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Selection of Inexpensive Vibroactuators for a Wearable Haptic Based Pattern Feedback Sleeve

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1. ABSTRACT

This research addresses the challenge of selecting similarly operating inexpensive vibroactuators to study the feasibility of creating a haptic based pattern feedback sleeve. In order to develop a wearable haptic based pattern feedback sleeve, it is required to have all vibroactuators operating in similar behavior. Unfortunately, the performance of the locally available vibroactouators are not performed similarly under the same conditions. In this work vibration of the motors were investigated with an MPU6050 motion tracking device. To find the suitable motors, frequency domain analysis was carried out. Finally, seven vibroactuators were selected where vibration frequency in 200 Hz ± 20 Hz. Those seven motors were used to develop the haptic and each motor in the sleeve vibrated in different Pulse Width Modulation (PWM) signals to mimic a pattern. The findings showed that participants could accurately identify minimal-intensity (FL) and full-intensity (FH) patterns. Other than those patterns, Gaussian type five different patterns used to get users' feedback. Gaussian template (T), Left Shifted (TL), and Right Shifted (TR) patterns were identified successfully with more than 75% accuracy.

Keywords: Haptic, Gaussian templates, Virtual Reality, Human-Robot Interaction, Fast Fourier Transform

2. INTRODUCTION

Haptic feedback systems have many uses, and responding with accurate, significant input is occasionally essential. For instance, robotic tools will enter the body through small incisions during Robot-assisted Minimally Invasive Surgery (RMIS) and operate soft organs that can move, deform, or deform in stiffness[1]. Therefore, it is essential to get immediate input. Due to the manipulator's lack of haptic input and insufficient flexibility, classic robotic manipulators perform only so well. [2] suggests a tactile sensor that makes use of fiber-optic light intensity modulation as an enhancement of this idea.

Using natural language, haptic feedback technology can be used to interact with persons with communication difficulties, such as hearing and vision loss. Studies have been conducted on transmitting natural language contents via a wearable haptic display employing skin reading [3]. In the experiment, three wearable combinations are first suggested based on the principles of haptic perception. An overlapping spatiotemporal stimulation (OST) approach had been employed to encode symbols. Then an encoding for the entire English alphabet was proposed and a training method for letters, words and phrases was introduced. A second investigation looks at communication accuracy. According to the findings, individuals could distinguish 16 letters and recognize two to three-letter words after just one hour of training. After three hours of training and after five hours participants could recognize the entire English alphabet (26 letters, 92% accuracy). Additionally, trials have been done to let people with hearing impairments feel the music utilizing a vibrotactile system of bone-conduction speakers, audio speakers, and vibration motors [4]. Vibrotactile feedback can help people with hearing, and vision impairments communicate better.

Many researchers have also explored using skin deformation to provide directional guidance cues. [5]studies on applying shear forces to the fingertip to display four directions of guidance cues, when a pedestrian navigates around a city by GPS than the display. Here, a skin deformation can provide navigation instructions [6]. Likewise [7] studies the feasibility of a finger sleeve for an eye-free navigation system.

Humans commonly use social touch to gain others' attention in daily life. [8] Describes an early exploration of how an expressive, wearable, or holdable haptic display could emulate human social practices to invoke comparable user responses. Furthermore, the haptic perception can help in robots inference of the relationship between clothing and the human body on robot-assisted dressing [9].

The aging population in the world is increasing rapidly. Because of that, there is an increasing need for health assistance personnel, in developed countries, such as nurses and physiotherapeutic experts. So, there is an improvement in the demand for health care assistance to the population, especially elderly people. [10] discuss Different sensing technologies, and a new architecture for providing haptic feedback through patterns created by multiple actuators. Their three different posture-sensing technologies (inertial, optics, and flex) were considered.

