Evaluating a Multipoint Tactile Renderer for Virtual Textured Surfaces

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Abstract. This paper details a pilot study done to assess the effectiveness of a tactile rendering strategy. The rendering strategy addresses the tactile receptors in the skin via stimuli consisting of superimposed sine waves. To assess the validity of this strategy, subjects were presented with sets of four virtual textiles and asked to rate them in terms of similarity to a real textile. The results showed that 38.1±3.1% of textiles were accurately identified as the most similar, with systematic error patterns in the identification of textiles. We conclude that the virtual textiles are discriminable to test subjects, with 4.54±0.13 of the subjects consistently choosing the same textile, but in many cases none of the virtual textiles is a good match to the real textiles.

Keywords: haptic interface, tactile display, virtual touch, tactile rendering.

1 Introduction

In order to verify the effectiveness of a tactile rendering strategy, designed to represent virtual surfaces, it is necessary to compare the real surfaces to their virtual representations. To that end, this paper details a study using tactile rendering based on that developed as part of the HAPTEX project on virtual textiles [1]. Users rate virtual textiles in order of similarity to a chosen real textile.

2 Vibrotactile Renderer

A variety of methods exist for generating virtual tactile surfaces, mostly based on direct stimulation of the tactile receptors [2] or mechanical stimulation of the skin's surface, as in the present study used here. The renderer consists of two parts: the hardware, which is a 24-contactor tactile display and its driving electronics, and the rendering software, which can be run on a standard PC and is responsible for calculating the drive signals (in 24 channels) for the display as the user explores the virtual environment. The hardware is connected to the PC,

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and the software, via a USB cable, allowing this system to be implemented on a wide variety of devices. The hardware and software were originally developed as part of the HAPTEX project [1], but the present study involves a substantially improved system.

2.1 Hardware

The tactile display used here is a 24 contactor display developed at Exeter University. The contactors are arranged in a 6-by-4 array, covering 1 cm^2 of the skin's surface, and are driven by piezoelectric bimorphs which convert electrical signals from the driving electronics to mechanical movements of the contactors. The display is designed to be in contact with, and moving with, the user's fingertip during active exploration of the virtual environment. For the purpose of the present study, which is concerned only with display of surface texture, the 3D virtual environment of the HAPTEX system is replaced by a 2D virtual environment. The display is connected to a graphics tablet to provide the position and velocity of the tactile display to the software for the output calculations.

Each contactor in the display is driven by a superposition of two sine waves, 40 Hz and 320 Hz, with the amplitude values calculated by the rendering software. Spatial aspects of the surface texture are represented by the distribution of touch stimuli over the contactor array; spectral aspects are represented by the balance between 40 Hz and 320 Hz drive signals for each contactor.

2.2 Software

The rendering software calculates the amplitudes of the 40 Hz and 320 Hz stimulus components in 24 channels, based on the position and velocity of the tactile display, a description of the surface texture, and filter functions designed to appropriately target Pacinian and non-Pacinian touch receptors in the skin via 320 Hz and 40 Hz stimulus components, respectively. These filter functions are derived from the detection threshold curves for the tactile receptors that innervate the skin, given in [3].

The amplitudes are calculated separately for each of the 24 contactors (updated every 25 ms), for frequency n, using

$$A_n = \sqrt{\sum_{i=x,y} \sum_{f=1\ Hz}^{1000\ Hz} a_{n,i}^2(f).H_n^2(f)}\ . \quad (1)$$

The surface texture of each of the virtual textiles is described in terms of a localised spatial spectrum and its variation with position on the surface, derived from measurements on real textiles.

