Haptic Simulation of Fabric Hand

M. Govindaraj[1], A. Garg[1], A. Raheja[2], G. Huang[3] and D. Metaxas[4]

[1]School of Textiles and Materials Technology, Philadelphia University, Philadelphia, PA, USA
[2] Department of Computer Science, California State University, Pomona, CA, USA
[3]Department of Computer and Information Science, University of Pennsylvania, Philadelphia, PA, USA
[4]Division of Computer and Information Sciences, Rutgers The State University of New Jersey, NJ, USA

Abstract. The objective of the research reported here is to develop a virtual fabric handling experience using a haptic display. Development of the capability for haptic simulation of fabric hand requires a feedback system to translate fabric property data into a virtual haptic display. First of all we are establishing the representative force profile for a fabric and develop a touch feedback system capable of accurately simulating the amplitude and frequencies required. The Kawabata KES-F system provides the basis for these force profiles. The reactive forces on the fingers and hand associated with feeling a fabric are duplicated using highly sensitive touch response transducers. The user of this device will be able to evaluate fabrics in a virtual sense. Ultimately such a device could be coupled with a web-based system to allow consumers to make a hand evaluation of fabric before making purchase decisions on garments.

1 Introduction

Computer simulation of virtual environments has improved tremendously in the past several years. It is now possible to simulate not only rigid objects but also flexible materials such as fabric and paper. A logical extension of visual simulation is the capability to feel objects. Haptics research is now yielding results that we all will ‘experience’ in the near future.

1.1 Tactile Response

Human mechanoreceptor cells respond to a change in external stimulus such as pressure, temperature, etc. The change in the external stimulus is converted to a voltage pulse across neurons. While the voltage pulses occur immediately after the external stimulus, the pulse rate declines over time and returns to normal level. The rate at which the pulse returns to normal after an external stimulus is called the rate of adaptation. Thus there is a change in signal required even if the quantity is static such as roughness of a surface.

Based on the sensitivity of the Pacinian and Meissner corpuscles and Ruffini endings, several researchers (Peine et al. [1] Johnson and Phillips[2]) have determined that humans can reliably distinguish, by the tip of their fingers, two points as close as 0.9 mm and that the rate of change of the surface undulations (bandwidth) is around 30 Hz.

1.2 Tactile Display Devices

To give the sensation of contact to the skin, some type of device is required to translate the force profiles to a system of actuators. These types of devices have come to be known as 'tactile display'. While 'tactile display' is used to describe all types of haptic feedback systems, Howe [3] makes a distinction between vector force feedback and distributed surface contact devices. The skin responds to several distributed physical quantities including high-frequency vibrations, small-scale shape or pressure distribution and thermal properties.

1.3 Fabric and Haptics

Quantification of fabric 'handle' is complex due to the range of responses that people experience when they touch and move a fabric in their hand. Through work performed by Kawabata , Postle [4], and a number of other researchers, there is a knowledge base of objective fabric sensory values. Researchers have used the Weber-Fechner law to translate instrumental measurements of fabric mechanical properties into corresponding hand parameters (Matsuao et al. [5]). Stevens [6] has further refined this law; the Stevens Power Law states

$\ln R = \ln k + a \ln S$, where R is the response, k is an empirical constant, and S is the stimulus.

Hu et al.[7] used a stepwise regression method to obtain the best fit Stevens law equations containing the minimum number of independent variables (KES-F parameters) to predict fabric stiffness, smoothness, softness and fullness

2 Methodology

Development of the capability for haptic simulation of fabric hand requires a feedback system to translate fabric property data into a virtual haptic display. In our work, we are using a two-fold approach to develop the capability for haptic simulation of fabric hand. First of all it is necessary to establish the representative force profile for a fabric and develop a touch feedback system capable of accurately simulating the amplitude and frequencies required The force profile that represents fabric hand must be quantified in a detailed manner. The Kawabata KES-F system provides the basis for these force profiles. Initially, we are attempting to simulate the surface characteristics of fabrics.

The signal for the surface and friction profile are shown in Figure 1. The signals deliver a sense of perioditicity for the fabric surface. Removing noise from these signals can help remove the high frequencies. Two popular methods for removing noise from the signals are using low pass filters and other Fourier transform methods. The problem with Fourier transform methods is that they provide good frequency localization but fail to provide any spatial localization. Hence, the use of wavelet transforms in such signal processing applications where certain frequencies that can be spatially localized and removed to help generate a better noise free signal. Further, a Fourier transform of such a uniform signal can easily generate the most dominant frequency.

