Improving Texture Discrimination in Virtual Tasks by using Stochastic Resonance

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ABSTRACT

We investigate enhancing virtual haptic experiences by applying Stochastic Resonance or **SR** noise to the user's hands. Specifically, we focus on improving users' ability to discriminate between virtual textures modelled from nine grits of real sandpaper in a virtual texture discrimination task. We applied mechanical SR noise to the participant's skin by attaching five flat actuators to different points on their hand. By fastening a linear voice-coil actuator and a 6-DOF haptic device to participants' index finger, we enabled them to interact and feel virtual sandpapers while inducing different levels of SR noise. We hypothesize that SR will improve their discrimination performance.

KEYWORDS

Stochastic Resonance; Virtual Tasks; Haptics; Virtual Reality; Texture Rendering

CHI'19 Extended Abstracts, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5971-9/19/05…$15.00
https://doi.org/10.1145/3290607.3312839

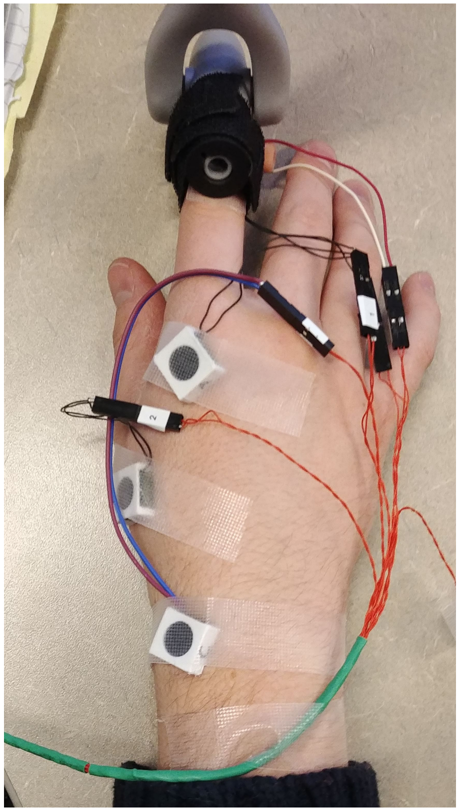

Figure 1: SR actuators are mounted on five points on a participant's dominant hand.

INTRODUCTION

Haptic feedback systems are prevalent in modern devices such as mobile phones and portable gaming devices. However, most of these devices are limited to vibrational feedback. Wearable and portable haptic interaction devices have proliferated thanks to the advent of commercially available head-mounted virtual reality (VR) systems like the *Oculus Rift and HTC Vive*.

Wearability brings in additional constraints of weight, comfort, portability and general usability of the device. Most lighter devices tend to have limited power to render precise haptic information.

Our primary motivation is to enhance the capabilities of lightweight wearable haptic devices. We look to the neuroscience concept of Stochastic Resonance or **SR**, which improves the sensitivities of the human fingertip [8]. To explore the applicability of SR within haptics, we chose a task of virtual texture discrimination. Fine texture discrimination is considered a moderately difficult task requiring skilled dexterous control and sensations at the fingertip. In a previous experimental setup [8], an average participant successfully identified sandpaper textures with an accuracy of 45% and SR boosted the accuracy to about 70%. This research aims to translate the improvement offered by SR in texture discrimination to virtual textures.

BACKGROUND

Stochastic Resonance is a phenomenon in sensory systems, where adding the right amount of noise to a signal can enhance the signal-to-noise ratio, such that a weak signal becomes detectable [1]. Stochastic resonance must be finely tuned: too much noise will obscure the signal, while too little noise will not provide an adequate boost. The amplitude of SR is expressed relative to the sensory threshold (**T**) or threshold. The threshold is the minimum amplitude at which the participant barely feels the presence of the noise. Some researchers focus on the misconception that SR offers "good noise" [13]. On the contrary, SR is "randomness that makes a nonlinearity less detrimental to a signal" [13].

Research by McDonnell et al. [13] explores SR and the "noise benefits" it provides for signal processing in biological systems. Their paper provides a list of recommendations for a biologist to consider while evaluating the useful functional role of SR.

Experiments [5, 8] have established that the ideal level of SR is between 0.25 to 1.25T, where **T** is the sensory threshold of the individual at the location where SR is induced. Any value below 1T is called *sub-threshold SR*, and any value above 1T is considered as *supra-threshold SR*. Both sub-threshold and supra-threshold stochastic resonance is likely to provide diminishing improvement to the signal as the SR intensity deviates away from the threshold.