A study has been carried out on the forearm on studying the haptic feedback on squeezing, rubbing, poking, stroking, massaging, pressing, scratching, tapping, hitting, trembling, and pinching using a coding scheme. The results from the user study indicate that participants had the most difficulty imitating the type of touch when they received a dynamic touch through the output layer. When participants received a simple or protracted touch, they mostly responded with a touch from the same touch category[11]. Similarly, a study was carried out on the ability of subjects to detect the rotation of the skin stretch device. Two studies were completed there, one in which the subjects were in control of the device and the task was to orient the device to match the orientation shown visually on a computer screen, and another in which subjects sat passively while the device rotated autonomously, and subjects were asked to report the final orientation.[12]

Haptic applications are often used with Virtual interactions as mentioned above. Many studies explore different techniques to display stiffness using haptic devices. [13] use vibrotactile cutaneous cues to display stiffness for virtual interaction. Humans can perceive stiffness changes as changes in vibration force strength. They have built a single and multiple-finger vibrotactile device that takes touch feedback signal from a VR (Virtual Reality) Haptic experimental setup developed in Unity 3D environment.

In developing a wearable haptic-based feedback sleeve, one of our main objectives is to identify the pattern recognition ability of humans. Here, we constructed a linear array of vibrators and studied the identification of the vibration pattern felt by the subject to determine the effectiveness of using a vibrotactile vibration feedback pattern in communication. A similar, study was carried out in [14] and [15] where the subject is asked to draw the felt pattern after each trial. Those studies further suggest that the frequency is better for persistent perception than the amplitude according to the effective nature of human skin mechanoreceptors. When constructing the Haptic Sleeve, it is necessary to have identical vibroactuators. However, the locally available inexpensive vibroactuators performs differently under the same conditions and manufactures data sheet related to the motor characteristics were not available. In order to overcome this issue we proposed a method that one can select vibroactuators performs in similar behavior.

When selecting the motors one of the main criteria that we used is the operating frequency of the motors. [16] describes human vibrotactile frequency adaptation for 25 Hz and 200 Hz after a 15s stimulation for a specific frequency. According to it each subject rated 200-Hz stimulus as equal in subjective magnitude to a 25-Hz even though stimulus whose amplitude was four to five times larger. [3] indicates the vibrotactile range of human skin varies form 20 Hz-1000 Hz while reaching the peak around 250Hz. In [17] they mentions that nociceptive sensitivity gradually declined as vibration amplitude increased, where they have investigated effects of vibration amplitude and frequency. [18] has 16 vibrator matrices around the 4 cross sections of the forearm to understand of the human perception of location and the intensity of the sensation after a vibrotactile stimulation. Furthermore, this research suggests that the operating vibrocatuator in the frequency range of 100–200 Hz is an innovative gaining device-operator feedback. Therefore, in this research we have used vibroactuators with the approximate operation frequency of 200Hz which is also a typical frequency investigated in [16][19] for vibrotactile stimulations.

We think that by bridging the gap between those with sensory impairments and the digital world, this research will improve accessibility. By enhancing and modernizing haptic signal patterns and meanings, we can develop user-friendly interfaces that support more immersive and natural experiences when it comes to HRI. The capacity to communicate through touch improves the sincerity and depth of our ties with machines, whether it be in virtual reality settings or robotic interactions. This research would be a basic foundational step toward that future.