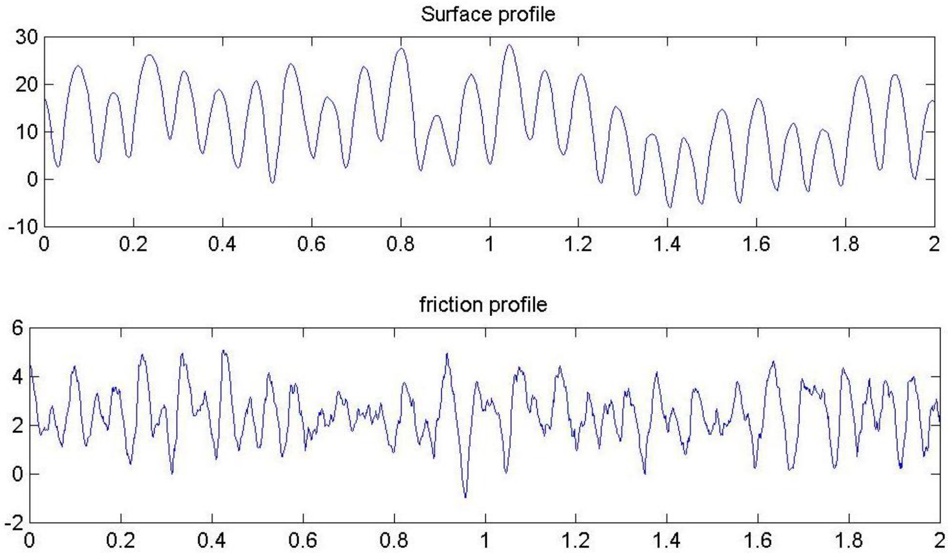

Fig. 1. Fabric surface and friction data signals as collected by KES tester. In both graphs the *x* axis is the contactor displacement from 0 to 2 cm. The *y* axis is the height variation (maximum range of 2 mm) in the case of surface profile and force of maximum 0.05 N in the case of friction profile.

For the purpose of evaluating our method of simulation we made three different fabrics with varying degrees of surface roughness. The surface characteristics of these fabrics, both roughness and friction profile, were generated using the KES tester.

Wavelet analysis was performed on the surface profile signals in order to denoise the signal. It is important that we generate a three-dimensional surface profile of the fabric from these measurements before we generate a virtual surface. The reason behind doing so is the need to corroborate the use of wavelet analysis to denoise these signals. The warp and weft signals have been padded up in the horizontal and vertical directions. Three-dimensional surface profile of the fabric has been reconstructed by performing convolution using the Fourier transform.

The complete process of reconstruction of the three-dimensional surface of a fabric involved the following steps:

The signals in the warp and weft direction undergo the wavelet analysis. Wavelet analysis is a process where the signal is successively broken up into low and high frequency components by performing a discrete wavelet transform. This process of analysis is also termed as the multi-resolution representation of a signal. A generalized wavelet transform of a function *f(t)* can be written as:

$$F(a,b) \;=\; a^{-1/2}\int f(t)\;\psi\left(\frac{t-b}{a}\right) \qquad \textbf{(1)}$$

and the inverse transform is given by

$$f(t) \;=\; K\iint \frac{1}{s^{2}}\,F(a,b)\;\psi\left(\frac{t-b}{a}\right)\, d \qquad \textbf{(2)}$$

where, a and b are the dilation and translation parameters respectively. The wavelet analysis of a signal to 2 levels is shown in Figure 2 below.

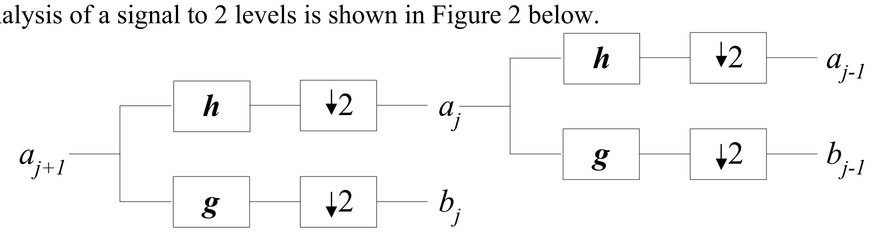

Fig. 2. Two-stage two-channel analysis tree. ***h*** and ***g*** are the low-pass and high-pass decomposition wavelet filters

At this point, high frequencies that exhibit irregular behavior can be unselected and the original signal can be reconstructed using these selected frequency components. This process of performing the inverse wavelet transform is called the synthesis. Figure 3 below demonstrates the synthesis process.

