Data Physicalization SlopeScope

CSC 413

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Introduction

The goal of this assignment is to provide students with hands-on experience in designing and developing Creativity Support Tools (CSTs) within data visualization. The proposed **SlopeScope** system is an innovative data physicalization tool that enables skiers to interact with real-time weather data through a tangible, intuitive interface. Featuring a 3D mountain model divided into advanced, intermediate, and beginner slopes, the system uses RGB LEDs to represent skill levels at a glance—green for beginner, blue for intermediate, and red for advanced. This clear, color-coded feedback allows skiers to quickly assess the terrain's difficulty and accessibility, empowering them to make informed decisions and creatively explore the mountain based on their skill level and changing conditions.

Aim & Motivations

The **SlopeScope** system is a data physicalization tool designed to merge a 3D mountain model with real-time weather data, enhancing decision-making and fostering creativity for freeride skiers. The mountain is divided into beginner, intermediate, and advanced sections, with each area represented by a gondola position and RGB LED indicators—green for beginner areas, blue for intermediate, and red for advanced. Using live data from Environment and Climate Change Canada, SlopeScope updates these indicators weekly, giving users an intuitive visualization of terrain accessibility and potential risks. For instance, when conditions indicate an avalanche warning, the LED flashes red to alert skiers to potential dangers, further enhancing their environmental awareness.

The system also provides weekly recommendations on a built-in LCD display: the first line shows the current week number, while the second line offers skiing guidance based on conditions, such as "Groomers" for packed trails or "Backcountry" for more rugged terrain. This dynamic feedback embodies the freeride skiing ethos of "negative freedom," allowing skiers to interpret data flexibly and chart their own courses, free from predetermined guidelines. By linking real-time environmental data to the skier's experience, SlopeScope invites exploration and self-expression, empowering skiers to plan routes, adapt to changing conditions, and immerse themselves meaningfully in the mountain landscape. This tangible interface supports creative engagement with the terrain, blending structure with freedom to enrich skiers' connection to the environment and their sport.

Justification for CST

The 3D mountain model functions as an innovative Creativity Support Tool (CST), converting detailed, real-time weather data into an interactive, intuitive display that fosters creative decision-making for freeride skiers (Impiö et al., 2024). By using RGB LEDs (Wang et al., 2008) to represent dynamic environmental factors, the model translates data on temperature, humidity, snowfall, and precipitation into a physical, tangible form, aligning with CST objectives to enhance users' creative potential and encourage open-ended exploration. This approach enables skiers to experience the mountain in fresh, imaginative ways, adapting to real-time weather insights, which promotes self-expression, adaptive problem-solving, and exploratory learning.

Freeride skiing(Impiö et al., 2024). is inherently creative, merging physical prowess with environmental awareness and improvisation in natural, ungroomed terrains. This “negative freedom” empowers skiers to carve personal routes, respond intuitively to obstacles, and interact with the mountain without strict guidelines. Reflecting this concept, the model uses real-time data to update LED indicators for various zones—green for beginner slopes, blue for intermediate, and red for advanced. For instance, a flashing red LED might signal dense fog in challenging areas, encouraging skiers to adapt and navigate around complex terrain based on their skill level and style.

The data, sourced from Environment and Climate Change Canada (Historical Climate Data, 2024), provides essential, real-time insights that align with skiers' unique creative goals. With updated measurements on precipitation, temperature variations, and visibility, the model empowers users to tailor their route planning thoughtfully. This approach ensures they can proactively identify potential icy patches or changing visibility, fostering a dynamic, creative interaction with the environment.

Through its color-coded, LED-responsive design (Augello et al., 2013), the model makes complex weather data accessible and easy to interpret, enabling skiers to make informed route choices that suit their goals and creativity. The interactive, real-time setup bridges digital data with hands-on engagement, supporting a creative, exploratory approach that allows skiers to confidently and intuitively connect with the mountain environment.

