Dtact: a tactile device which changes how a surface is perceived

Frederic Giraud, Christophe Giraud-Audine, Michel Amberg, Betty Lemaire–semail

Dtact: a tactile device which changes how a surface is perceived

Frédéric GIRAUD*, Christophe GIRAUD-AUDINE, Michel AMBERG, Betty LEMAIRE−SEMAIL
Univ. Lille, Centrale Lille, Arts et Metiers ParisTech, HEI, HeSam, EA 2697 - L2EP - Laboratoire d'Electrotechnique et d'Electronique de Puissance, F-59000 Lille, France

Abstract:
Among human senses, touch is much less understood than hearing or sight. However, today, new emerging technologies are placing tactile interaction at the heart of the communication with smart devices (smartphones, tablets, …). Hence, studying the sense of touch is now very important, in order to better understand the mechanisms induced from the mechanical excitation of skin to the feeling experienced by a user. Also, being able to detect and measure tactile disabilities, and to propose rehabilitation is a challenge; otherwise, numerous people can drift away from these objects as they can't be used easily by them.
In the paper, we present Dtact, a device which stimulates the finger pulp with a calibrated stimulation. It is designed to be used during experimental studies aiming at recording nerves and brain activity of a user touching its surface. It will be used to detect tactile disabilities, and perhaps some exercises could be programmed for the purpose of rehabilitation.

Keywords: Piezoelectricity, tactile, power electronics

Introduction

Among human senses, touch is much less understood than hearing or sight. However, today, new emerging technologies are placing the tactile interaction at the heart of the communication with smart devices. Tablets, smartphones are now commonly used by people all around the world, and many human to computer interfaces use flat tactile display made of glass to the detriment of knobs and buttons which produce a physical interaction much more contrasted. Hence, studying the sense of touch is now very important, in order to better understand the mechanisms induced from the mechanical excitation of skin to the feeling experienced by a user. Also, being able to detect and measure tactile disabilities[1], and to propose rehabilitation is a challenge; otherwise, numerous people can drift away from these objects as they can't be used easily by them.
One can find many examples of tactile devices in the literature. For example, Variable Friction Devices use electrostatic forces [2] or Ultrasonic Vibrations [3] to modify friction between the fingertip and the touched surface. If the fingertip's position is measured, it is possible to modulate the friction in order to create the same lateral forces as those created when the finger touches a real rough surface [4]. These devices are now widely studied, and the contact mechanisms were finely described [5]. However, the tactile stimulation is very dependant with regards to the user and some external factors like the cleanness of the surface, the property of the user's skin,...[6] If a tactile stimulation can actually be provided to the users, the stimulation is not calibrated, and this alter the reliability of the studies.

In the paper, we present Dtact, a device which stimulates the finger pulp with a calibrated stimulation. It is designed to be used during experimental studies aiming at recording nerves and brain activity of a user touching its surface. It will be used to detect tactile disabilities, and perhaps some exercises could be programmed for the purpose of rehabilitation. To be efficient, the device needs to accurately present a calibrated stimulus to the user. Hence, the paper is organized as follows: first, we present Dtact, and the principle of the tactile stimulation, then we present the system and the control achieved to obtain a same stimulation from one user to the other. A conclusion is finally given.

Presentation of the Device

When a surface vibrates, the perception of its roughness is altered by vibrations. This phenomenon was firstly introduces by [7], and has been attributed to the squeeze film effect: the air trapped between the finger and the plate compresses and depresses at high frequency according to a non-linear polytropic transformation. Friction reduction results from this process. The authors have confirmed through a psychophysical study that their surfaces made of sand paper could be perceived more or less rough as the vibration amplitude increase. The device is built up with a plate actuated by two langevin transducers at its edges. Because the plate shows nodes of vibration, the feeling is not equal all over the device. To operate, the plate has to vibrate at a frequency above 25kHz, with a vibration amplitude within the range of 1 μm. This effect is confirmed by [8]; in this paper, the authors measured the vibration produced by the contact with a real rough surface.

they demonstrate that with vibration, the vibrations are reduced. This result is confirmed by an experimental study.