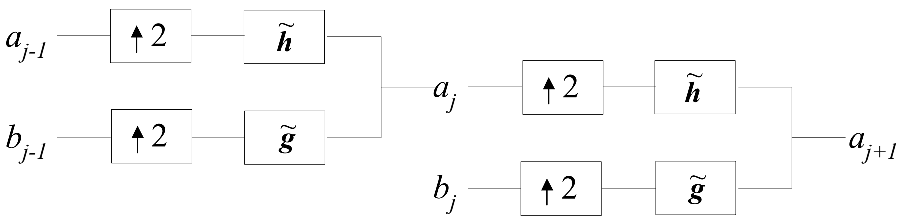

Fig. 3. Two-stage two-channel synthesis tree. $\tilde{h}$ and $\tilde{g}$ are the low-pass and high-pass reconstruction wavelet filters.

A few different wavelet filters were evaluated for the purpose of removing noise and the bi-orthogonal spline three tap wavelet with eight coefficients was selected. The two signals (warp and weft) with the noises removed, are padded to generate two three-dimensional profiles in either direction. Fourier convolution has been used to combine the two orthogonal surface profiles to reconstruct the 3D surface profile of the fabric. Figures 4, 5 and 6 show the three-dimensional reconstruction of the fabric surface from measured data (which has undergone some signal processing for the purpose of removing noise), the actual surface the fabric and the fabric surface simulation respectively.

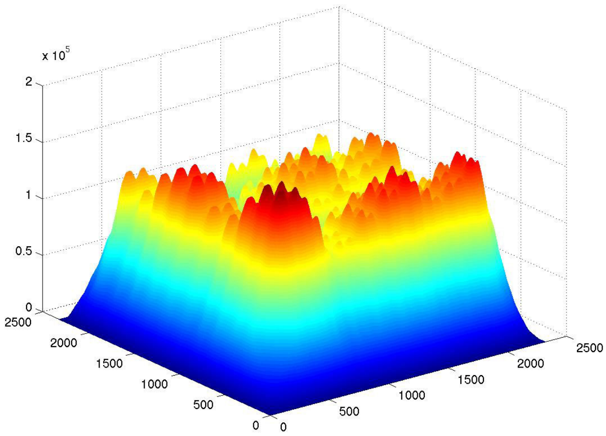

Fig. 4. Regenerated surface plot from noise reduced and convoluted waveforms from KES data.

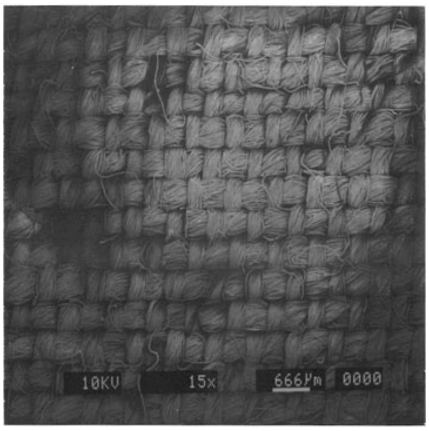

Fig. 5. Fabric as seen under a microscope.

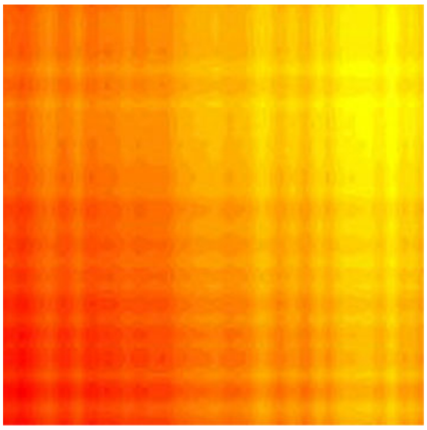

Fig. 6. Reconstructed fabric surface.