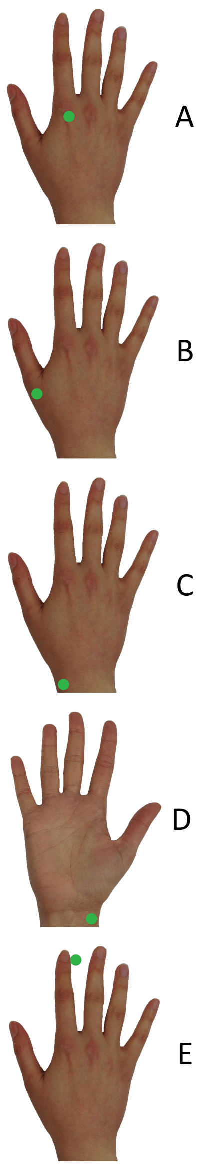

Figure 2: Hand mount points for five SR actuators, adapted from Enders et al. [5]

Research [12, 20] have explored supra-threshold stochastic resonance. In supra-threshold SR, the user can feel the sensations or input produced by the SR system, as it is above the threshold of sensation.

Neuroscience studies [16] found that stochastic noise improved the quality of the perceived touch sensation. Several studies [3, 4] investigated the positive impact of SR in touch perception. Similarly, some neuroscience studies [2, 18] established that **electrical stimulation** also can enhance humans' ability to detect subthreshold mechanical cutaneous stimuli, for example, fine texture discrimination.

Similarly, studies [5, 17] found that noise improved light touch sensation in stroke survivors' fingertips via SR. An electroencephalogram (EEG) study [19] of remotely-induced SR at the wrist (while the participants' fingertip was being stimulated) showed higher levels of electrical activity to the brain from fingers as compared to an EEG without the SR.

Moss et al. [14] described different applications of SR and how it could be applied to biological systems such as the touch perception on the skin. Researchers conducted exploratory studies [8] with a "sensorimotor enhancer." This device used SR to improve the tactile sensitivity of the fingertips. A preliminary investigation into the effects of SR [6, 9], established that it could enhance real-world texture discrimination ability and can sense lighter touches.

In this work, we want to establish the value of using SR in haptic devices to improve human performance in a virtual task, specifically aimed at the task of texture discrimination.

METHODOLOGY

Most wearable haptic devices are designed for the fingertip of the user [15]; thus, we focus on developing a study on a wearable haptic device that performs fingertip actuation. The primary aim of this research is to validate the impact of stochastic resonance in haptic interfaces. There are several unknowns in applying SR to haptics that need to be addressed. For this initial exploration, we aim to use mechanical SR, which has previously worked for physical texture discrimination tasks [8].

Texture Discrimination Setup

We base our texture discrimination task on Kurita et al.'s [8] work on a sensorimotor enhancer. We obtained sandpapers of nine different grit sizes (ISO/FEPA Grit designation from rougher to finer grit sizes: P40, P80, P120, P140, P180, P220, P240, P280 and P320). We digitized these sandpapers using a technique similar to haptography [7]. This is achieved by recording acceleration waveforms via a piezoelectric sensor while moving across textured sandpaper at a controlled velocity. We used these digital haptic recordings of sandpapers in a virtual environment laid out in a grid as shown in Figure 3. A "test" sandpaper is placed on the left side of the grid arrangement of the sandpapers numbered 1 through 9. The "test" sandpaper can be changed on demand to any one of the other nine sandpapers. The digitized sandpapers are rendered via a linear resonant actuator (LRA) model

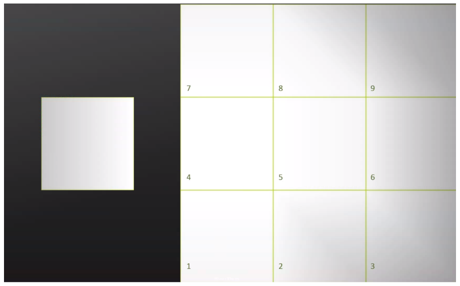

Figure 3: The texture discrimination task interface, which shows a $3x3$ layout of textures (right) ordered from bottom-up / left-right order from $P40$ to $P320$ along with the test surface (left).

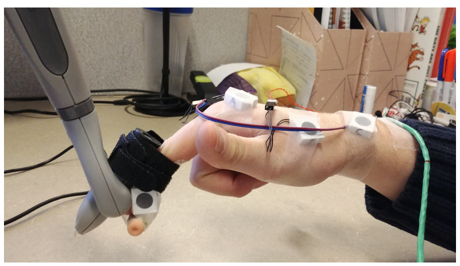

Figure 4: The *MM3C* is mounted on the fingertip along with SR actuators on the hand.

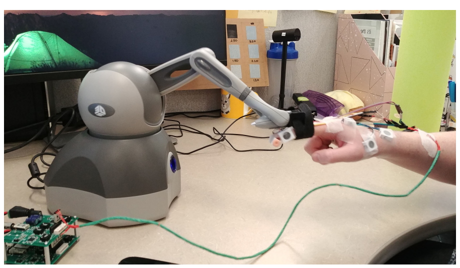

Figure 5: A participant interacts with the virtual textured sandpaper surface. The attached *Phantom Omni* provides kinesthetic feedback while the finger-mounted LRA provides cutaneous feedback.