CST Design

Design Rationale

The 3D mountain model CST transforms complex weather data into an intuitive, interactive physical format, enhancing creative decision-making in skiing. By using RGB LEDs to indicate conditions across beginner, intermediate, and advanced slopes, and signaling high avalanche risks, the model allows skiers to make dynamic, informed decisions. This design leverages tangible interfaces, proven to facilitate understanding and engagement, thus boosting creativity (Huron et al., 2017)

***Figure 1**: 8 examples of skiing styles*

Scenario for Creative Tasks

A group of skiers use the 3D model to assess post-snowfall mountain conditions. The model displays Red, Blue, or Green to indicate the difficulty level based on various data points on the area. The skiers plan a route starting from the Eastern ridge, known for its steepness. They use the LEDs to determine if it is safe for their newer skiers to ski and practice new techniques, thus allowing creative exploration of new paths and jumps. This scenario demonstrates how the CST supports creative route planning and strategy formulation based on recent or real-time data.

Implementation

The **SlopeScope** system is designed to provide skiers with an interactive, tangible representation of weather data affecting ski slopes. Below is a detailed guide on how the system was built, including the components used, the assembly process, and how each part contributes to the overall functionality.

Components Used

1. Hardware Components

1. **Arduino Uno R3**: Serves as the microcontroller to process data and control peripherals.
2. **Stepper Motor with ULN2003 Driver Board**: Moves the gondola figurine up and down the 3D-printed mountain to indicate skill levels.
3. **RGB LED (Common Cathode)**: Displays different colors to represent skill levels and avalanche warnings.
4. **16x2 LCD Display**: Shows skiing recommendations based on the current weather data.
5. **Two Push Buttons**: Allow users to cycle through different weeks of weather data.
6. **Breadboard and Jumper Wires**: Used for assembling the circuit and making connections.
7. **Resistors (220 Ω)**: Limit current to the RGB LED.
8. **10 kΩ Potentiometer**: Adjusts the contrast of the LCD display.

2. Software Components

- **Arduino IDE**: For writing and uploading the code to the Arduino.
- **Libraries Used**:
    - <Stepper.h>: Controls the stepper motor.
    - <LiquidCrystal.h>: Interfaces with the LCD display.

3. Materials for the Physical Model

- **3D-Printed Mountain Model**: Represents the ski slope with beginner, intermediate, and advanced sections.
- **Gondola Figurine**: Attached to the string.

System Assembly

1. Building the Physical Model

- **Designing the Mountain Model**:
  - Used a free model online and tuned it using CAD software
- **3D Printing**:
  - Printed the model using a 3D printer, ensuring it did not exceed the size and time constraints (maximum 7 hours of print time).
- **Attaching the Gondola Mechanism**:
  - Connected a fishing wire to the gondola figurine.
  - Attached the other end to the stepper motor shaft.
  - Mounted the stepper motor underneath the mountain, allowing the gondola to move smoothly along the slope.

2. Assembling the Electronic Circuit

A. Stepper Motor Connection

- **ULN2003 Driver Board to Arduino**:
  - IN1 to Arduino **pin 8**
  - IN2 to Arduino **pin 9**
  - IN3 to Arduino **pin 10**
  - IN4 to Arduino **pin 11**
- **Powering the Driver Board**:
  - VCC to Arduino **5V**
  - GND to Arduino **GND**

B. RGB LED Connection

- **Common Cathode Connection**:
  - Cathode (-) to Arduino **GND**
- **Anodes through Resistors**:
  - Red anode via 220 Ω resistor to **pin 5**
  - Green anode via 220 Ω resistor to **pin 6**
  - Blue anode via 220 Ω resistor to **pin 7**

C. Push Buttons Connection

- **First Button (Next Week)**:
  - One side to **GND**
  - Other side to **pin 2**
- **Second Button (Previous Week)**:
  - One side to **GND**
  - Other side to **pin 3**
- **Configuring Pull-Up Resistors**:
  - Used internal pull-up resistors by setting pin modes to INPUT_PULLUP

