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HapTex: A Database of Fabric Textures for Surface Tactile Display

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***Abstract*—Understanding physical properties of real-world haptic interaction is fundamental to create realistic virtual textures. Existing databases on haptic texture information are mainly constructed based on tool-surface interaction, which might be inappropriate to reveal the mechanical behavior of finger-texture interaction. In this paper, we introduce a haptic texture database of fabrics defined by friction force during the interaction between bare-finger and real-fabric. The database includes the friction force, the normal force applied by the fingertip, friction coefficient, displacement and velocity of the fingertip. These data were acquired when sliding a fingertip across 120 kinds of fabrics. We illustrate the application of the database through one example of haptic texture modeling and rendering, which allows users to feel virtual haptic texture on an electrostatic tactile display. In the end, we envision and exploit several potential applications for the database. The database is available online for free access and use by the research community.**

I. Introduction

In recent years, due to the growing presence of plentiful tactile rendering methods, surface tactile displays showed a great prospect of application [1], [2], [3]. Surface tactile displays can produce tactile sensation by modulating friction force while sliding a finger on the surface of the screen [4], [5], [6]. Using surface tactile displays, users can experience the tactile sensations of object surface properties, such as textures [7], [8], when interacting with virtual environment.

Many previous studies have shown that the data-driven modeling methods can create realistic haptic textures using the data from the real-world interaction [9], [10], [11]. However, it can be extremely expensive and time-consuming to collect data during real-world interaction [12], [13]. The open-resource databases are able to provide researchers with a real-world set of data and save the consumption of data collection during real-world interaction. Some texture databases have a vigorous development for use in computer vision research [14], [15], such as the VisTex database [16], and the ImageNet database [17]. The contributions of open-resource databases have been very prominent in the research community by the use of the databases.

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Several prior works have developed haptic texture database, which included the data occurring due to sliding a rigid tool over real surfaces [18], [19]. However, there is great differences in mechanical behavior between the tool-texture and finger-texture interaction [20], [21]. Compared with the rigid tool, the skin of the finger is a flexible medium. The flexible deformation of the finger skin occurs when a finger interacts with the fabric texture. Moreover, this will lead to a buffer mechanism between the finger and the texture when sliding a finger across texture surface. Therefore, the tool-surface interaction information is unable to reveal the mechanical behavior of finger-texture interaction. In this paper, we introduce a database of real texture defined by friction force during finger-fabric interaction. When rendering haptic textures based on friction modulation, it is fundamental to know friction force occurring due to sliding a finger across real material surfaces [11], [22], [23]. Therefore, we built a haptic texture database of fabrics defined by the friction force resulted from the interaction between bare-finger and real-fabric. The database includes the friction force, the normal force exerted by the finger, friction coefficient, displacement, and velocity of the finger when sliding a fingertip across 120 kinds of fabrics. We make the database publicly available for download at *http://haptic.buaa.edu.cn/English_FabricDatabase.htm* under copyright from Beihang University permitting for the use, reference, copy, and analysis. Additionally, we also created virtual haptic textures of fabrics through modulating the applied voltage on an electrostatic tactile display using the data in the database. Establishing the database is our first step work. Our long-term goal is to construct a repository consisting of a large scale of haptic textures of fabrics to serve Internet shopping.

The remainder of this paper is structured as follows. In Section 2, we discuss the related work in constructing texture databases. The details of the method for measuring haptic interaction signals of fabric textures are elaborated in Section 3. Section 4 describes the application of the database through one example. Finally, Section 5 concludes this work and points out the future work and the potential applications for the database.

II. Background

Several haptic texture databases based on tool-surface interaction have been established for haptic texture rendering or identification and classification of features. Culbertson et al. [18] developed a haptic texture database (HaTT) for 100 different surface materials. These materials include ten categories: plastic, metal, stone, wood, carbon paper, fiber, tile, fabric, carpet, and foam. The database includes the frictional and normal force applied by the pen-type tool, speed, and accelerations of the pen-type tool. These data were recorded

