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INSTITUTE OF GRADUATE STUDIES

DEVELOPING A TACTILE DISPLAY USING AIRFLOW AS A TACTILE FEEDBACK

MASTER'S THESIS

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Department of Mechanical Engineering
Mechanical Engineering Program

SEPTEMBER, 2023

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APPROVAL PAGE

DECLARATION

I hereby declare with respect that the study "Providing Tactile Feedback to a Drone User while Picking an Object", which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the References. (…/…/2023)

Haroune BOUDJELLAL

FOREWORD

As the author of this work, I am humbled and excited to be your guide through these narratives, ideas, and emotions. This foreword serves as a gateway to the worlds that lie ahead – worlds shaped by imagination, research, and a genuine desire to share something meaningful.

So, dear reader, whether you are embarking on this literary journey for pleasure, knowledge, or introspection, I invite you to open your mind and heart. Let your imagination roam freely, your thoughts intertwine with the text, and your emotions resonate with the words on the page. As you embark on this adventure, remember that every story has multiple layers, and every idea can spark new insights.

Finally,Iwill thank my advisor for helping me and also my parents and my familythus I am very happy that I completed this Project.

September, 2023 Haroune BOUDJELLAL

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ABSTRACT

Scientists who are working in the field of haptic would like to overcome one of the profound challenges which is developing a multimodal tactile display. The user interfaces developed by them must include a higher number of modalities to create maximum realism while interacting with a user interface. However, advances in digital systems require a new method to create them and add additional factors for maximum satisfaction. In this paper, a tactile display that uses air to create a texture feeling is introduced. In addition, the convection method is employed for temperature feeling and the sense of smell is added in addition to the conventional modalities. The performance of the system was tested through psychophysical evaluation. The results showed that the developed surface has the potential to integrate into the current digital devices where human-machine interaction is a matter of interest.

Keywords: Haptics, Multi-modal tactile display, Sense of smell (Olfaction), Airflow

DOKUNMATİK GERİ BİLDİRİM OLARAK HAVA AKIŞINI KULLANARAK DOKUNMATİK BİR EKRAN GELİŞTİRME

ÖZET

Haptik alanında çalışan bilim adamları, çok modlu bir dokunsal ekran geliştiren derin zorluklardan birinin üstesinden gelmek istiyor. Geliştirdikleri kullanıcı arayüzleri, bir kullanıcı arayüzü ile etkileşim kurarken maksimum gerçekçilik yaratmak için daha fazla sayıda modlar içermelidir. Bununla birlikte, dijital sistemlerdeki gelişmeler, bunları oluşturmak için yeni bir yöntem gerektirir ve maksimum memnuniyet için ek faktörler ekler. Bu yazıda, doku hissi yaratmak için havayı kullanan dokunsal bir ekran tanıtılmaktadır. Ayrıca sıcaklık hissi için konveksiyon yöntemi uygulanmakta ve alışılagelmiş modalitelere koku alma duyusu da eklenmektedir. Sistemin performansı psikofiziksel değerlendirme yoluyla test edilmiştir. Sonuçlar, geliştirilen yüzeyin insan-makine etkileşiminin ilgi konusu olduğu mevcut dijital cihazlara entegre olma potansiyeline sahip olduğunu göstermiştir.

Anahtar Kelimeler: Haptik, Çok modlu dokunsal ekran, Koku duyusu (Koku alma), Hava akışı

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ABBREVIATIONS

AR : Augmented Reality

ERM :Eccentric Rotating Mass (ERM)

LRA : Linear Resonant Actuator (LRA)

VR : Virtua

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I. INTRODUCTION

Haptic technology is a field that has gained considerable attention in recent years. It focuses on creating an experience of touch, through vibrations, forces, or other tactile sensations. This technology has an array of applications and the potential to bring about changes in various industries.One of the uses of haptic technology is seen in virtual reality (VR) and augmented reality (AR) systems. By providing users with feedback these systems can greatly enhance the immersive experience and make it feel more true, to life. For instance, in a VR game, haptic feedback can mimic the feeling of holding an object or experiencing the impact of a punch.Haptic technology is also commonly employed in medical training and simulations. Using haptic feedback technology, surgeons may practice operations and hone their abilities in a secure setting. With the use of this technology, they may feel the digital organs and tissues, giving them a more lifelike training experience.

Overall, haptic technology has the potential to transform the way we interact with technology and the world around us.It has numerous uses in a variety of fields, including gaming, healthcare, the automotive industry, and others. As this technology develops, we may anticipate seeing even more cutting-edge applications and enhancements to the user experience.

A. Motivation

In recent years, tactile display has become an effective tool for communicating with users. This type of display goes beyond what traditional displays can provide including other senses such as taste, smell, hearing, and sight in addition to touch. Through careful design, they can be used to create natural, organic, and intuitive interactions that promote engagement and learning. Tactile displays are developed using Haptic technology. Haptic technology allows users to explore digital spaces in the same way they would explore physical objects. However, the majority of touchscreen devices only utilize audio-visual feedback to convey information instead of tactile feedback. The most common tactile feedback in the current display such as smart phones is vibration. They employ low-cost vibration components such as eccentric rotating mass (ERM) or linear resonant actuator (LRA) to provide primitive tactile information(Siegel, 2011). Although some applications have been introduced such as using vibration as an alerting tool in smartphones the advances in digital technology require a sophisticated way to engage the user with the phone. Therefore, additional toolsare required to integrate these technologies into the current devices.

The researchers have suggested various technologies to develop a sensation of touch such as electrostimulation (Electrocutaneous)(Levesque et al., 2011; Liu, Davidson, Taylor, Ngu, and Zarraga, 2005; Taylor, Moser, and Creed, 1998; C.R Wagner, Lederman, and Howe, 2004; Christopher R. Wagner, Lederman, and Howe, 2002). Although these technologies introduce some applications, a practical solution does not exist. For this reason, in this study, we aimed to introduce a multimodal display to overcome mentioned obstacles.