3 Experimental Setup

In order to assess the fidelity of the virtual textiles, it is necessary to compare them to their real equivalents. The experiment is based on 16 real textiles and

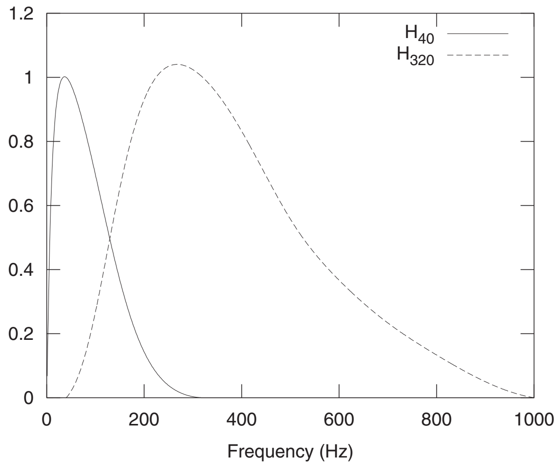

Fig. 1. The filter functions, H_{40} and H_{320}, used to reduce the broadband signal derived from the virtual textile to components at 40 Hz and 320 Hz only

their 16 virtual equivalents, which we derived from measurements on the real textiles [1]. Test subjects were each presented with a virtual environment containing four virtual textiles. The real equivalent of one of these virtual textiles was also presented, and the subject was asked to rank the virtual textiles in order of similarity to the real textile. Each subject repeated this task 80 times: the 16 real textiles were each presented alongside 5 different virtual environments (each containing the virtual equivalent of the real textile, but with different selections for the 3 accompanying textiles). Data were obtained from 8 subjects, age range 22 to 37.

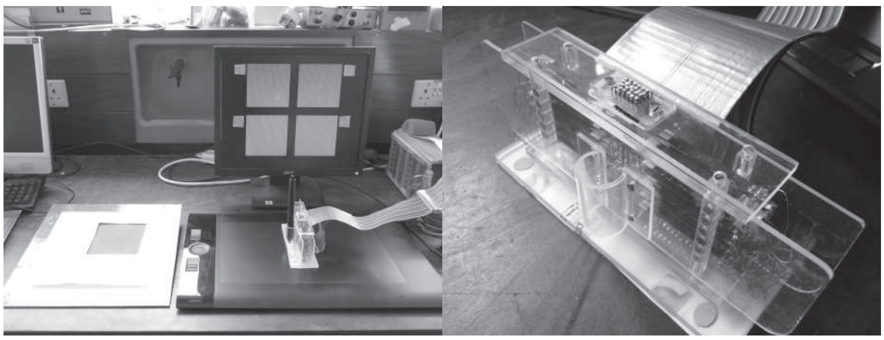

Fig. 2. The left picture shows the experimental set-up, with the 2D workspace for the virtual textures (right side of the picture, together with visual display and the tactile display described in section 2.1) and the sample of real textile (left side of picture). The right picture shows the tactile display in detail.

To generate the virtual environments, a sample set of the available textiles was selected on the basis of the 2-dimensional plots presented in [4], where the tactile surfaces are characterised based on their spectral content. The 16 selected textiles were chosen so that, at a typical exploration speed of 10 cm s^{-1}, they were approximately equally distributed over the available dynamic ranges of A_{40} and A_{320} (fig. 3).

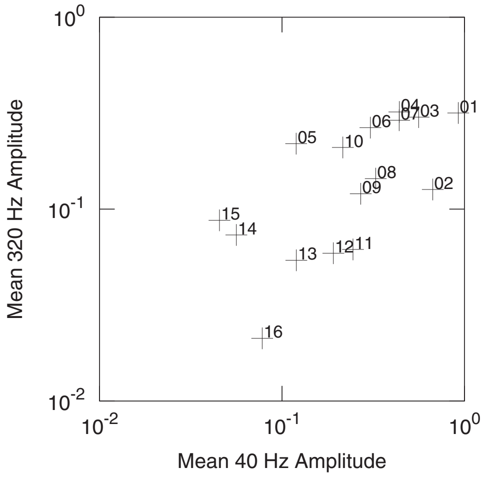

Fig. 3. Characterisation of the selected virtual textiles based on mean spectral content (A_{320} vs A_{40}) when explored at 10 cm s^{-1}

4 Results and Analysis

Table 1 shows the running totals of where the real textiles were picked in the order of similarity to the virtual textiles. In order to establish if the rendering strategy is effective in recreating the surface textures, t-tests were performed comparing the success rate of choosing the equivalent virtual textile as the first choice, and the size of the similarity distance between the real and virtual textiles to chance.

