Dynamic Analysis of Force Feedback Devices

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Abstract

A haptic display system is a force feedback device whereby a human operator can interact with a real or virtual environment for the purpose of perception or manipulation of objects in distant or unreachable environments. These systems are composed of three major components; haptic devices, real or simulated objects in the remote or virtual environment and haptic rendering algorithms. A Haptic device is usually a lightweight robot with which the human operator interacts. The performance of these devices is often considered in terms of dynamic range of impedance they may generate [1]. The lower and higher ranges of impedance are limited by the inherent dynamics of the interface device. The sampling rate, sensor resolution, and actuator/sensor collocation greatly affect this dynamics. Due to these limitations the maximum stiffness of any virtual object is limited. Therefore, a crisp contact with a hard object often cannot be achieved, or the fine features of a textured surface cannot be sensed. A primary challenge in design of a haptic devices is to broaden the aforementioned range.

According to the current literature, dynamic analysis of an impedance-type haptic device is usually done by modeling the device as a single degree-of-freedom (DoF) point mass with intrinsic friction attributed to both viscous and dynamic Coulomb components [2]. Applied forces to the device are composed of exerted force by human operator and actuator forces commanded based on a computer interface simulating the virtual environment. A simple model of a virtual environment is the virtual wall represented via a Kelvin-Voight model. This can be implemented by a discrete-time PD control. Thus, considering a haptic display as a sampled-data system, in which the haptic device is a continuous-time plant and the contact force is a discrete-time signal from a digital controller, brings in some important phenomena which can de-stabilize the system and need to be taken in to account in dynamics analysis of these devices. Time delay induced by sampling and control signal computation, discretization, and sensor quantization are some of these factors [3].

To describe the dynamic behavior for high fidelity haptic rendering of virtual contacts, a detailed study of the mechanical system and the structural properties of these devices is considered in this work. Extension of the single DoF representation of the physical system into a multi DoF model requires to consider several elements. One important point is the dynamic coupling between rendered and free directions. A performance comparison between existing devices can give essential details about the differences in behavior stemming from different mechanical designs. For this

purpose, a two DoF PANTOGRAPH and a three DoF PHANToM (model 1.5) [4] were modeled with the aid of the Multibody Toolbox (MuT) [5], a multibody modeling environment developed by the Canadian Space Agency, and the associated dynamics equations were determined. The behavior of these two devices were compared in two different sets of simulations. In the first test, the maximum achievable stiffness of the virtual wall were obtained for stable behavior of the two devices in given configurations. In the second test as a benchmark example, the behavior of the two devices were compared while emulating a one DoF bouncing ball. In this test, the effects of dynamic coupling between controlled and free directions were investigated. Considerable difference in the behavior of these devices was observed that can stem from different design parameters. Experimental analysis on the two DoF PANTOGRAPH device was carried out to evaluate the simulation results and a very good agreement was found. These results show that the development of a detailed multibody dynamics modeling of haptic devices is an essential element to improve their design and performance.

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