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# Perceptually Correct Tactile Rendering in Mid-Air Using Ultrasound Phased Array Haptic Interface

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## Abstract

The current work provides a perceptually transparent rendering algorithm for an ultrasound-based mid-air haptic device. In a series of experiments, we derive a systematic mapping function relating from the device command value to final user's perceived magnitude of a mid-air vibration feedback. The perceived magnitude at the focal point is dependent on input parameters such as input command intensity, frequency, and position of the focal point in the workspace. This algorithm automatically tunes these parameters to ensure that the desired perceived output at the user's hand is precisely controlled. Through a series of experiments, the effect of the aforementioned parameters on the physical output pressure are mapped, and the effect of this output pressure to the final perceived magnitude is formulated, resulting in the mapping from the different parameters to the perceived magnitude.

## Author Keywords

Perceptually Correct Haptic; Ultrasonic Haptic Interface

## Perceptually Correct Rendering

Since the introduction of the approach, main research focus of ultrasonic-based haptic device has been on the enhancement of physical characteristics of rendered pressure (e.g., increased strength, more concentrated focus points, and enlarged workspace [1]), usability

issues and application ideas of the approach [2]. Thanks to these efforts, it is considered that the quality of current implementations of the concept is quite at the level of practical application, and the quantitative physical performances are somewhat saturated. Thus, it is nature that the focus is moved to the perceptual performance of the feedback.

As one of the first step in this line of research, we have worked on a perceptually accurate rendering algorithm specially designed for ultrasound-based haptic interfaces. Our algorithm takes the physical characteristics of the device into account. Due to the nature of phased-delay focus control, the perceptual characteristics of the finally rendered pressure change not only as command intensity of the transducer changes, but also as modulation frequency, distance from the transducer array, and lateral position of the focal point in the workspace change. Thus, it is not a trivial task to generate perceptually stable feedback under different situation. In this work, we tried to empirically find a function connecting from these parameters to perceptual strength of the feedback. This function plays a core role in rendering; the inverse of the function gets desired perceived magnitude and returns command intensity under a given frequency, height, and lateral position. This process can minimize the effect of device dynamics and allows us to solely focus on the final stimuli in feedback design.

This work is motivated by the work done by Ryu et al. in [3]. They proposed a perceptually transparent rendering algorithm for vibrotactile feedback. In their work, input parameters of vibrations, i.e., frequency and amplitude, are experimentally mapped to associated perceived magnitude, and then the mapping

is used in rendering for perceptually accurate feedback. While conceptual idea is similar, this paper takes a different approach for constructing the mapping, due to increased number of parameters; 4 inputs in our case while 2 inputs. Instead of directly derive the mapping, for each frequency, we first connect the inputs to generated pressure, and then the pressure is related to perceived magnitude (see Figure 1). This two-step mapping allows us to avoid nearly infinite number of input parameter combinations for the experiment and to separate the experiment into a physical measurement one and a psychophysical user study.

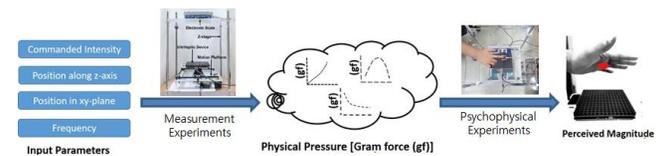


Figure 1. Mapping from inputs to perceived magnitude.

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