Table 1. Cumulative scores (% correct) for matching real and virtual textiles: Key: 1 = real textile matches 1^{st}-ranked virtual textile; 2 = real textile matches 1^{st}- or 2^{nd}-ranked virtual textiles; 3 = real textile matches 1^{st}-, 2^{nd}- or 3^{rd}-ranked virtual textiles; 4 = real textile matches 1^{st}-, 2^{nd}-, 3^{rd}- or 4^{th}-ranked virtual textiles.

Similarity Ranking	Mean Score	Standard Error
1	38.1	3.1
2	65.3	3.7
3	90.0	1.7
4	100.0	0.0

Looking at the situation where the subjects chose the equivalent virtual textile as the first choice, the mean score is $\bar{x} = 38.1\%$, with a standard error of 3.1%. When this is compared with the null hypothesis (25% correct identifications by chance), a t-value of 4.23 is calculated, which equates to a p-value of 0.0019. The histogram in fig. 4 shows a breakdown of the percentage correct for each of the separate textile surfaces.

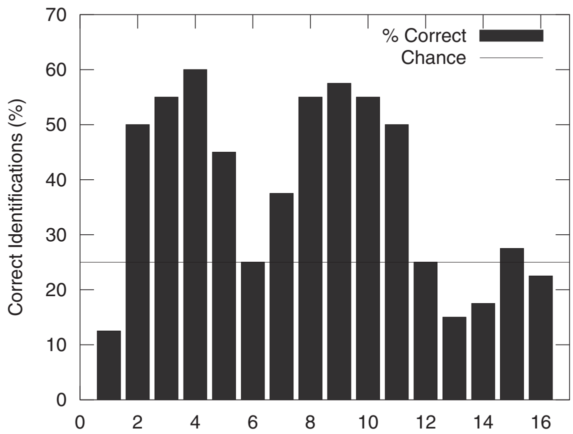

Fig. 4. A breakdown of the percentage in correct identification for each of the 16 textiles. For comparison, a line showing the chance result is also given on the plot.

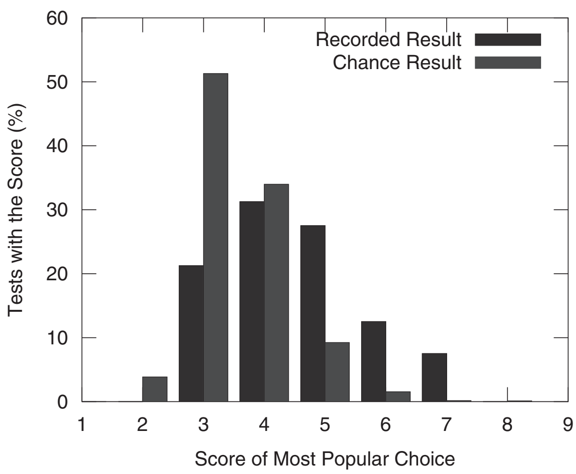

Fig. 5. A breakdown of the percentages of how the "most popular" choice scored across all the test items, compared to what would be expected from chance

5 Discussion

Although the mean first-choice score of (38.1±3.1)% is significantly greater than the chance first score of 25%, it is disappointingly low. However, examination of subjects' error patterns shows that errors are often systematic rather than random.

Fig 5 show the distribution of the scores for the "most popular" choices over the 80 test items. Also shown is the calculated distribution for chance responses. The mean experimental score is 4.54±0.13, compared to the calculated (chance) mean score of 3.54. From this we may conclude that the virtual textiles are discriminable to the test subjects, but in some cases the best match is not the "correct" choice. Anecdotal reports suggest that the majority of the virtual textiles provide touch sensations that are "textile-like", but in some cases none of the virtual textiles is a good match to the real textile.

6 Conclusion

Results suggest that modifications to the present rendering strategy are necessary to produce a better match between real and virtual textures. The observed systematic error patterns can provide information on the nature of the required modifications, which will be implemented in future versions of the renderer.

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