

**DEVELOPMENT OF WEARABLE THERMAL FEEDBACK FOR  
ADVANCED HUMAN MACHINE INTERFACE AND AR/VR  
APPLICATIONS**

by

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## Abstract

The integration of Augmented Reality (AR) and Virtual Reality (VR) with language models has significantly propelled the development of user interaction and immersive experiences. In order to enhance these interactions within AR/VR environments, our objective is to develop an intelligent glove enabling users to perceive the temperature of objects in gaming scenarios. Given the compact size of thermoelectric coolers (TECs) and their capacity to modify heating or cooling properties via voltage adjustments, TECs have been chosen to provide thermal feedback, complemented by integrated fans for cooling. The Arduino Mega 2560 serves as the control unit, managing voltage direction and duration to control the temperature variation of each TEC.

Furthermore, we have created a character and her animations within Unity. Through fine-tuning of the ChatGPT model, she embodies a female student at the College of Design and Engineering in the National University of Singapore (NUS). Voice interactions with this character are facilitated via APIs from OpenAI and Google Cloud, enriching the immersive experience within AR/VR environments.

**Key words:** thermal feedback, wearable electronics, virtual Reality, Language Models

# Chapter 1

## Introduction

### 1.1 Research Background

In recent years, the evolution of wearable glove technology has been primarily driven by its integration with Virtual Reality (VR) and Augmented Reality (AR) platforms. This synergy, facilitated by advanced sensors and haptic feedback mechanisms, significantly enhances user interaction, making the manipulation and perception of virtual objects more natural and greatly improving the digital user experience. A key innovation in this field has been the development of advanced temperature feedback systems that accurately simulate real sensations, not only enriching the immersive experience within virtual environments but also advancing healthcare, physiotherapy, VR training, and education.

Recent research on gloves incorporating temperature feedback has rapidly progressed in areas such as health care and educational entertainment, positively impacting our daily lives. For instance, smart thermal feedback gloves have assisted in learning calligraphy [13], helped amputees experience natural temperatures through prosthetics [15], and enabled therapeutic heat treatments via gloves[6].

In recent years, no scholars have specifically documented the history of thermal feedback gloves. However, from various studies, it can be inferred that the earliest instances of gloves providing thermal feedback date back to 1993, Caldwell D G introduced instrumented fingers [4] capable of sensing the hardness, texture, and temperature of objects. In 2020, Cai S released a pneumatic glove known as ThermAirGlove (TAGlove) [3], which provides a tactile experience of grasping

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objects with varying temperatures and materials in virtual reality. More recently, a system named ThermalGrasp has been launched, enabling individuals to feel the temperature and texture of objects through their palms and soles, such as grasping sand or standing on a beach. We will explore these innovations in detail through two specific articles focusing on gloves that combine tactile and temperature feedback.

Moreover, with the rapid advancement of machine learning technology, glove research has begun to incorporate elements of machine learning. ZHU [25] improved glove design on a multimodal basis and utilized machine learning algorithms to enhance object recognition. Researchers have also combined gloves with video, introducing the Video2Haptics application [5], which uses bio-inspired event cameras to estimate the intensity of video motion. Williams et al. [22] have explored the integration of artificial intelligence with tactile feedback systems to adjust processes in real-time.

In terms of multisensory virtual experiences, Weinbaum's story "Pigmalion's Spectacles" [21] describes virtual media as interactive computer systems that can detect the position and actions of participants and provide feedback across multiple senses (visual, auditory, tactile, olfactory, and gustatory). Recently, with the rise of the ChatGPT model, its application in virtual systems has been growing, showing substantial potential [18]. In education, scholars have proposed integrating ChatGPT with AR/VR technologies for teaching biology to high school students [16] and Korzynski P has suggested using AR, voice robots, and ChatGPT for teaching foreign languages to children [20]. In daily life, efforts are underway to use ChatGPT to address 3D modeling challenges in virtual worlds [8], and to combine it with animation production to synchronize lip movements of animated characters while speaking [11]. Additionally, researchers have found that using ChatGPT in virtual worlds can improve symptoms for patients with conditions like autism [2], claustrophobia [1], and other cognitive disorders [6].

Considering the above research, we believe that smart gloves can integrate various sensory stimuli in virtual worlds, providing users with a deeply immersive experience. Moreover, by combining the ChatGPT model with animation techniques, we can significantly enhance the interaction between smart gloves and animations. However, current temperature feedback typically allows only global adjustments. Therefore, we propose a new type of glove that can control localized temperatures, further

integrated with the ChatGPT model and animation effects, greatly enhancing the user experience.

## 1.2 Literature review

The rapid development of flexible and wearable electronic devices signifies a significant trend in contemporary research. Renowned for their adaptability, multi-functionality, and inherent flexibility, these devices are increasingly becoming integral components in various fields such as medicine, daily life, and education, playing pivotal roles therein. Their advancement is crucial for enhancing virtual reality (VR) and augmented reality (AR) technologies, thereby enriching the scope and depth of immersive experiences offered by these technologies.

Within the AR/VR domain, our focus lies on two aspects: the integration of intelligent gloves with artificial intelligence for thermal feedback and intelligent systems. Through the exploration of some specific papers, we have observed the gradual evolution of smart gloves towards a multisensory experience. Not only can they be combined with machine learning techniques such as gesture recognition and intelligent systems, but they can also integrate with 3D animation, thus facilitating a comprehensive experience within virtual reality environments.

### 1.2.1 Thermal feedback

Thermal feedback heating involves various technologies, and currently, we are aware of five: resistance heating, thermoelectric effect, Peltier effect, heat pipe technology, and nanotechnology. Among them, resistance heating is one of the earliest and most common heating methods. Early heaters used electric current passing through conductive materials to generate resistive heating effects, transferring heat to surrounding objects. This method is widely used in industrial and household heating devices. Additionally, the thermoelectric effect is a physical phenomenon that converts electrical energy into thermal energy. Thermoelectric materials can generate electric currents under a temperature gradient to heat the surrounding environment. This technology has been applied in some small and portable heating devices. Furthermore, the Peltier effect is a temperature change phenomenon that occurs when an electric current passes through thermoelectric materials between two

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different materials. This effect can be used for cooling or heating. Peltier elements have been widely used in small refrigeration devices and temperature control systems. Heat pipes are devices that transfer heat by utilizing the heat transfer effect of liquids or gases under a temperature gradient. Heat pipes can transfer heat from one area to another to achieve heating or cooling. This technology has been widely used in many thermal management applications. Lastly, nanotechnology provides new possibilities for heating and cooling technologies. For example, nanostructured materials can achieve more efficient heating or cooling effects by adjusting their structure and properties. Nanotechnology also provides new opportunities for the development of micro heating and cooling devices. The diagram below summarizes these five technologies, facilitating our project selection.

Method	Advantage	Disadvantage	Domain	Heat or Cooling
Resistance heating	Simple, low cost, easy to control	High energy consumption, limited heating uniformity	Industrial and household heating devices	Heat Only
Thermoelectric effect	No external power source required, simple structure	Low efficiency, slow heating speed, limited applicability	Small and portable heating devices	Heat Only
Peltier effect	Reversible, precise control, compact structure	Low energy efficiency, high cost	Small-scale refrigeration devices and temperature control systems	both heat and cooling
Heat pipe technology	Efficient heat transfer, simple structure, high reliability	High cost, requires large volume space	Thermal management applications	Heat Only
Nanotechnology	Efficient, precise control, compact structure	Complex technology, high cost, demanding manufacturing process	Development of microscale heating and cooling devices	both heat and cooling

Figure 1.1: 5 Methods of Thermal Feedback

If we have chosen the method, how to use the method into our wearable devices? Here are some recent studies that provide detailed insights into the application of thermal feedback.

Zhongda Sun [19] provided augmented tactile-perception and haptic feedback rings (ATH-Rings) for VR applications. The ATH-Rings consists of four parts: TENG tactile sensors for continuous bending sensing, flexible pyroelectric sensors for temperature detecting, eccentric rotating mass (ERM) vibrators for vibro-haptic feedback and nichrome(NiCr) metal wires for thermo-haptic feedback.

