Tactile Sensing System Using Electro-tactile Feedback

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Abstract — Tactile or touch sensing can enable an object's surface texture and other properties to be perceived which can facilitate grasping and manipulating various objects. Prosthetic hand users and operators of tele-operated robot arms also need to perceive these tactile properties by some means to effectively manipulate objects and performed skilled work. This paper introduces a tactile sensing and feedback system that is based on detecting surface vibrations in an artificial finger, when contact or friction with a surface is made, and appropriately stimulating nerves in the user's skin with electro-tactile feedback. This feedback system has benefits over existing systems because it can deliver a wide variety of sensations to the user and is compact, non-mechanical, wireless and comfortable for the user to wear. Experimental results are provided which show the potential of our system at achieving remote tactile sensing and feedback of textured surfaces.

Keywords-haptic feedback; electro-tactile feedback

I. Introduction

Delivering tactile sensations to amputees with prosthetic hands, operators of tele-operated robotic arms and users of immersive technologies, such as virtual reality, has become a significant challenge in recent times. Tactile or touch sensing is important because it can not only enable the presence of objects to be detected by touch, it can also enable an object's properties to be determined by feeling the object's characteristics such as shape, size and texture. Detecting the texture of an object's surface by touch is particularly important because it can also be used to determine the pressure required for grasping and lifting an object and for determining an object's hardness and surface rigidity.

The aim of this research is to develop a tactile sensing and feedback system that can enable amputees with prosthetic hands, operators of tele-operated robotic arms and users of immersive technologies to be able to determine the texture of various surfaces without imposing on the user cumbersome mechanical actuators or evasive surgery. To achieve these goals we have been experimenting with vibration sensors and an electro tactile feedback.

Electro-tactile feedback involves delivering electro-neural stimulus to the user via electrodes placed on the skin. This can enable a wide variety of sensations to be delivered to the skin, ranging from mild tingling sensations to painful sharp jolts, by varying both the frequency and amplitude of pulses delivered to sensory nerves in the skin. This form of feedback has previously been used in interfaces for teleoperation[1], hearing aids [2], blind perception [3] and prosthetic hand [4].

To gauge the texture of a surface we use a vibration sensor which is mounted within a synthetic finger and coupled to the synthetic skin covering. When rubbed over a surface, this type of sensor detects vibrations caused by friction between the surface and synthetic skin. The sensor data is then processed and delivered to adhesive TENS electrodes that can be placed on the user's skin at various locations. To produce electro-tactile sensations that can be used to interpret texture we use the intensity of the electro-stimulus to approximate the coarseness of the surface and the electrical pulse frequency to represent the granularity of the surface. By having no electro-mechanical or moving parts our tactile feedback system is compact, convenient and less expensive than other types of tactile feedback systems. It is also capable of delivering a wide variety of sensations for representing different textures.

This paper is organized as follows: Section II provides a brief overview of previous research in this field. In Section III the implementation details of our system are presented. Section IV describes experiments which demonstrate the effectiveness of our system at remote surface texture classification. Finally, concluding remarks are provided in Section V.

II. Background

Touch sensing in humans is possible because of sensory neuron receptors in the skin that are capable of receiving tactile stimulus from contact with objects. The most sensitive skin areas of the human body with respect to the touch sensations are the hairless regions or glabrous skin, like the finger tips. There are four mechanoreceptors responsible for touch sensations. These are the Meissener corpuscle, Merkel disk, Pacinian corpuscle and Rufini corpuscles, see [5] for further explanation. These mechano-receptors can be stimulated by different sensations making it possible for humans to recognize objects based on their texture as well as other properties like size, edges, shape, temperature, etc.

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Several studies have tried to develop feedback devices for sensing tactile information that can enrich the use of prosthetic hands and legs, as explained in [4] and [8]. Operators of the teleopereated robots and users of virtual reality technology can also benefit from this technology, see [1], [7] and [12]. These feedback systems mostly involve sensors that can detect or measure the pressure applied to an object or variations in the surface texture. The sensor data is then delivered to some type of wearable haptic device that usually involves some type electro-mechanical device to mechanically stimulate the sensory nerves in the skin [5].