B. Objectives

In order to improve the user experience in touch screen devices such as smartphones and tablets, a more engaging and interactive interface is introduced in this study to overcome the problems stated before. Therefore, during this research, we aimed to reach the following objectives:

- Developing a new method to create a rough feeling in tactile displays.
- Dveloping illusion of temperature feeling in the tactile displays.
- Integrating sense of smell in the tactile displays.

C. Outline

In the first chapter brief introduction to haptic technology and its application is provided.

In Chapter 2 state-of-the-art of current technology on tactile displays is presented. Different methods to create roughness, temperature, and, the sense of smell are introduced.

In Chapter 3 the methodology is explained and the components which were used to accomplish this study are stated.

In Chapter 4 the result which was obtained through the experiment is stated. Finally, the contribution of the current research is explained and the research direction in the future is discussed.

II. LITERATURE SURVEY

Different technologies have been proposed by researchers to create a multimodal tactile display. The aim was to create a display to enhance user interaction, improve user engagement, and improve accessibility. This was achieved by adding perception factors such as temperature to the other factors in touch screens. Acquisition of tactile information happens kinesthetically and through cutaneous feeling. Kinesthesia (proprioceptive) perception is spatial perception. It is the internal perception of body position and displacements through muscles, tendons, and joints. The cutaneous feeling is the perception of heat, pressure, vibration, slip, and skin deformations. In tactile display only cutaneous sensation is available. While touching the surface signals formed in the skin reach the brain via the human nervous system. With the help of these signals reaching the brain, it detects the speed of the body if it is in motion, and the temperature, weight, and surface properties (texture) of that object if it is in contact with it. In this chapter, the state-of-the-art of multimodal tactile display will be explained.

A. Texture perception (Roughness)

While touching a surface the quality of the surface is perceived through cutaneous perception. Qualities or perceptual dimensions help the user to gain knowledge about the object's properties such as softness, temperature, etc. In the literaturefour main dimensions are stated to perceive surface quality that are 1) rough/smooth, 2) hard/soft, 3)sticky/slippery, and 4)warm/cold(Okamoto, Nagano, and Yamada, 2013). Roughness is considered the most important quality of a surface.

In recent years, surface texture (roughness) has been simulated using friction modulation. There are two main technologies for friction modulation between the finger and the tactile surface: Electrovibration (Ilhan and Kacanoglu, 2021; Ilkhani, Aziziaghdam, and Samur, 2014) and Ultrasonic vibration (Vezzoli et al., 2017).

B. Electrovibration

Electrovibration method a capacitive field is formed between the finger and a conductive surface covered with an insulator. When the finger contacts the surface an electrostatic attraction force is built between the finger and the surface. By modulating the attraction force, the friction force is varied and as a result, a texture feeling could be created. The low force, requiring high voltage signal amplitude are the drawbacks of this method. In addition, relative motion between the finger and the surface must be available in order to create a tactile feeling(Bau, Poupyrev, Israr, and Harrison, 2010). Figure1Shows electro vibration working principle. Fe is an electrostatic attraction force. Fr is modulated lateral friction force. An AC signal is applied to a conductive surface covered with an insulator.

C. Ultrasonic vibration

In the Ultrasonic method, a vibrating surface is used for the creation of tactile feedback. Ultrasonic vibration reduces surface friction, as opposed to the electrostatic approach, which increases it. A glass plate is excited at its resonance frequency using piezoelectric actuators that are adhered to the plate's edge [46]. By varying the amplitude of the vibration, the friction force is modulated and as a result, a tactile feeling is created. Being bulky and energy consumption are the most important shortcomings of this method(Gueorguiev, Vezzoli, Mouraux, Lemaire-Semail, and Thonnard, 2017).Figure2shows the working principle of an Ultrasonic vibration system. Caution of air has been created under the fingertip while vibrating the surface.

D. Air stimulation

Using air as a tool for creating feedback rarely has been addressed. In an application known as Midair, tactile feedback is elicited using air modulation. In this method, fingers do not touch the display. The hand is kept above the surface and sound transducers focus the air toward the hand which evokes a sense of contact (Gavrilov, 2008; Iwamoto, Tatezono, and Shinoda, 2008). The range, size, and weight are some of the drawbacks of using this technology (Rakkolainen, Sand, and Raisamo, 2019). Another technology developed by Arai et al.(Arai et al., 2012)micro venturi array of nozzles was used to create feedback on the fingertip. The micro-fabricated device was demonstrated to have the capability for shape rendering. In a recent application, Shultz et al. (Shultz and Harrison, 2022)proposed a scalable, non-contact method based on an air jet that delivers air pulses to the skin.

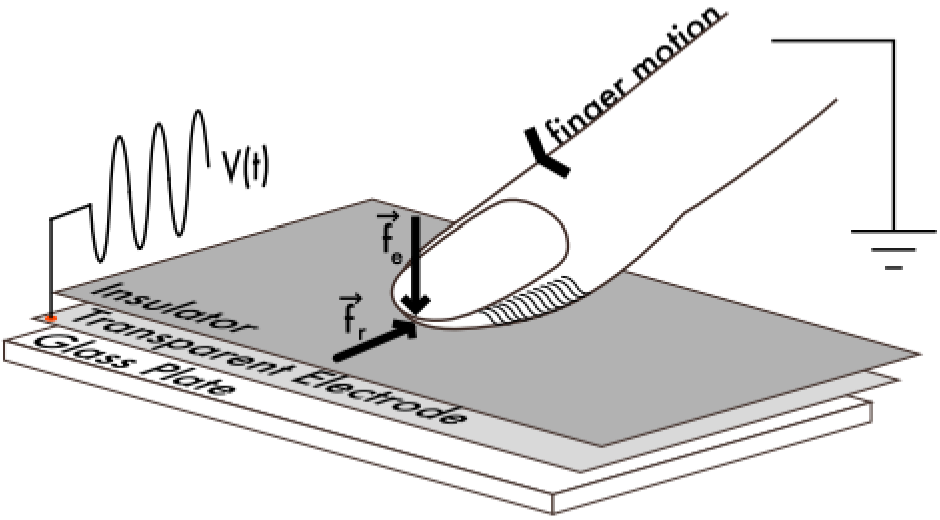

Figure 1: Electro vibration Working Principle (Bau et al., 2010)