As depicted in Figure 1.2, the thermal feedback mechanism in the device is facilitated by the TENG tactile sensor featuring a NiCr heater. This sensor is strategically positioned on the inner surface of the ring, allowing direct contact

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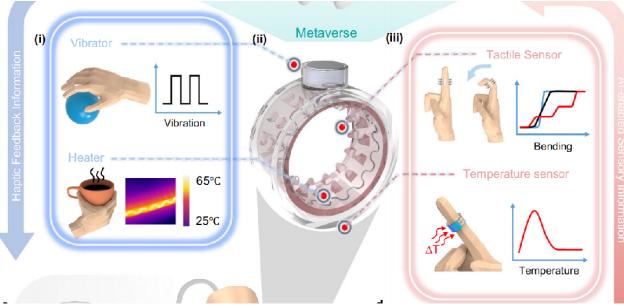


Figure 1.2: Component of ATH-Rings

with the skin of the finger. Its primary function is to accurately monitor muscle swelling during finger movements and to deliver thermo-haptic feedback to the skin. Additionally, each ring is equipped with an ERM vibrator situated at the top, which administers vibration stimuli throughout the finger. Meanwhile, the PVDF sensor, affixed to the outer surface of the ring, serves to gauge the temperature of objects touched during grasping actions.

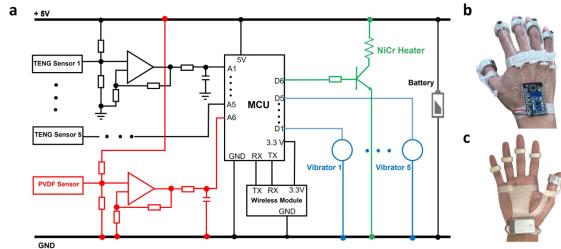


Figure 1.3: The Architecture of the entire system.

In terms of design, as seen from autorefbbackground:fig:circuit design, the entire device is controlled by an MCU. The feedback system is placed on the back of the hand to control whether the palm perceives pressure and temperature, with the battery positioned at the wrist.

In the thermal feedback aspect, the authors utilized a NiCr metal wire, as illustrated in Figure 1.4. Through research, it was found that the response time of the heater varies with different drive powers. Higher drive power can achieve a higher stable temperature, but it also requires a longer response time, which is relatively prolonged due to the silicone encapsulation effect. For applications requiring faster response time, an alternative drive strategy can be employed, whereby high power is initially used to reach the desired temperature, followed by a power reduction to

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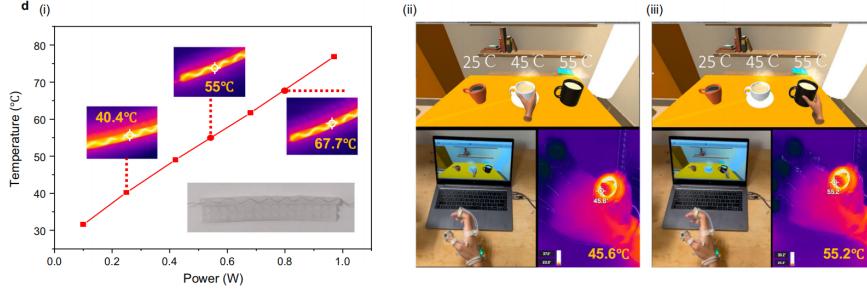


Figure 1.4: Utilization of thermo-haptic feedback

maintain the temperature. In practical applications, when the device comes into contact with human skin, higher power and longer response time are required to reach the same temperature level on the heating interface. At the maximum output power of the IoT platform (approximately 3.5W), a temperature of 61.9°C was reached within 9.4 seconds. To optimize the power consumption of the entire system (and considering the necessity of the thumb in grasping tasks), the authors only added a thermal feedback component to the thumb ring to reduce power consumption and system complexity. As shown in (1), which evaluates the stable temperature range of the NiCr heater-enabled temperature feedback unit under varying power inputs. Additionally, with virtual temperatures set at (ii) 45°C and (iii) 55°C, the embedded NiCr heater heats up to a specific temperature according to predefined temperature values.

Another article presents ThermalGrasp devices [14] that also integrate thermal feedback. However, they utilize a thermoelectric material capable of sensing not only hot temperatures but also cold temperatures.



Figure 1.5: ThermalGrasp devices

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In terms of thermal feedback, the authors employed Peltier elements, which are thermoelectric materials that heat up on one side and cool down on the other when powered. Due to their simple electrical control and lack of moving parts or fluids, they are attractive for wearable devices. As depicted in Figure 1.6, ThermalGrasp devices consist of three components, as illustrated in Figure 2: (1) a thermal element (typically Peltier, but possibly other types), (2) a thermally conductive yet flexible material (e.g., heat pipes, metal sheets, etc.), and (3) insulation (e.g., foam, plastics, etc.). The thermally conductive material makes contact with the surface of the thermal element (in this case, Peltier element) and guides the flow of heat. Consequently, when the Peltier element heats up, heat is conducted through the conductive material. By wrapping the channel in insulation, the authors improved the efficiency of heat transfer. Users feel heat in the correct location because the target area's skin is exposed to the conductor, while insulation covers all other surfaces. Similarly, when the Peltier element cools down, heat is conducted away from the user, providing a sensation of cooling.

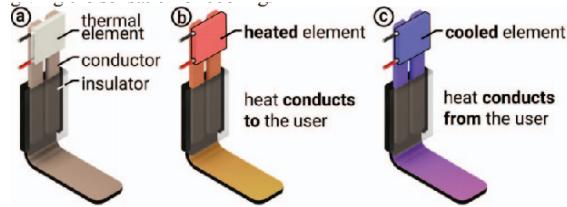


Figure 1.6: three components of ThermalGrasp

In terms of conductive materials, the authors conducted thermal conductivity tests using copper mesh, copper foil, and silicon rubber doped with liquid metal (EGaIn). They found that compared to the thin flexible copper sheet ultimately used, the thermal efficiency of other materials was somewhat reduced. Furthermore, although Peltier elements have certain advantages in generating both heat and cold sensations (especially for durations exceeding several seconds, such as rendering the temperature of objects and terrains), both rigid and flexible Peltier components require additional heatsinks and fans to remove excess heat from the hot side. However, placing them on the palms or soles would be inconvenient for participants to grasp objects or walk. Therefore, the authors proposed relocating the Peltier and its cooling unit to areas not involved in grasping or walking, such as the top of the

foot or the back of the hand. Subsequently, they used thin and flexible materials to conduct the heating or cooling from the Peltier to the palm or sole.

Unlike the first article, its advantage lies in providing convenient wearable components that can offer both heating and cooling functionalities. It relocates the bulky yet necessary cooling hardware away from body parts involved in grasping or walking, such as the palms and soles of the feet. Then, it utilizes robust yet flexible and thin thermal conductors to transmit thermal feedback to the central areas of the palms/soles, allowing users to perceive both cooling and heating effects.

### 1.2.2 Thermal feedback used in AR/VR

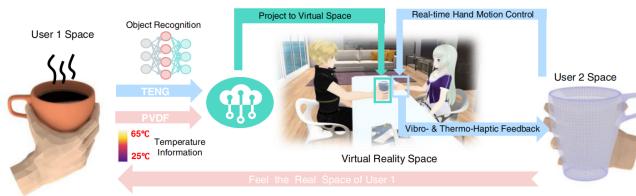


Figure 1.7: An example of catching coffee

In the preceding ATH-Ring paper, the authors not only established a tactile feedback system but also utilized an IoT platform to control temperature in AR/VR environments. They designed an animated scenario where two users could achieve cross-space perception and sensation through the multimodal sensing and feedback capabilities enabled by the highly integrated system. One user grasps an object in the physical world, and then the TENG tactile sensor and PVDF temperature sensor can instantly recognize the shape and temperature of the corresponding object. This recognition result can be shared with other users in the same space. User 2, utilizing the shared temperature data, engages in an animation involving grasping a coffee cup. The embedded NiCr heater heats up to a specific temperature according to the predefined temperature value of the selected coffee cup. The final stable temperature captured by the infrared camera is nearly equal to the preset temperature of the corresponding coffee cup in the virtual space, validating the temperature feedback capability of the system.