Some researchers sense vibrations as the haptic/tactile feedback stimulus. For example, Tanaka et al [6] established a bidirectional system which used the piezo material as a sensor to detect bumps together with a speaker as a feedback actuator. With this system, the user feels the vibration of the speaker when the sensor detects a bump in the sensed surface. Sarakoglou et al also utilize a vibration and electro-mechanical tactile system to obtain tactile feedback from a robot arm [7]. They use a soft finger sensor array attached to robot finger that can enable the user to feel the surface using arrays of tactors actuated by DC motors. These tactors deform the skin proportionally to the surface touched by the robot. However, this system only detects a single (binary) height of the surface texture, and cannot easily recognize the texture of the surface based on friction. It is also considerably cumbersome for the user to wear.

Other researchers have also used tactors to deliver tactile sensations to the user from various sensors mounted in prosthetic hands. For example, Jimenez and Fishel [8] devised a system that can enable a user to differentiate the weight of an object held by a prosthetic hand. However, this system is cumbersome and can interfere with the user's movements. Furthermore, the feedback system has limited bandwidth for interpreting tactile information on objects.

Another system, proposed by McMahan et al [9], uses a voice coil pressure sensor to detect the forces applied to objects by a teleoperated robot which is sent to a phantom Omni [16] which is operated by the user. This device can produce force feedback to the user and was implemented to facilitate the use of a surgical robot [10]. Here, force touch feedback sensations are used to help the operator of the robot to interact with the internal body parts encountered in minimally invasive surgery. Although this feedback system is suitable for performing tele-surgery it use in other applications is limited due to the cumbersome size and weight of the Omni feedback device.

Other researchers have used non-mechanical feedback systems based on electrically stimulating sensory nerves in the skin with sensor data. For example, Yamamoto et al [11] used a piezoelectric polyvinylidenefluoride (*PVDF*) film as a tactile sensor array for detecting surface irregularities. Any deformations in the polymer sensor array are delivered to an electrostatic display which can enable the user to feel the irregularities as electrostatic sensations when the user slides their finger across the display. However, this is a relatively bulky device and limited in it applications due to the need for the user to slide their finger along the electrostatic display area in order to "feel" the remotely sensed surface.

Kajimoto [12] introduced an optical sensor combined with electrotactile feedback system known as SmartTouch and SmartTool. See [12] and [13]. These systems are comprised of an optical sensor that is attached to a tool that swipes the surface to detect stripes or edges on the surface based on colour variations. This information is fed to a small array of electrodes that is placed on a finger of the user. Although this system can enable the user to feel surface variations on the electrotactile display, based on colour variations, it is unable to detect textures on surfaces that have an almost uniform colour.

Edwards *et al* [14] used a microphone as a texture sensor in an artificial finger to mimic some of the characteristics of mechanoreceptors in human skin. In their research, the sounds produced by friction between an artificial finger and various textured surfaces was recorded and then processed offline by using a FFT, principal component analysis and a clustering algorithm. Although this system was able to learn to classify the given surfaces, the output produced from unknown textures remains uncertain. Furthermore, the need to record and process sensor data makes it unsuitable for users of prosthetic hands or teleoperated robots where the user is available to monitor and interpret streaming sensor data.

To overcome some of the limitations of existing tactile feedback systems, we have developed an electrotactile feedback system that is based on detecting vibrations in an artificial finger with a crystal sensor and stimulating sensory nerves in the skin with TENS electrodes placed on the user's skin. This type of feedback system can reduce the hardware required to give tactile sensations to the user because it does not use mechanical actuators or linkages. Furthermore, electro-tactile feedback can be modulated by varying both the frequency and amplitude of the electric stimulus to deliver a wide variety of sensations, as explained in [1], [12] and [15]. In the following sections we provide a detailed description of our electrotactile feedback system and the results we were able to obtain on various textured surfaces.

