Vibrotactile Device for Optimizing Skin Response to Vibration

Kou, W. McGuire, J. Meyer, A. Wang, A.
Department of Biomedical Engineering, University of Wisconsin-Madison

Abstract

It is important to understand stochastic resonance on the hands in order to prove how it effectively enhances vibrosensory perception. To do this, an MR-compatible tactor is needed to provide a vibration stimulus to the hand during an MRI of the brain. The key design requirements of the device are that it must run at a frequency range of 30-300 Hz, and be small enough to fit on the subject's finger while maintaining a 1 mm thickness. In order to achieve these requirements, three design options were evaluated: solenoid, piezoelectric, and pneumatic. Of these three options, the piezoelectric device was determined to be the best-suited design. Using a 741 operational amplifier circuit, a random audio signal was amplified to drive the piezoelectric circuit. Testing of the device consisted of circuit gain and amplitude tests, along with a perception test of the fingers on both left and right hands. The index and thumb fingers were determined to be the most sensitive to vibrations. Future work is to be conducted by Professor Na Jin Seo to test the piezo buzzer's displacement, along with stochastic resonance in an MRI to observe brain function.

Motivation

Falling from ladders or scaffolds is of the leading causes of workplace injuries and fatalities. Professor Na Jin Seo of UW-Milwaukee is examining methods of improving reaction time to vibrations to possibly reduce the number of fall-related injuries. According to previous studies, the skin sensation of hand is believed to be the first available sensory cue for workers to detect and react to the fall initiation. On average, healthy young people took about 100 ms to arrest and stabilize their bodies when sudden forces were applied to the ladder [1]. Out of the 100 ms period, approximately 40 ms was because of the delay in the brain cortical reflex loop, while the other 60 ms was mainly from the delay of hand skin receptors to detect the change in contact force [1]. If this 60 ms time period could be reduced by decreasing the amount of time skin receptors used for detecting the change in force, then the person's ability to rescue the fall could be greatly enhanced [1].

The principle the Professor Seo is exploring for improving vibration perception is called stochastic resonance, which is a phenomenon that occurs when a sub-threshold signal is enhanced by the presence of noise [2]. Stochastic resonance can assist a sensing system in detecting a signal by adding a predetermined amount of noise. This noise has the same modality as the signal, but does not contain significant information to the system, or is sub-threshold. When adequate noise is added to the signal, it increases the amplitude of the signal, which can bring it above threshold. In most cases, it is preferred to eliminate noise from a signal; however, in the case of sensing small vibrations, an outside noise is helpful for bringing the signal above threshold and allowing the body to sense the small vibrations.

Setup

The goal of this project is to improve the workers' response time by stimulating their sense of touch through vibrations in their hands. The device must be MR-compatible in order to analyze brain activity during the stimulus to the hand. The overall goal is to prove that a continuous stimulus on the hand can improve the range of sensory frequency perception. Client specifications also include that the device must operate at a vibration frequency of 30-300 Hz (the optimal frequency for the vibration receptors in the hands). Ideally, the stimulator device will fit on the tip of the subject's finger, having an outside diameter of 2 cm, and a thickness of 1 mm. A diameter of 2 cm was calculated the Digit 2, Distal Interphalangal joint breath for the 95th percentile male using anthropometric survey data from the U.S. Army [3].

Based on the above design criteria, a piezoelectric system for vibration was chosen to provide adequate noise for stochastic resonance. When a mechanical force is applied to some solid materials, an electrical charge will form as a result. This is known as piezoelectricity [4]. The piezoelectric vibrator chosen was a Digikey (Part number 668-1004-ND) piezoelectric buzzer, which is made from MRI-compatible materials; the device has a thickness of less than 1 mm, and an outside diameter of 2 cm. The final device assembly can be seen in Figure 1.

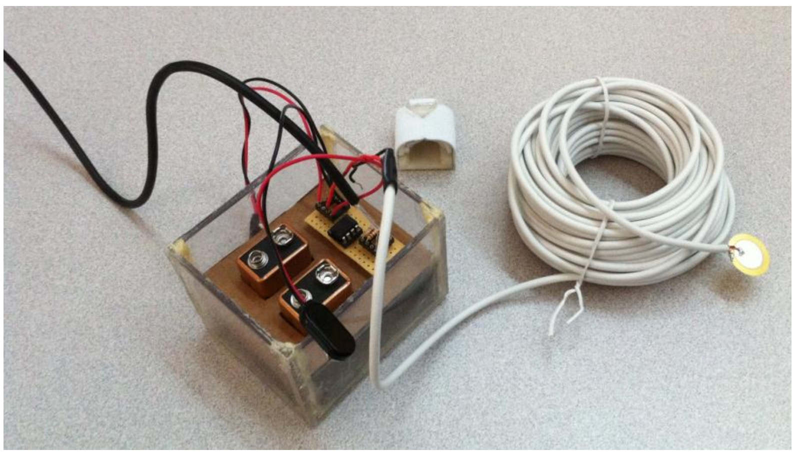

Figure 1: Final assembly. The audio cord (black) supplies the input waveform from the source, the batteries and circuitry rest in the housing, the 50 ft shielded cable (white) runs from the control room to the MRI room, supplying the amplified waveform, piezo attached to shielded cable, and finger holder (white, center of picture) designed to stabilize piezo on subjects finger.