Currently, there is no technology available that integrates gloves with ChatGPT language models in virtual environments. Existing techniques primarily focus on

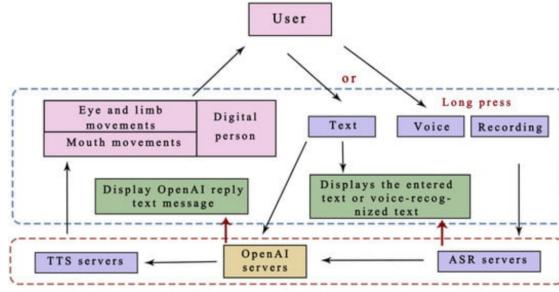


Figure 1.8: Flowchat of the system

using Unity animations and ChatGPT models for language-based interactions. In this paper [11], the authors utilized Microsoft Azure and Baidu Intelligent Cloud APIs to program language communication for digital characters in animations. Figure 1.8 illustrates the dialogue process using APIs as employed by the authors. When users interact with digital characters, they can choose between text or voice input. If voice input is selected, users can long-press the voice button, indicated by a gray "recording" status. The recorded voice is then sent to an Automatic Speech Recognition (ASR) server for processing. Simultaneously, the corresponding text information is sent to the OpenAI server to generate text-based responses.

## 1.3 Objective and main work

### 1.3.1 Objective

After reviewing the aforementioned research findings, we have observed a lack of existing technology that combines intelligent gloves capable of both localized heating and cooling on the palm, as well as enabling communication with characters in virtual environments. Therefore, we aim to develop an intelligent glove that can regulate local temperature on the palm while also facilitating communication with virtual characters in the digital realm.

### 1.3.2 Mainwork

Our main work is divided into circuit design, thermal feedback design, animation production, and API programming.

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In terms of circuit design, we chose the Arduino Mega 2560. On one hand, it has multiple input/output pins, allowing us to connect more external devices and sensors to meet the possible requirement of multiple coolers. On the other hand, it provides voltage selection between 5V and 3.3V, which can support commonly available coolers on the market.

For the thermal feedback design, we focus on simplicity, compactness, low cost, and accessibility. Therefore, we chose the widely popular TEC elements available in the market. Compared to the expensive and fragile Peltier elements, TEC elements are more cost-effective, albeit less flexible. However, their small size (approximately 12.5mm) allows us to temporarily overlook their lack of flexibility. Additionally, we considered some research on using hot and cold fluids for feedback [17] [10] [24]. For example, HydroRing provides fingertip temperature control with liquid, while Therminator [7] developed a hydraulic system for thermal feedback on the arm in virtual reality. However, due to the large size of these systems, we temporarily ruled them out for this project. Furthermore, we added fan cooling to the TEC elements to ensure they return to room temperature quickly after heating or cooling.

In terms of animation production, we chose to design a character that closely resembles our academic life: a female student majoring in computer engineering at the National University of Singapore, experimenting with different temperatures of coffee in her home kitchen. Since we communicated entirely in English, Baidu's speech technology may be slightly lacking, while Microsoft Cognitive Services are more suitable for large-scale enterprises and projects. Therefore, we ultimately chose OpenAI for its low cost and the ability to freely apply for access to its API. Finally, we fine-tuned the language model through fine-tuning to better immerse ourselves in virtual campus life and engage in conversations with characters.

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# Chapter 2

## Experiment Design

This section primarily encompasses the design of the thermal feedback system and control system, spanning from circuit design and selection of suitable materials to the utilization of Arduino for temperature control via various signals.

### 2.1 Temperature Feedback

Temperature feedback plays a crucial role in smart gloves, enhancing the overall user experience by providing realistic sensations and improving comfort. By integrating temperature feedback mechanisms into smart gloves, users can perceive virtual environments more realistically, as temperature cues contribute significantly to immersion. Moreover, precise temperature control ensures user comfort by regulating thermal sensations according to the virtual environment or user preferences. This capability not only enhances the realism of virtual experiences but also enables applications in various fields such as virtual reality gaming, medical simulation, and industrial training, where accurate temperature feedback is essential for realistic interaction and training scenarios. Overall, temperature feedback in smart gloves contributes to a more immersive, comfortable, and effective user interaction experience across different applications and domains.

#### 2.1.1 Methods

Different heat transfer technologies offer diverse characteristics, providing a range of options and applications. Resistive heating utilizes the resistance effect generated by electric current passing through conductive materials to heat objects, suitable for

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various fields such as heating components and household appliances. Thermoelectric effect involves the principle of generating electric current in thermoelectric materials under a temperature gradient, applicable for energy-efficient heating and temperature regulation systems. The Peltier effect induces temperature changes when electric current passes through thermoelectric materials between two different materials, suitable for temperature controllers and refrigeration systems. Heat pipe technology transfers heat by utilizing the heat transfer effect of liquids or gases under a temperature gradient, applicable for heat dissipation and temperature regulation devices. Nanotechnology, through the design of nanostructured materials, achieves more efficient heating or cooling effects, offering new possibilities in the field of thermal management.

The recent popularity of neck-hanging cooling devices utilizes electronic cooling technology. This technology, based on the Peltier effect, creates a wearable cooling device by passing electric current through thermoelectric materials between two different materials. As electric current passes through these thermoelectric materials, a temperature difference is generated, resulting in one side cooling and the other side heating. By placing the cooling side near the body and suspending the heating side in the external air, this neck-hanging cooling device achieves localized cooling effects. This portable cooling device is suitable for outdoor activities, sports, and daily life scenarios where temporary cooling is needed, providing users with convenience and comfort. This realization highlights the potential to apply temperature variations to our gloves using electronic cooling technology based on the Peltier effect.

### 2.1.2 TEC

A thermoelectric cooler (TEC), also known as a Peltier cooler, is a solid-state device that utilizes the Peltier effect to transfer heat between two different temperature zones. The Peltier effect occurs when an electric current flows through two dissimilar conductors, generating a temperature difference across the junction of the conductors. In a TEC, this effect is harnessed to create a cooling effect.

As shown in Figure 2.1, TEC includes 4 parts: 1. Thermoelectric Materials: The core of TECs utilizes thermoelectric materials, typically semiconductor materials such as Bismuth Telluride ( $\text{Bi}_2\text{Te}_3$ ) and Lead Telluride ( $\text{PbTe}$ ). These materials are

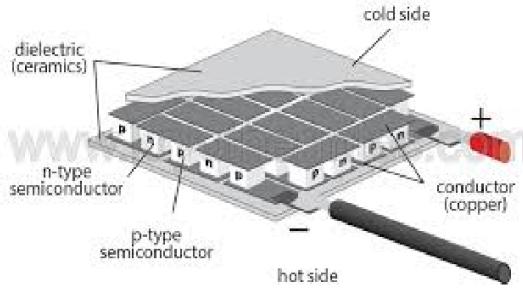


Figure 2.1: The component of TEC

capable of generating the Seebeck effect, which produces a temperature gradient across the material when a current flows through it.

2. PN Junctions: TECs typically consist of multiple PN junctions. These PN junctions are crucial for creating the temperature difference. P-type semiconductors absorb heat under the influence of current, while N-type semiconductors release heat.
3. Electrodes: Electrodes are used to introduce current into these PN junctions. Typically, electrodes are made of highly conductive materials to ensure smooth current transmission.
4. Ceramic Plates: TECs often feature ceramic plates at the top and bottom, serving as structural support and aiding in heat dissipation and insulation. Ceramic plates also help protect the internal semiconductor materials from external environmental influences while providing a stable thermal interface.

In this project, we chose TEC for several reasons. Firstly, TEC devices are compact in size, making them suitable for cooling applications in limited spaces and easy to install. Secondly, TEC cooling operates without mechanical movement, eliminating the presence of moving parts and associated vibrations and noise. Thirdly, TEC devices boast high reliability and stability due to the absence of vulnerable components. Lastly, TEC cooling allows for precise temperature control through current adjustment, making it well-suited for applications requiring high temperature accuracy. These attributes collectively make TEC an ideal choice for our project requirements.

### 2.1.3 P-N Junction

Tec usually is based on the thermoelectric effect, utilizing the P-N junction (the junction between P-type and N-type semiconductors) to generate a temperature

difference when current passes through.