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when sliding a hand-held pen-type tool across material surfaces. The database is used for rendering haptic texture via tool-mediated interaction devices. Strese et al. [19] presented a haptic texture database of 43 surface materials. These materials include eleven categories: stone type, glass, metal, timber, rubber, plastic, paper, foam, textile, floor pad, and leather. The database contains the acceleration signals recorded during controlled and uncontrolled free hand texture exploration using the tool-mediated interface. These data were acquired when sliding a hand-held tool-mediated interface across material surfaces. The database is used for texture recognition and classification with machine learning algorithms. Later, Strese et al. [24] introduced a surface material database for 108 textures. These textures include twelve categories: mesh, stone, metal, glass, ceramic, wood, rubber, fiber, foam, plastic, paper, and fabric. The database includes the recorded acceleration, friction force applied by the Texplorer, sound and reflectance signals during tool-surface interaction. These data were collected used a handheld recording tool (Texplorer) across the material surfaces. The database can be used for the content-based surface material retrieval using machine learning approaches. Zheng et al. [25] established a haptic surface database for 69 materials. These materials include eleven categories: mesh, stone, glossy surface, wood, rubber, fiber, foam, foil, paper, textile, and fabric. The database contains the acceleration, friction force applied by the haptic stylus, and sound signals during tool-surface interaction. These data were captured when scanning a hand-held recording tool (haptic stylus) over material surfaces. The database can be used to jointly recognize the surface material together with surface images using deep learning method.

To summarize, existing databases on haptic texture information are mainly constructed based on tool-surface interaction. There has been no report on databases of texture signals during the process of sliding a bare finger across diverse fabric samples.

III. Data Acquisition

In this section, the information about the fabric samples in HapTex is presented, as well as the introduction of measurement device and the measurement procedure of the haptic texture data for the fabrics. Format of the recorded data files in the database is briefly described.

A. Fabric Texture Samples

We collected 120 fabric samples from a fabric store, which are in common use in daily life, as shown in Figure 1. After cleaning, these fabrics were cut into squares with the size of 200×200 mm^2. In order to distinguish in the following measurement process, we added a label on each fabric sample from No. 1 to No. 120. The fabrics are divided into ten categories: velvet, cotton, leather, fiber, chiffon, wool, nylon, polyester, linen, and silk.

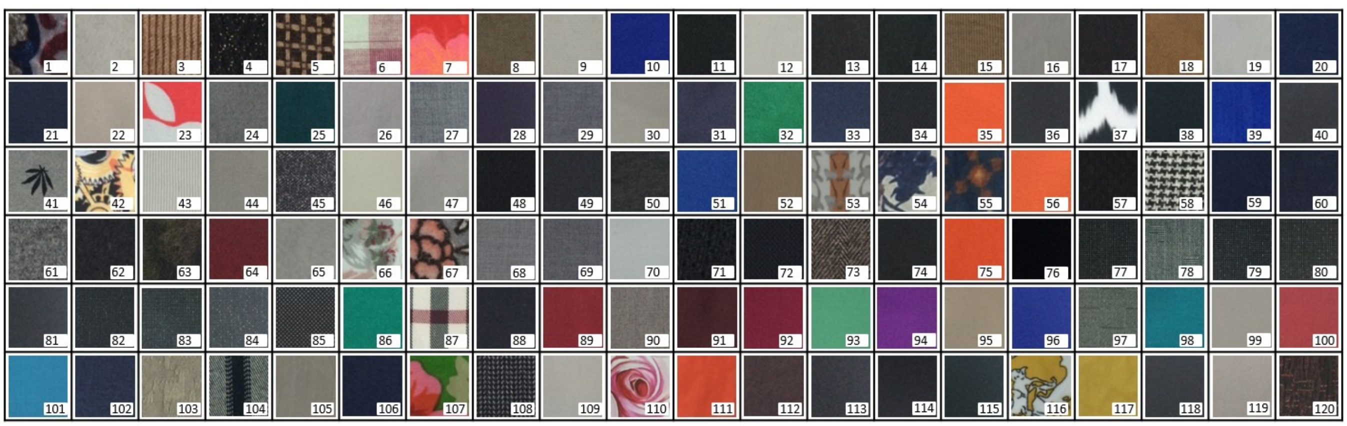


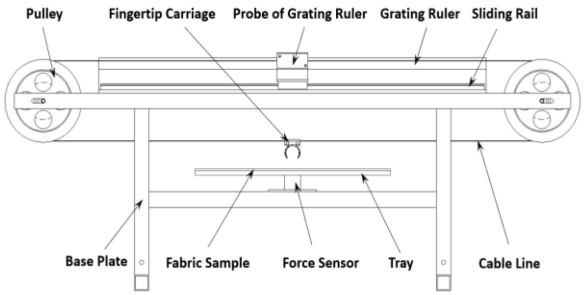
Figure 1. 120 kinds of fabrics for the establishment of tactile texture database. The fabrics are divided into ten categories (1-4: velvet, 5-31: cotton, 32-33: leather, 34-48: fiber, 49-57: chiffon, 58-73: wool, 74-85: nylon, 86-101: polyester, 102-108: linen, and 109-120: silk).