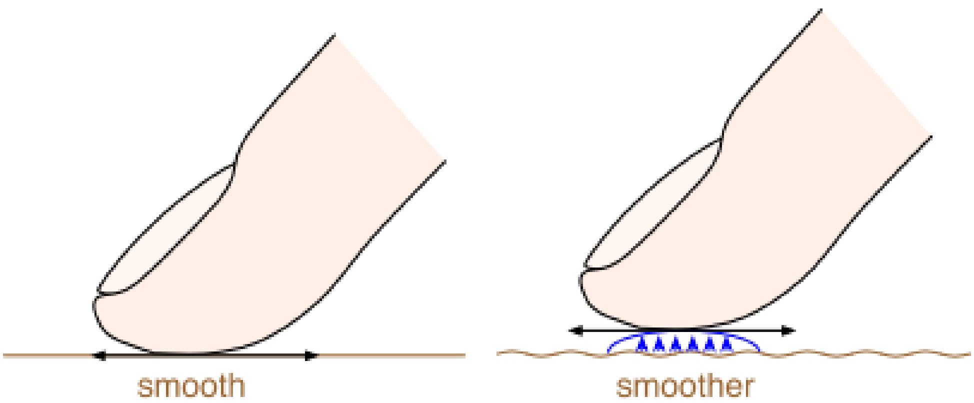

Figure 2: Working Principle of an Ultrasonic Vibration System(Casiez, Roussel, Vanbelleghem, and Giraud, 2011)

Figure 3: Working Principle of a Midair Tactile Display. (Long, Seah, Carter, and Subramanian, 2014)

E. Sense of temperature

Temperature can be an important consideration in the design of haptic devices and applications, as it can significantly affect the user's haptic experience. For example, a warm surface may feel more pleasant to touch than a cold surface, and a sudden change in temperature can be jarring or unpleasant (Hojatmadani and Reed, 2018). Several researchers have attempted to include thermal feedback into tactile haptic devices that thermoelectric devices have been utilized to create warmness and coldness(Caldwell, Tsagarakis, and Wardle, 1997; Gallo, Cucu, Thevenaz, Sengül, and Bleuler, 2014; Ilhan and Allahverdiyev, 2021). The slow response time and power consumption are the two major problems of developed devices. Using noncontact technology to develop temperature feeling Xu et al.(Xu, Yoshimoto, Ienaga, and Kuroda, 2022) developed cooling sensation using vortex technology. In another application, ultrasound transducers were employed to transfer the cold air to a localized spot on the user's skin (Nakajima, Hasegawa, Makino, and Shinoda, 2018).

F. Sense of smell (Olfaction)

It is possible to integrate the sense of smell into tactile displays in order to increase realism and enhance the overall user experience. The sense of smell is closely linked to the sense of taste and can have a strong impact on our perception of the world around us. By adding the sense of smell to tactile displays, it might be possible to create more immersive and realistic virtual environments or experiences.

There are several different approaches that have been used to integrate the sense of smell into tactile displays. One approach is to use an olfactory display, which is a device that releases specific odors on command. Olfactory displays can be controlled using a computer or microcontroller, and they can release a wide range of different odors to correspond with different events or actions in the virtual environment (Dobbelstein, Herrdum, and Rukzio, 2017; Nakamoto et al., 2008).

The developed tactile display in this study introduces an exciting new way to interact with digital media. The developed tactile display includes a sense of touch along with the sense of temperature and smell in order to have a comprehensive sensory experience. The methodology will be explained in the next chapter.

III. METHODOLOGY

The developed tactile display is capable of providing three factors of perception. An airflow was employed to create a sense of touch. Hot and cold sources were used to create a temperature gradient and odor sources were integrated to provide Olfaction. Thedeviceanditsschematicrepresentationareshown inFigure4andFigure5Thewholesystem was controlled using Arduino Uno.