D. LCD Display Connection

- **Standard Parallel Interface**:
  - RS to **pin 12**
  - E to **pin 13**
  - D4 to **pin A0**
  - D5 to **pin A1**
  - D6 to **pin A2**
  - D7 to **pin A3**
- **Power and Contrast**:
  - VSS to **GND**
  - VDD to **5V**
  - RW to **GND**
  - VO connected to the middle pin of a 10 kΩ potentiometer (other two pins to **5V** and **GND**)
- **Backlight**:
  - Anode (A) via 220 Ω resistor to **5V**
  - Cathode (K) to **GND**

3. Writing the Software Code

A. Defining the Weather Data

- Created a WeatherData structure to store:
  - Maximum and minimum temperatures
  - Mean temperature
  - Total snowfall
  - Avalanche warning status
  - Skill level required
  - Skiing recommendation
- Populated an array weeksData with 14 weeks of weather data based on real-world information from the Government of Canada on Whistler, BC.

B. Controlling the Stepper Motor

- Initialized the stepper motor using the Stepper library.
- Implemented a moveSkier function:
  - Calculates the target position based on the skill level.
  - Determines the number of steps to move from the current position.
  - Updates the currentPosition variable after moving.

C. Implementing the RGB LED Indicators

- Used PWM via analogWrite to control the RGB LED colors.
- Implemented an updateRGB function:
  - Displays solid colors based on skill level:
    - Green for Beginner
    - Blue for Intermediate
    - Red for Advanced
  - Flashes red when there's an avalanche warning.

D. Handling User Input with Buttons

- Configured the push buttons with internal pull-up resistors.
- In the loop function:
  - Detected button presses to increment or decrement the week variable.
  - Implemented debounce delays to prevent false triggers.

E. Displaying Information on the LCD

- Used the LiquidCrystal library to interface with the LCD.
- In the updateDisplay function:
  - Cleared the LCD screen.
  - Displayed the current week number.
  - Showed the skiing recommendation for that week.

F. Serial Monitoring

- Implemented serial output for debugging purposes.
- Printed detailed weather data and system states to the Serial Monitor.

4. Integrating the System

A. Testing Individual Components

- **Stepper Motor**:
  - Verified movement to each position corresponding to skill levels.
- **RGB LED**:
  - Confirmed color changes and flashing functionality.
- **LCD Display**:
  - Ensured correct display of week numbers and recommendations.
- **Buttons**:
  - Tested responsiveness and correct cycling through weeks.

B. Combining Components

- Assembled all components onto the breadboard.
- Ensured neat wiring to prevent electrical issues.
- Mounted the physical model and tested the movement of the gondola along the mountain.

C. Final Testing

- Ran the full system, cycling through all 14 weeks.
- Observed the synchronization between the data and the physical representations.
- Made adjustments for smooth operation and accurate data display.

System Operation

When powered on, the SlopeScope system initializes and displays the first week's data. Users can interact with the system using the two push buttons:

- **Next Week Button**: Advances to the next week's weather data.
- **Previous Week Button**: Returns to the previous week's data.

For each week, the system performs the following actions:

1. **Updates the Gondolas Position**:
   - The stepper motor moves the gondola to the position corresponding to the required skill level:
     - **Beginner (Level 0)**: Gondola at the bottom of the mountain.
     - **Intermediate (Level 1)**: Gondola at the middle section.
     - **Advanced (Level 2)**: Gondola at the top of the mountain.
2. **Updates the RGB LED**:
   - Displays a solid color based on skill level:
     - **Green** for Beginner
     - **Blue** for Intermediate
     - **Red** for Advanced
   - If there's an avalanche warning, the LED flashes red to alert the user.
3. **Displays Recommendations on the LCD**:
   - **Line 1**: Shows the current week number.
   - **Line 2**: Provides a recommendation for the type of skiing suitable for the conditions (e.g., "Groomers," "Backcountry").
4. **Outputs Data to the Serial Monitor** (for debugging):
   - Prints detailed weather data and system states.