B. Measurement Apparatus

In order to acquire haptic interaction signals while sliding a finger over real texture surfaces, a custom-designed measuring device (TexRecorder) was used during the measurement. Figure 2 illustrates the composition of the measuring device. The device consists of a force transducer, a grating ruler sensor, a sliding rail, two pulleys, a tray, a cable line, and a base plate. The force transducer can record the normal force and the frictional force applied by the finger as swiped a finger across a textured surface. The grating ruler sensor is used to measure the displacement during the finger motion.

In the measurement, the fabric to be measured was put on the tray of the measuring device. In order to record the displacement of the finger movement over the surface of fabric, the grating ruler (MII1630S-20, MicroE Systems, US) was installed on the top of the base plate. The measuring range of the grating ruler is from 0 to 400 mm and the resolution is 1 μm. The probe of the grating ruler is moved on a sliding rail. The probe and fingertip carriage were coupled to a cable line and moved synchronously with the finger via a pulley. The displacement of the finger can be recorded when scanning over the surfaces of fabrics. In order to record the normal and frictional force applied to the fabrics by fingertip during finger motion, we mounted a six-axis force/torque transducer system (ATI Nano17, ATI Industrial Automation Inc., US) under the tray. The bottom of force transducer was fixed on the base plate. The sensor offers a force range from 0 to 17 N and has a resolution of 3 mN. The sampling rate is 1 kHz.

In addition, the software was developed in Microsoft Visual Studio 2013 by C++ language and ran on a 3.60 GHz Intel(R) Core(TM) i7-4790 CPU E4500 PC with the Windows 7 operating system.



(a)

(b)

Figure 2. Force and displacement measuring device. (a) Whole schematic design of the measurement device. (b) Physical prototype of the measuring system.

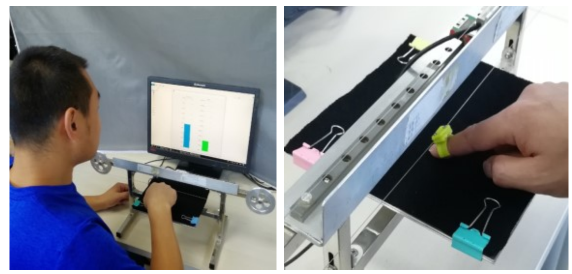
C. Recording Procedures

We recorded the normal force and the friction force applied by the finger, and the friction coefficient, the displacement and the velocity of the finger. These data were collected via the measuring device (TexRecorder) when sliding a fingertip across 120 kinds of fabrics. Among the data, the friction force, the normal force, and the displacement were directly measured by the sensors. The friction coefficient and the velocity were indirectly obtained through calculating using the measured data.

During the measurement, each fabric sample was placed flatly on the tray and fixed by binder clips to prevent it moving as a finger scanned. Experimenter washed the hands with soap and rinsed with water, and then dry them using an electric drier to eliminate the effects of moisture before the experiment. Indoor temperature and humidity in the laboratory were kept at 23 ℃ to 28 ℃ and 35 % to 55 %, respectively. The fingertip carriage was taken on the finger of the dominant hand. The data were measured for each fabric sample while the fingertip swiped across a texture surface from one side of the fabric to the other. In order to eliminate artifacts in the whole experiment, the direction of the fingertip motion was kept parallel to the cable line on the fabric surface. The motion of finger was carefully attempted to approximately maintain the exploration with the normal force between 0.8 and 1.2 N [23], [4], [10] and the speed between 40 and 80 mm/s [4], [26] using visual bars displayed on a monitor. Figure 3 illustrates the collecting procedure of the haptic texture signals occurring due to sliding a finger across these fabric surfaces. We defined once single sliding from one side of fabric to the other as a trial. After the trial was finished, the finger lifted from the fabric and had a break. The current fabric sample was replaced to the next one. When the finger scanned over the surface of fabric again, the next trial began. The measurements were repeated four times for each fabric. The displacement signals of finger were low-pass filtered at a cut-off frequency of 20 Hz [9], [27] and then differentiated to calculate the velocity of finger. The friction coefficient is computed using the recorded frictional force and normal force, via

$$f(s) = \frac{F_f(s)}{F_n(s)} \tag{1}$$

where s is the displacement of finger movement, $f(s)$ is the friction coefficient between fingertip and fabric surface at position s, $F_f(s)$ and $F_n(s)$ are the frictional force and normal force exerted to finger at position s respectively.