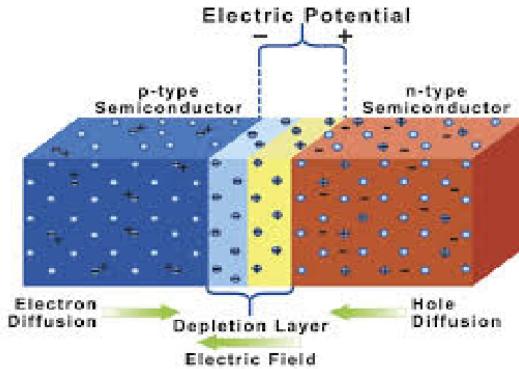


Figure 2.2: P-N Junction

A thermoelectric cooler (TEC) is constructed with a series of P-type and N-type semiconductors arranged alternately, interconnected by conductive materials, typically metals, to create a multilayer structure. When an electric current passes through the TEC, the thermoelectric effect comes into play, generating a temperature gradient across the P-N junction. This phenomenon leads to cooling on one side of the junction while the opposite side experiences heating. Through precise control of the current direction, it becomes feasible to selectively cool a designated side, thereby achieving the desired cooling effect. This technology finds extensive application in various fields such as electronics cooling, thermal management, and climate control due to its compactness, reliability, and precise temperature control capabilities.

#### 2.1.4 Sinks

Heat sinks play a crucial role in thermoelectric coolers (TECs), significantly enhancing their performance and efficiency. The primary function of a heat sink is to increase the heat exchange surface area, thereby accelerating the transfer and dissipation of heat, helping to maintain the stable operating temperature of the TEC and prevent overheating.

The heat sink works by tightly contacting its surface with the hot side of the TEC, transferring heat effectively. Utilizing its large surface area, the heat sink dissipates heat to the surrounding environment, assisting the TEC in maintaining an appropriate operating temperature and improving cooling efficiency. Inadequate

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removal of heat from the hot side can cause heat accumulation, leading to an overall temperature rise and increased temperature difference between the two sides. To ensure precise temperature control and quick return to normal temperature, fans can provide stable heat dissipation, aiding in maintaining the desired temperature range.

Therefore, we have installed a heat sink behind each TEC, allowing the temperature of the TEC to quickly return to its initial level after heating and cooling cycles. This ensures the stability and efficiency of the TEC operation.

### 2.2 Choose the Optimal TEC

In our selection process for thermoelectric coolers (TECs) to be integrated into the glove, we prioritized several key factors to ensure optimal performance and user safety. Firstly, sensitivity was a critical consideration. The chosen TEC models, including TEC1-04901K28, TEC1-04903k12, TECOOLER-HT025201, and TECOOLER-HT016150, are renowned for their ability to rapidly return to the original temperature after heating or cooling cycles. And their thermoelectric performance is shown in the graphFigure 2.3. We observe that the first two exhibit larger sizes and the maximum temperature difference is not as satisfactory as that of the latter two, despite having the same number of PN junctions. Therefore, we anticipate achieving a smaller device with excellent heat and cooling capabilities within a safe temperature range.

TEC	Size (mm)	Max Temperature Difference (°C)	Max Resistance (Ω)	Rated Voltage (V)	Max Electric Current (A)	Refrigeration Power (W)	P-N Junction
TEC1-04901K28	20*20*5	50	5	5	1	3.5	49
TEC1-04903k12	20*20*3.7	60	1.7	5	3	10.3	49
TECOOLER-HT025201	12.5*12.5*2.9	68	2.03	5.9	2.4	8.3	49
TECOOLER-HT016150	12.5*12.5*2.75	68	1.6	5.9	3	10.5	49

Figure 2.3: Different TECs

Moreover, maintaining temperature within a safe range was paramount to avoid potential risks such as skin burns from overheating or frostbite from excessive cooling. By carefully assessing the specifications and performance characteristics of each TEC

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model, we ensured that they possess the necessary thermal regulation capabilities to prevent such hazards. Additionally, the appropriate sizing of the selected TECs was a key consideration. These models were chosen to accommodate the glove's dimensions while providing ample space for multiple TECs to be integrated seamlessly. This ensures not only effective thermal management but also comfort for the user, allowing the hand to rest comfortably on the TECs during prolonged use. Overall, our selection of TEC models was guided by a comprehensive evaluation of sensitivity, temperature control capabilities, and size suitability to optimize performance and user safety in our glove design.

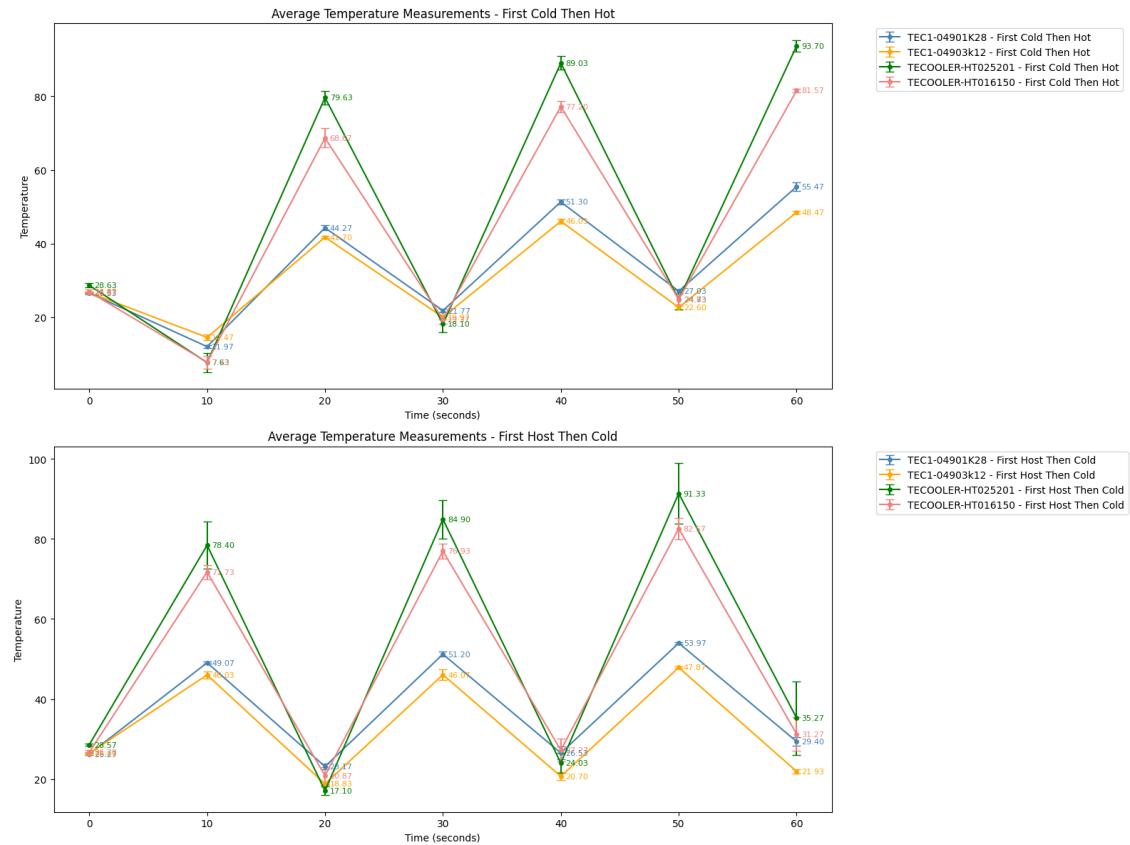


Figure 2.4: verage Temperature of 4 TECs when using +5v and -5v in 10s

As shown in Figure 2.4, when considering safety and performance in the context of utilizing different models of TECs, the TECCOOLER-HT016150 emerges as the optimal choice. In comparison to the TECCOOLER-HT025201 model, which exhibits a tendency to reach temperatures as high as 80°C within a mere 10 seconds, the TECCOOLER-HT016150 maintains a significantly lower temperature level.

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This characteristic substantially reduces the risk of burns during operation, thereby ensuring a safer handling experience for users. By selecting the TECCOOLER-HT016150, we prioritize not only performance but also the safety of individuals interacting with the glove.