III. ELECTRO-TACTILE FEEDBACK SYSTEM

A. Overview

The electrotactile feedback system is comprised of an artificial finger with a vibration sensor coupled to the artificial finger's latex skin. The signal from the vibration sensor is first filtered and amplified to reduce noise and then streamed into the host computer via an Analogue to Digital Converter (ADC), as shown in figure 1. The sensor stream data is then processed to deliver the appropriate pulse frequency and intensity and sent to the TENS electrodes fitted to the user's hand via a wireless transmitter and receiver.

This arrangement enables the user to experience a wide variety of sensations by modulating the frequency and intensity of the TENS stimulus delivered to the user's skin on a hand or elsewhere. For example, to represent coarse grain textures with hard contact we use a low frequency and high intensity TENS signal. To represent fine grain textures with light contact we use a high frequency and low intensity TENS signal.

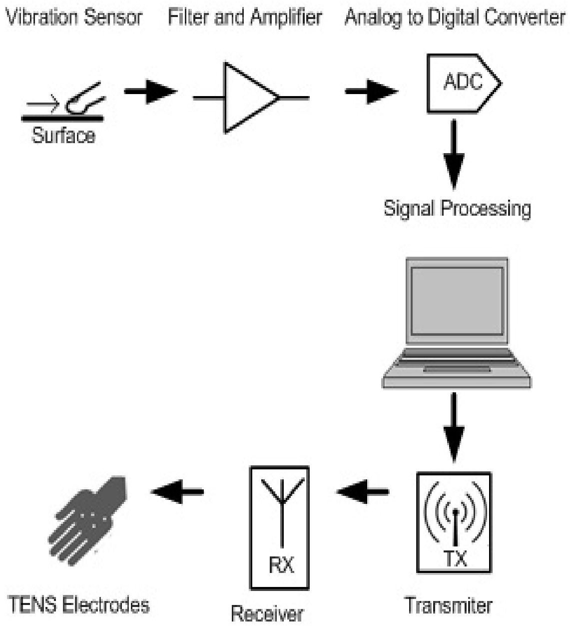


Figure 1. Block diagram of the system

B. The Vibration Sensor and Signal Processing

To test our system we constructed an adult sized artificial finger and a textured rotatable platter, as shown in figure 2a. Figure 2b illustrates the location of the vibration sensor within the finger. The artificial finger is covered with a thin layer of latex to both protect the sensor from the environment and to propagate vibrations to the sensor. A moving magnetic cartridge vibration sensor with diamond stylus needle is used to sense the texture of the surface. To reduce unwanted noise a low pass 300 Hz filter is used. The signal is also amplified to increase the signal to noise ratio before being delivered to the host computer for further processing.

a

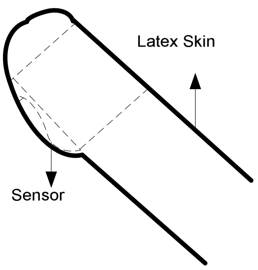


Figure 2. a. Artificial finger. b Sensor inside the artificial finger.

An NI-DAQ 6210 data acquisition interface card and LabView software was used to process the signal and prepare it for delivery to the TENS unit. This data acquisition device has 16 bits resolution and 250ks/s sampling rate which proved more than sufficient for our application.

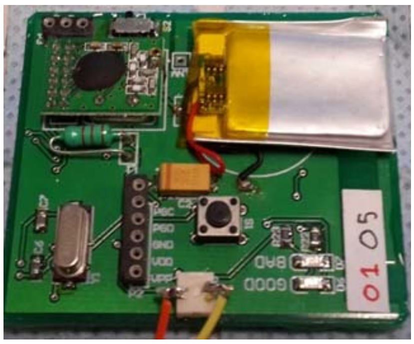
Our tests showed that the frequency output from the vibration sensor to contain multiple frequencies. Consequently, and the main signal processing task involved identifying the principal frequency component and mapping this to frequencies to between 10Hz to 120Hz - which is the frequency range of our TENS unit.

