# ThermalPen: Adding Thermal Haptic Feedback to 3D Sketching


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**Figure 1: 1) ThermalPen, 2) Snow Blue texture - Cold, 3) Flame Red texture - Hot, and 4) Views of the 3D sketching application, a user sketching (top) and the menu to change color and textures (bottom)**


## ABSTRACT

Sketching in virtual 3D environments has enabled new forms of artistic expression and a variety of novel design use-cases. However, the lack of haptic feedback proves to be one of the main challenges in this field. While prior work has investigated vibrotactile and force-feedback devices, this paper proposes the addition of thermal feedback. We present ThermalPen, a novel pen for 3D sketching that associates the texture and colour of strokes with different thermal properties. For example, a fire texture elicits an increase in temperature, while an ice texture causes a temperature drop in the pen. Our goal with *ThermalPen* is to enhance the 3D sketching experience and allow users to use this tool to increase their creativity while sketching. We plan on evaluating the influence of thermal feedback on the 3D sketching experience, with a focus on user creativity in the future.




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## CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**; **Virtual reality**.

## KEYWORDS

Virtual Reality, 3D Sketching, Creativity, User Experience, Haptics, Pen-input, Thermal

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## 1 INTRODUCTION

Virtual Reality (VR) continues to develop as an interaction space that is becoming increasingly available to consumers. Original to VR is the ability to use 3D sketching applications that allow artist to draw in 3D. We can define 3D Sketching or VR Sketching as:

> "a type of technology-enabled sketching where: 1. the physical act of mark making is accomplished off-the-page in a 3D, body-centric space, 2. a computer-based tracking system records the spatial movement of the drawing implement, and 3. the resulting sketch is often displayed in this same 3D space, e.g., via the

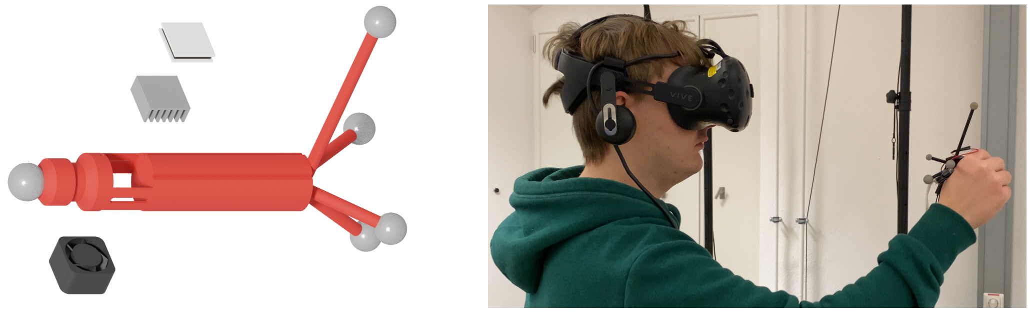

**Figure 2: 3D rendered exploded view of the pen (left) and ThermalPen in action (right).**

use of immersive computer displays, as in virtual and augmented realities (VR and AR)." (Arora et al. [1], p. 149).

For artists, the venture into 3D drawing is not without limitations; particularly, current 3D sketching systems provide limited sensory feedback while sketching. When compared to traditional art tools, sensory feedback in VR might affect the estimation of object properties and affects the user experience. For example, without a physical space feedback cues from the application of the drawing utensil to the canvas, it can be harder to apply paints to simulate varying stroke pressure. As artists often use tools to create different textures and meaning within their art [3]. Although sensory feedback is important to the creation of art, VR is a new modality and limitations to sensory feedback provide an opportunity to encode new information within the interface. Touch and haptic interaction is an area of exploration for the development of VR space; as such, we propose to engage sensory feedback by adding temperature. In this paper, we aim to solve the problem of limited sensory feedback by presenting *ThermalPen*, a drawing device for 3D sketching that provides visual-haptic feedback by combining the visual cues of the stroke color and texture with thermal stimuli created by the pen. In other words depending on the color and texture the user selects, the pen changes in temperature to be cooler or warmer. By using visual-haptic feedback we aim to increase user's creativity when sketching in 3D by providing artists with more tools to experiment and express themselves freely.

## 2 THERMALPEN

*ThermalPen* works with a standard 3D sketching system where the user is able to choose a color and texture combination for their strokes. After the user selects it, the pen automatically heats and cools depending on the color and texture selected. Our work extends previous work that uses haptic feedback to help users better control their stroke [7, 8, 14], to provide a drawing surface when sketching in mid-air [2, 4, 6, 9, 11, 12], and to emulate the sensation of drawing in different materials [5]. We also extend previous work that merge visual-haptic feedback to enhance the user experience [13, 15].

