DeMaMech Report

Japan

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Tin Yan Nai

1. Personal Data

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1. Executive Summary

The Asian culture always interested me. Due to my Chinese origin I've been taught lots about the history, cultural difference and similarities within Asian countries. Since I've been born and raised in The Netherlands, the thought of living in an Asian country always appealed to me. The DEMAMECH programme gave me the opportunity to get a preview of this desire. During a period of 5 month I've joined the BioRobtics Laboratory of Prof. Maeno at Keio University in Tokyo Japan.

In the period of stay in the laboratory I joined their already consisting research in developing a tactile display. The goal of this development is to enable the projection of certain textures on the finger. Resulting the same tactile sensation as if you are touching the texture yourself. In the laboratory an ultrasonic transducer is used as a tactile display. This transducer has a vertical vibration mode and with use of ultrasonic vibrations we were able to control the surface friction. This development is still in a young state of development. So I've focused on acquiring quantitative data on human difference thresholds to these ultrasonic vibrations, which is used to control the surface friction.

The research started out with the trajectory of the problem analysis, literature survey, followed by building the experiment setup, conducting the experiment and data analysis. The collaboration with two other students who are in the same project was hard, mainly due to the communication barrier and difference in approaching problems.

For the difference threshold experiments, 18 subjects were tested for the sensitivity towards changes in the amplitude of the ultrasonic vibration and the frequency after amplitude modulation. The vibration amplitude of 2 um results in the maximum of sensitivity in detecting a change in the amplitude. The frequency difference threshold was tested using amplitude modulation. This means that the surface friction changes according to the frequency. The resulting tactile sensation is feeling an alternating convex and concave surface, which could be described as perceiving ridges. Just like in reality the human finger is more sensitive perceiving changes in bigger spatial coding of the ridges. But unlike reality, a small spatial coding doesn't result in the sensation of roughness.

During my stay I did manage to finish the research like planned. But due to the fact that the ultrasonic transducer used wasn't strong enough, a small error is included in the resulting data.

Life in the laboratory is nothing but a new experience for me. Long hours in the lab and joining the lab activities like summer camp, drinking parties and going to hot springs (*Onsen*). Beside the lab life I tried to explore Japan and also its culture and language. With a vocabulary that could be counted on both hands I did managed to get by. I also found the chance to explore countries around Japan. Which really showed me how unique this culture actually is. The whole experience gave me a whole new perspective of how different cultures could influence the way people think and act. Not only academically but also socially. I've learned to coop with these differences and tried to pick up the best out of it.

2. Travel schedule

Towards Japan:

Swiss International Airlines	
8 April 2007	Amsterdam – Zurich
9 April 2007	Zurich – Tokyo

Towards The Netherlands:

Swiss International Airlines	
17 September 2007	Tokyo – Zurich
17 September 2007	Zurich - Amsterdam

3. Research paper

Analysis of difference thresholds of fingertip using amplitude modulated ultrasonic vibrations

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Abstract – *In the present study an assessment has been conducted in order to find the difference thresholds of the human fingertip for two aspects of amplitude modulated ultrasonic vibrations. First the threshold for amplitude change of the carrier wave was assessed. The change in this amplitude is correlated to the surface friction of the ultrasonic transducer used. Second is the threshold for the change in frequency of the signal wave. The frequency and waveform here determines the behaviour of the surface friction. These data reveal the sensitivity of the fingertip for change in friction on the surface of the transducer.*

1. Introduction

The human skin is not only a first barrier against bacteria and viruses but it also plays an important role in tactile perception. When looking at the skin of a human finger, there are several layers: epidermis, dermis and subcutaneous fat tissue, in which mechanoreceptors are embedded. These receptors react to mechanical deformation of the skin. Four mechanoreceptors can be found in the glabrous skin of the palm and fingertips, which each has its own task in the tactile perception. Furthermore they differ in density and the location within the skin. More to the surface of the skin are the Merkel receptors, indicated as SAI (slow adapting afferents, type 1, pressure sensor) and the Meissner receptors, indicated as FAI (fast adapting afferents type 1, velocity sensor). Embedded deeper in the skin are the Pacinian Corpuscles, indicated as FAII (fast adapting afferents type 2, acceleration sensor) and the Raffini endings indicated as SAII (slow adapting afferents, type 2, direction sensor) [1].