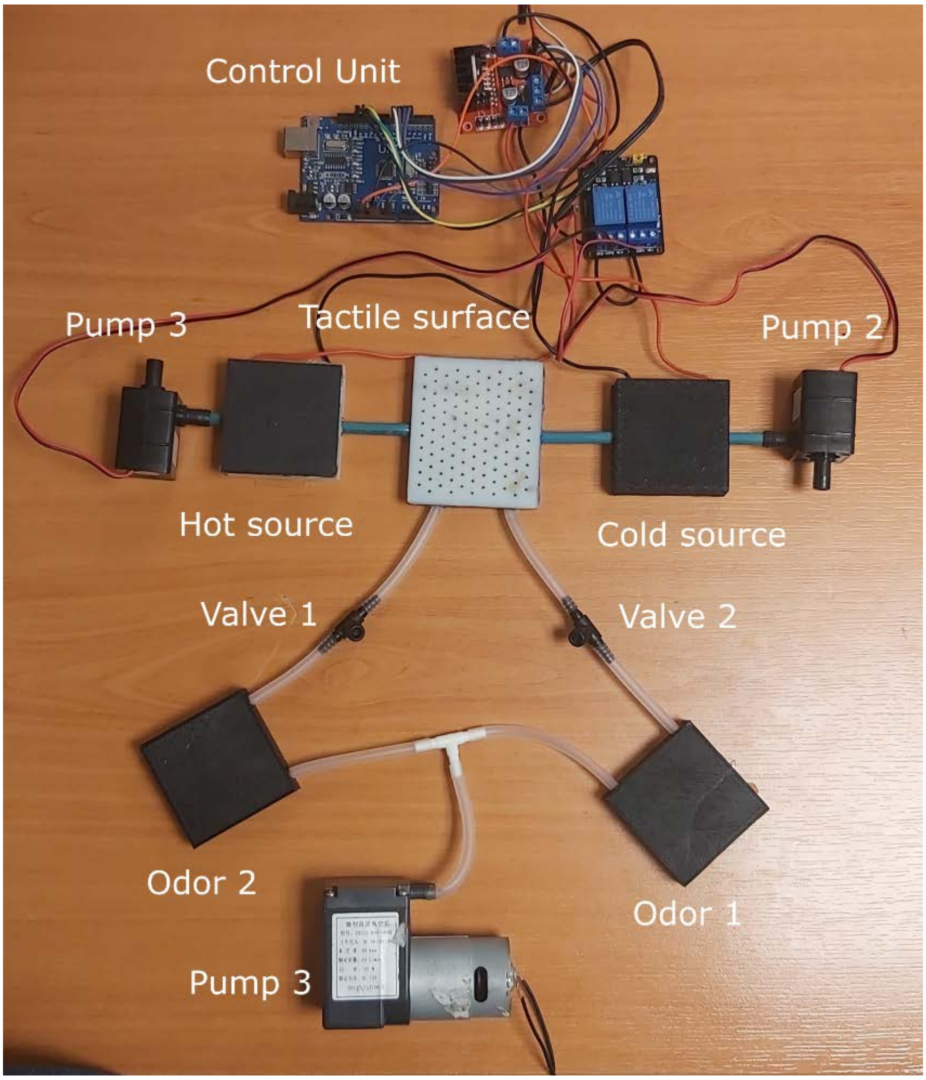

Figure 4: The Developed Tactile Display

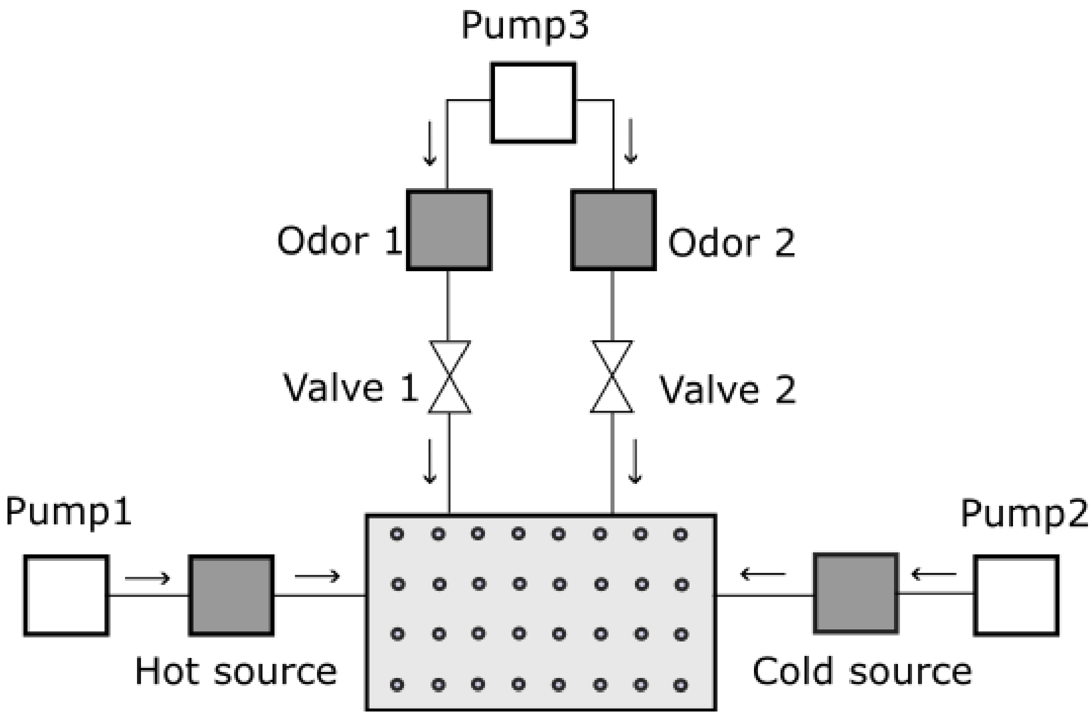

Figure 5: Schematic Representation of The Tactile Display

A. Touch feedback

The tactile surface is composed of a 70 mm × 60 mm × 10 mm surface. It consists of 110 holes on the surface. The diameter of each hole is about 1 mm. The distance between two holes is about 5 mm. The air was pumped using two AD20P-1230C pumps and transmitted to the surface using pipes with 5mm diameters and exits from the holes. The sense of touch is created when the finger is stationary or moving. A 3D printer was used to make the surface using PLA. (SeeFigure4andFigure5)

B. Thermal feedback

In order to create thermal feedback two thermoelectric devices (Peltier TEC1-12705) were considered. The two Peltiers were located inside 3D printed 50 mm × 50 mm × 15 mm boxes. The inner surface of the box is covered with thick Aluminium foil. The performance of the thermoelectric was monitored by a handheld thermometer. The PWM signal was generated with a duty cycle changing from 0% to 100% to cool down and warm up the peltiers. Two pumps were utilized to pump hot and cold air to the tactile surface. The air exits the surface throughtheholescreated on thesurface as is seeninFigure6.

