Preliminary study of the influence of skin stretching in force perception

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Introduction

Haptic technologies, that affect our sense of touch, have experienced a steep development in the last decades, being increasingly implemented in multiple fields [1]. Multiple technologies have been designed in various shapes, such as grounded devices, gloves, thimbles [2], or even haptic suits, with different actuator technologies and stimuli signals. Different criteria has been taken into account for it, varying in function of the goal, context, part of the body or available technologies. However, due to its multidisciplinary nature, multiple aspects need to be taken into account, thus various challenges remain unsolved.

With regard to haptic technology design, there are a myriad of aspects that need consideration, depending on the type of device, application and the body areas that are stimulated. For example, in haptic gloves, the most common design requirements are wearability and portability, notable actuator force capabilities, low weight and volume, minimal power consumption and good ergonomics, among others [3]. Acoustics, however, seems to not be taken into account with the same consideration.

This work focuses on two issues. First, the acoustical perception of the actuators. Haptic systems require, in order to provide feedback, an actuation system, but it generates acoustic noise which, as mentioned before, is not taken into account as much as other features. Therefore, the first part focuses on how each actuator technology affects the users, from an acoustic annoyance point of view.

The second part of this paper addresses one specific type of haptic stimulus. Commonly, haptic research has focused on vibration and electrical stimulation, however there are other less common feedback modalities. Here, the focus is laid on skin stretching. Various devices have been designed with this type of feedback, in most cases focusing in proprioceptive tasks. Bark et al. [4] present a wearable device for the forearm that applies rotational skin stretching, alongside various tests where it was used as a proprioceptive feedback device. Chinello et al. [5] also present a device with this type of stimulation. Here, stretching is applied by servomotors around the forearm, in order to provide cues about a desired pronation or supination rotation of the forearm. In [6], Aggravi et al. combine skin stretching with pressure and vibrotactile feedback, using it for motion control in virtual reality. The Rice Haptic Rocker [7] is another example, aiming to convey proprioceptive information from a myoelectric prosthetic hand, being in this case tested through a size discrimination experiment.

Skin stretching has also been applied with different goals. Ploch et al. [8] implemented it in a steering wheel, with the aim of using it in autonomous cars in order to provide information to the driver about the car's actions. Haynes et al. [9] focus instead on subtle stretching of the skin in the inner forearm with Shape Memory Alloy (SMA) actuators, seeking to study its pleasantness and capability of providing information.

However, its effects on force perception have not been explored in detail. In the second part of this work, a perception study is performed in that regard.

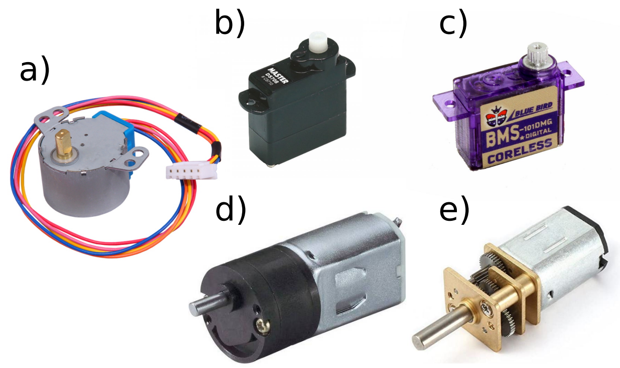

Figure 1: Actuators used in the acoustic annoyance test. a)28BYJ-48 b)Master Servo DS708 c)Blue Bird BMS101DMG d)ASLONG JGA12-N20 e)IGARASHI 20G-50

Acoustic annoyance

In this section, an acoustic annoyance perception study for various motor technologies, within a haptic wearable context, is presented. Electromagnetic actuators are commonly used in various haptic devices, more specifically for force feedback, pressure, squeeze or vibrotactile sensations. However, within this category, there are multiple possibilities. Here three different motor technologies, with a total of 4 actuators operating in various operation modes have been used, as shown in Fig.1, :

- One stepper motor, the 28BYJ-48. It was driven with three different voltage supplies: 6, 9 and 12 VDC.

- Two servomotors, the Master Servo DS708, with plastic gears, and the Blue Bird BMS101DMG, with metallic gears. Both were controlled at two different speeds (slow and fast), with a power supply of 5

VDC.

- Two geared DC-Motors, the ASLONG JGA12-N20 and the IGARASHI 20G-50. The first motor was driven at 6 and 9 VDC, and the second motor at 6, 9 and 12 VDC. These voltages were continuous.