Perceiving a certain texture does not only depend on the tactile sensing of the skin. However, it is also correlated to the visual, audio and kinaesthetic cues. Through experience in life, a human being is able to build connections between these cues. This would make it possible to recognize a certain texture and its characteristics when one gets exposed to it. In recent studies, one tries to imitate the tactile sensation of certain textures. In other words, triggering the mechanoreceptors in the finger in such a way the subject perceives it as the texture stored in his or her memory. In this framework, the focus will only lie on the tactile perception in the distal phalange.

Up until now there are several ways to display tactile sensation on the finger. Purposed methods are such as ICPF actuators, electro stimulation and acoustical vibrations. However, all these designs face problems with power management and control accuracy. In this research the ultrasonic transducer will be used to induce tactile sensation. This tactile display makes use of piezoelectrics to generate ultrasonic vibrations. It is able to display small amplitude vibrations, in the range of a few micrometers as it has a high response. It also has the characteristic of a larger frequency resulting in smaller amplitude needed for producing a certain output power. Due to the promising characteristics of this tactile display, several parties have been conducting research on tactile displaying using this method.

T. Watanabe proposed a way for controlling the tactile sensation of the surface roughness making use of the 'squeeze air film effect' [2]. M. Biet has investigated the determinants of friction at contact. Suggesting that the tactile perception of texture depends on the bearing forces exerted by the surface on the skin [3]. T. Maeno confirmed that realistic surface waves can de displayed with the use of amplitude modulation of ultrasonic vibration [4]. L. Winfield purposed a method to create spatial sensation by using the feedback of the finger position and velocity and varying the surface friction accordingly [5].

Purpose

The ultimate goal of tactile displaying is that one could actually feel and recognize a certain texture in virtual reality. In order to achieve this goal one of the requirements is to design the display signal, which corresponds to a certain texture. This study aims at collecting quantitative data of amplitude and frequency difference threshold of the fingertip for ultrasonic vibration using Amplitude Modulation (AM). These data provide more fundamental knowledge when designing a display signal. This might allow the possibility to subtract the characteristic wave for a certain texture.

Amplitude Modulation

Amplitude modulation has been used to control the vibration of the ultrasonic transducer. The applied AM wave consists of two components, the carrier wave and the signal wave. The carrier wave has a constant amplitude and frequency. The amplitude of the carrier wave will be modulated according to the characteristics of the signal wave. The resulting waveform will have a signal strength that corresponds to the signal wave, like shown in figure 1. When this is applied to an ultrasonic transducer, the signal strength will determine the amplitude of the vibration. The carrier wave frequency is in the range of tens of kHz. This is way above the tactile range of the mechanoreceptors in the fingertip; the subject will not be able to feel the vibration. But the subject will be able to feel the effects of the ultrasonic vibration, which is called the squeeze film effect.

Between the surface of the ultrasonic transducer and the pad of the fingertip a squeeze air film will arise. Basically this means that due to the high vibration frequency and the relative small gap distance between the finger and surface, the air gap will almost get enclosed. This causes the pressure in this air film to rise above ambient pressure. This causes an upward force called the squeeze force and it lowers the actual contact force. This means that this air film between the finger and surface will act as a lubricant and lower the surface friction. The amplitude of the vibration determines the magnitude of the squeeze force. Either increasing or decreasing the amplitude of the vibration will indirectly result in respectively lower or higher shear forces on the ridges of the skin. When the signal wave is applied on the carrier wave, the result will be a controlled variation of the surface friction. This will allow us to create virtual gratings on the surface of the ultrasonic transducer.

Figure 1. Schematic representation of an amplitude modulated ultrasonic vibration, with a sinusoid signal wave.

Hypothesis

Changing the carrier wave amplitude will result in a change in the shear force applied on the finger during exploration of the surface of the ultrasonic transducer. A change in the higher range of vibration amplitude will result in a high amplitude difference threshold. Since the lubrication effect of the surface by the squeeze film effect has its limit.

