Towards Just Noticeable Differences for Natural Frequency of Manually Excited Virtual Dynamic Systems

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Abstract

This paper explores the experiment design to determine a human's ability to discriminate the natural frequency of manually excited virtual dynamic systems. We use a one degree-of-freedom haptic interface with a coupled graphical display to render a virtual mass-spring system, which is excited by the human operator using his/her dominant hand. The results from the preliminary experiment indicate a JND value of approximately 8%. However, results also indicate that excitation strategies have a significant effect on the discrimination threshold determination of this dynamic property. In this paper, along with a discussion of the preliminary results, a refined experiment design that accounts for different factors influencing the discrimination of manually excited natural frequency is presented.

1. Introduction

This paper explores preliminary experiment results and implications for experiment design to determine the just noticeable difference (JND) for natural frequency of manually excited virtual dynamic systems. Kinesthetic and visual feedback are provided during the interactions with the system, and subjects are asked to excite the system in order to distinguish different natural frequencies. We are interested in knowing the JNDs for natural frequency when the system is manually excited so that we can develop active haptic assistance paradigms that exploit knowledge of JNDs to increase the efficiency and effectiveness of motor skill training in virtual environments.

Current studies of JNDs for kinesthetic and tactile senses have focused on discrimination of geometries, textures, and volumetric properties of objects held by the human, or have focused on discrimination of the subject's own limb movements (see [1] for a review). This study extends prior work listed in [1] by investigating a human's ability to discriminate between systems with dynamics, in other words, for systems whose behavior is dependent on time as well as other factors. Furthermore, this work differs from the previous work in that subjects are actively involved in selecting the excitation that they apply to the system. Since the natural frequency is a dynamic property and this causes a close coupling between excitation and perception, the discrimination task investigated does not solely depend on the subject's ability to perceive or the subject's ability to excite, but on his/her ability to judge this input output relationship and act appropriately to extract relevant information from the system.

Due to the relative complexity of the discrimination task undertaken in this paper, the design of the experiment procedure is not trivial. A well-controlled experiment design needs to take into account the different factors that might influence the discrimination thresholds. In this paper, effects of various factors on the discrimination thresholds are investigated to design a refined experiment.

2. Experiment Setup and Task

An experimental setup consisting of a one-degree of freedom haptic interface is utilized. The force-feedback device is used to synthesize a virtual resonance task by rendering a linear mass-spring system. The sensed motion at the handle of the device (which is assumed to be massless due to its low apparent mass) is used to excite a virtual spring that is connected to a virtual cart of specified mass. Whenever the human subjects excites the haptic interface, the resulting motion of the virtual cart is determined solely by dynamics of the virtual system and is displayed graphically to the user along with an image of the handle position. The natural frequency of the virtual system is proportional to the ratio of the virtual spring and mass rendered.

3. Preliminary Results

A preliminary experiment has been conducted with four subjects, utilizing a constant stimuli like paradigm. The experiment consists of at least 120 comparisons. Five different frequencies are selected in addition to the reference value with 5% increments. Each comparison consists of three trials, in which the first two trials are reference trials, and the third trial is test trial. Subjects are asked to discriminate the natural frequency of the third trial from the first two reference trials. Correct answer feedback is given just after the subject selects an answer. In this preliminary experiment, the human excitation strategy is not controlled and the JND of natural frequency for manually excited virtual dynamic system is determined to be around 8% (see Figure 1). This value serves as a starting point for the refined experiment design.

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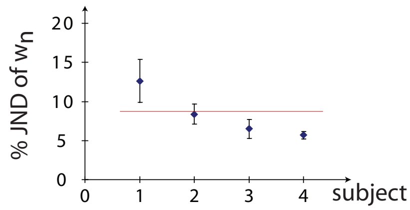

Figure 1: JND values per subject for the manual excited natural frequency discrimination task.