Actuator sounds were recorded with a Bruel & Jaer, Type 2671 microphone, and a SQuadriga II recording system from HEAD Acoustics, in an anechoic chamber located at the TU Dresden facilities. As the actuators cause vibration during their operation, they were placed on a damping foam during the measurements, in order to isolate them from the base structure and minimize possible additional vibration and, therefore, acoustic noise. As the context of this work is within haptics, and therefore on devices that would be worn in various parts of the body such as the hand, a distance of 30 cm is chosen between the sound source and the microphone. Sound recordings present a duration of 6 seconds.

Experiment setup

For the experiment setup, the aforementioned sounds are used. The reproduction system consists of Sennheiser HDA 200 headphones, with their volume adjusted in signal level in order to match the original sound recordings. For every test subject there are 5 training sounds, one sound per type of actuator. After the training, they listen to 3 repetitions of each sample, which accounts for a total of 36 sounds, presented to each participant in a different randomized order. 20 test subjects took part in the experiment, 14 males and 6 females, ranging from 21 to 40 years old. For evaluating the annoyance of the experiment, a semantic test was used. It consisted of 5 annoyance labels: nothing, little, medium, quite and very much. It was possible for the users to choose values in between. Semantic ratings were saved as a value between 0 and 100.

Acoustic annoyance ratings

The sounds and their annoyance are represented in Fig.2. In each spectrogram, the A weighted sound pressure level is represented, alongside the median values for the annoyance, which were obtained through a semantic test, whose range of values is shown in the right.

The first three sounds, which correspond to the stepper motor, present a low annoyance value alongside low loudness for most frequencies. As voltage is increased, loudness increases for higher frequencies too, thus increasing the sharpness. Annoyance's values increase accordingly, as seen in sounds 2 and 3.

For the servomotors the results are more diverse. Unlike the stepper motor, where the motion was continuous in the same rotational direction, the motion range of the servomotors is limited, therefore they move in loops. In sounds 4 and 5, the motion range is 180º, while in samples 6 and 7 it's 120º, due to the servomotor's construction. Thus, sounds 4 and 6, which correspond to higher velocities, present a higher temporal variation (intermittence), showing an increase in high frequency components, thus increased sharpness, alongside loudness. As we can see, users rated sounds 4 and 6 as more annoying. In samples 5 and 7, which recorded only one loop at low velocity, high frequencies present lower loudness, being rated as less annoying.

The geared DC motors, which are signals 8 to 12, were driven at continuous speeds. As voltage is increased, high frequency components and loudness are incremented too, thus having also a higher sharpness. For the small DC motor, in sounds 8 and 9, annoyance remains below medium values, but for the other motor, sharpness and loudness present higher values, alongside a high annoyance rating.