By mapping the frequency spread of the vibration sensor to the frequency spread of the TENS unit and by using the sensor signal's amplitude to determine the intensity of the TENs stimulus we found we were able to obtain a reasonable representation of both the granularity of the surface and the pressure applied to our artificial finger on a variety of textured surfaces.

C. Electro-tactile Feedback

To deliver the electrical stimulus to the user we devised a wireless TENS system, as shown in Figure 3. This system gives electrical stimulus to the user's skin with both controlled frequency and intensity. The electro-tactile feedback system consists of a USB transmitter, shown in Figure 3a, and the self contained receiver unit as shown in Figure 3b.

a



b

Figure 3. a. TENS USB transmitter. b.TENS receiver

The transmitter unit transmits the processed sensor data from a computer to the wireless TENS receiver unit connected to the electrodes. The electrodes stimulate the skin with electrical pulses between 10Hz to 120Hz, as shown in Figure 4. The amplitude of the pulses is set by the user to between 40V to 80V to achieve the best resolution and comfort. The intensity of the stimulus is controlled by the width of the pulse which is varied between 10 to 100µs and depends on the principal frequency signal produced by the sensor.

For our experiments, the TENS electrodes from the receiver were placed on the centre of the back of the hand, as shown in figure 5. This arrangement allowed the user to receive information via the skin and does not cause the hand to contract because the electrodes are not directly stimulating the muscles. In fact, the stimulus is mild and completely painless.

D. Textured Surfaces

To test our feedback system we constructed a rotatable platter with four different textured surfaces on it, as shown in figure 6. The outer track is comprised of smooth plastic. The next two tracks of the textured platter ware comprised of a bonded sand and rice to provide surfaces with different granularity. The inner track was comprised of spaced matchsticks to give a very rigid bumpy textured surface.

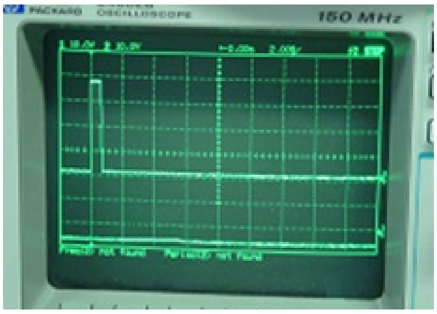


Figure 4. TENS output waveform

Figure 6. Platter with textured surfaces

IV. EXPERIMENTAL RESULT

Experiments were conducted with the artificial finger described in the previous sections on five users. The main aim of these experiments was to see if the users could interpret the TENS signal and correctly name the textured surface and the pressure (low, medium or high) applied by the artificial finger.

Prior to conducting these experiments each user was familiarized with the artificial finger and rotating platter and given about 10 minutes to move the finger over various surfaces and at various applied pressures and told to adjust the level of the TENS signal to suit their comfort level.

The artificial finger and platter were then placed out of sight from the user, as shown in figure 7. The user was also fitted with ear muffs so that no sounds produced by the apparatus could be heard. The operator then repeatedly placed the artificial finger on randomly selected tracks on the rotating textured platter and applied randomly selected pressure to the artificial finger. Each time the user was asked what type of surface they thought the artificial finger was touching and how much pressure was being applied.