Link to Code

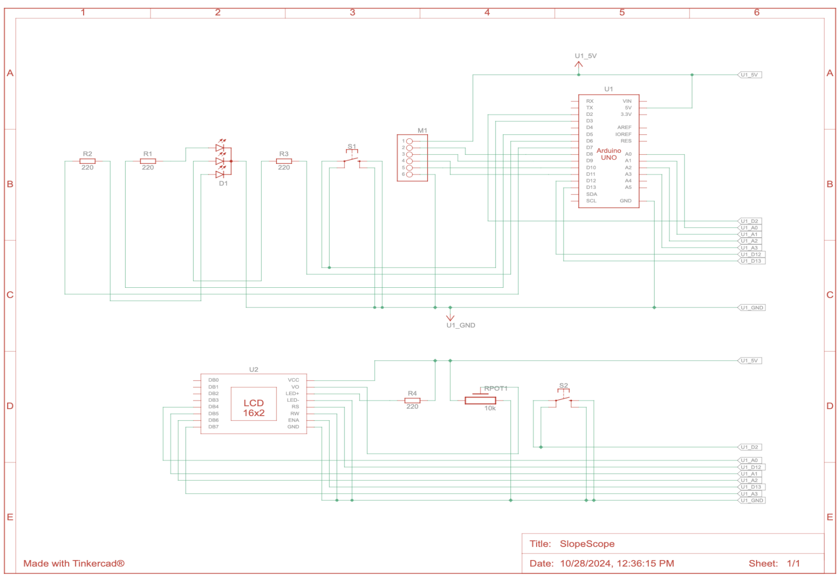
The Arduino code for the SlopeScope project is available on **TinkerCad**:

https://www.tinkercad.com/things/hZBLGMvf2iZ-slopescope?sharecode=q_HURu-dGtt2aVbEg4mta-C5f_XLCRw6S5b3-FdLqfw

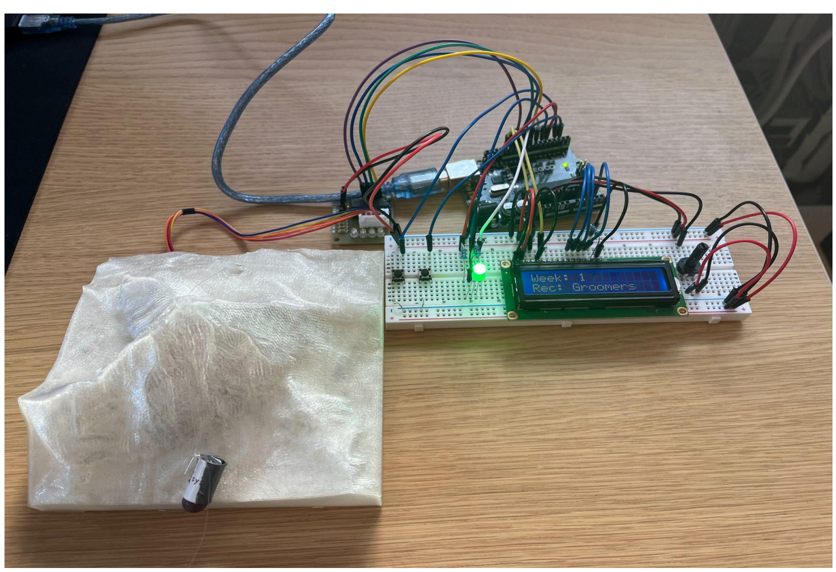
Images and Diagrams

To complement the explanation, refer to the following images:

- **Figure 2: Circuit Diagram**



- **Figure 3: Physical Assembly**



References

[1] Augello, A., Infantino, I., Pilato, G., Rizzo, R., & Vella, F. (2013). Binding representational spaces of colors and emotions for creativity. *Biologically Inspired Cognitive Architectures*, *5*, 64–71. https://doi.org/10.1016/j.bica.2013.05.005

[2] *Historical Climate Data - Climate - Environment and Climate Change Canada*. (2024, October 1). https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=Whistler&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2024&Year=2024&Month=10&Day=22&selRowPerPage=25