3 Fabric Haptic Device

Current touch feedback systems do not have the sensitivity required for accurate simulation of fabric hand. We developed a new device to meet these requirements. Before we developed a haptic device that can simulate the feel of touch, we used a device called the PHANToM® (Figure 7) that uses a pen like probe to scan a virtual surface and generate the feel of surface. The two primary parameters required to generate a virtual surface are the frequency of the surface profile and the friction (the drag) of the profile. These two data sets are available from KES measurements of our fabric samples.

Fig. 7. PHANToM® haptic device.

The PHANToM® is a multi-axis feed back system. By holding a pen with a stylus at the end of the PHANToM® articulated robot, and moving the pen over a constructed surface in the virtual space, a feed back response can be felt on the hand. The limitation of the device is that the contact with the virtual surface is over a line. However, Katz [8] in his study of surface texture perception noted that it was possible to gain considerable information about a surface by moving a pencil-point across the surface.

In the case of fabrics, the contact is over a surface. The PHANToM® device, as it exists today, is designed for force feed back applications and does not provide a tactile feeling, We understand this limitation and accordingly designed our own haptic device.

3.1 PhilaU Haptic Device

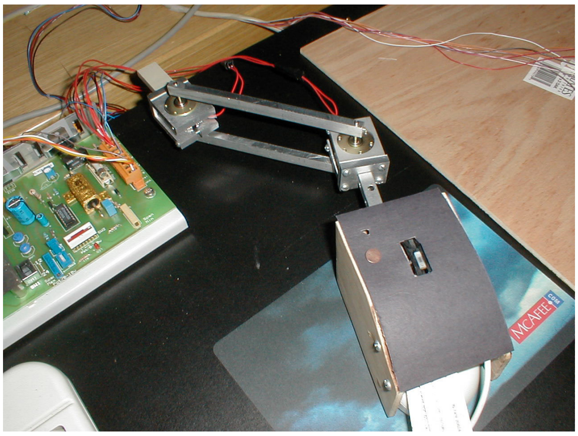

Fig. 8. PhilaU Haptic Device

The PhilaU Haptic Device is designed as a combination force feed back and a tactile display. The device consists of a feeler pad at the end of an articulated arm. The feeler pad consists of an array of pins (tactors) with a horizontal spacing of 0.6 mm and a vertical spacing of 0.3 mm. This resolution is adequate to simulate most fabric textures. The bandwidth is 10 Hz which again satisfies the requirement for the simulation of most apparel fabrics.

The articulated arm joints are equipped with magnetic brakes that apply a force feed back to the hand holding the feeler pad assembly. The magnetic brakes get their input voltage proportional to surface friction of the fabric, while the tactor pins follow the contour. Together, the device provides a virtual fabric touch and feel.

4 Work in progress

The PhilaU Haptic Device is being improved to include the feeling of compressional compliance of a fabric. Also, an opposing thumb configuration is being designed for the feeler pad so that a fabric can be felt between the index and thumb of a person. Subjective evaluation of the PhilaU Haptic Device is in progress and initial results are encouraging.

5 Acknowledgement

The work reported here was sponsored by the National Textile Center, USA.

References

1. Peine, W.J., Foucher, K.C., and Howe, R.D. Finger speed during single digital palpation, Human Factors, 1997
2. Johnson, K.O., and Phillips, J.R. Tactile spatial resolution I.,, Two-point discrimination, gap detection, grating resolution, and letter recognition, J. of Neurophysiology, 46.6, 1177-1191.
3. Kontarinis, D.a. and Howe, R.D. “ Tactile display of vibratory information in teleoperation and virtual environments,” Presence, 4(4):387-402,1995
4. Kawabata, S., The development of the objective measurement of fabric handle, Objective specification of fabric quality, mechanical properties and performance. Edited by Kawabata,S. , Postle, R. and Niwa, M., The Textile Machinery Society of Japan, pp. 31-59, 1982.
5. Matsuo, T. Nasu, N and Saito, M., J. Text. Mach. Soc. Japan, 1971, 17, 92.
6. Stevens,S.S., Psychology review, 64, 153, 1957
7. Hu,J., Chen,W., and Newton, A. J. Text. Inst. 1993, 84,354
8. Katz, D. The world of touch (L.E. Kruger, trans.), Hilldale, NJ:Erlbaum.