The complete *ThermalPen* with all sensors and tracking markers has a total weight of 44 g. Due to the small form factor of the Peltier device (15 mm by 15 mm) we were able to keep the dimensions of the pen relatively compact. The main shaft itself is 11 cm long with a diameter of 2 cm. When including the reflective markers, the pen dimensions add up to 17 cm x 14 cm x 7 cm .

*2.1.1 Temperature Feedback.* *ThermalPen* consist of a 3D printed body with a cavity in the main shaft where the various sensors reside that allow the heating and cooling of the pen. We utilize a Peltier thermoelectric cooler that converts electric energy directly into thermal energy to create the thermal feedback. Depending on the polarity, the Peltier device is able to generate hot and cold temperatures which is necessary for our design. Attached to the Peltier device are a heat sink and an axial fan that help boost the thermal device's effectiveness. The pen has to be held with the Peltier device facing upwards, so that the user's index finger can rest on it. Users can utilize the pen in either the left or the right hand, which allows for better accessibility and prevents any issue handedness. The Peltier device is regulated through an Arduino micro-controller connected to a motor driver for which an electrical diagram is presented in figure 3. The L289N motor driver controls voltage and current direction for DC stepper motors but can be used for our use case. Temperature can be set by changing a PWM value on the Arduino which results in the motor driver converting the 12 V input into the desired voltage. The apparatus is placed on a table next to the computer and the thermoelectric cooler is attached via cable to the motor driver. Automatic temperature control is achieved by a predefined set of voltage values that are broadcasted via the serial port. Maximum current is 2 A while maximum voltage is set to 1 V. Due to the size of the Peltier device a thermal sensor would have not been viable, so during operation it is not possible to monitor the current temperature. This results in uneven heating or cooling periods also because it is highly dependent on ambient and previous temperature. Therefore, we continue to send thermal feedback for five seconds after the pen left the sketch surface. This number stems from the average time the Peltier device takes to reach its programmed temperature.

We determined the discrete temperature values of the pen by running a pilot user study. In this pilot study, our participants cycled through all texture-color combinations and gradually adjust the temperature setting starting from ambient temperature. We accumulated 24 results for each color and texture and the final values were determined via averaging. The final values for every possible combination can be seen in figure 1. Considering the pain threshold, the highest average temperature we measured in this experiment coincides with the pain threshold found byKuhtz-Buschbeck et al. with 45.7 °C used for the red flame texture. On the bottom end of the spectrum there is the cyan snow texture with 19.9 °C.

| Color | Default | Snow | Flame |
|---|---|---|---|
| Magenta | 32.6 °C | 32.2 °C | 36.2 °C |
| Red | 45.1 °C | 42.1 °C | 45.7 °C |
| Yellow | 40.0 °C | 37.1 °C | 42.8 °C |
| Green | 30.8 °C | 28.0 °C | 34.3 °C |
| Cyan | 20.9 °C | 19.9 °C | 21.6 °C |
| Blue | 20.8 °C | 20.1 °C | 31.3 °C |

**Table 1: Table with temperature values in degree Celsius**

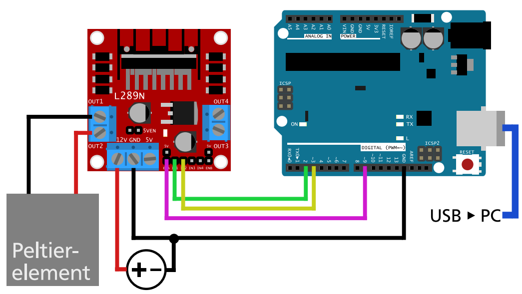


**Figure 3: The circuit diagram for the temperature control setup**

*2.1.2 Tracking.* Tracking the pen is done with the *Optitrack* position tracking system. At the front and at the back there are reflective markers attached for passive tracking using *OptiTrack*, which allow us to detect the pen's movement in VR. We tested multiple prototypes to find the optimal marker distribution for the best tracking while 3D sketching. The final prototype has extruding sticks of different lengths and angles at the back of the pen so that rotation is perceived unambiguously. We used a total of six OptiTrack Flex 3 cameras with 100 frames per second and a resolution of 640x480 to track the pen inside the virtual space.

*2.1.3 User Interface.* We implemented a 3D sketching application using the game engine *Unity 3D* version 2021.3.1f1 to test the *ThermalPen* prototype. Our system ran using an Intel i7-4790 on a Gigabyte B85M mainboard and 16GB of RAM in combination with an NVIDIA GTX 970. The VR head mounted display used for this project is the HTC Vive with a resolution of 1080x1200 alongside we used an HTC Vive controller.

