setup to emulate a haptic interface, within 10% errors.

5. CONCLUSIONS

a) The proposed HIL experimental setup proved to be a feasible solution for developing haptic interfaces.
b) The errors between HIL measured force and theoretical values are about 10%.
This confirms that a general purpose robot under impedance control can be build as a haptic device for static case.
c) HIL experimental approach, that combines the real hardware and mathematically simulated components, provides the ideal platform for testing conceptual designs for haptic interface, before prototypes are available.
d) In the next step of this work, impedance control with force compensation should be implemented for dynamic case and a corresponding evaluation should be performed.

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