When a sinusoid is used as the signal wave, it is possible to create alternating surface friction. When relating this to the shear forces in the skin, this results in the perception of alternating convex and concavity. Lower signal wave frequency will generate a larger virtual spatial coding. This means that when the frequency gets too high, the subject will not be able to discriminate the spatial resolution anymore. The difference threshold frequency will get larger when the reference frequency gets higher since it will be even harder to differentiate two signals with a high frequency.

2. Preliminary Experiment

The preliminary experiments are designed to find the characteristics of the ultrasonic transducer, which will be used throughout the experiments. With use of the Polytec-laser Doppler velocity meter CLV3000, the vibration amplitude of the ultrasonic transducer could be measured. The first test showed the input voltage and vibration amplitude relation, which is displayed in figure 2. As the graph indicates the ultrasonic transducer has a vibration limit around 3µm. The second test, displayed in figure 3, shows the normal force on the surface in relation to the vibration amplitude. Weights are put on the ultrasonic transducer with an elastic body between the vibrating surface and the weight itself. The result of the experiment indicates a change in the vibration amplitude when a normal force is applied on the surface. Since the aim is to find a difference threshold, we only consider the

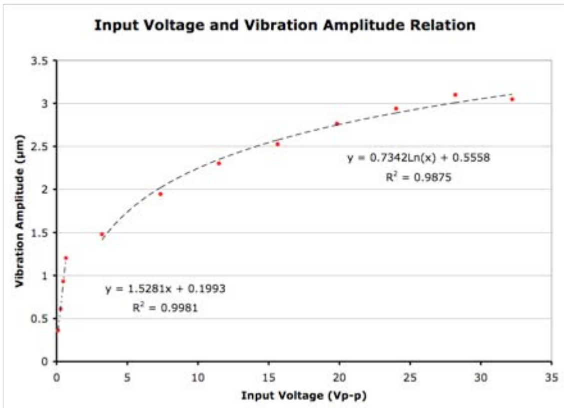

Figure 2. Relation is shown between the input voltage and the vibration amplitude of the ultrasonic transducer.

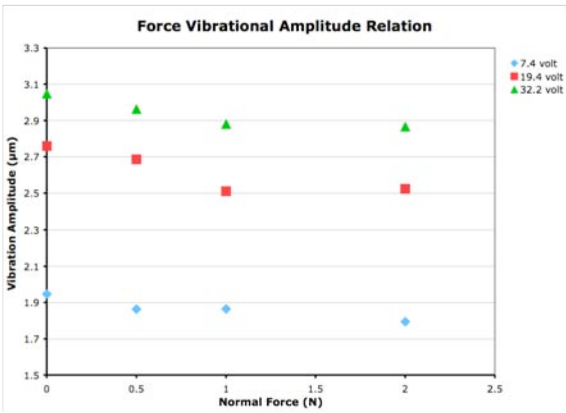

Figure 3. Change in vibration amplitude occurs when a normal force is applied on the surface of the ultrasonic transducer.

values relative to the reference amplitude. This change caused a deflection of the obtained vibration amplitude threshold values of 3% under a normal force of 0.5N. The normal forces during the experiments varied between 0.1 and 0.5N.

3 Method

Experiment setup

In order to display the ultrasonic vibration to the finger of the subject, an ultrasonic transducer of the type Fuji Ceramics Corporation, FBL28452HS has been used throughout all the experiments. The ultrasonic wave will be designed by using the computer wave editor program NF 1050 and fed to the NF wave factory WF 1946A 2CH. This wave factory is able to generate the AM wave. The output signal will be amplified using NF HSA 4011 and finally led to the ultrasonic transducer. To monitor the exerted normal force on the surface of the transducer, a Wheatstone bridge has been built. And the applied force will be constantly logged using Keyence NR500 and Wavelogger. The ultrasonic transducer has its natural frequency at 28.5 KHz. Due to housing used to keep the transducer upright; the resonant frequency differ slightly to 28.35 KHz. All the vibrations will be displayed on the distal phalange of the index finger of the dominant hand. The subjects will all be blindfolded to remove the visual cues. And given a headphone with white noise to mask the audio cues.