(a) (b)

Figure 3. Force and displacement measurement of fingertip moving on fabric surface. (a) Full view of measurement. (b) Posture of fingertip scanning across a fabric surface.

D. Recorded Data

We established the haptic texture database using these recorded haptic interaction signals. These data were uploaded to BUAA Human-Machine Interaction Lab website to share with researchers online. The database includes the frictional force, normal force applied by the finger, friction coefficient, displacement, and velocity of the finger when sliding a finger across each of 120 kinds of fabrics. Figure 4 shows a recorded friction coefficient data for one fabric sample.

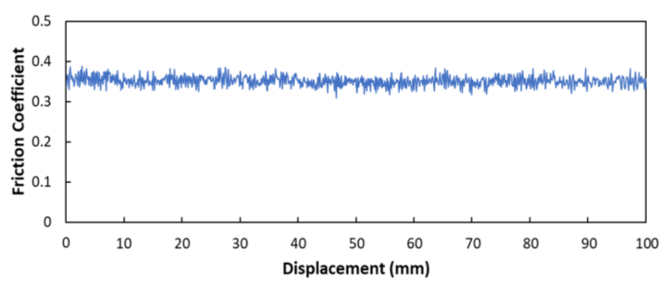


Figure 4. A recorded friction coefficient data for a fabric sample.

The file folder name is "FrictionDisplacement". The data was saved using Microsoft Excel 2010 and the file format is ".xlsx". The data file is named using the code of fabric images so that the users can easily search for the data file corresponding to the fabrics selected. Four sets of repeatedly measured data for each fabric were stored in four sheets of the Microsoft Excel file, respectively. The sheets are named using Measurement I, Measurement II, Measurement III, and Measurement IV, respectively. Each column of data represents a set of corresponding signals (i.e., frictional force, normal force, friction coefficient, displacement, and velocity) in each sheet of the data file. This database is publicly available for download. Table 1 summarizes the data included in the database. The database contains close-up color texture images of all fabric samples, which were taken using a digital scanner (ApeosPort-IV C77980, Xerox, US). The texture images stored in the database are square pictures with 2362 pixels for each edge of picture, corresponding to a physical scale of 24 pixels/mm. The file name is “FabricPicture”.

TABLE I. DATA FOR EACH FABRIC STORED IN FILES

Data	Unit
Normal Force	N
Frictional Force	N
Friction Coefficient	None
Displacement	μm
Velocity	mm/s

Friction is a major tactile dimension for texture perception [28], [29]. In order to observe the friction coefficient values, we present the distribution of friction coefficients for 120 fabric samples, as shown in Figure 5. We find that the mean values of friction coefficients for these fabric samples mainly distribute between 0.3 and 0.6. The fabric samples No. 67 and No. 111 have a larger average value of friction coefficient. Previous literature [30] pointed out that the friction represented slippery/sticky dimensions. Therefore, the results indicate that the adhesion of the finger pad to the textures is much stickier when a finger contacting the surfaces of the two fabric samples.

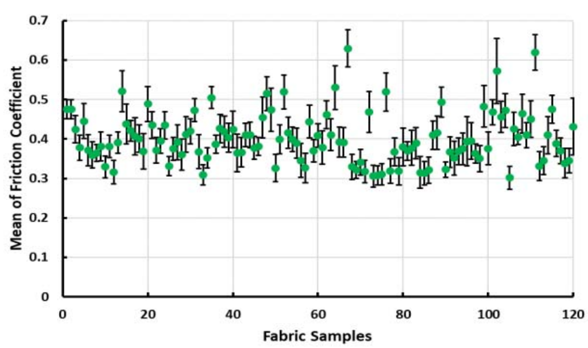


Figure 5. Distribution of friction coefficients for 120 fabric samples.