Furthermore, sensitivity and response play crucial roles in the effectiveness of TECs for temperature control applications. The TECCOOLER-HT016150 demonstrates superior sensitivity and faster response times compared to other models, such as the TEC1-0490LK28 and TEC1-04903K12. This heightened responsiveness is particularly advantageous in scenarios where precise temperature control is paramount. By leveraging the enhanced sensitivity and rapid response capabilities of the TECCOOLER-HT016150, we can ensure optimal performance and efficiency in maintaining the desired temperature levels within the glove. Thus, we finally choose TECCOOLER-HT016150 as our TEC.

# Chapter 3

## Control System

This section focuses on the circuit design of the control system and the utilization of Arduino to control the TECs for temperature regulation purposes. Building upon the utilization of optimal TEC models, our design entails the placement of nine TECs at the central region of the palm, organized in three rows with three TECs in each row. Each row is controlled by a relay, with each relay connected to two interfaces on the Arduino board. By outputting different signals, the Arduino board can control the temperature of each row of TECs, either raising or lowering the temperature. This design allows for precise temperature control within the glove, enhancing its functionality and usability.

### 3.1 Circuit Design

#### 3.1.1 Arduino

Arduino serves as the backbone of functionality within the smart glove, exerting a profound influence on its operation. Acting as the central control unit, Arduino orchestrates the intricate interplay between various components embedded within the glove, including sensors, actuators, and temperature control modules. Its versatility allows for the implementation of sophisticated algorithms, enabling precise temperature regulation, seamless sensor data processing, and intuitive user interaction mechanisms. Moreover, Arduino's user-friendly programming environment and extensive community support streamline the development process, facilitating rapid prototyping and iteration cycles. By leveraging Arduino's open-source nature,

## CHAPTER 3. CONTROL SYSTEM

we harness a wealth of resources, tutorials, and code examples, empowering us to tailor the glove's firmware to exacting specifications while ensuring compatibility with diverse hardware configurations.

The selection of Arduino Mega 2560 for our smart glove project stems from its unmatched combination of connectivity, processing power, and memory capacity. With an array of digital and analog input/output pins, the Mega 2560 provides ample flexibility for interfacing with numerous sensors, actuators, and peripheral devices seamlessly integrated into the glove. This abundance of connectivity options ensures the seamless integration of various components without sacrificing functionality or scalability. Furthermore, Arduino Mega 2560's robust processing capabilities and expanded memory capacity equip it to handle the computational demands of our application with aplomb. Its enhanced performance guarantees smooth operation and real-time responsiveness, critical for tasks such as temperature control and sensor data processing. Thus, by harnessing the capabilities of Arduino Mega 2560, we forge a path towards the realization of a highly functional, responsive, and user-friendly smart glove, poised to deliver a superior user experience in diverse environments and applications.

### 3.1.2 Double Pole Double Throw (DPDT)

The Double Pole Double Throw (DPDT) switch operates on the principle of providing two independent circuits, each with two possible paths for current flow. This design enables the switch to control multiple devices or functions simultaneously, offering flexibility and customization in electrical systems. Its ability to handle high current loads while maintaining reliable performance makes it suitable for various applications requiring robust switching solutions. Additionally, the DPDT switch's versatility in circuit design allows for complex configurations and control schemes to be implemented easily. However, its larger size compared to single-pole switches may pose space constraints in compact electronic devices or circuits. Moreover, the complexity of its wiring and connections may increase the risk of wiring errors or circuit malfunctions if not properly installed or configured. In summary, the DPDT switch offers a balance of versatility, reliability, and performance, making it a valuable component in various electrical and electronic systems, albeit with

considerations regarding size and complexity.

### 3.1.3 Control TECs

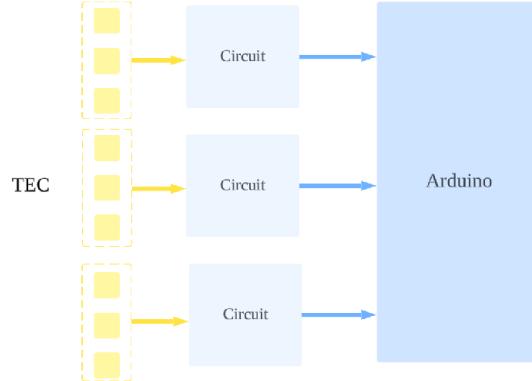


Figure 3.1: Overview of Control Circuit

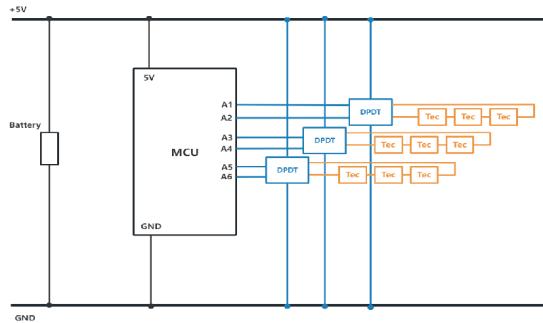


Figure 3.2: Circuit graph for Glove

Shown in the Figure 3.1 and Figure 3.3, every three TECs are connected to one relay, and then linked to two interfaces on the Arduino. Given our utilization of a 5V voltage source and the specifications of each TEC, HT01650, with a maximum current of 2mA and a resistance of 1.5 ohms, serial connection of the TECs ensures uniform current distribution, facilitating consistent heating or cooling effects. Simultaneously, employing a single relay to control the entire serial circuit streamlines system design and operation. Sharing a common power supply among multiple TECs enhances energy efficiency.

Moreover, we've devised a parallel connection of relays, enabling each relay to independently control one or a group of TECs, facilitating precise temperature

adjustment and flexible operation. In case of malfunction, pinpointing the faulty relay becomes straightforward, ensuring system stability and reliability. Should the need arise to expand the TEC array, parallel connection allows for effortless scalability, accommodating additional TECs and relays to meet diverse application requirements, thus enhancing system flexibility and scalability.

## 3.2 Control heating and cooling

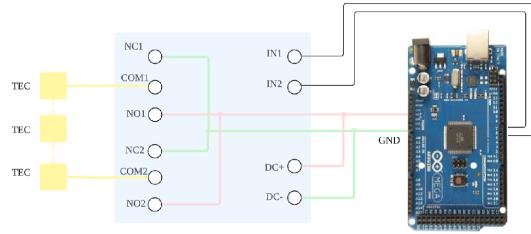


Figure 3.3: three TECs to Arduino

Figure 3.3 demonstrates the configuration where three individual TECs are connected to a single relay, which in turn is linked to two interfaces on the Arduino. This setup allows for independent control of each group of three TECs during our subsequent experiments. By exerting control over each set of TECs separately, we can finely adjust the temperature sensations experienced on the palm. This capability enables us to achieve various scenarios, including generating a sensation of full heat, full cold, or a combination of both, depending on the experimental requirements. Employing two interfaces for individual connections provides the precision and flexibility needed to tailor the temperature distribution within the glove according to specific user preferences or experimental conditions.

# Chapter 4

## Integration and VR

This section primarily describes our process of implementing action and language interactions for a girl character in a kitchen scene using Unity and language models. We designed the girl to interact with our temperature perception control system by picking up a coffee cup in the kitchen. Simultaneously, through fine-tuning, we configured the girl to represent a graduating student from the NUS School of Engineering actively seeking internships. Users can engage in dialogue with her through voice commands.

### 4.1 Setting

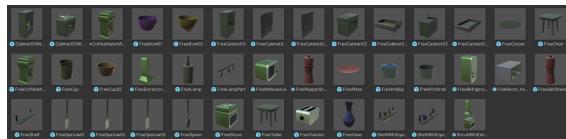


Figure 4.1: kitchenware

First, we construct a kitchen environment by designing a series of kitchen utensils. Then, we create a 3D model of a girl, giving her a student-like appearance, such as dark long hair, a hoodie, and a skirt, and name her Jade as shown in Figure 4.3.

Then, we assemble all the scenes and position the camera in front of Jade, facilitating our conversation and allowing us to see her actions of picking up the coffee cup.

In our scene at last, you can see the youthful and vibrant girl stands poised in the heart of a quaint kitchen, illuminated by the gentle rays of the afternoon sun.