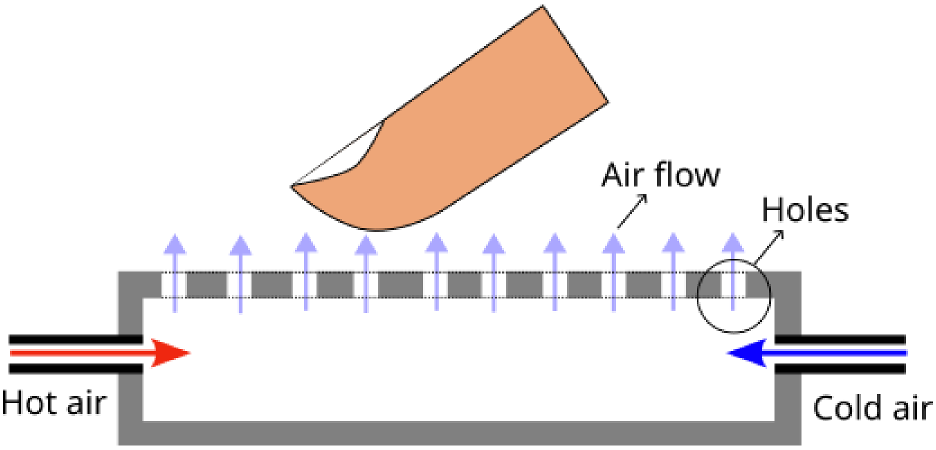

Figure 6: Finger Stimulationin Stationary and Moving Conditions

Figure 6 illustrates cold and warm air pumped to the display and exits through the holes created on the surface. The finger is stimulated in stationary and moving conditions.

C. Sense of smell (Olfaction)

The olfactory display was created using airflow to make the odor reach the noise. The odors were conventional sprays that were available in the market. Two distinguishable scents were stored in the two boxes. A ZX512-806-4800 pump was dedicated to creating the airflow. Two valves were used to control the airflow toward the display.

IV. EXPERIMENTAL EVALUATION

The performance of the system was tested with a temperature source (hot and cold) and two odors (pleasant and unpleasant). A combination of stimuli was utilized. Subjects were asked to write experienced conditions with H (hot), C (cold), P (pleasant), and U (unpleasant). The ambient temperature was about 26^{oC}. Figure 7and Figure 8 show a user testing system for touch, temperature, and smell feedback.

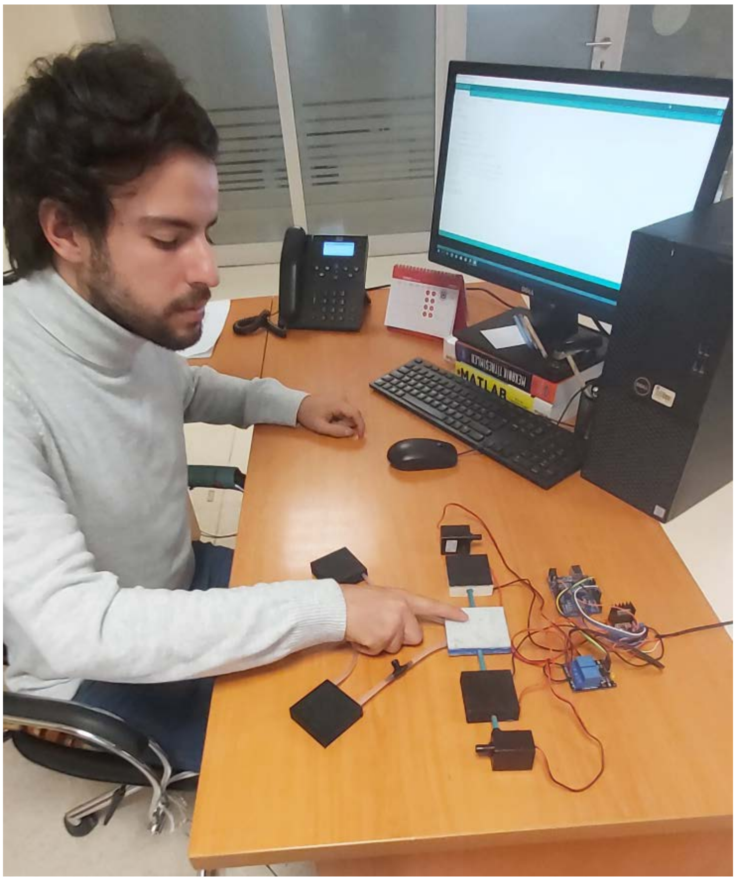

Figure 7: Testing the System for Tactile and Temperature Feedback.

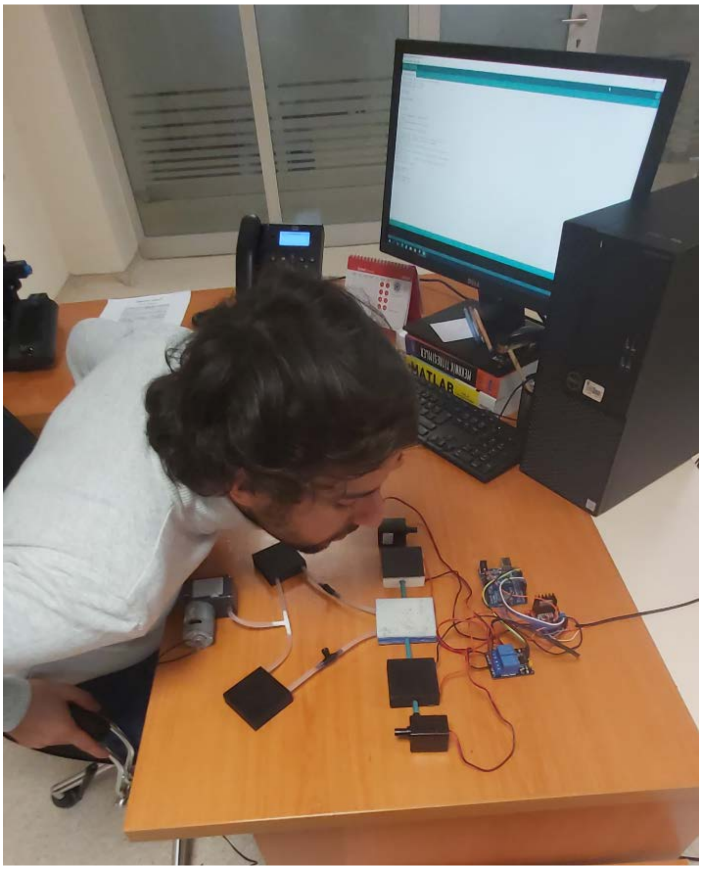

Figure 8: System Testing for Sense of Smell.