In [8], The vibrating plate is directly mounted on a Langevin transducer. The plate uses its first bending mode, and shows antinodes of vibration arranged on a circle. In the middle of the plate, the vibration is equal, but the exploration area is limited. Figure 1 presents the perception of a rough surface according to the vibration amplitude of the plate.

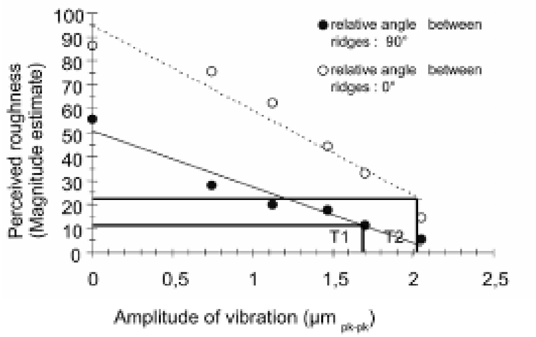

Fig. 1: *perceived roughness as a function of the vibration amplitude*

In order to obtain a same vibration amplitude all over the vibration area, Dtact uses a large area piezoelectric Langevin transducer. The FBL28502HA from Fuji Ceramics has a ϕ50mm diameter, a resonant frequency of 28kHz. The tests have shown that it could vibrate at more than 3µm with a supply voltage of less than 30V. Figure 2 shows the one Dtact.

Fig. 2: *Dtact when touched by a user*

In use, a rough surface is glued at the top of the Langevin transducer. The operator of Dtact needs to change the surface, to present several initial roughnesses, as depicted in figure 3.

In order to facilitate the work of the operator, several transducers receive a different rough surface. In order to calibrate the vibration amplitude, it is necessary to implement a control, so that the experimental tests can be achieved with the same operating conditions. The next section presents the control developed for Dtact. In the paper, a head designate the langevin transducer and the rough surface mounted on top.

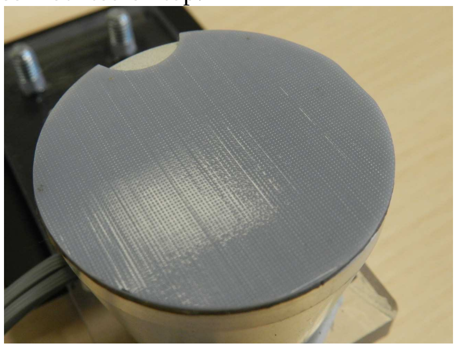

Fig. 3: *The rough surface glued at the top of the Langevin transducer*

For the experiments, it is necessary to measure the forces of the contact between Dtact and and user's fingertip. For that purpose, the head is mounted on a mounting piece. This piece has two functions. First, it has to easily couple the head to the force sensor. Second, it has to firmly attach the transducer without damping the vibration. The head is then maintained in position by a claw which is closed at the position of the vibration node of the transducer.

Design of the vibration amplitude controller

To operate efficiently, the Langevin transducer has to be supplied with a sinusoidal voltage at the device's frequency. However, from one head to the other, the resonance frequency may change due to geometry or materials 'properties variations. In use, the temperature also affect its value, and its tracking is then necessary.

Moreover, the voltage amplitude has to be adjusted to compensate for the electromechanical conversion factor's variations from one head to the other, and also because the finger damps differently the vibration from one user to the other. For example, figure 4 shows how the vibration amplitude w(t) is modified when the voltage amplitude and frequency supplied to the transducer is maintained constant, and when a user press more or less on the surface. As it can be seen, the vibration amplitude vary, depending on how the user touches the surface, which is not acceptable in our application.