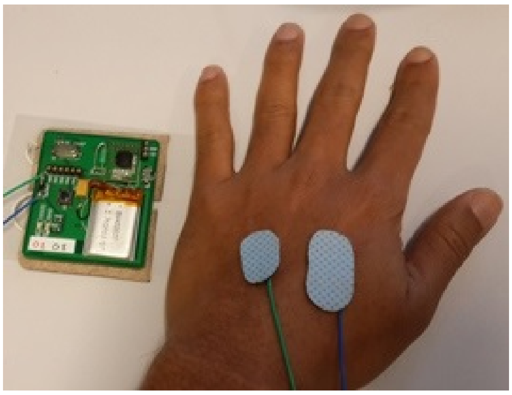


Figure 5. Electrodes attached in the skin of the user

Figure 7. Texture discrimination test

Figure 8 shows typical example output signals produced by the sensor when placed on the different textured surfaces. For the smooth surface at medium pressure there was very little vibration (see figure 7a). This produced TENS stimulus around 100Hz with low intensity. Figure 7b and 7c shows the output produced by the sensor when the finger was placed on the sand and rice surface, respectively, at medium pressure. This produced TENS stimulus at frequencies of 90Hz and 50Hz, respectively, with medium TENS intensity. Figure 7d shows the output from the sensor when the finger was placed on the matchstick surface at medium pressure. As shown, the matchstick surface produced brief periods of high frequency bursts as the sensor bumped into the matchsticks. This caused the TENS stimulus to deliver corresponding 100Hz bursts at high intensity with low intensity in between.

We found all the users were able to correctly classify the surface textures. On average, 75% of the time the users were also able to correctly classify the applied pressure.

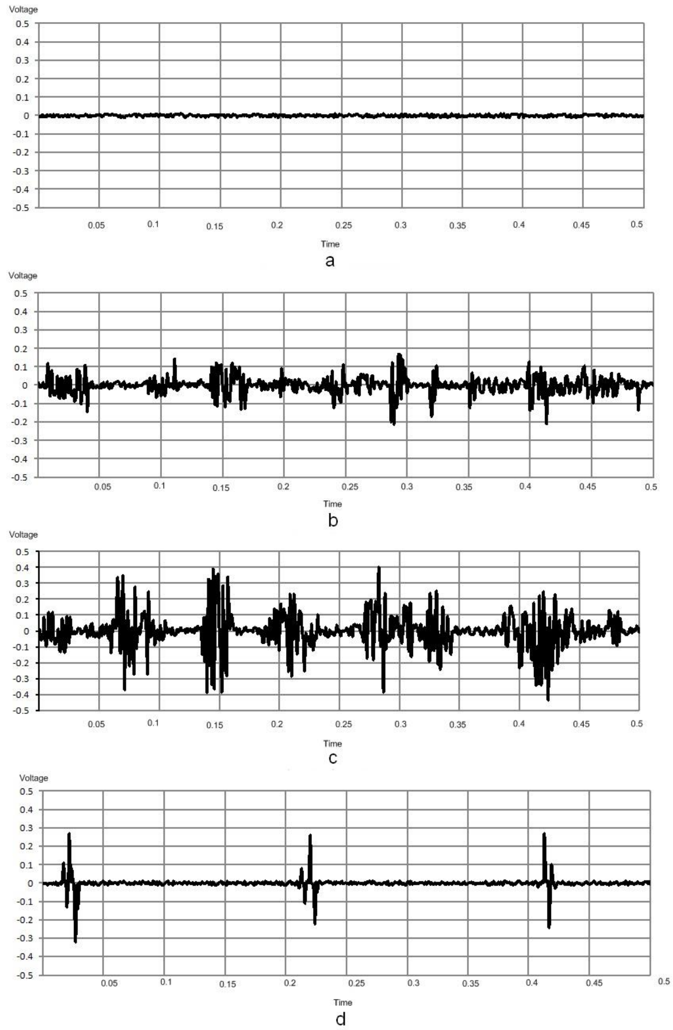


Figure 8. Sensor output signals. a. plastic b. sand c. rice d. matchsticks

V. CONCLUSION

In this paper we propose a tactile sensing and/or feedback system that is based on detecting surface textures with a vibration sensor and interpreting this information via electro-neural stimulation of the user's skin. This feedback system has benefits over existing systems in that it can deliver a wide variety of sensations to the user and is compact, non-mechanical, wireless and comfortable for the user to wear. Our experimental results show that this feedback system is capable of enabling various textured surfaces to be identified to within a reasonable degree of accuracy. For future work we intend applying our electrotactile feedback system to providing improved touch sensing to users of virtual reality, patients with prosthetic limb and operators of teleoperated robots.

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