Stochastic resonance requires that the vibration signal must be randomly changing within the range of 30-300 Hz, which was most easily achieved through the use of an audio signal to drive the vibrator. The audio signal (from a computer or mp3 player) was then amplified using a 741 operational amplifier circuit. The audio source and circuit are to be located in the control room for the MRI, where ferrous materials are not a problem. The signal is then passed to the piezoelectric buzzer through a 50-ft. shielded wire into the MRI room.

Testing

The gain of the circuit was experimentally determined in order to obtain exact values for the output voltage to the piezo from the circuit. Using the random frequency audio file, the peak-to-peak voltages from a computer (Apple MacBook Pro was used) were measured and served as the input voltages for the 741 operation amplifier circuit. The volume of the computer was slowly increased in order to increase the voltages from computer, and that increasing input voltages were matched with the corresponding output voltages generated by op-amp circuit to produce Figure 2.

After determining the output values for the device, perception testing was conducted to determine the most sensitive areas of the hand. This information will be useful for Professor Seo when determining the best location for the piezoelectric buzzer when testing stochastic resonance. It is ideal for testing to be done on the most sensitive areas of the hand because these areas will sense vibrations earliest, and thus would be the best for improvement of reaction time.

Data

The results of the gain testing for the 741 op-amp circuit indicated a gain of approximately 4.6. The gain was relatively linear with an increase in the input voltage, and had an R^2 value of .988.

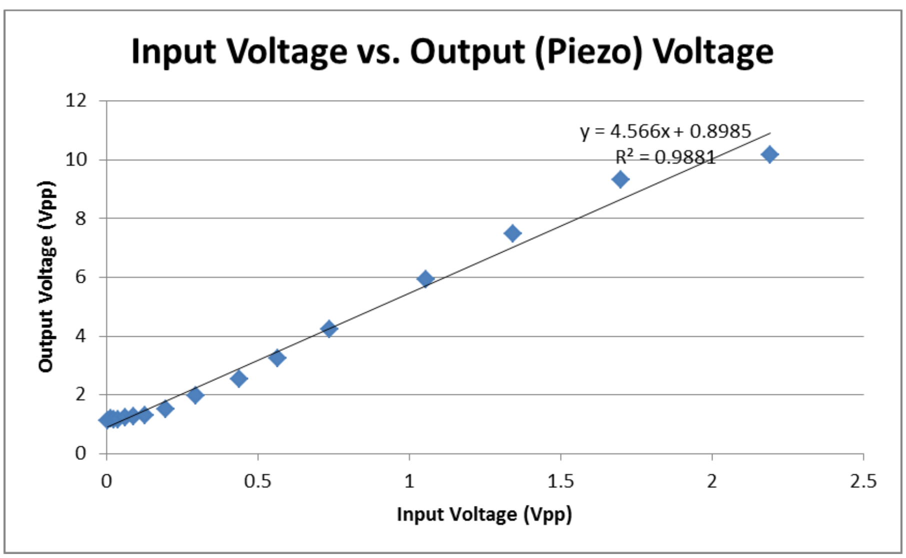

Figure 2: Correlation of input voltage from audio source to voltage at piezo.

The perception tests indicated that the left and right hands of test subjects had approximately the same level of sensitivity, as shown in Figure 3. Although the displacement of vibration was not determined by these tests, the most sensitive regions of the hand could still be determined assuming that the displacement was directly related to the voltage input for the piezo.

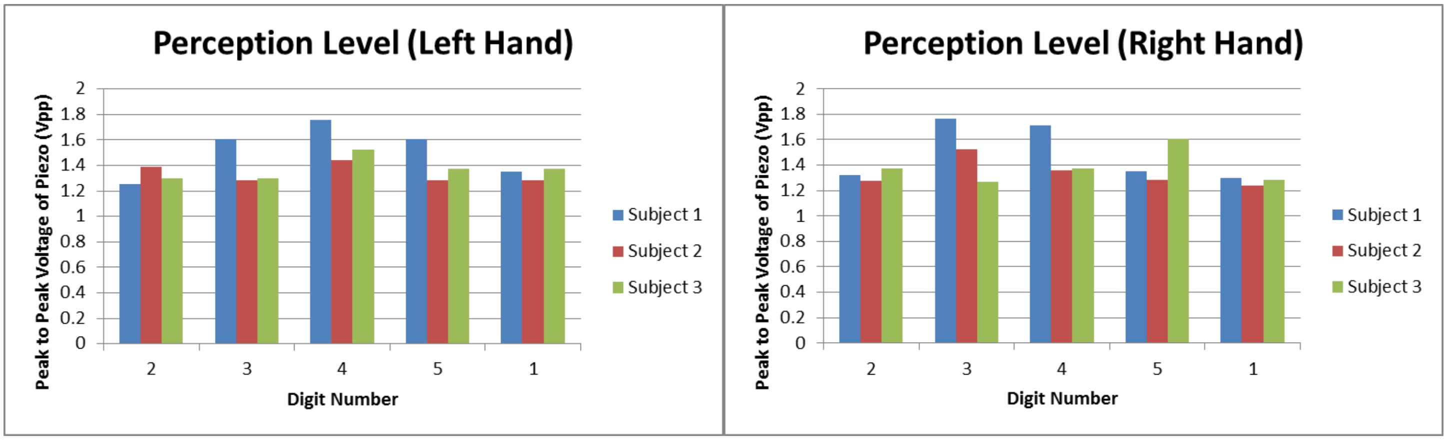

Figure 3: Perception voltages for the Left and Right hands of test subjects.