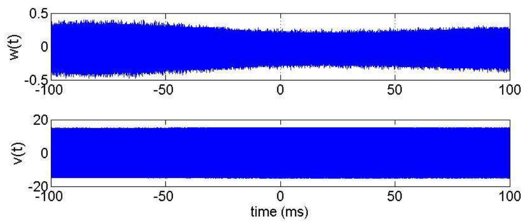

Fig. 4: *vibration amplitude w(t) of the transducer (top) when the voltage's amplitude and frequency are maintained constant (bottom) when a user modifies his pressure on the head's surface*

To compensate for the vibrations' variation, a closed loop control is achieved. With DTact, we use a vector control in order to track the resonance frequency and to control the vibration amplitude in the same time. For that purpose, an additional piezoelectric patch is glued on the counter mass of the transducer. It is used to measure the vibration amplitude w(t) in real time. The Analog to Digital Converter (ADC) of a microcontroller is used to measure w(t) in the rotating reference frame of the voltage, and we write:

$$w(t) = (W_d + jW_q)e^{j\omega t} \qquad (1)$$

where Wd and Wq are the co ordinates of the vector w in the rotating reference frame attached to the voltage, and $\omega=2\pi f$ is the pulsation of the voltage. In [11], it is shown that at resonance frequency, Wd=0; the resonance frequency tracking consists in:

- increasing the frequency if Wq>Wth,
- decreasing the frequency if Wq<-Wth.

where Wth is a threshold which deactivate the strategy. In our application, Wth is equal to 0,1µm. Of course, this method needs to know an approximation of the resonance frequency. This is why, every head is identified once. This method is explained figure 5.

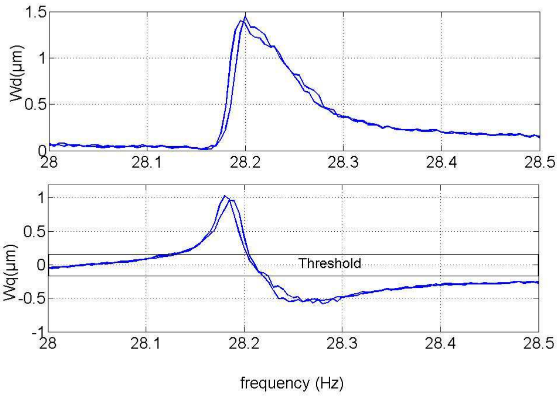

Fig. 5: *Wd and Wq at variable frequencies. The resonance apprears around Wq=0*

The langevin transducer is a mechanical resonator, and the relationship between the voltage v(t) and w(t) is given by:

$$M\ddot{w} + D_s w + Kw = Nv \qquad (2)$$

where M, Ds, K and N are the modal mass, the internal damping coefficient, the modal stiffness and the force factor respectively.

At resonance, eq (2) is simplified, and leads to write:

$$2M\dot{W}_d + Ds\dot{W}_d = NV \qquad (3)$$

where V is the voltage amplitude. This is a first order equation, and this is why, a simple PI controller for the closed loop control is used. Figure 6 shows the result obtained for a step variation of Wd from 1µm to 1.5µm.

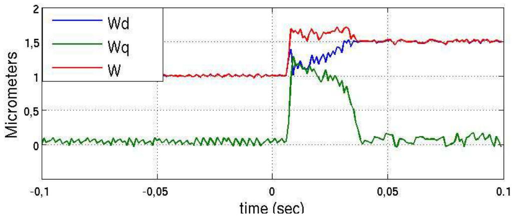

Fig. 6: *response of the transducer to a step variation from 1µm to 1.5µm*

The figure shows that at before t=0, Wd=1µm and Wq=0, meaning that the transducer operates at resonance. Then, at t=0, the reference change and Wd suddenly increases, due to the PI controller. However, this induces also an increase of Wq: the transducer is going away of its resonance. This is due to the non-linearity of the transducer, which resonant frequency shifts with the operating point. The frequency shift is compensated by the frequency tracker which decreases the working frequency f of the transducer. The time response is equal to 40msec for Wd and Wq. This is long. But the response time of $W = \sqrt{Wd^2 + Wq^2}$ which represents the vibration amplitude, is much faster.

Figure 7 presents the vibration amplitude as a function of time when the user is pressing more or less on the head's surface. As it can be seen, the vibration amplitude is now kept constant. Compared to the figure 4, the voltage now vary with time in order to compensate for the damping produced by user's finger: when a reduction in vibration is observed, the controller compensate by increasing the supply voltage.