[3] Huron, S., Gourlet, P., Hinrichs, U., Hogan, T., & Jansen, Y. (2017). Let's Get Physical: Promoting Data Physicalization in Workshop Formats. *DIS '17: Proceedings of the 2017 Conference on Designing Interactive Systems*. https://doi.org/10.1145/3064663.3064798

[4] Impiö, J., & Parry, J. (2024). Freeride skiing – the values of freedom and creativity. *Journal of the Philosophy of Sport*, *51*(2), 350–366. https://doi.org/10.1080/00948705.2024.2308899

[5] Wang, L., Giesen, J., McDonnell, K. T., Zolliker, P., & Mueller, K. (2008). Color design for illustrative visualization. *IEEE Transactions on Visualization and Computer Graphics*, *14*(6), 1739–1754. https://doi.org/10.1109/tvcg.2008.118

Appendix

https://climate.weather.gc.ca/climate_data/daily_data_e.html?hlyRange=%7C&dlyRange=1972-11-01%7C2024-10-19&mlyRange=1973-01-01%7C2007-02-01&StationID=924&Prov=BC&urlExtension=_e.html&searchType=stnName&optLimit=yearRange&StartYear=1840&EndYear=2024&selRowPerPage=25&Line=9&searchMethod=contains&txtStationName=Whistler&timeframe=2&Day=23&Year=2024&Month=1#

```
{ -2.0, -6.0, -4.0, 0.0, false, 0, "Groomers" },     // Week 1
{ -1.0, -5.5, -3.3, 6.0, false, 0, "Groomers" },     // Week 2
{ -1.5, -2.5, -2.0, 4.0, false, 1, "Trees" },        // Week 3
{ -3.0, -4.0, -3.5, 4.0, false, 1, "Trees" },        // Week 4
{ -4.5, -7.0, -5.8, 48.0, true, 2, "Backcountry" },  // Week 5
{ -5.0, -9.0, -7.0, 0.0, false, 0, "Groomers" },     // Week 6
{ -8.0, -12.5, -10.3, 30.0, false, 1, "Powder Runs" },// Week 7
{ -3.0, -13.5, -8.3, 29.0, false, 2, "Backcountry" }, // Week 8
{ -5.0, -7.0, -6.0, 5.0, false, 1, "Trees" },        // Week 9
{ -7.0, -9.5, -8.3, 4.0, false, 0, "Groomers" },     // Week 10
{ -12.0, -20.5, -16.3, 6.1, true, 2, "Backcountry" }, // Week 11
{ -11.0, -30.7, -20.9, 0.0, false, 2, "Free Ride" },  // Week 12
{ -6.0, -27.5, -16.8, 0.0, false, 1, "Trees" },       // Week 13
{ -6.0, -12.5, -9.3, 0.0, false, 0, "Groomers" }      // Week 14
```

Glossary of term

Negative freedom	The freedom to explore the mountain without set paths or restrictions, allowing skiers full control over their descent, a concept often associated with freeride skiing
Freeride skiing	Navigating ungroomed, natural terrain with complete freedom, allowing skiers to carve unique paths down the mountain while adapting creatively to obstacles and changing conditions.
Downhill skiing	A high-speed form of skiing on groomed trails, where gravity-driven descents and precise turns are key
Backcountry skiing	Skiing in ungroomed, natural terrain beyond resort boundaries, requiring navigation skills and avalanche awareness.

Alpine Touring	Skiers climb uphill under their own power and descend, combining elements of both cross-country and downhill skiing
Telemark Skiing	A traditional style with free-heel bindings, where skiers make turns by lunging, offering a unique blend of control and fluidity
Ski Mountaineering	Combining skiing with mountaineering, this style involves climbing and skiing down mountainous terrain, often in remote locations
Cross-Country skiing	Skiers use a rhythmic gliding motion to travel across flat or rolling terrain, focusing on endurance and technique
Freestyle Skiing	An acrobatic style with jumps and tricks, performed on slopes or in terrain parks, emphasizing creativity and skill
Adaptive Skiing	Skiing modified for individuals with disabilities, using specialized equipment to make the sport accessible and enjoyable for all abilities