A. Development Of Thermal Feedback Mechanism

The establishment of thermal feedback in our experimental setup involved the utilization of a dual-box configuration. Within each of these boxes, two Peltier devices were strategically incorporated—one operating as a cooling element and the other as a heating element. To further regulate and stabilize temperature levels, an aluminum layer was introduced within the confines of each box.The interconnection of these two chambers was achieved through the integration of two pumps, each serving a distinct purpose—one for the circulation of cold air and the other for hot air. Positioned at the focal point of this thermal system is a touchscreen interface, designed to monitor and record temperature variations.

B. Implementaion Of Olfactory Sensation

The establishment of olfaction within our setup involved the incorporation of two separate boxes. In the first box, we placed spray room (fruit and flower) while Smell room spray (Strawberry)" was positioned in the second box.To create a system for simulating the sense of smell, we interconnected two separate boxes, each containing a distinct perfume, using a single pump and a network of pipes. Additionally, we integrated a touchscreen interface into this system, featuring a perforated screen through which the fragrance from both boxes is released. The distance between the subject and the screen was adjusted to be around 15 cm in order to achieve accurate results.

C. Development of Tactile Feedback Mechanism

The development of tactile feedback within our system involved the meticulous construction of a specialized tactile surface measuring 70mm x 60mm x 10mm, featuring 110 evenly spaced 1mm-diameter holes at 5mm intervals. To transmit tactile sensations, two AD20P-1230C pumps were employed to generate airflow, which was then channeled through 5mm-diameter pipes, exiting through the surface holes. This carefully designed mechanism provided users with dynamic tactileinteractions, enhancingtheoveralluserexperience.

V. CONCLUSION

A novel method to create a sense of touch, temperature, and olfaction was introduced. The air stream was employed to create a sense of touch, the thermoelectric device was used to create a temperature feeling using convection heat transfer and, two odor sources were utilized to create a sense of smell. The performance of the system was tested through user evaluation. The device showed acceptable achievement, however, needs some improvement regarding design, isolation, and piping system. The proposed concept could be integrated into the current haptic devices where building a multimodal haptic system is important.In summary, the journey to develop tactile displays using airflow as a tactile feedback medium holds immense promise for enhancing sensory experiences, improving accessibility, and driving innovation across industries. As research continues and applications expand, we can anticipate a future where the sense of touch becomes a more integral and enriching part of our digital interactions and daily lives.

VI. FUTURE WORK

- Development of methods to maximize the diffusion of air and aroma molecules in a dynamic and spatially precise way.
- Developing methods for controlling the concentration of air and aromatic substances released
- Explore methods for sensing and controlling the density of substances and air that flow through a chamber.
- Shrinking the technology to make it suitable for wearable devices or even clothing could open up numerous applications. Imagine a jacket that provides tactile feedback for navigation or a glove that enhances the sensation of objects in a virtual environment.
- Designing systems that use airflow to create tactile patterns or maps for the visually impaired could revolutionize mobility and accessibility. These systems could provide real-time feedback about the user's surroundings, helping them navigate unfamiliar environments.

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Xu, J., YOSHİMOTO, S., IENAGA, N., and KURODA, Y. (2022). Intensity-Adjustable Non-Contact Cold Sensation Presentation Based on the Vortex Effect. **IEEE Transactions on Haptics,***15*(3), 592–602. https://doi.org/10.1109/TOH.2022.3187759

APPENDICES

APPENDICES 1 : Circuit elements

Circuit elements

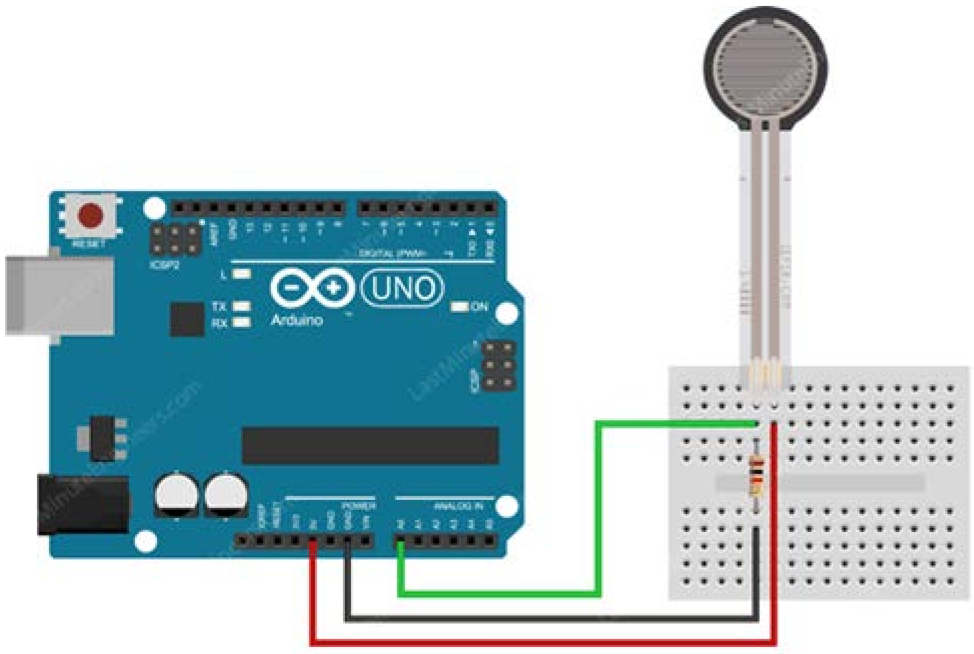

Figure 9: The Developed Circuit and its Components

Peltier

Peltier is a thermoelectric device formed by two different metals or semiconductor materials. When the electric current passes through the junction of these two conductive materials, causes one side of the junction to absorb heat while the other side releases the heat.