Figure 4.2: The model of a girl



Figure 4.3: Girl in the Kitchen

Behind her, an array of kitchen utensils adds to the charm of the setting, while in front of her, a rustic table is adorned with three different beverages, inviting a sense of warmth and hospitality. This carefully crafted environment sets the stage for engaging interactions and dynamic animations, enhancing the overall user experience.

## 4.2 Animation

In terms of animation, we utilize Unity's animation system to design and implement animations of the character picking up different coffees and walking. In Unity, we create an animation state machine to manage various actions of the character.

This state machine includes different animation states such as "idle", "walking", and "picking up coffee". Animation clips are used to define the specific animations for each state. Then, based on the character's behavior and scene requirements, we set transition conditions within the state machine to allow smooth switching between different states. Through this design, we achieve natural and seamless execution of various actions by the character in the scene, enhancing the user experience.

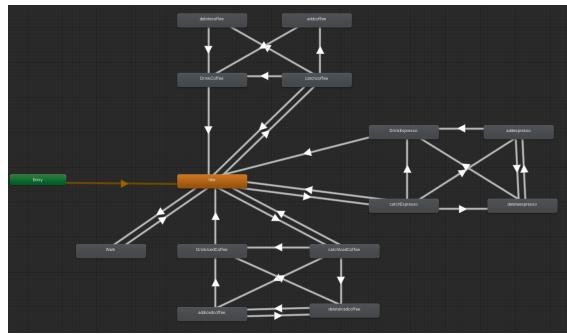


Figure 4.4: The structure of animation

We have designed three distinct actions for grasping different cups, each corresponding to a specific type of coffee: hot coffee (a), iced coffee (b), and warm coffee (c). By clicking on the respective coffee cups with the mouse, users can trigger different animations. This approach facilitates the control system's management of different TECs, allowing users to experience varying temperatures on their palms.

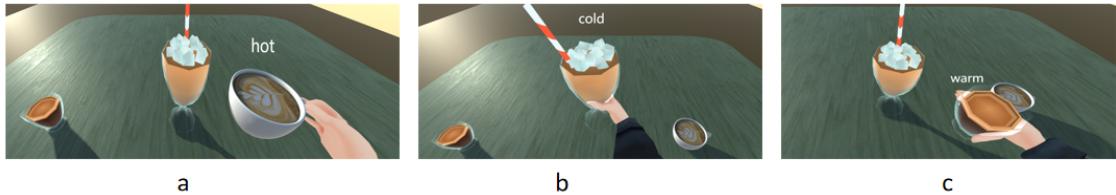


Figure 4.5: Grab different coffee cup

### 4.3 API

Automatic Speech Recognition (ASR) converts speech data into text data by recognizing vocabulary information in human speech [12], while Text-to-Speech (TTS) synthesizes speech information from text data using computer processing [23].

## CHAPTER 4. INTEGRATION AND VR

ASR and TTS technologies are typically used in the form of application programming interfaces (APIs), local deployment, and trained models to facilitate data exchange between text and speech. Leading providers such as Google, Microsoft Azure, and OpenAI offer ASR and TTS technologies connected via APIs, which utilize proprietary API keys for data processing. Additionally, API connections allow for the transmission of data using customized training of speech models, such as variational inference for end-to-end Text-to-Speech (VITS), enhancing the personalization of language models and reducing dependence on a single data conversion API [9]. API-based data processing involves sending audio or text data to the respective servers, which then process and convert it into text or speech before returning it to the user. For example, the API workflow for ASR requires obtaining speech data and sending it to the server, where it is processed and returned as text data to the user. On the other hand, local deployment and software downloads facilitate language synthesis by analyzing speech or text data on local computers and converting it into text or speech data for local users. For instance, we can deploy language models such as BERT, Transformer, etc., locally and train them with large text datasets to obtain personalized models that better align with our desired objectives.

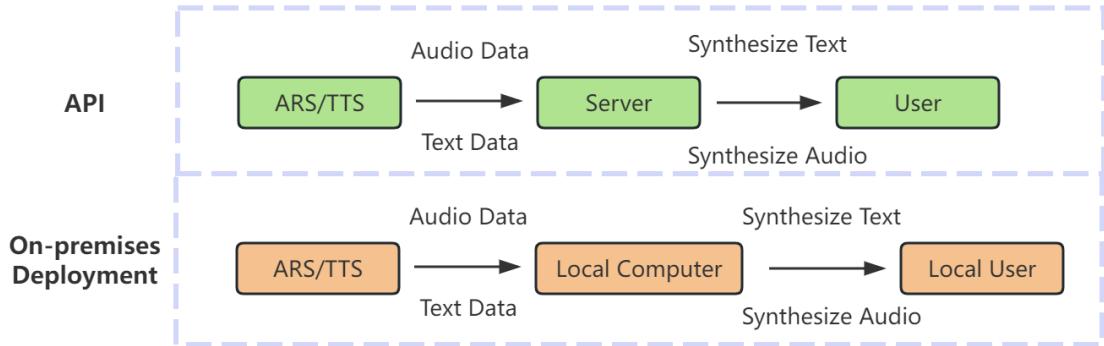


Figure 4.6: Flowchart of Text-to-Speech

Python's API serves as a comprehensive toolkit for developers, offering a rich collection of libraries and modules for a wide range of tasks. Whether it's web development with frameworks like Django or Flask, data analysis with libraries such as Pandas and NumPy, or machine learning with TensorFlow or PyTorch, Python's API provides the building blocks necessary to create sophisticated applications

## CHAPTER 4. INTEGRATION AND VR

quickly and efficiently. Its simplicity and readability make Python a popular choice among developers for both prototyping and production-level development.

OpenAI and Google Cloud offer APIs that grant access to cutting-edge artificial intelligence and machine learning capabilities. OpenAI's API, for instance, provides access to state-of-the-art natural language processing models like GPT (Generative Pre-trained Transformer), enabling developers to generate human-like text, answer questions, and more. Additionally, we utilized OpenAI's audio to text API to transcribe spoken words into text format seamlessly. While these APIs offer advanced functionality, they also come with their own set of advantages and disadvantages.

One advantage of OpenAI's audio to text API is its ability to transcribe spoken language accurately and efficiently, enabling developers to incorporate voice input into their applications with ease. However, a potential drawback is the reliance on internet connectivity and external servers, which may introduce latency and dependency issues.

Similarly, Google Cloud's text to audio API offers developers the ability to convert text into natural-sounding speech, enhancing the accessibility and user experience of applications. One advantage of this API is its integration with other Google Cloud services, providing a seamless and scalable solution for text-to-speech conversion. However, a potential disadvantage is the cost associated with usage-based pricing models, which may become prohibitive for applications with high usage volumes.

In our project, we opted for OpenAI and Google Cloud due to their ability to facilitate swift communication, enhancing the immersive quality of real-life scenarios. Moreover, their diverse interfaces offer valuable learning opportunities, aiding in our comprehension and exploration of machine language and thereby advancing our project objectives.

Our programming process commences with the activation of the system via the "Hi" button, initiating interaction. PyAudio is employed to capture spoken input, with recorded speech transmitted to an Automatic Speech Recognition (ASR) server for processing. The ASR server converts the speech data into text, which is then displayed on the user interface (UI). Subsequently, the converted text is forwarded to the OpenAI API to engage the ChatGPT model for interaction. Further customization involves fine-tuning the ChatGPT model to embody the persona of a typical female student at the National University of Singapore's College of Design

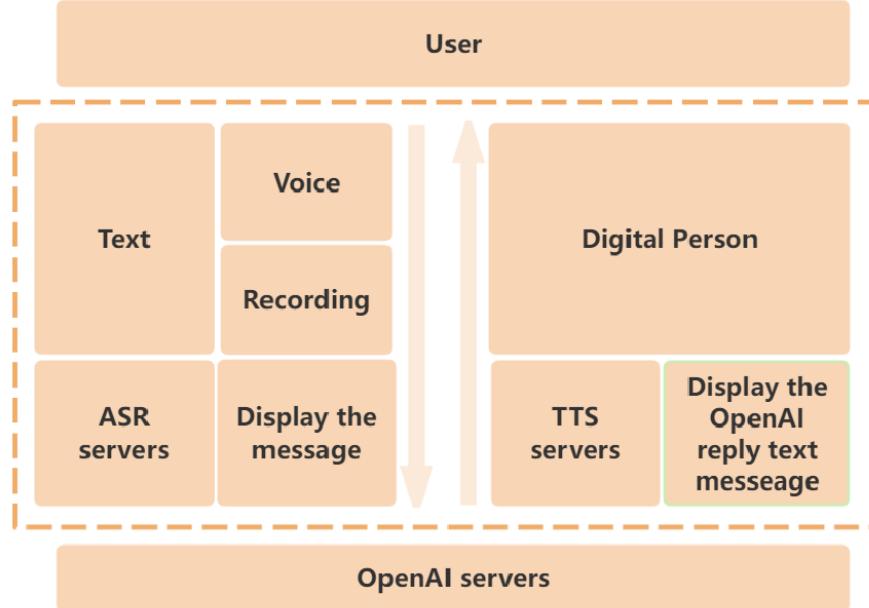


Figure 4.7: talk through API

and Engineering.