In our sketching environment we included a uniformly colored default texture, as well as a snow and flame texture to incorporate two extremes of the temperature spectrum. Considering colors, for each texture we included the three base colors blue, green and red in addition to the mixed colors cyan, magenta and yellow. Both flame and snow texture are colored respectively resulting in a total of 18 individual color-texture combinations. Figure 1 shows some possible combinations of colors and textures, and the temperature the user would felt.

In VR, the user is able to move around a sketching surface which automatically triggers pen strokes if touched with the pen. Only during contact, the thermal element within the pen starts setting the respective temperature. The above mentioned sketch surface that automatically triggers pen strokes can be dragged around in 3D-space. When relocating the board the previously drawn pen strokes stay floating in the air. This enables fully three dimensional drawing. We first considered placing a button on the pen itself, similar to other VR sketch applications, but we did not find a suitable location due to the index finger reserved for the Peltier device. The sketch surface can be moved by grabbing it with a controller. The second purpose of the controller is the selection of the desired color-texture combination. Since we used an *HTC Vive* controller, we utilized the touchpad to control a menu that resembles a color palette. It consists of a main menu with the ability of deleting and undoing certain pen strokes and within three sub-menus it is possible to change color, texture and line width. To not distract the user while drawing, the color palette only appears when a finger is placed on the touchpad.

## 3 DISCUSSION

Our project presents *Thermal Pen*, a peripheral controller that aims to enhance creativity in VR by adding temperature feedback to textures while drawing, painting, sketching in 3D space. Our work expands the capability of VR environments to interface physically with the user, thereby expanding the modalities for interaction.

### 3.1 Future Work

Our current prototype is a first approach to including thermal feedback to a 3D sketching application. In the future, we are planning to add more functionalities to it. For example, currently we only included six colors, and in the future we plan to extend them to a broader range of colors to give users more options. Also, since we extracted the temperature values from a user study, we did not plan personalized temperature ranges. However, thermal pain thresholds might differ between users, so an adjustable range could be included in the future. Furthermore, the sketch pen itself could be more refined with wireless operation for example. Especially as the pen's diameter is large enough due to the Peltier device so that a battery and antennas could be placed inside it. Lastly, user interaction could also be improved with abilities like retroactive movement of the pen strokes and multiple virtual environments. Considering mutlimodal feedback, the inclusion of vibrotactile feedback in combination with different sketch surfaces could also improve immersion and creativity. In the future we also plan to evaluate *ThermalPen* in a usability study to understand how people use it to draw in VR.

### 3.2 Conclusion

In this paper we discuss the design of *ThermalPen*, a thermal pen for 3D drawing. Our proposed sketch pen automatically changes temperature depending on the texture-color combination in use. The advantages of using such system while sketching are that unlike drawing in real life, drawing in 3D is an novel experience with no physical surface (e.g. canvus, clay surface). As such, drawing and sketching in virtual reality could be better grounded to the physical

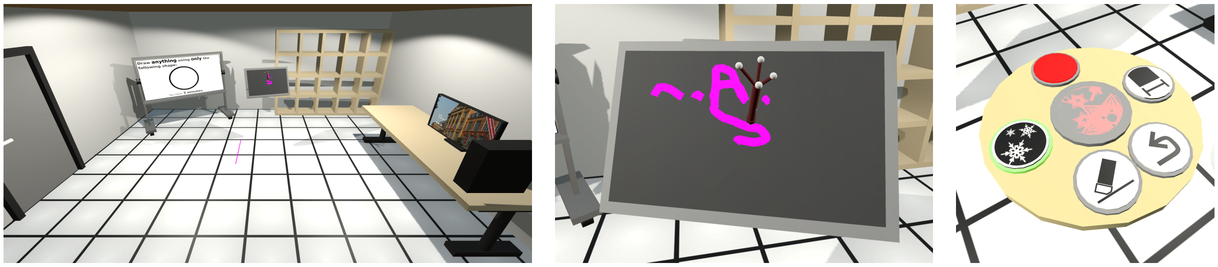

**Figure 4: Virtual environment (left), sketch surface (mid), color palette main menu (right)**

world to increase immersion in the virtual environment. To connect to the physical environment we add a new modality of feedback - temperature. Artists often use many tools to create within the world. instruments of art and design allows for immersive work, to increase immersion our VR thermal pen through temperature feedback.

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