The Peltier device has two sides known as the hot side and the cold side. When a DC current flows through the device, it will cause one side of it to cool down while the other side to heat up. Reversing the direction of the current will reverse the direction of the heat transfer.

Figure 10: Thermoelectric Peltier Device

L298 motor drive

In order to control the direction of the current to heat up and cool down peltiers, an L298 motor drive controller was used. It has been made of a dual H-bridge motor driver integrated circuit (IC) that allows control of the direction of the current. It has two outputs (Motor A and Motor B). The supply voltage ranges from 5 to 35 volts which makes it a suitable choice for this study. The maximum output current for each channel is 2A. Each output is activated using Enable pins.

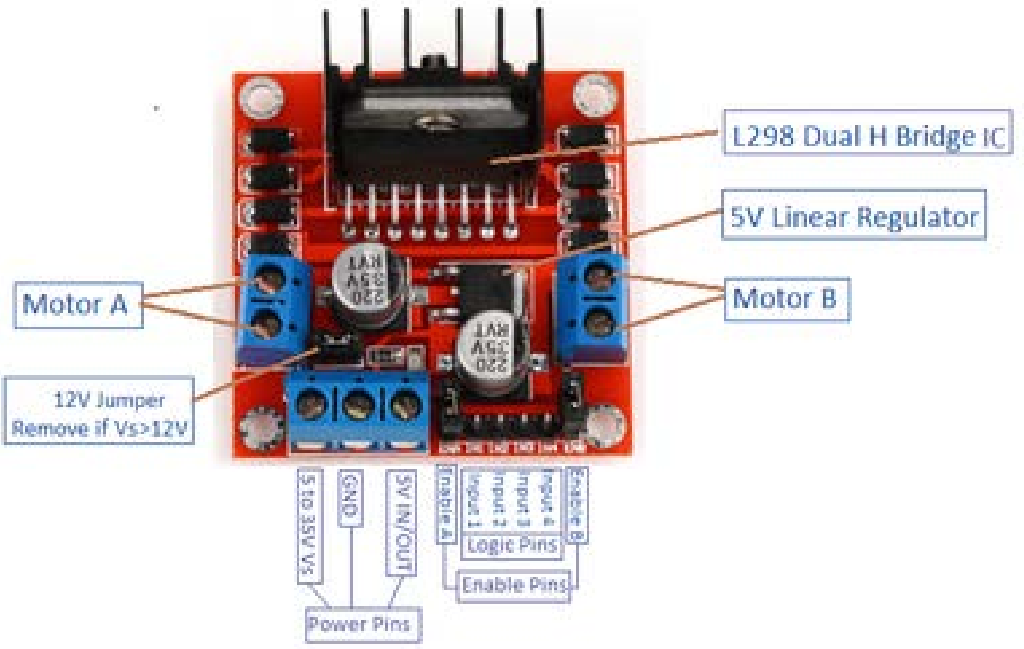

Figure 11: L298 Motor Drive

Embedded programs

```
int chambreA = 12 ;
int chambreB =11 ;
int chambreA_chaude_in1= 4;
int chambreA_froide_in2=5;
int chambreB_chaude_in1=6;
int chambreB_froide_in2=7;
void setup() {
  // put your setup code here, to run once:
pinMode(chambreA,OUTPUT);
pinMode(chambreB,OUTPUT);
pinMode(chambreA_chaude_in1 ,OUTPUT);
pinMode(chambreA_froide_in2 ,OUTPUT);
pinMode(chambreB_chaude_in1 ,OUTPUT);
pinMode(chambreB_froide_in2 ,OUTPUT);
}
void loop() {
  // put your main code here, to run repeatedly:
digitalWrite(chambreB,HIGH);
digitalWrite(chambreA,LOW);
//CHAUD
digitalWrite(chambreB_chaude_in1,LOW);
digitalWrite(chambreB_froide_in2,HIGH);
delay(5000) ;

// FROID
```

```
digitalWrite(chambreB,LOW);

digitalWrite(chambreA,HIGH);

digitalWrite(chambreA_chaude_in1,HIGH);

digitalWrite(chambreA_froide_in2,LOW);

delay(5000) ;
```