Annoyance results are shown in detail in Fig.3. Al-

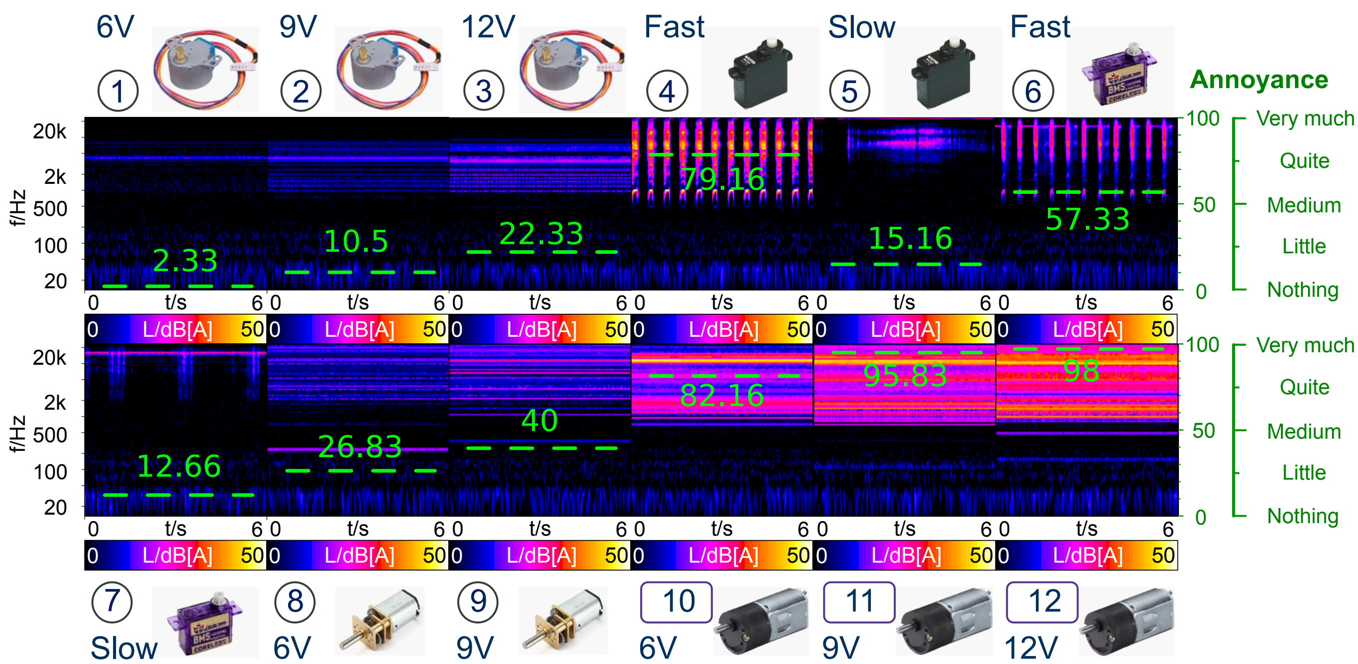

Figure 2: Spectrograms displaying the A-weighted sound pressure levels for every actuator sound, alongside the median of their annoyance values, displayed in green.

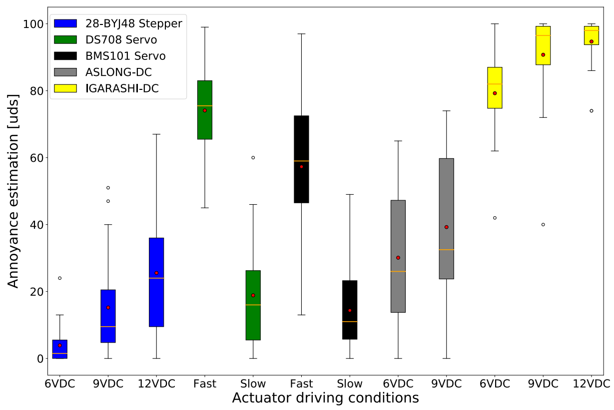

Figure 3: Annoyance values, using median values from each subject for every case. Median and mean values for each case are displayed with orange lines and red dots, respectively.

though there is certainly some variance and a few outliers, the previously mentioned trend for the motors can be appreciated. The stepper motor presents in general a lower annoyance rating. For the servomotors it depends on their speed. Geared DC motors have, in overall, a worse acceptance, which in the case of the small DC motor is medium, but for the other motor the results indicate that it's extremely annoying.

Skin stretching on force perception

Hypothesis

There are multiple physical exercises and interactions where, when the muscles actuate, they move certain parts of our bodies, being good examples of that our hands and arms. For example, when a force is applied with the hand by flexing or extending the wrist, this joint rotates. While doing so, the skin around it is stretched or compressed, depending on the direction. Our hypothesis is that applying additional stretching or compression in those areas may affect our perception of force during such activities. For testing this hypothesis, the dorsal part of the hand, that is affected by the wrist's movements, has been chosen for skin stretching stimulation.

Experiment setup

Therefore, an experiment setup is prepared, as shown in Fig. 4. Users are required to lift weights by flexing their wrists, and skin stretching is applied during the movement. A test bench is designed for that purpose. It is composed of two components: first a load system, shown in Fig. 4 c), where different weights are placed and suspended mid air, held by cables. These weights are changed for every stimulus during the experiment. This system includes a rotary encoder, used to detect weight pulling by the user.

The second subsystem is a wearable dorsal device, shown in Fig. 4 a), which is connected mechanically by a cable to the load system (Fig. 4 b)), in order to be able to pull the corresponding weight when flexing the wrist. In this dorsal device, haptic feedback is performed by a stepper motor, using the same actuator model as in the previous section, the 28BYJ-48, driven by an Arduino Micro alongside an ULN2003 driver board. This stepper motor drives a flexible plastic belt, made of Thermoplastic Polyurethane (TPU), manufactured in blue, as shown in the pictures. Such belt is in contact with the hand, pulling the skin when it's moved. In this experiment, skin stretching is performed in two directions. In the "positive" direction, it pulls the skin from the hand's dorsal towards the wrist. "Negative" stretching does, therefore, the opposite, pulling such skin towards the knuckles.

