Perceived Magnitudes of Vibrations Transmitted Through Mobile Device

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Abstract

In this paper, we report the design and results of a psychophysical experiment wherein the perceived magnitudes of vibrations with various frequencies (20 – 360 Hz) and amplitudes (6 – 45 dB SL) transmitted to the hand through the mobile device were measured using the absolute magnitude estimation paradigm. For an apparatus, a mini vibration shaker on which a mock-up mobile device was mounted was used. We fitted a non-linear regression model to the measured data in order to obtain the perceived magnitudes in a large range of vibration frequency and amplitude. The findings of this paper can be used to assess the perceptual characteristics of vibrations from mobile device we experience everyday.

Keywords: Magnitude estimation, vibration, mobile device.

Index Terms: H.1.2 [Models and Principles]: User/Machine Systems—Human Factors H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O;

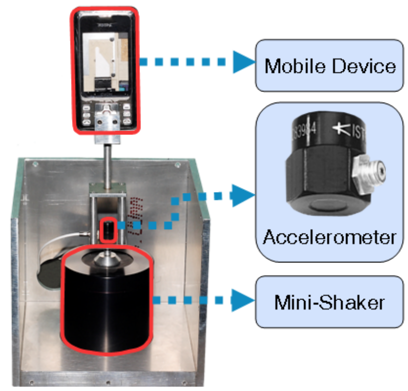

Figure 1: The shaker system used in the experiment.

1 Introduction

Personal mobile devices, such as the cellular phone, PDA (Personal Digital Assistant), and portable gaming device, are one of the recent technical advances that have dramatically impacted our daily life. Vibration feedback in the mobile devices listed above is actively used for various purposes, but related studies for the perceptual characteristics of such vibrations have been rather lacking.

In this paper, we report the design and results of a psychophysical experiment where the perceived magnitudes of vibrations transmitted to the hand through a mobile device were measured for various frequencies and amplitudes of vibrations. Although there have been some studies for the perceived magnitudes of vibratory feedback (e.g., see [2]), those for the mobile device have not been present in the literature, to the best of our knowledge. For displaying vibrations, we used a shaker system that contained with a mock-up mobile device on a mini-shaker. The psychophysical experiment was designed using the absolute magnitude estimation paradigm. The findings of this experiment contribute to the better understandings of the perceptual characteristics of vibrations from a mobile device we experience everyday.

2 Methods

Most mobile devices use a vibration motor for vibration generation due to its many advantages such as small size and low cost. However, the amplitude and frequency of vibrations produced from the vibration motor are correlated [1], and thus other actuation means were needed to measure the perceived magnitudes at various amplitudes and frequencies. In the experiment, we used a mini-shaker (Brüel & Kjær; model 4810) on which a mock-up cellular phone (LG Electronics; model KH-1000) was mounted (see Figure 1). An accelerometer (Kistler; model 8630C) was attached between the shaker and the phone to measure vibration accelerations. The system was controlled by a PC through a data acquisition board (National Instruments; model PCI-6229). More details about the apparatus and its calibration procedure can be found in [1].

Eleven graduate students (eight males and three females) with an average age of 25.1 participated in the experiment. All participants were everyday users of a mobile device, and reported no known sensorimotor abnormalities.

The experiment consisted of three sessions. The first session was for training, and its data were discarded. Each session had 30 conditions by combinations of two factors, five frequencies (20 – 320 Hz) and six amplitudes (6 – 45 dB SL). The amplitudes were determined in terms of sensation levels using the detection thresholds measured in our previous study [1]. In each trial, the participant was asked to hold comfortably the mock-up cellular phone with the right hand and to feel sinusoidal vibrations generated with the corresponding frequency and amplitude during one second. The order of conditions to be presented was randomized in each session for each participant. After each trial, the participant answered the perceived magnitude of the vibration in free scales without a modulus following the absolute magnitude estimation paradigm [4]. To block any auditory cues, the participant wore a headphone that played white noise.

During trials, vibration acceleration was also captured at 10 kHz sampling rate and converted to vibration displacement. A amplitude of vibration actually displayed through the mobile device was computed from this measured data, and compared to the nominal amplitude of the experimental condition. This was to understand the amount of errors in vibration amplitude due to the loading effect of the participant's hand. After the experiment, the measured perceived intensity was normalized by multiplying each data with a normalization constant $M_n = M_s/M_g$ where M_s is the geometric mean of responses of each subject and M_g is the grand geometric mean of all responses of all participants.