3. METHODOLOGY

3.1 Motor Characterization

In the process of developing the Sleeve, the first part was to select 7 vibroactuators with the same vibration characteristics. For the implementation, we obtained inexpensive coin vibrators (Figure 1(a)) (10 mm width, 3 mm height) from the local market. The fact that the motors were not operating at the same vibration characteristics meant that they had not being quality controlled, and non-existence of a manufacturer datasheet made it difficult to learn about the motor's characteristics. In order to select the vibroactuators with the same vibration characteristics, we have used a MPU6050 IMU (Inertial Measurement Unit) which consist of 3 axis gyroscope and an acetometer. But in here we use the accelerometer to identify the operating frequencies of the motors when the maximum voltage is supplied (3.3V). In this experiment we have investigated 28 vibroactuators in order to select 7 of them. Here, we had to collect several readings from MPU6050 Module’s accelerometer in all directions with the help of a pre-programmed Atmega328 MCU (Figure 1 (b)). During the experiment we collected 150 data points for each axis with a sampling rate of 1 kHz. Then, frequency domain analysis was carried out to investigate the vibration frequencies of each motor by Fast Fourier Transforming (FFT) the collected time domain data set (Figure 2(a)). In here, it was noticed that the frequency that was obtained for each axis was varied slightly around the same frequency showcasing an operating frequency for each motor. In here MPU6050 was fixed in the middle of the air without any movement restrictions and the vibroactuator was fixed to the back with the help of a double tape. In here the setup was not fixed to any surface due to a surface can absorb the vibration and can lead us for incorrect conclusions. A similar investigation was carried out in [20] which used triaxial ADXL345 digital accelerometer for the data collection. Afterwards they have used FFT for the frequency domain analysis. From literature it was found that for the human skin vibrotactile stimulation peak around the 200Hz. Therefore, Through the frequency domain analysis finally we were able to select 7 motors that have 200 Hz ± 20 Hz vibration frequency [16][19][15](Figure 2(b)).