Besides the the initial JND value range it provided, the results from this preliminary experiment indicate that subjects prefer different excitation strategies for the same discrimination task. Even though all subjects preferred a periodic excitation strategy, analyzing the temporal characteristics, these strategies can be classified into two different schemes. A group of subjects (subjects 3 and 4) excite the system actively with relatively large amplitudes at the beginning of the trial, and after this initial excitation, stay passive observing the system response. We call this approach the *sequential strategy* since it allows excitation and perception to occur at different time intervals. Another group of subjects (subjects 1 and 2) maintains a constant excitation amplitude throughout the trial. This strategy is called *concurrent strategy* since excitation and perception are required to take place during the same time interval. Representative plots corresponding to each excitation strategy are presented in Figure 2.

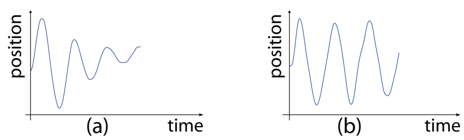

Figure 2: Representative excitation plots. Subfigures (a) and (b) correspond to sequential and concurrent strategies, respectively.

Preliminary results indicate that the discrimination thresholds for subjects using different strategies are significantly different ($t(18) = -2.63, p = 0.017$), and that subjects using the sequential strategy outperform the subjects using the concurrent strategy, with average JND values of 6.2% and 10.6%, respectively. This significant difference in subject performances suggests that the excitation strategy plays an important role on discrimination threshold determination of dynamic properties. Although other strategies may be possible, these two were identified by analysis of the subjects' excitation data. Therefore, future experiments will separate these strategies to determine if they indeed affect performance, or if this is merely an artifact or result of limited subject data.

4. Experiment Design

Given the preliminary experiment results, a refined experiment is designed to take into account different factors that influence the discrimination of manually excited natural frequency. Subjects are given initial training to familiarize them with the resonance task and the different excitation strategies. Throughout the experiment, subjects are asked to focus on the graphics display and the view of their hand is blocked using a curtain. Moreover, a headphone is provided to prevent any auditory cues.

To account for the effects of excitation strategy, the subjects are asked to complete two sessions of the experiment, using the instructed strategy in each. An experiment session consists of 4 portions, each portion corresponding to one increment frequency. The increment percentages are selected as 5%, 10%, 15%, and 20%. Each discrimination portion includes 100 total trials. A one-interval two alternative force-choice paradigm is used for each portion. Once a trial is complete, the subjects are requested to answer questions on that trial. Correct answer feedback is provided after each trial. There are two stimuli for each discrimination, reference, w_n, and reference plus increment, $w_n + \Delta w_n$. Correspondingly, two responses are allowed: "lower" and "higher", lower for the reference frequency, higher for the increment frequency. In each trial, one of the two stimuli is presented randomly with a priori probability of 0.5. For each stimuli, two equivalent systems (i.e. two different virtual spring stiffness k and mass m combinations to results in the same natural frequency) are used so that the subjects cannot rely solely on the force magnitude cues to discriminate different natural frequencies. The equivalent systems are also presented to the subject randomly with an equal priori probability. A schematic representation of the experiment protocol for one increment frequency (one portion) is presented in Figure 3.

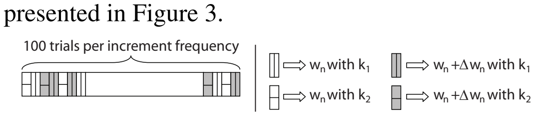

Figure 3: A schematic representation of a discrimination portion.

5. Summary

An experiment design is presented to determine the JND for natural frequency of manually excited virtual dynamic systems. The methodology is based on results from a preliminary experiment which indicate significant dependence on excitation strategy for the task. Therefore, in the proposed experiment design, the excitation strategy is considered as a factor. Furthermore, an equivalent system idea is introduced to eliminate the possible force cue human subject might use to distinguish different natural frequencies.

Once the experiment is completed, the results are expected help us make conclusive statements about the effects of the excitation strategies and equivalent systems on the discrimination task. Moreover, these results will shed light on how human subject judge the input output relationship of a dynamic system and to what level can they act appropriately to extract relevant information from the system dynamics. Finally, JND values for natural frequency of manually excited dynamic system will be quantified.

References

[1] N. Durlach and A. Mavor, Eds., *Virtual Reality: Scientific and Technological Challenges*. National Academy Press, 1995.

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