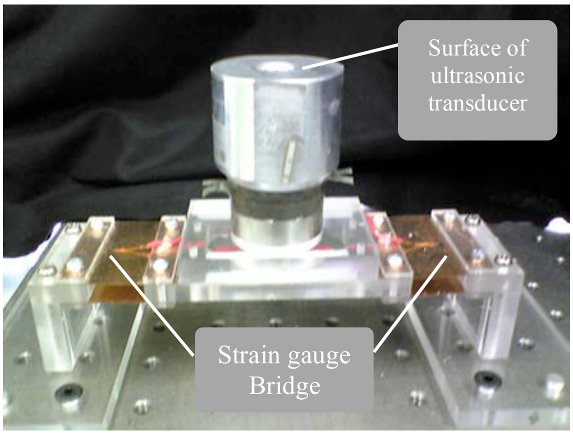

Figure 4. Experiment setup showing the ultrasonic transducer in its strain gauge bridge housing.

Experiment I

The first experiment will quantify the threshold for detecting a change in the amplitude of the carrier wave. Large numbers of trials will cause fatigue for the subject, which causes bias in the results. So the method of Best Parameter Estimation by Sequential Testing (Best-PEST) will be used to conduct the experiment. This is an adaptive procedure suggested by Pentland (1980) [6,7].

Every trial the subject will be asked to compare two signals. First the reference signal will be displayed for 4 seconds then the comparison signal will be displayed for another 4 seconds. Within this interval the subject has to explore the surface of the ultrasonic transducer. Each test will consist of 10 trials around 7 different reference amplitudes {0 3.2 5.2 7.4 9.4 11.5 15.6$V_{p\text{-}p}$}. The carrier wave is a sinusoid with a frequency that remains constant at 28.35kHz. The signal wave component will be left out during this experiment. The subject will be asked to answer whether a change could be perceived within the exploration interval. The answer that the subject gives will be either yes or no. The amplitude will be decreased by a step when there is a perceived difference, until the response changes. The amplitude will be increased until the next change of response. The comparison signal will be calculated with the use of the Best-Pest calculator, developed by the Swiss Federal Institute of Technology Zurich. With this calculator the threshold will be statistically estimated after each trial and the comparison signal will be changed accordingly. The threshold for change in amplitude of the carrier wave will be at 50% of detection.

Experiment II

In this second experiment the applied signal has been amplitude modulated. The signal wave is chosen to be a sinusoid. As mentioned before the subject will perceive this as feeling ridges on the surface of the transducer. The spatial code of these virtual ridges is determined by the frequency component of the signal wave. The following experiment aims at finding what change in the frequency of the signal wave human beings could detect. The method will remain the same as in experiment 1. The frequency of the carrier wave still remains 28.35kHz. The set of reference frequencies will be {10 50 100 300 Hz} chosen within the range of high tactile sensitivity. The experiment will be conducted around two signal wave amplitudes of {8, 20 $V_{p\text{-}p}$}.

4. Results

For each experiment subjects between the age of 20 and 26 has been assessed. As mentioned before the applied normal force on the transducer varies in the experiments between 0.2 and 0.5 Newton.

Vibration Amplitude Difference Threshold

In total 13 subjects participated in this experiment. The group has been split into two, each with different reference amplitudes. When the difference between the reference and comparison amplitude is large, at least 2 times the reference amplitude, the subjects described the sensation as feeling a ‘bump’. If the difference was less severe the subject described it as a change in ‘smoothness’ of the surface. The result of the experiment is indicated in figure 5. It reveals that up until the vibration amplitude of 2μm, the squeeze force is still lower than the applied force. So consequently the subject only feels a change in the surface friction when the comparison amplitude is chosen larger than 2µm. When the vibration amplitudes become larger, the subject will get more difficulties in distinguishing the difference between the two signals. During the experiments reference amplitude of 15.6V (2.5µm) has been taken out since the subjects were insensitive in perceiving the change in vibration amplitude. Figure 5 also shows the start of this increasing insensitivity for change in surface friction as the reference amplitude becomes larger. This is due to

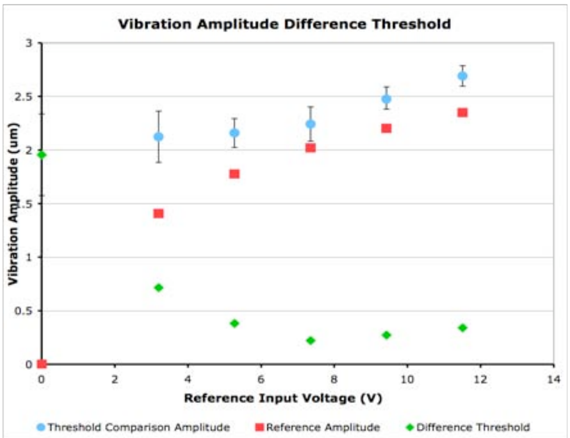

Figure 5. Shows the relation between the difference thresholds at its correlated reference amplitudes.