IV. EXAMPLE APPLICATION OF HAPTEX

In this section, we show one application example of HapTex through rendering virtual haptic fabric textures. In the example, we present our approaches for generating texture models from the friction coefficient information measured in the above section. We introduce the typical electrostatic surface tactile display device that is used to render haptic textures [31], [32], [22]. From our previous work [22], we present how the database is employed to create haptic texture via an electrostatic tactile display device.

A. Electrostatic Tactile Display

For creating haptic textures of fabrics, an electrostatic tactile display was utilized, as shown in Figure 6. The haptic interface was composed of following three layers. The top layer is an optical positioning sensor (GSC0320, TMDTOUCH, China) with the accuracy of 0.01 mm for detecting the displacement of finger movement. The middle layer is a haptic capacitive touch screen panel (SCT3250EX, 3M Touch Systems Inc., US), which can generate the electrostatic tactile stimulation. The bottom layer is an LCD screen (Surface Pro 3, Microsoft, US) for displaying visually information of material. The previous works have indicated that the electrostatic tactile display device can render haptic textures of images and detailed shapes on the surface by modulating input voltage signals [22], [33], [34].

Figure 6. Electrostatic tactile display used for rendering haptic fabric texture in the current work [22], [31], [32].

The size of Microsoft touchscreen is 12 inches and the resolution of the screen is 2160×1440 pixels. The tactile controller module produces the tactile stimulation and conveys to the Microsoft touchscreen, allowing the tactile stimuli information to be applied to the finger. Tactile stimulus signal generator is a programmable voltage source. It is able to generate four waveforms of voltages (sinusoidal, triangular, square, and sawtooth wave). The voltage has an amplitude range from 0 to 350 Vpp (± 2 Vpp) and a frequency range from 1 to 10 kHz (± 1 Hz). The current limit is 10 mA to ensure the safety of users. The software platform and graphical user interface were developed in custom software written with C++.

B. Modeling

The friction coefficients were modulated as the input voltage signals. The input voltage signals were then played back on the electrostatic tactile display device to create the virtual haptic fabric textures. In the haptic texture rendering approach, the input voltage signals were computed in the following way.

The friction coefficient signals were used to specify the nominal voltage to be provided to the electrostatic tactile display, via

$$V(s) = bf(s)Y(t) \tag{2}$$

where $V(s)$ denotes the amplitude of square wave applied voltage on the electrostatic tactile display at position s, b denotes the voltage amplification factor from friction coefficient, t is the time, $Y(t)$ is the carrier square wave function, and

$$Y(t) = \begin{cases} 0, & \frac{n}{f_0} \le t < \frac{n}{f_0} + \frac{1}{2f_0} \\ 1, & \frac{n}{f_0} + \frac{1}{2f_0} \le t < \frac{n+1}{f_0} \end{cases} \tag{3}$$

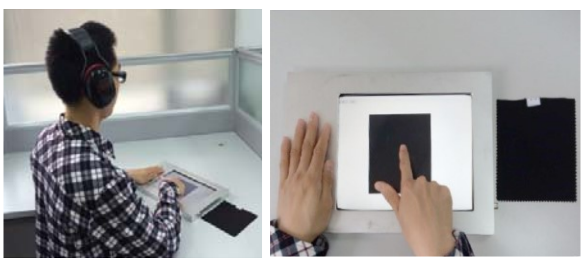
where n denotes an arbitrary positive integer, f_0 denotes the frequency of applied voltage.

The factor b was used to match the real and virtual textures. We preliminarily set an initial voltage amplification factor value (b), with its final value determined in a psychophysical experiment, described below.

During rendering the tactile textures, the input voltage provided to the electrostatic tactile display device was determined by the position s of the fingertip scanning movement.

C. Texture Rendering

In this section, we take one of 120 fabric samples as an example to illustrate the rendering procedure of virtual haptic texture. We first found the recorded friction coefficient files for this sample from the database. The friction coefficient signals are then modulated and amplified using the model (Equation 2 and 3) as applied voltage for generating haptic texture on electrostatic tactile display. In addition, the picture with detailed texture of this fabric sample can also be added in the rendering process. The picture of this fabric sample can be selected from the database. Finally, the software used for rendering haptic texture was implemented in C++ with Visual Studio 2010 using the modulated friction coefficients, displacements, and fabric texture image on the electrostatic tactile display.



(a) (b)

Figure 7. A user interacted with the virtual haptic fabric texture via an electrostatic tactile display. (a) Full view of test. (b) Detailed view of experiencing a virtual tactile texture.