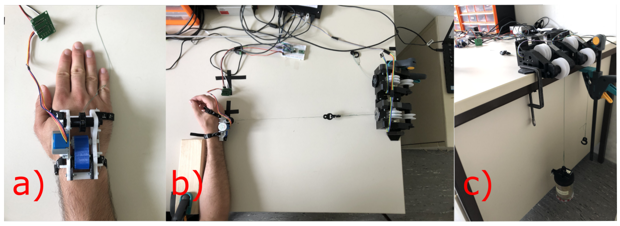

Figure 4: Setup for the force perception experiment. a) Skin stretching wearable device. b) Cable connection for weight lifting. c) Load system.

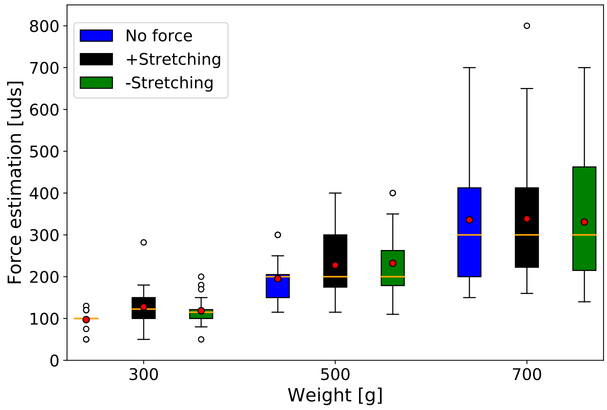

Figure 5: Force perception values obtained through magnitude estimation in the skin stretching experiment. Median and mean values for each case are displayed with orange lines and red dots, respectively.

With such setup, the experiment is configured in the following way. It's a magnitude estimation test, thus the users have to assign a value to the stimulus in comparison with a reference, which is assigned a value of 100 uds. This reference weighs 300 grams. For every stimulus the user needs to lift first the reference, then the target load. The ammount of skin stretching depends on each subject, and is measured before the experiment, by asking the users to flex their wrist, measuring the skin length difference in that area in comparison with the normal relaxed position. There are 3 possible weights: 300, 500 and 700 grams. Regarding skin stretching, also 3 values: no stretching, positive stretching, and negative stretching. In total 9 combinations, with 3 repetitions each, in a randomized order. No prior training was performed.

Ratings

For each condition, only the median value for every stimulus from each subject is used. Nine combinations, grouped according to their weight in the horizontal axis, are shown in Fig. 5. The orange lines are the median values, and the red dots represent the mean values. Let's analyse them in order. First, 300 grams, which is the same value for the reference. We can see that most assessments without skin stretching have been correct, presenting a value around 100. When applying skin stretching with that weight, force perception presents, in general, higher mean and median values. It's worth mentioning that, although it's not the trend, some users reported values lower than 100, which would imply that they felt the load lighter.

For the middle weight (500 grams) the median for all cases is similar, although the mean is higher in the stretched cases. These present a positive skew, towards higher values, while the results without stretching have a negative skew, leaning towards lower values. For 700 grams no noticeable differences are found.

Another interesting detail is the accuracy of the weight assessment. The weight estimation should be 100 uds for 300 grams, 166 for 500, and 233 for 700. For 300 grams users estimations are usually correct, but for the other cases the weight is usually overestimated.

Conclusions

Regarding motor annoyance, stepper motors have presented the lowest annoyance values, although it's important to mention that their speed was lower compared with the other cases. With regard to servomotors, their speed and higher temporal variation (intermittent motion) probably presented a notable influence in the annoyance ratings. Comparing one servomotor with the other, it's surprising that the BMS101DMG servomotor, which has metal gears, reported lower annoyance values in comparison with the other servomotor, which uses plastic gears. This is an aspect that should be further investigated, and could be caused by the shorter motion range, as the DS708 performed 180º rotations, while the BMS101DMG only 120º. Geared DC motors presented, in overall, the highest annoyance values. The ASLONG actuator displayed medium values, and the IGARASHI was perceived as extremely annoying. Thus, according to these results, geared DC motors would be less suitable. However, further work should be performed in this field, where acoustic noise is taken into account alongside other motor features, such as torque, volume, weight and power consumption. Additionally, for better comparison, the motion should be as similar as possible, in terms of range of motion and motor speed, in this case according to the context, which is haptics.

Regarding skin stretching, results are varied. Test subjects reported a mixed response to this type of feedback. According to our results, skin stretching affected users' force perception mostly for low weights, having also a mild influence for 500 grams, but no effect whatsoever for 700 grams. This may be caused by multiple reasons, such as a lack of synchronization between the feedback and the flexion of the wrist, or the use of this effect in the incorrect activity or context. A different test scenario should be prepared in order to confirm the effects of this type of haptic feedback in force perception.

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