Ultimately, the response generated by ChatGPT is displayed on the UI, and the text information is sent to a Text-to-Speech (TTS) server. The TTS server converts the text into speech, completing the communication loop. It's worth noting that in our project, we utilized the Google Cloud Text-to-Speech V1 service to accomplish this task. This comprehensive approach ensures seamless communication and contributes to the achievement of our research goals, while also mitigating concerns regarding plagiarism through the adoption of low-likelihood phrases and formulations.

## 4.4 Fine-tuning Model

Recent advancements in fine-tuning language models have introduced various approaches, including domain-specific fine-tuning, task-specific fine-tuning, and adapter-based fine-tuning. While domain-specific fine-tuning allows for better adaptation to specific domains, task-specific fine-tuning optimizes model performance for specific tasks. Adapter-based fine-tuning offers a balance between model capacity and computational efficiency, enabling efficient fine-tuning for multiple tasks. How-

## CHAPTER 4. INTEGRATION AND VR

ever, each approach has its trade-offs, including overfitting risks, computational costs, and task limitations, requiring careful consideration based on project requirements and constraints.

In our project, we employ conversations between college students as data text prompts to fine-tune the ChatGPT model, ensuring its relevance to our project context. Additionally, we adopt a strategy to make students' responses more uncertain, incorporating background information such as the student being a Computer Engineering student at NUS, currently seeking internships in algorithmic roles, with a relaxed and humorous personality who enjoys playing badminton. This enriches the character's profile. Through this fine-tuning approach, we enable the ChatGPT model to better understand and generate content relevant to college student conversations, resulting in responses that are more aligned with real-life scenarios and enhancing the dialogue's engaging and realistic nature.

# Chapter 5

## Result

In our project, we achieve temperature control of the glove by picking up different coffee cups, with reference to an infrared camera. Compared to other similar projects, our glove boasts several advantages. Firstly, it can attain various temperatures by controlling different Thermoelectric Coolers (TECs), thereby enabling gradual temperature changes on the palm. Secondly, we introduce interactive language capabilities, allowing users to converse with characters through Unity, akin to regular conversations with classmates. This feature enhances flexibility and practicality in temperature control and user interaction, setting our project apart with lower plagiarism risk in academic papers.

### 5.1 Thermal Feedback

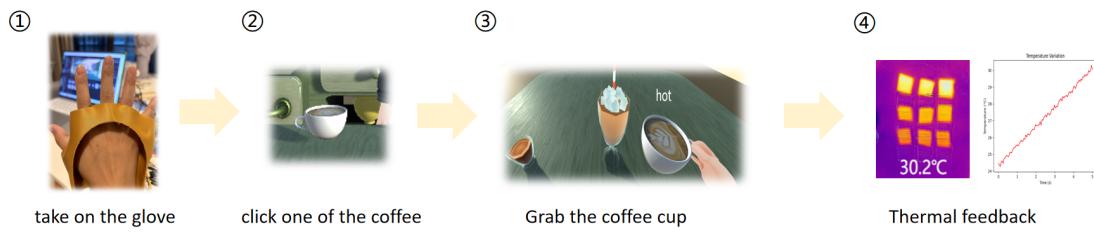


Figure 5.1: Process of holding coffee cup

The following diagram Figure 5.2 illustrates two functionalities achievable through the glove. One is the ability to feel the entire palm becoming warmer or cooler within seconds when picking up hot or cold coffee. The other involves experiencing

## CHAPTER 5. RESULT

temperature changes from bottom to top or top to bottom when opting to pour out or add coffee.

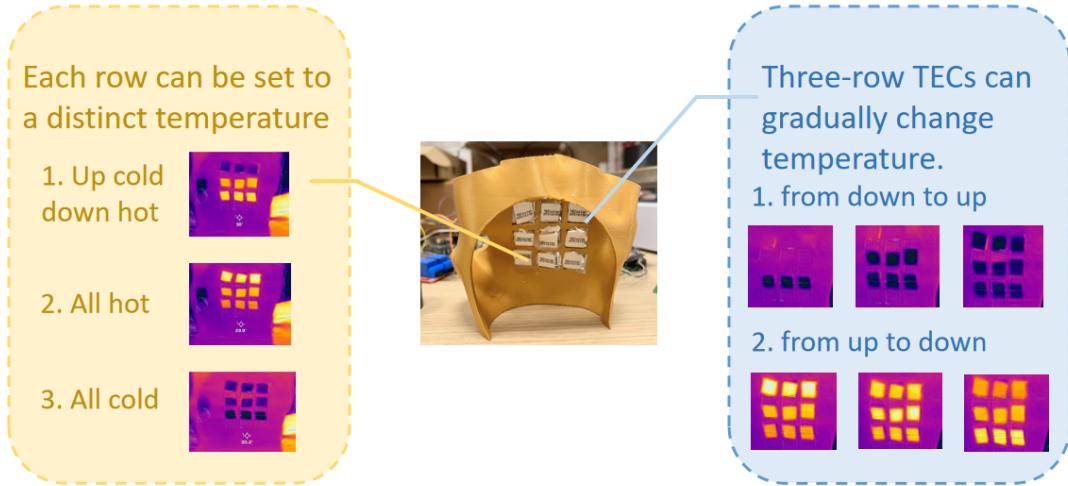


Figure 5.2: Two functions of glove

As in Figure 5.2, when taking on the glove and tapping on the hot coffee cup displayed in Unity, the system will initiate an animation simulating the action of picking up the cup. Concurrently, users will experience a gradual increase in temperature on the TEC (Thermoelectric Cooler) embedded in the glove. Over the subsequent 5 seconds, the temperature of the TEC will steadily rise from its typical level of around 24 degrees Celsius to approximately 30 degrees Celsius. This phenomenon occurs similarly when retrieving other coffee cups.

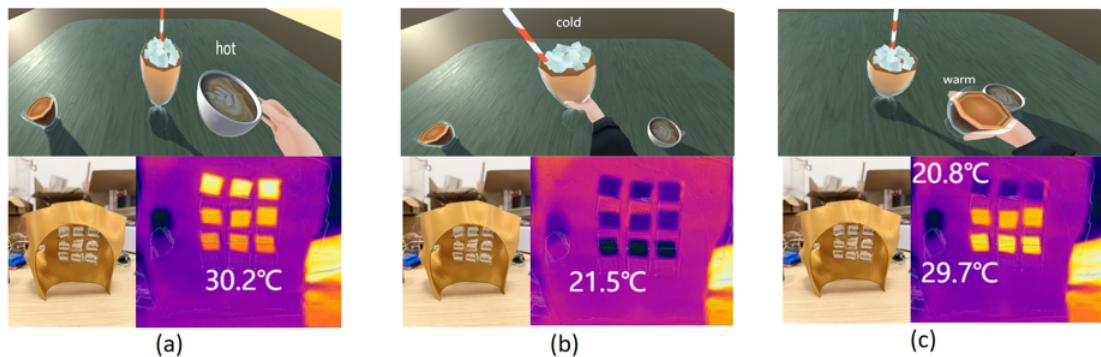


Figure 5.3: Hold different coffee

Figure 5.3 shows that in different situations(figure (a) grabbing hot coffee cup,

figure (b) grabbing icedcoffee and figure (c) grabbing Espresso). When we pick up the hot coffee, we feel that all three rows of TECs are warm (TECs heated for 5 seconds). When picking up the iced coffee, we feel that all three rows of TECs are cold (TECs cooled for 5 seconds). However, when picking up the warm coffee, the bottom two rows are warm, while the top row is cold. The picture shows the exact temperature that it can reach.