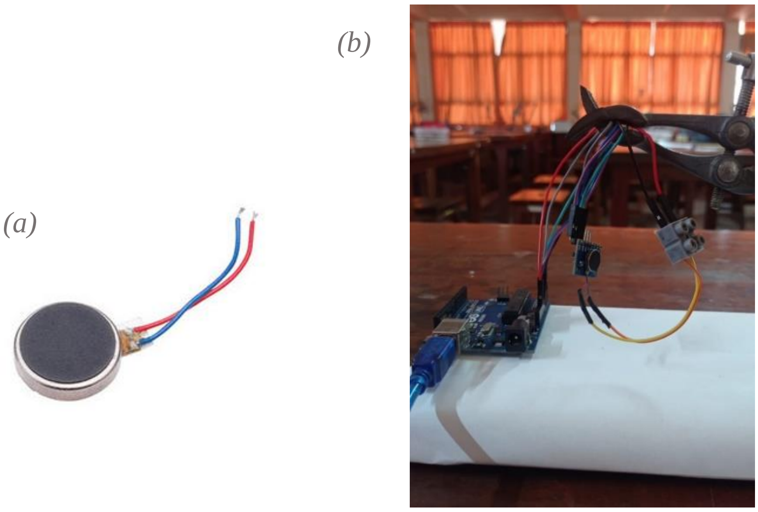

Figure 1: (a)Coin Vibrator Motor (b) Experiment Setup for motor Characterization

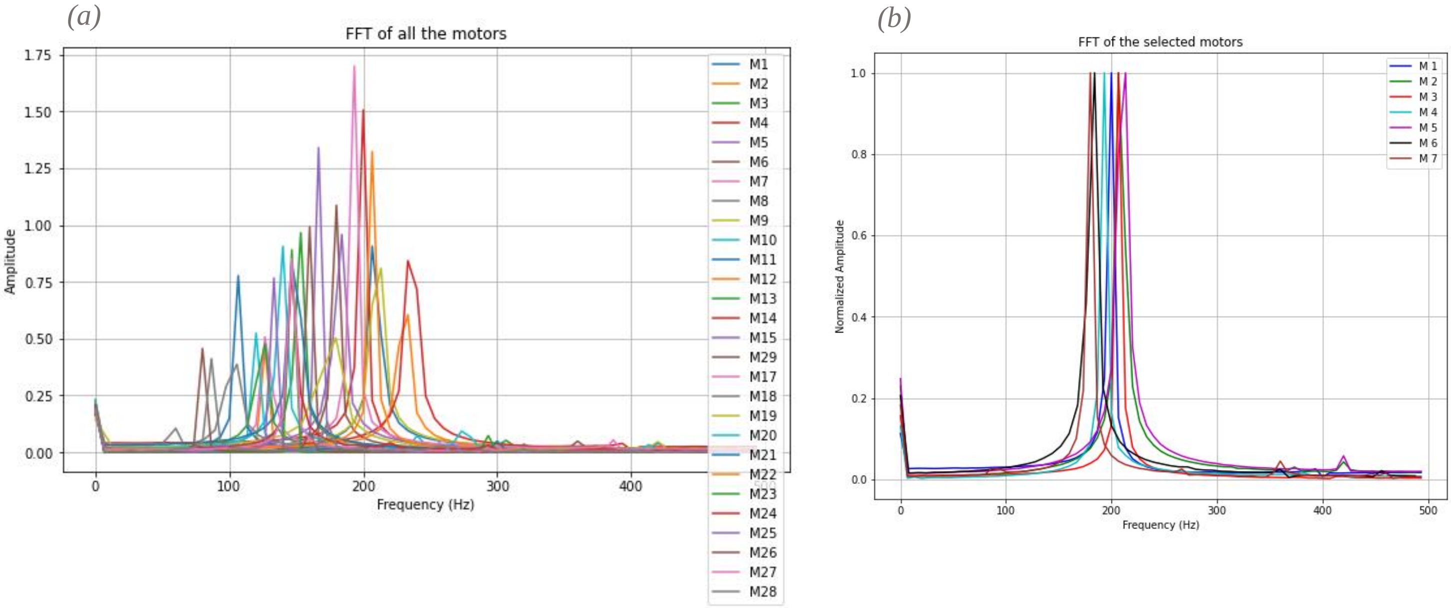

Figure 2: (a) Frequency Domain Data Analysis of all the Motors used for the Experiment. (b) Frequency Domain Data Analysis of the selected 7 Motors

3.2 Development of the Sleeve

After the motors were selected, the next step was to create the sleeve. Here, the sleeve was constructed as shown in Figure 3. The average human forearm length is about 12 inches, so 7 motors were placed 4cm apart to create the sleeve. Vibro-actuators were attached to these seven belts and could be securely strapped to the arms of various subjects. Since Atmega328 MCU can't supply the total current to all the motors a simple power amplifying circuit was created. In here PWM signal was input to the base of the transistor which was powered by an external DC power supply. The amplifying circuit for a single motor was shown in Figure 4.

During the experiment, five different Gaussian-type intensities feed to the seven motors. The used intensity patterns were labeled as Gaussian template (T), Left Shifted Pattern (TL), Right Shifted Pattern (TR), Half Magnitude Gaussian Template (THA) and Shrink Template (THS) [14], and motors work at their total capacity (FH), and the minimal capacity (FL). Those patterns are shown in Figure 5. Furthermore, the PWM values sent to each motor in each template are depicted in Table 1.

Table 1: PWM values are sent to each motor in different templates.

	M1	M2	M3	M4	M5	M6	M7
T	66	90	180	255	180	90	66
TR	62	64	66	90	180	255	180
TL	180	255	180	90	66	64	62
THS	62	64	90	255	90	64	62
THA	33	45	90	128	90	45	33
FH	255	255	255	255	255	255	255
FL	66	66	66	66	66	66	66