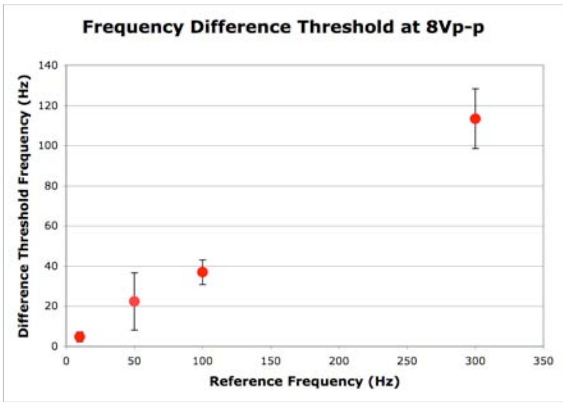

Figure 6. Shows the difference threshold as function of the reference frequency.

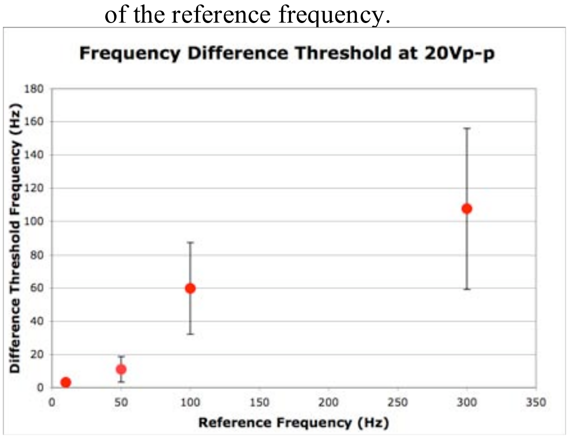

Figure 7. Shows the difference threshold as function of the reference frequency.

the fact that when the finger gets completely supported by the air film, any change in the thickness of this film will not change the surface friction anymore. Thus generating large difference thresholds.

Frequency Difference Threshold

Five subjects have been tested in this experiment. Figure 6 & 7 presents the frequency difference threshold at several references. The data shows an increasing insensitivity for change in frequency. The ability to distinguish the difference between two spatial resolutions becomes hard when the frequency gets higher. The threshold of a human finger to discriminate a spatial resolution lies between 1-2mm. Beyond this point it will feel more like a roughness than an spatial coding. This experiment was able to show that with amplitude modulation, the same effect could be recreated. Although at frequencies higher than 500 Hz the subject didn't perceive it as roughness but rather as vibration.

5. Conclusion

The hypothesis has been verified. However, the test for vibration amplitude difference thresholds, with reference amplitude larger than 15.6V has been aborted. This has been done due to safety considerations. In the future work, the change in vibration amplitude due to the applied force needs to be compensated. And real texture wave should be analysed with the obtained difference threshold data. Appropriate textures could be selected to display with the use of the ultrasonic transducer.

References

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4. Exchange student life

On my first day in Tokyo one of my lab mates picked me up from the bus station. He showed me the way to the dorm, the lab, gave me tour around campus and he arranged a meeting with the professor for me. Keio University is quite big and has several campuses spread around town. My lab is in the Science and Technology Campus called Yagami is situated in Hiyoshi. The professor gave me a lot of freedom in choosing my research topic and working hours. Every month we arranged an individual meeting to discuss the progress of the research. He usually approves any plans for your research, as long as it sounds interesting to him. The amount of freedom could be quite scary, since you only have little guidance and the responsibility is in your own shoes. So the first thing I did was making a rough time schedule for literature survey, research topic, experiments and analysis. Once in two weeks there is a lab meeting which attendance is obligated. The lab members will have to present their progression of their research. Since most of the lab members weren't very proficient in English, they decided to do the presentation in Japanese but have the slides in English for me to write.