MM3C manufactured by *tactile lab*. The LRA is mounted on the fingertip of the participant using surgical grade tape. In our study the cutaneous feedback (vibration) is rendered through the LRA, and the kinesthetic feedback (force, friction) are rendered through a 6-DOF haptic device, the *Phantom Omni* (see Figure 4).

Stochastic Resonance Setup

Another vital part of this setup is to create SR noise at various points on the hand performing the texture discrimination tasks. Based on previous papers by Enders et al. [5] and Kurita et al. [8], we chose five unique points on the hand to provide SR actuation. The software system developed is capable of rendering SR noise at each site at different levels. The SR actuators are mounted at the locations shown in Figure 2:

(a) dorsal hand approximately 2 cm proximal to the index finger knuckle
(b) dorsal hand approximately 2 cm proximal to the thumb knuckle
(c) dorsal wrist, medial to the radial styloid process
(d) volar wrist, medial to the radial styloid process
(e) proximal to the fingertip next to the actuator providing the texture rendering

Experiment

We recruited four pilot study participants from our research lab to perform multiple rounds of texture discrimination tasks. We mounted SR actuators on 5 points as shown in Figure 1, based on Figure 2. We affixed the *MM3C* LRA to render texture at the fingertip. We then connected the participant's finger to a custom mount on the *Phantom Omni*. We then asked participants to wear active noise-cancelling headphones to ensure that no auditory feedback from the haptic hardware could aid them in the discrimination tasks.

Before the experiment, we conducted four rounds of tests to determine the sensory threshold level (**T**) at each of the five points using the staircase method [11]. These values are stored for calibrating the level of SR noise rendered in the experiment. In our experiment, we asked participants to identify which one of the nine sandpaper texture is being rendered at "test" sandpaper location. A trial block of texture discrimination tasks was given to the participants to familiarize them with the software and hardware setup (see Figure 6).

At the end of the trial block, we asked participants to perform 20 blocks of texture discrimination tasks, each block comprising of 9 texture discrimination tasks. The blocks were counterbalanced to minimize learning effects. A mandatory break of at least 30 seconds was enforced after each block. At each discrimination task, we randomly allocated among four discrete SR noise levels (0.5T, 0.75T, 1.00T and 1.25T) and the location to one of the five points or the base condition of no SR.

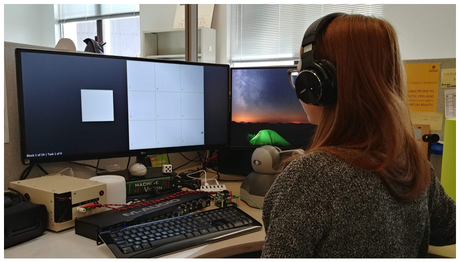

Figure 6: A pilot participant performing a texture discrimination task.

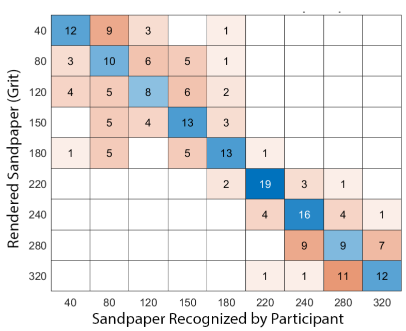

Figure 7: Preliminary confusion matrix results showing participant perception of grit size (x-axis) compared to the rendered sandpaper grit size (y-axis). Cells report number of trials resulting in each perception-rendered pair; diagonal cells reflect accurate perceptions of rendering.

FINDINGS FROM PILOT STUDIES

After each pilot study, we systematically identified issues with the setup, ranging from software issues, hardware issues and physical configuration. We iteratively refined the study set up with each pilot participant. One of our key findings from the pilot study was that the planar haptuators that we used to render stochastic resonance could not optimally actuate at low levels, especially in the 0-100 Hz range. For the next round of pilot studies, we plan to use the same actuator as Kurita et al.'s study [8], *APA50S* from *Cedrat Technologies*.

EXPECTED RESULTS AND REMARKS

In stochastic resonance for haptics, specifically for a virtual texture discrimination task, we expect a similar range of improvement as the sensorimotor enhancer [8] (see Figure 7). A potential concern of this study is the ability of the SR actuator to produce the required vibrations at the sub-threshold levels, and the quality of the digitized sandpapers via haptography.

Stochastic Resonance (SR) is likely to improve the ability of an individual to discriminate various virtual textures, for example, virtual reality (VR) prototypes like *RollingStone* [10] or *Haptic Revolver* [21]. An exploration into electrical SR could provide a more accessible, and reproducible SR setup. Additional exploration can also shed some insights into the use of SR in improving dexterous manipulation of virtual objects, a fine grip of ultralight virtual objects, and more.

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