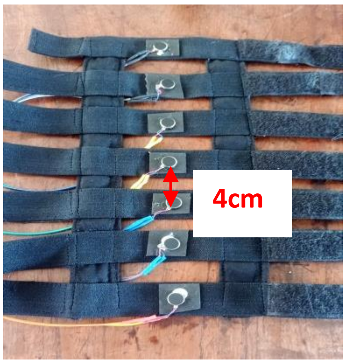

Figure 3: Wearable haptic

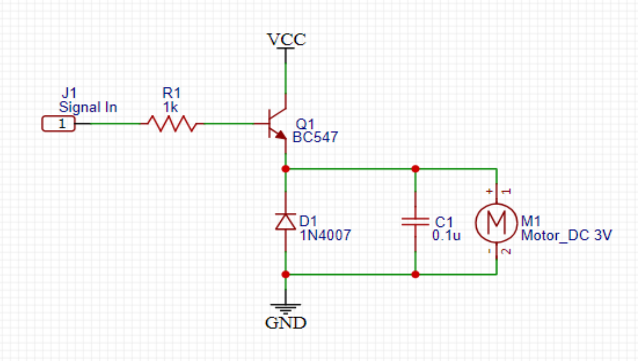

Figure 4: Amplifier Circuit Block

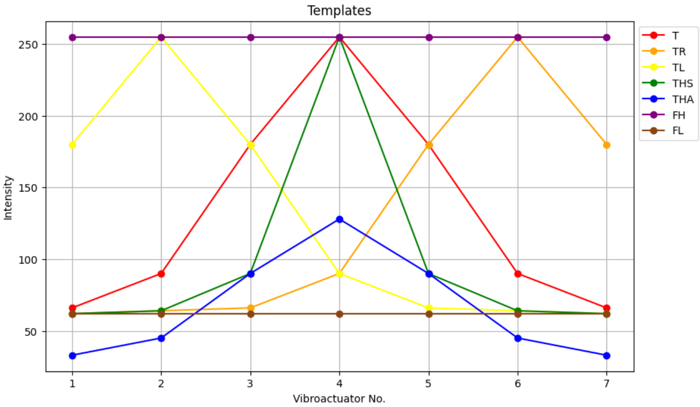

Figure 5: Gaussian Templates Used in the Experiment

3.3 Data Collection

The developed experimental setup is shown in Figure 6. In order to collect data, a questionnaire was created using the Google form. Furthermore, a sheet including all the templates, was created to explain the patterns to the participants.

For each subject, the experiment took about 20mins. Firstly, the sleeve was placed and tightened up to the forearm of the subject. Before the experiment began the subjects were trained for each pattern by sending each pattern one by one and repeating it once they requested. After that, the experiment began.

The experiment consisted of 5 trials; each trial consisted of 10 patterns. Trials began with a FH template and a FL Template. Then the same pattern was sent the following 3 times, and afterward, the patterns were sent randomly. Participants were informed that sometimes, that same pattern can be repeated consistently, but the entire experiment was random from the participant's perspective. Template-sending patterns are available in Table 2.

When it comes to the subject pool, 12 participants took part in the experiment. Six of them were male and 6 of them were Female. We only took participants between the age range of 20 and 30. Participants had the freedom to use any hand they wished but it was noted whether they were using their dominant hand or not. During the Experiment, Participants were given the template sheet and a tablet with the questionnaire loaded to mark their responses.

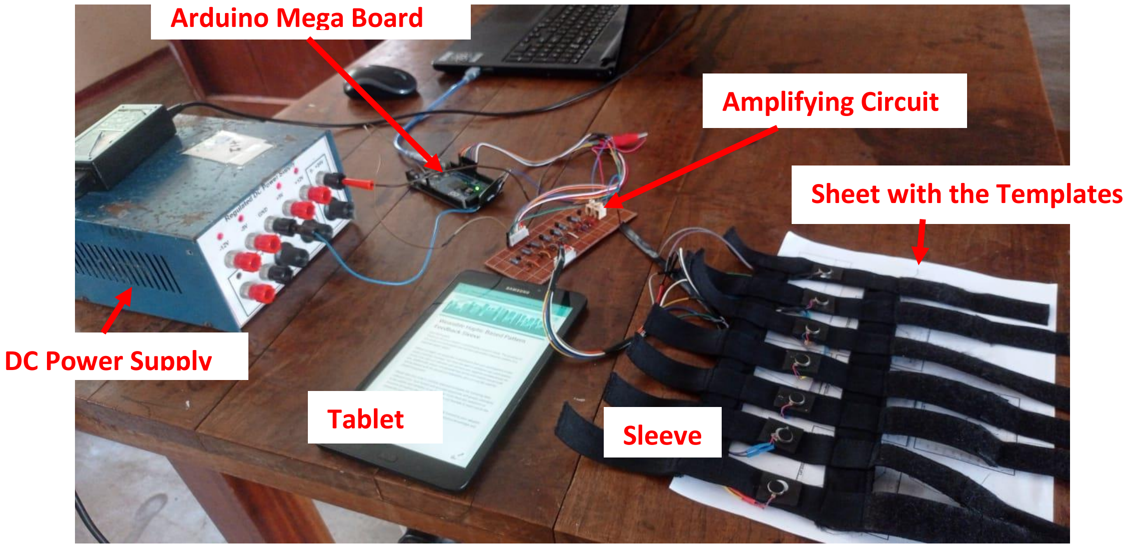

Figure 6: Experiment Setup

Table 2: The order for different templates in experiment

FH	1,11,21,31,41
FL	2,12,22,32,42
T	3,4,5,10,16,26,36,46
TL	6,13,14,15,20,27,37,47
TR	7,17,23,24,25,30,38,48
THA	9,19,29,39,42,43,44,50
THS	8,18,28,33,34,35,40,49