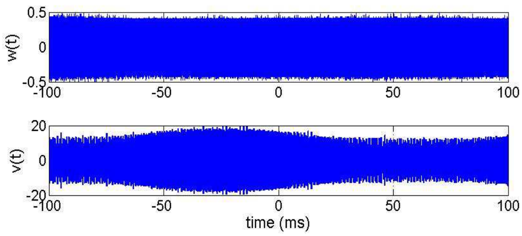

Fig. 7: *vibration amplitude w(t) of the transducer (top) in closed loop; the amplitude of the voltage (bottom) vary when a user modifies his pressure on the head's surface.*

This control is embedded into a tiny ARM core Microcontroller (STM32F4 from STMicroelectronics), as depicted figure 8.

Conclusion

We present Dtact, a device which can modify how a surface is perceived. Because it will be used in a medical environment to study the sense of touch, a particular attention has been made to obtain a

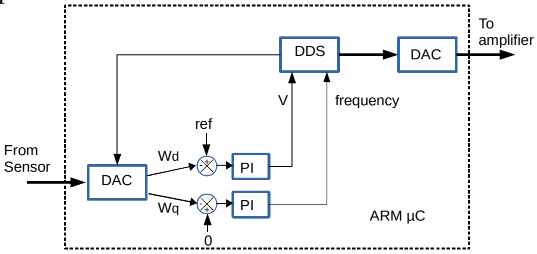

Fig. 8: *The control scheme as embedded into a microcontroller*

constant vibration amplitude during touch. It is achieved by choosing a large area Ultrasonic transducer to produce the vibration. A closed loop control has been implemented in order to compensate for the discrepancies from one to the other, and also, for the damping added when the user presses on the head's surface.

In future work, Dtact will be used as a tool to study how rough surfaces are perceived.

Acknowledgements

This work was realized within the framework of the MINT project of the IRCICA. It has been also supported by the interdisciplinary mission of the CNRS (Defisens) through the Costam Project.

References

[1] Decorps J., Saumet J.S., Sommer P., Sigaudo-Roussel D., Fromy B., Effect of ageing on tactile transduction processes, Ageing Research Reviews, 13, 90-99 (2014),

[2] Bau, O., Poupyrev, I., Israr, A., Harrison, C. TeslaTouch: electrovibration for touch surfaces. In: Proceedings of the 23rd Annual ACM Symposium on User Interface Software and Technology, pp. 283-292 (2010)

[3] Giraud F, Amberg M, Lemaire-Semail B, Casiez G, Design of a transparent tactile stimulator, IEEE Haptics Symposium, Vancouver, 485-489 (2012)

[4] Biet M, Casiez G, Giraud F, Lemaire-Semail B, Discrimination of Virtual Square Gratings by Dynamic Touch on Friction Based Tactile Displays, symposium on haptics, Reno, 41-48 (2008)

[5] Vezzoli E, Ben Messaoud W, Amberg M, Giraud F, Lemaire-Semail B, Bueno MA, Physical and Perceptual Independence of Ultrasonic Vibration and Electrovibration for Friction Modulation, IEEE Transactions on Haptics, 8, 2, 235-239 (2015)

[6] Cornuault PH, Carpentier L, Bueno MA, Cote JM, Monteil G, Influence of physico-chemical, mechanical and morphological fingerpad properties on the frictional distinction of sticky/slippery sufaces, Journal of Royal Society Interface, 12, 110, 40p (2015)

[7] Watanabe T., Fukui S., A method for controlling tactile sensation of surface roughness using ultrasonic vibration,IEEE ICRA, 1, 1134–1139 (1995)

[8] Biet M, Boulon L, Martinot F, Giraud F, Lemaire-Semail B, Using an Ultrasonic Transducer: Evidence for an Anisotropic Deprivation of Frictional Cues in Microtexture Perception, World Haptics, Tsukaba, 385-390 (2007)

[9] Ochiai Y, Hoshi T, Rekimoto J, Takasaki M, Diminished Haptics: Towards Digital Transformation of Real World Textures, in Haptics: Neuroscience, Devices, Modeling, and Applications. Springer Berlin Heidelberg, , 409–417 (2014)

[10]Ben Messaoud W, Lemaire-Semail B, Bueno MA, Amberg M, Giraud F, Closed-Loop Control for Squeeze Film Effect in Tactile Stimulator, Actuator 2014, Bremen, Germany, 4p (2014)