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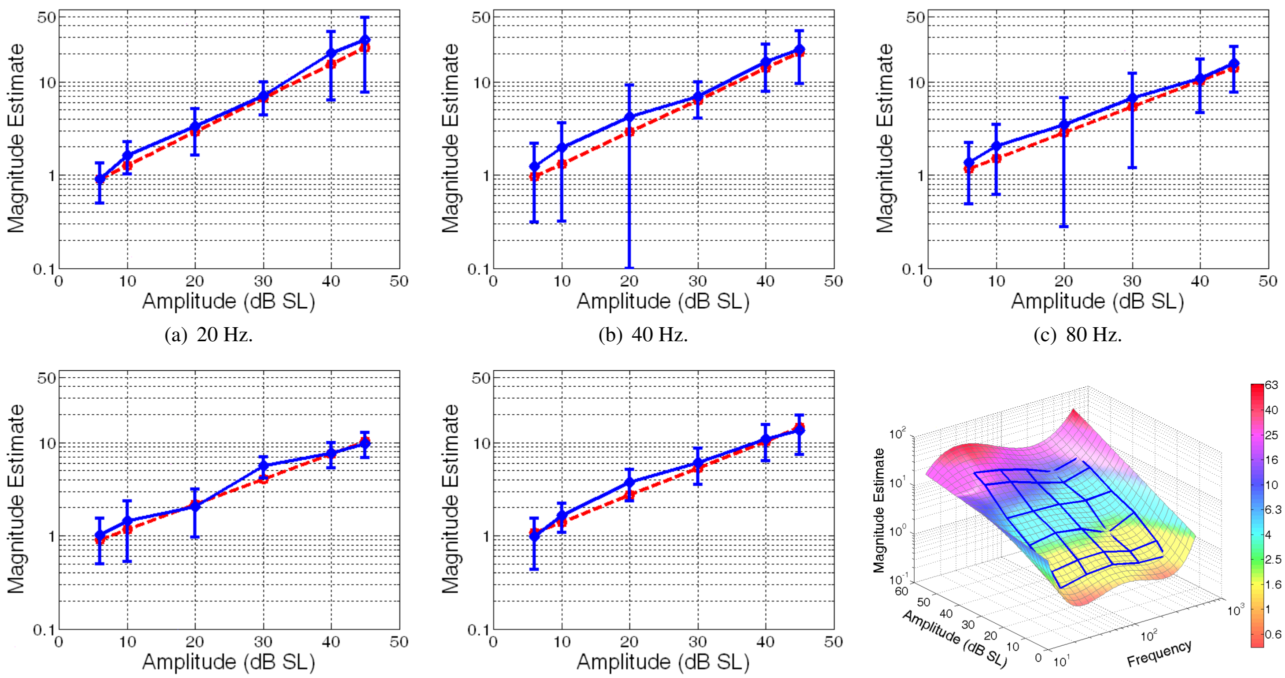

(a) 20 Hz. (b) 40 Hz. (c) 80 Hz.

(d) 160 Hz. (e) 320 Hz. (f) 3D representation.

Figure 2: Measured perceived magnitudes for each frequency (a–e) and their 3D representation (f).

Table 1: The coefficients for equation 1

i	α_i	β_i
4	-0.0682	3.5759
3	0.5419	-27.0254
2	-1.5739	75.0109
1	1.9688	-90.4316
0	-0.8592	39.6979

3 Results and Discussion

Figures 2(a) – 2(e) shows the measured perceived magnitudes for the corresponding frequency. The blue solid line in each plot represents the perceived magnitudes and the error bars the standard deviations. In each plot, it is clear that the logarithm of the magnitude estimate is linearly proportional to vibration amplitude, consistently with Stevens' power law. However, the range of perceived magnitudes and the increase rate seem to be dependent on the frequency. This was confirmed in a two-way ANOVA which showed that amplitude ($F(5,50) = 35.98$, $p < 0.0001$), frequency ($F(4,40) = 5.88$, $p = 0.0008$), and interaction between them ($F(20,200) = 6.33$, $p < 0.0001$) were statistically significant for the perceived magnitudes.

In Figure 2(f), the perceived magnitudes are shown in a 3D space in the blue solid line, along with a surface fitted to the measured data. For the data fitting, we used the following non-linear regression model:

$$\log_{10} PM = A \sum_{i=0}^{4} \alpha_i (\log_{10} F)^i + \sum_{i=0}^{4} \beta_i (\log_{10} F)^i \,, \qquad (1)$$

where PM is perceived magnitude, A is amplitude in sensation level, F is frequency. $\log_{10} PM$ and A are linearly related, and the coefficients are represented by the fourth order polynomials of $\log_{10} F$. The fitted coefficient values are summarized in Table 1. R^2 of the non-linear regression was 0.7622, which was adversely affected by the a few large standard deviations of the perceived magnitudes shown in Figure 2. The red dashed lines in Figures 2(a) – 2(e) also show the fitted data points.

The errors between the measured and commanded values for vibration amplitudes and frequencies were less than 2 dB. This indicates that the loading effect of the participant's hand did not significantly affect the stimuli.

4 Conclusion

We reported the results of a psychophysical experiment in which the perceived magnitudes of vibrations transmitted to the hand through a cellular phone were measured for various vibration amplitudes and frequencies. The presented data can serve as a reference to assess the perceptual characteristics of vibrations in the use of mobile devices. In the future, we plan to apply the findings of this experiment to the "perceptually transparent vibration rendering" [3] by predicting a relation between input (vibration magnitude and frequency of a mobile device) and output (resulting perceived magnitude) without the need of performing psychophysical experiments.

Acknowledgements

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