4. RESULTS AND DISCUSSION

According to the collected data of the motors it is visible that frequency range of the motors varied in a wide range from 80Hz to 250Hz. The research work carried in the [3][18], authors claimed that humans have a higher sensitivity in vibrotatile stimulations the frequency around 200 Hz. Therefore, in this research, we have selected seven motors with the operating frequency 200 Hz ± 20 Hz to construct the haptic sleeve.

Twelve volunteer subjects participated in this experiment. 50% of them were male, and 50% were female. The subjects' age range varied from 24 to 27. Seven participants used the right hand for the experiment, while the others used the left. Similarly, 58.3% said that the used hand was their dominant hand. During the experiment, they had to fill out the questionnaire from their available hand.

After the data collection, responses were sorted manually and analyzed. The results show that FH and FL patterns were recognized successfully. Regarding the Gaussian templates, each template was played eight times during an experiment with one subject. 96 responses for each template indicate that a single Gaussian pattern was tested 96 times during the whole experiment. Participants correctly recognized the TL & TR patterns but were confused about the T, THS and THA Templates. Subjects' answers for each template are available in Table 3, and the correct percentage for each pattern is available in Table 4. Furthermore, participants' answers for each Gaussian template are depicted in figure 8.

Table 3: Subjects Answers for each Template

	T	**TL**	**TR**	**THS**	**THA**	**FH**	**FL**
T	73	4	6	11	1	0	1
TL	2	87	0	4	0	1	2
TR	2	2	86	2	4	0	0
THS	16	7	1	52	19	1	0
THA	2	1	1	15	75	0	2
FH	0	0	0	0	0	60	0
FL	0	0	0	0	0	0	60

Table 4: Accuracy of each template recognition

Template	**Correctly Guest Percentage**
T	76.0%
TL	90.6%
TR	89.6%
THS	54.2%
THA	78.1%
FH	100%
FL	100%