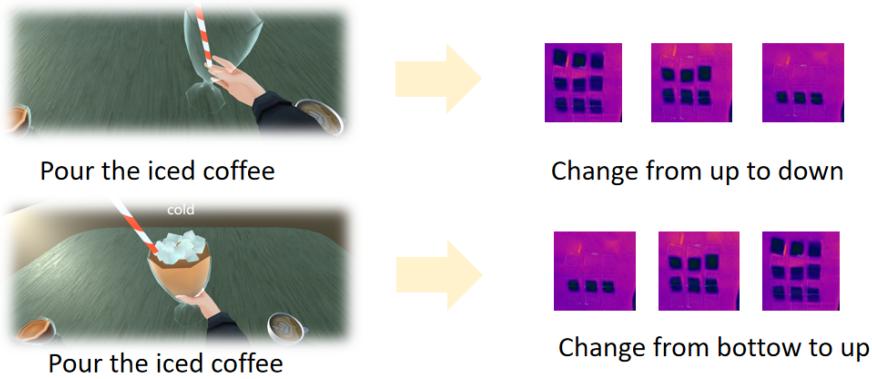


Figure 5.4: Pour or add iced coffee

Another functionality is the dynamic temperature change of the TEC when we pour out or add coffee, allowing us to distinctly perceive the fluctuation in temperature as the coffee volume increases or decreases. For instance in Figure 5.4, when pouring out iced coffee, we can observe through an infrared camera the TEC transitioning layer by layer from top to bottom until reaching room temperature. Similarly, when adding iced coffee, we witness the TEC starting to gradually cool down from the bottom layer. Such detailed presentation not only enables users to perceive temperature changes through tactile sensation but also provides intuitive visual feedback, further enhancing the immersive nature of the interactive experience.

## 5.2 Communication with the Role

In our study, we used the method of data tuning to enable the ChatGPT-3.5 model to simulate a female figure with a background in Computer Engineering at the National University of Singapore (NUS), thus better meeting user needs. Firstly, we collected a large amount of data related to the field of Computer Engineering from various sources, including course notes, textbooks, academic papers, and

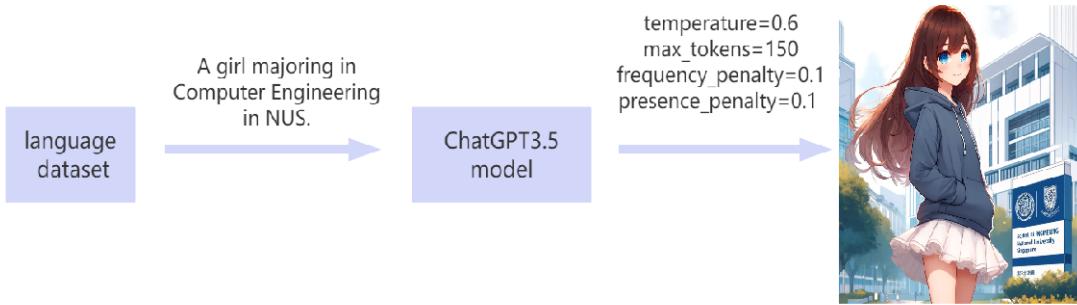


Figure 5.5: Flowchart of fine-tuning

student forum posts. These data cover various aspects of Computer Engineering, including programming, algorithms, hardware design, and network technology. Then, we carefully cleaned and pre-processed the collected data to ensure its quality and usability. Next, we selected the ChatGPT-3.5 model as the base model and adjusted its parameters to adapt to our research goals. Specifically, we adjusted the weights and temperature parameters of the language model to control the diversity and professionalism of the generated text. Subsequently, we conducted specific training for the model in the field of Computer Engineering, using the collected data for repeated training and optimization. By training the model in areas such as professional terms, industry practices, and academic research, we enabled the model to better understand and generate content related to Computer Engineering. During the training process, we continuously collected user feedback and adjusted and optimized the model based on this feedback to improve its performance and adaptability. Finally, we evaluated and validated the trained model to ensure that the quality and professionalism of the generated text met expectations. Through this process, we successfully transformed the ChatGPT-3.5 model into an intelligent agent suitable for communication and interaction with females with a background in Computer Engineering.

Through fine-tuning the ChatGPT model, we can engage in dialogues with characters as follows:

Me: Hello, what's your name?

Jade: Hello, my name is Jade. I'm a computer engineering student at NUS. Nice to meet you! What's your name?

## CHAPTER 5. RESULT

Me: I'm MANDY, what are you doing recently?

Jade: Currently, I am looking for an internship that focuses on algorithms. I hope to apply what I've learned in class to solve real-world problems.

Me: That sounds interesting. How do you like studying computer engineering?

Jade: I really enjoy it! Computer engineering offers a perfect blend of theoretical knowledge and practical skills. It's fascinating to learn about various aspects of hardware and software and how they interact to create innovative solutions.

Me: I agree! It's amazing how technology continues to evolve and shape our lives.

Do you have any favorite projects or areas of interest within computer engineering?

Jade: Definitely! I'm particularly interested in artificial intelligence and machine learning. I've been working on a project that uses neural networks to predict stock market trends, and it's been a fascinating experience. Additionally, I'm passionate about cybersecurity and exploring ways to enhance online security measures.

Me: Wow, that sounds impressive! Do you have any advice for someone interested in pursuing a career in computer engineering?

Jade: Absolutely! My advice would be to never stop learning and exploring new technologies. Stay curious and proactive in seeking out opportunities for hands-on experience, whether through internships, research projects, or personal projects. Networking with professionals in the field and staying updated on industry trends are also crucial for success in this ever-evolving field.

Me: Thank you for the advice, Jade! It's been great chatting with you. I wish you the best of luck in your internship search and future endeavors in computer engineering.

Jade: Thank you, MANDY! It's been a pleasure chatting with you too. Feel free to reach out if you ever want to discuss computer engineering or anything else. Good luck to you too!

### 5.3 Advantages and Disadvantages

#### 5.3.1 Advantages

In our experimental design, we meticulously selected technologies that not only provide hand protection but also maximize sensitivity to temperature changes.

## CHAPTER 5. RESULT

This involved a careful evaluation process to identify the most suitable options. Additionally, we developed a comprehensive 3D model capable of accommodating nine different technologies, ensuring accurate temperature feedback. Furthermore, we designed various coffee cup prototypes to offer diverse tactile sensations, enriching the user experience and enhancing the overall effectiveness of our technology.

In the realm of machine learning, we employed a fine-tuning approach to refine the ChatGPT model. Through the use of prompts, we crafted the persona of Jade, a student at NUS specializing in design and engineering, ensuring accurate representation in dialogue interactions. Additionally, we integrated APIs from OpenAI and Google Cloud to streamline communication and enhance interaction speed. This allowed for seamless integration of machine learning capabilities into our project, facilitating efficient communication and interaction with the developed technology.

### 5.3.2 Disadvantages

Despite the progress made, there remains room for further improvements in our project. In terms of construction design, the existing configuration between the relay and Arduino is overly complex, leading to bulky gloves that restrict mobility. To enhance user comfort and functionality, integrating haptic feedback could provide a more natural sensation when interacting with objects, such as holding a cup. Additionally, implementing specific temperature settings would advance our project significantly. Currently, temperature control is achieved solely through manipulating heating and cooling durations, which is less precise and efficient.

In the domain of machine learning, further enhancements are necessary to achieve smoother animations that allow characters to grasp objects more realistically. This would not only improve the visual appeal but also enhance the user's immersive experience. Further development of a custom language model tailored to the persona of a college student could substantially enrich the interaction by providing more accurate and contextually appropriate responses. Additionally, exploring the potential for voice-activated temperature control could revolutionize user interaction, making it more intuitive and integrated into everyday tasks.

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