Keio University arranged my accommodation at one of its dormitories before my arrival. My dorm is called Hiyoshi International House, as the name already reveals it's a dorm for international students. So it was quite easy to get around there, since everybody speaks English. Everyone is very helpful when you need some translation, a guide to show you around or just a drinking partner, it wouldn't take long to find someone. And otherwise there are Residents Assistants who are locals who could assist you as well. The apartment I had to share with one housemate. The room is well furnished with a bookcase, a bed, a table, we even have our own refrigerator and Internet connection. We had to share the kitchen, toilet and bathroom. The location of the dorm couldn't be better. It only takes 10 minutes by foot to get to Yagami campus. Saved me the daily experience of commuting in overcrowded trains during rush hours and the experience of sleeping in the lab. Apparently is quite usually for students to sleep in the lab after overtime in the lab. So the first thing that I noticed when entering the lab is seeing two mattresses, blankets, refrigerator, water boiler and cooking appliances. Luckily I could enjoy all of this in my own dorm.

Daily I went to the lab to work on my research. Most of the lab mates start their day around noon and leave around midnight. I've noticed my inefficiency at night, so I kept the Dutch hours of 9 to 5. I knew very little of the subject I've spend a long time gathering information and finding a research topic. The troublesome thing was that most of the documents of past researches were in Japanese. Only some of the papers were translated into English, but then again usually they are fairly brief. Luckily there were enough foreign papers touching the same subject.

At night we usually go out for dinner. Cooking dinner could save you some money. But my aim was to try as much different Japanese dishes as possible, so I didn't cook at all. Food isn't too expensive in Tokyo and in a suburb like Hiyoshi it is quite reasonable. There is so much choice, whether you just want a quick ramen or a five-course meal, you can find it all. Usually we go for pasta, sushi (鮨), yakiniku (焼肉) or bento (弁当) set.

The one thing that I've immediately noticed during my stay is the tremendous amount of drinking parties, nomikai (飲み会). Either held by the lab, clubs or friends. I do have to say that is the best way to get to know the locals and to learn Japanese. Since most of the Japanese drinking games requires you to speak a little Japanese. Sometimes it may be counting numbers or naming the Yamanote Line train stops. When you aren't able to do so you loose. I guess the consequences are clear. Getting to know a local is much easier during these drinking parties. I've noticed that they feel looser and their ability to speak English increases with the amount of glasses they have drunk. So it made it easier to get to know each other better.

When I reached Japan, my knowledge of Japanese was limited to the two-hour crash course Japanese that I practiced on the plane towards Tokyo. And luckily I could read some of the kanji characters, which usually are similar to Chinese. But communication was really the biggest trouble. Very few people on the streets are able to speak English, but strange enough I do see a lot of people studying English. Even in the laboratory this was one of the major problems. I've soon noticed that most of them weren't able to understand when you speak English, but when you write it down then they'll usually get it. To make things easier I did sign up for the Nihongo Club. Every week a party of Japanese elderly will gather and try to teach foreigners some Japanese. I've managed to attend this for a couple of months. And also with a little help of my lab mates I've learned a handful of Japanese phrases, enough to get me through daily life and of course through the drinking games.

Since most of the international students do like to travel around when there is a holiday or weekend, it is quite easy to find a travel companion. Besides exploring sights around Japan, we got to see other cities like Taipei and Seoul as well. This was good experience to compare a few Asian cities. You'll soon notice that you've already adjusted to the orderly Japanese society and customs. And you'll soon start to realize that the town and laboratory you have been walking around in has become your home.

5. Summary

To be in such a magnificent metropolis as Tokyo has been quite an experience. Firstly I needed to adjust to enormous crowd of people on the streets at any hour of the day. Second I needed to learn the language and find ways to communicate. And thirdly I needed to get used to the Japanese customs and traditions. In this environment you still needed to start a research and get to finish it as well. So one big advise is preparation. Knowing what you need to do and what you want to accomplish safes you a lot of time and trouble. All the hard work and long hours in the lab didn't go in vain. Every day in Japan was something new and special; the people, cars, trees, streets, buildings, dogs and even toilettes.

I'll defiantly want to go back again!