During rendering, the optical sensor of the electrostatic tactile display detected the position information of the finger, when a user sliding a finger across a virtual haptic texture of this fabric sample. The captured position information of the fingertip was transferred to the host computer. The host computer calculated the applied voltage via the haptic rendering algorithm using the position information of the finger. The applied voltage calculated was then transferred the haptic capacitive touch screen panel of the electrostatic tactile display to generate the tactile sensation. Meanwhile, the picture of this fabric sample was display on the screen as well. Finally, the virtual haptic texture of this fabric sample was presented to users on the electrostatic tactile display. As shown in Figure 7, a user interacts with the virtual haptic fabric texture via the electrostatic tactile display.

V. Future Work and Potential Applications

In this work, we developed the HapTex, a publicly available repository of haptic texture based on bare-finger and real-fabric interaction. The establishment of this database is a preliminary work. Our ultimate goal is to build a large scale of database of haptic fabric textures for the online shopping. HapTex includes the haptic texture information for 120 fabrics when stroking a finger over real surfaces. Note that this database does not include acceleration signals, as our previous work has confirmed that the friction signals can replace the acceleration for rendering haptic textures. We presented one application of the database through the haptic rendering of fabric textures. We created the virtual tactile textures of the 120 fabrics via an electrostatic tactile display. Moreover, considering some potential applications such as haptic texture recognition and classification using deep learning approaches, we openly share the haptic texture database for use by the research community and make the database freely available for download as well.

A. Future Work

Our future work has three goals:

(1) We plan to improve our measurement device to acquire more parameters such as the acceleration, temperature, hardness, acoustical signals, etc. Adding these signals may enable a better understanding of the fingertip-fabric interaction behavior. Moreover, the sampling rate of the force sensor of the measurement device used in this paper is 1 kHz. In next work, two one-dimensional force sensors will be adopted on the improved measurement device to measure the frictional force and normal force, respectively. This will be able to replace the multi-dimensional force sensor used in the current work to enhance the sampling rate to 10 kHz.

(2) More fabric samples will be collected and measured to construct a large scale of haptic texture database that could be as an experimental platform for the study of haptic texture rendering.

(3) We intend to develop an automatic finger-like robotic hand to enhance the efficiency of data acquisition so as to be able to efficiently collect the tactile texture signals of more fabric samples. In addition, the number of the repeated measurements for each fabric sample is four times in this paper. In the future work, we will increase the number of the repeated experiments to get enough data to ensure more stable measurement results.

B. Exploiting HapTex

We hope HapTex will become a resource for serving the online shopping by creating virtual haptic textures of fabrics via internet-connected tactile display terminals. In addition, we also envision the following possible applications in haptics research community.

(1) *A benchmark database*. To the best of our knowledge, HapTex is the first haptic texture database based on bare finger interaction. It is also the unique database containing haptic texture information with finger-fabric sliding interaction. Hence, we expect that HapTex will become a benchmark database with finger-fabric sliding interaction for haptic texture rendering. It can be also helpful to push forward the future development of online shopping.

(2) *Revealing interaction essence*. HapTex consists of a certain amount of haptic texture information due to scanning a finger over a number of real material samples. One could exploit the essential law of haptic interaction between finger and texture using the data in HapTex. The law will be able to better understand how the dynamic interaction between finger

and texture accounts for the force production. It could help to guide the design of haptic texture rendering algorithm.

(3) *A training resource*. Some scan-parameters, like the force and velocity, are varying for each surface exploratory movement behavior. It will cause that the recorded haptic texture signals cannot be consistent for different scan-parameters surface exploration. HapTex could be used as training dataset to identify invariant features from the captured haptic texture signals for each surface exploration. Because the texture is an inherent property of the surface material itself, some features could be invariant for the same surface material. The invariant features could be used to render haptic textures for different scan-parameters surface exploration. In addition, HapTex could also be used for haptic texture recognition and classification by machine learning algorithms.

(4) *Fitting rendering model*. The process of sliding finger on the surface of fabric can be regarded as an interaction system. In this system, the finger motion signals (e.g., normal force, displacement, and velocity) in the HapTex could be seen as input parameters, and the finger force signals (e.g., frictional force and friction coefficient) could be considered as output parameters. Using the input and output parameters, one could fit a common model for creating haptic textures for tactile surface display.

Acknowledgment

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