Table 1: Average Perception Rankings for Digits on Left and Right Hand (lower voltage level indicates a higher perception for the digit). Errors in this testing may have resulted from

Digit	Left Hand	Right Hand
2 (Index)	1.31 V (1)	1.32 V (2)
1 (Thumb)	1.33 V (2)	1.28 V (1)
5 (Pinky)	1.42 V (4)	1.42 V (3)
3 (Middle)	1.40 V (3)	1.52 V (5)
4 (Ring)	1.57 V (5)	1.48 V (4)

Analysis

The gain of the circuit was determined to be approximately 4.6; however, the theoretical gain of the system was calculated to be 5.5. The variances in the gain could have been due to a faulty 741 op-amp, which could deplete the gain. Another source for this variance could have been due to difficulties in obtaining accurate amplitude measurements from the randomly changing audio signal. The amplitude is constantly changing, and the voltage output measured could have varied enough to skew the gain of the system at the moments when the measurements were taken.

The hand sensitivity testing, as shown in Table 1, indicated that the index and thumb digits of the hand were the most sensitive areas. The data from these tests was compared with a previous project conducted by N. Alawieh at UW-Madison to determine the most sensitive regions of the hand. A diagram, shown in Figure 4, of the most sensitive regions of the hand was modified from this project in order to properly indicate the regions that Professor Seo should conduct testing on.

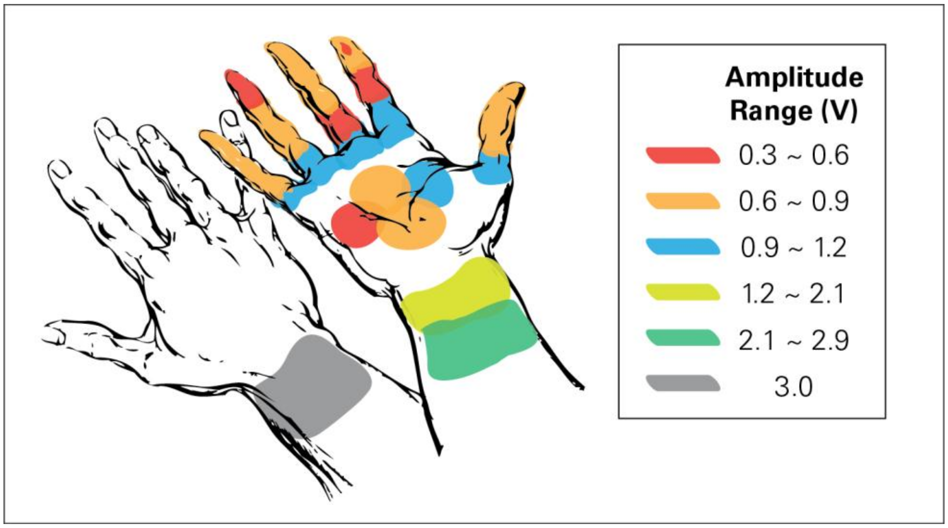

Figure 4: Map of hand sensitivities based on applied tactor voltage: Notice that there is an increased sensitivity a the tips of the fingers [Adapted from 5].

These tests also indicate that different test subjects will have different sensory levels, so it is important that the device can precisely adjust the level of actuation to accommodate various perception levels. This is something that is easily achieved through this device because the amplitude is changed by simply adjusting the volume of the audio source. The average perception rankings for the piezoelectric sensitivity testing are shown in Table 1, and indicate very similar results to the previously determined sensitivities from N. Alawieh, shown in Figure 4.

Conclusions

From the experiments conducted, it was determined that the thumb and index finger are the most sensitive regions of the hand. These areas should be focused on for testing of stochastic resonance. The output voltages of the circuit should also be continuously monitored throughout testing, because different points in the audio file seemed to produce different voltages. This could have been due to the random frequency, or quieter points in the audio signal.

Testing should be done to correlate the displacement of vibration of the piezo buzzer to the input voltage to the circuit. Although the most sensitive areas of the hand were determined, it is still necessary to relate those areas to the displacement of the vibrator. Displacement testing should be conducted by using a laser vibrometer, which uses light scattering to detect the displacement of vibration for the buzzer.

For MRI testing, Professor Seo must be wary of the device's compatibility inside the MRI room, and should conduct testing to determine that the device is indeed MRI compatible. Although the materials used are non-ferrous, it is impossible to be 100% sure that the device is MRI compatible without extensively testing the device (the resources were not available for the team to previously conduct such testing).

References

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