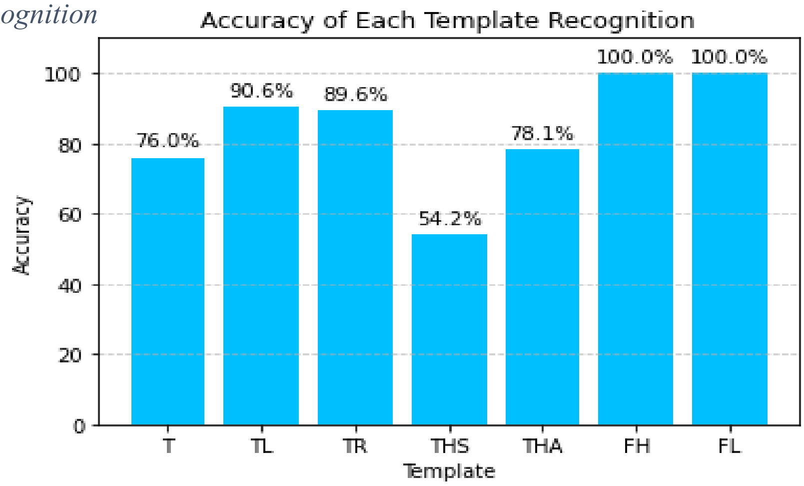

Figure 7: Accuracy of the Pattern Detection

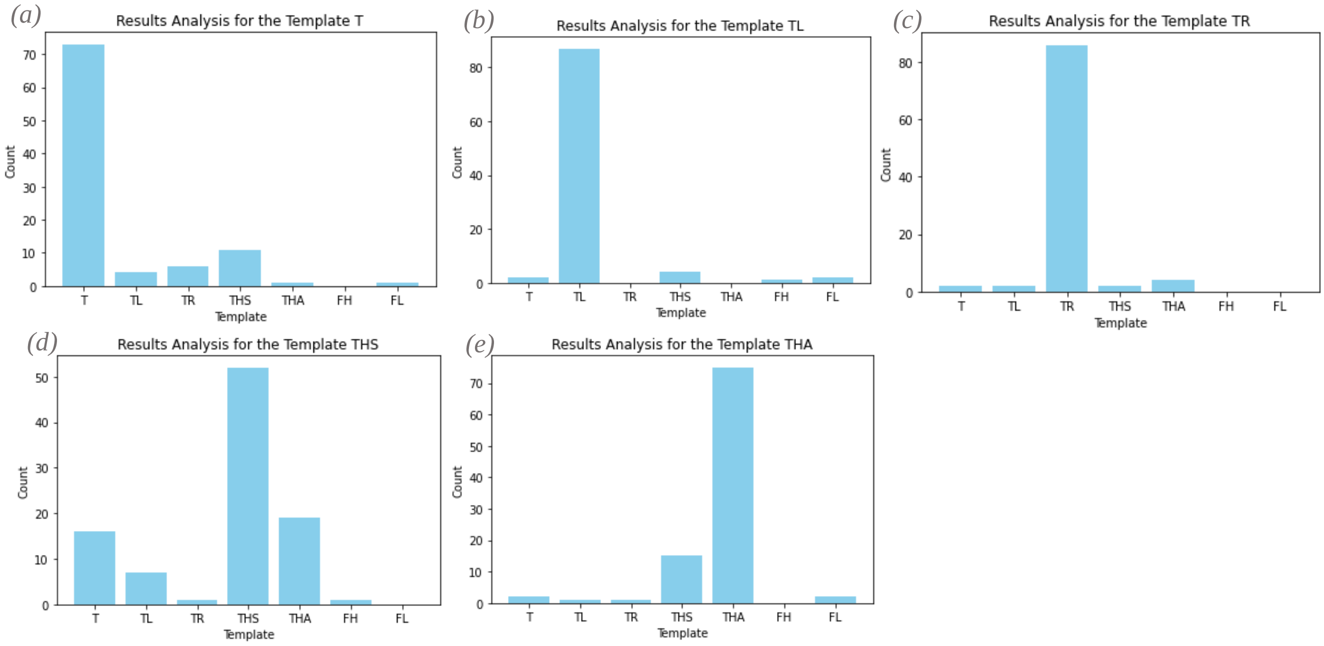

Figure 8: Results Analysis for the Gaussian Templates (a)T (b)TL (c)TR (d)THS (e)THA

5. CONCLUSION

The experiment was conducted in Two phases. Firstly, 7 vibroactuators with similar working capacity was selected and then a haptic-based pattern feedback sleeve was constructed using 7 vibroactuators arranged in a 1D array. In order to select the suitable vibroactuators, frequency domain analysis carried out based on the vibrations acquired via MPU6050 motion tracking sensor. Here, vibrocatuators with 200 Hz ± 20 Hz were used which is a widely used frequency in vibrotactile technology. The sleeve was constructed with a 4cm gap between motors to accommodate the average human forearm. An external power supply was used to power the motors. Participants were able to recognize the FH and FL patterns accurately. The experiment included 12 voluntary subjects, with an equal distribution of male and female participants. In the experiment. According to the result analysis, TL and TR patterns were easier to identify, while the T, THS, and THA patterns had lower accuracy rates. Therefore, with the TR, TL, and T patterns we can create an accurate communication language without a doubt. With practice, participants, improved in recognizing the patterns. Wearing the sleeve was comfortable, and no signs of fatigue were observed. According to the results it is visible that, the proposed method of selecting inexpensive suitable vibroactuators are exceptional to create a haptic feedback sleeve. Overall, the results show promise that the constructed haptic sleeve can be used as a communication tool, but improvements are needed in the device.

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