Temperature sensor

We use TM35 to meausure the temperature

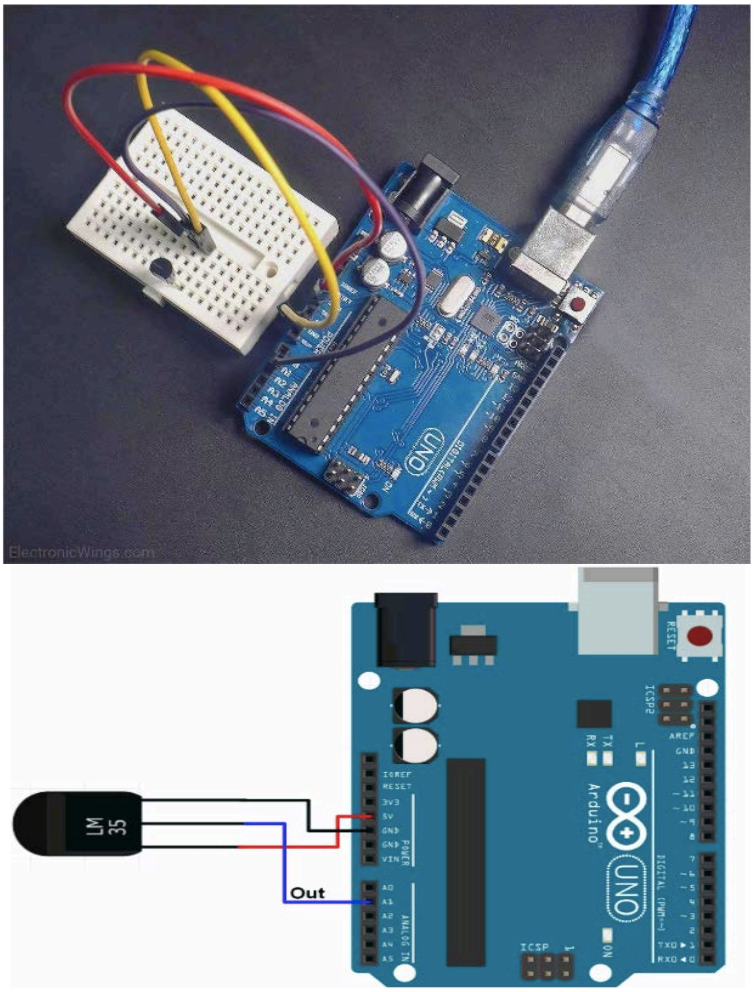

Figure 1: LM35 Sensor Connected with Arduino UNO

LM 35 sensor program:

```
const int lm35_pin = A1;       /* LM35 O/P pin */

void setup() {

  Serial.begin(9600);
```

```
}
void loop() {
int temp_adc_val;
float temp_val;
temp_adc_val = analogRead(lm35_pin);      /* Read Temperature */
temp_val = (temp_adc_val * 4.88);  /* Convert adc value to equivalent voltage */
temp_val = (temp_val/10);     /* LM35 gives output of 10mv/°C */
  Serial.print("Temperature = ");
  Serial.print(temp_val);
  Serial.print(" Degree Celsius\n");
delay(1000);
}
```

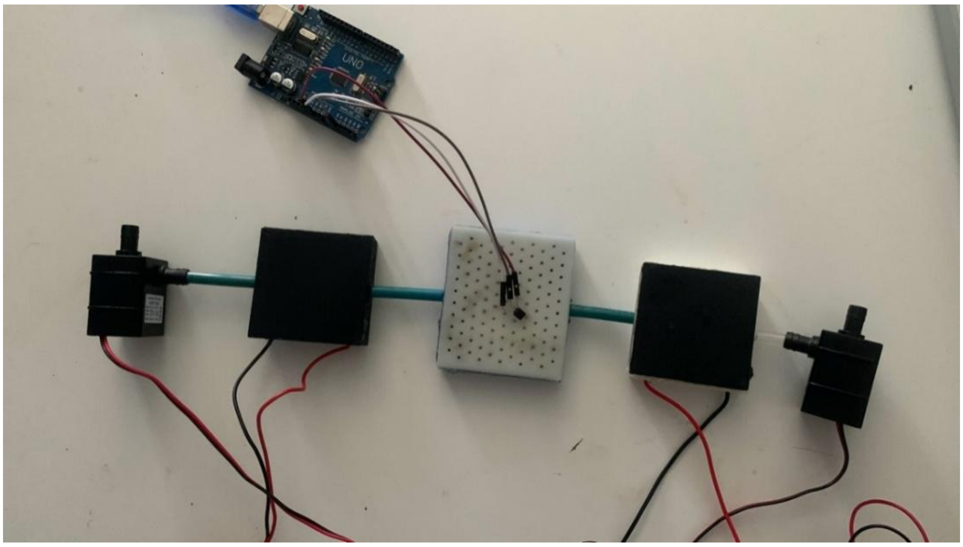

Figure 13: Complete Design Including the Temp Sensor

RESUME

Name– Surname

Haroune Boudjellal

Publications from Dissertation, Presentations and Patents

ILHAN, RIZA, and HAROUNE BOUDJELLAL. (2023).

Developing a tactıle dısplay us ın gaırflow as a tactıle feedback. International Journal of Engineering and ComputerScience,12(03),25658–25664.

1. Education

Baccalaureate in science (September2015-July2016)Belkacem El-Ouzri High school Blida, Algeria.

Bachelor’s degree (Mechanical energitique) (June 2016-June 2019).At Saad Dahleb University BLIDA,ALGERIA).

Master’s degree (Mechanical Engineeing) (Since April 2023) At ISTANBUL AydinUniversity,ISTANBUL,TURKEY.InprogressofdefendingThesisundertheTheme

:(developıng a tactile display using airflow as a tactıie feedback).

2. WorkExperience

Sales OfficerAtour company styles eramic algeria from(11/08/2017)to (19/08/2019).

Horse trainer Atnur horse clup İstanbul turkey. (May 2020-Septembe2022).

Practical mechanical constructionat sonatrach company FromApril 2019 to May 2019 Algeria.

SkillsandAbilities

Languages

- Arabic: Native Speaker
- English: Very Good.
- French: Excellent.
- Turkish: Good.

Skills

- Welcoming guests.
- Maintenance and Repair.
- Multi-line phone systems.
- Correspondence management.
- Flexible and Adaptable.

Computer and Software skills

- MS Word.
- MS Excel.
- MS PowerPoint. MS Outlook.
- MS Project.
- Auto Cad (basic).

Sport

- Horse Trainer (Coach)
- Tennisplayer