CornellEngineering
Electrical and Computer Engineering

Artificial Synesthesia Device

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Senses Impact Experiences

Why Color Matters

- Color is central to how we experience, interpret, and emotionally connect with art
- Existing accessibility tools for blind and low-vision users rarely address color perception
- The emotional meaning carried by vibrant colors is often lost without visual input

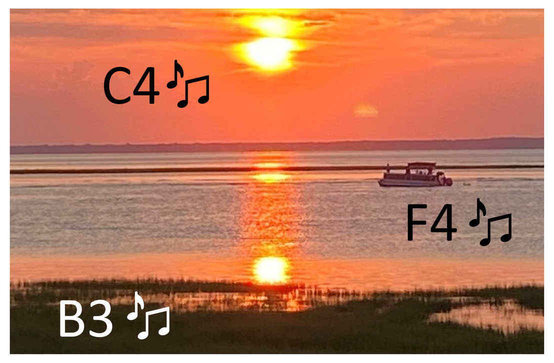
Goal

- Recreate the feeling of color through sound, allowing users to hear color in real time
- Explore whether people can be trained to associate specific sounds with specific colors
- Demonstrate how information—like color, brightness, or contrast—can be encoded into sound, enabling a new sensory pathway for interpreting visual scenes

Color Synesthesia Affects Interactions

Synesthesia: when the brain associates sensory information with other unrelated senses

Color Synesthesia: Color is associated with a different sense other than sight (often music/audio)



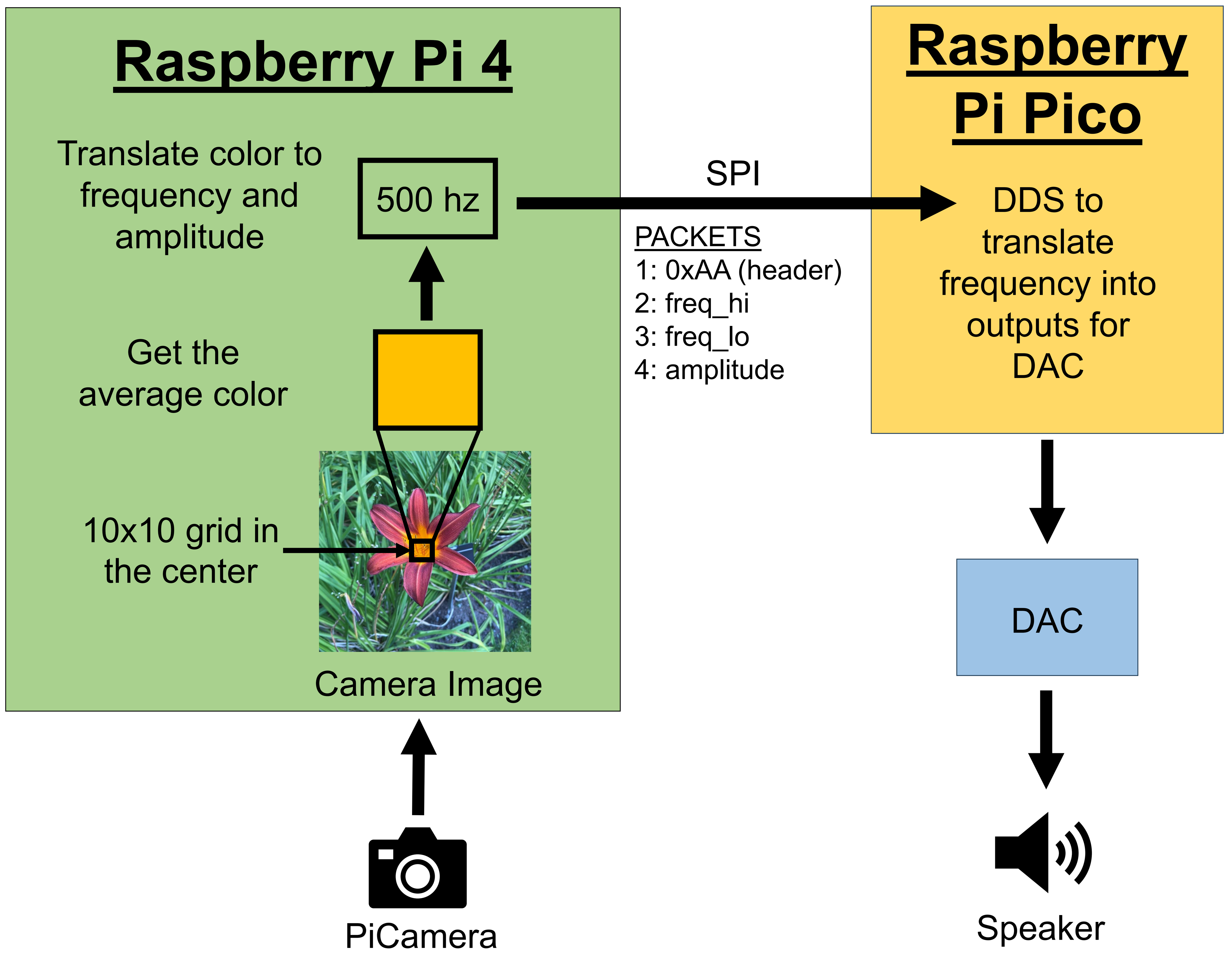
Engineering Synesthesia Tool

Static, non-exploratory experiences
Most audio descriptions are pre-written and fixed meaning users cannot freely explore an artwork or image

No real-time sensory feedback
Existing tools rarely respond instantly to user movement or gestures. Users cannot point, scan, or interact with visual content

Low awareness of cross-modal encoding
Synesthetic-style mappings like translating color into sound are not commonly used or understood, and as a result, many technologies overlook the potential of encoding visual information (like color values) into audio signals in a meaningful, learnable way

Creating Color Synesthesia with Raspberry Pi + Raspberry Pi Pico



Converting Color to Sound

Color to Frequency Algorithm:

1. Input: RGB color value (R, G, B)
2. Normalize RGB
3. Convert RGB → HSV
4. Extract Hue (H), Saturation (S), Value/Brightness (V)
5. Convert hue to degrees
   - hue_deg = H * 360 (Hue is in range 0–1)
6. Map hue to audio frequency
   - Linearly map 0–360° → 100–2000 Hz
   - frequency = 100 + (hue_deg / 360) * (2000 - 100)
7. Map brightness to amplitude
   - Scale value (V) into amplitude 1–10
   - amplitude = max(1, floor(10 * V))
8. Output: Frequency (Hz) Amplitude (1–10)

Digital Signal to Sound Output

Direct Digital Synthesis (DDS) Algorithm:

1. Maintain a 32-bit phase accumulator for position within sine wave
2. Calculate a phase increment from the desired frequency

$$DDS_{increment} = \frac{f \times 2^{32}}{sample_{rate}}$$

3. On every sample interrupt
   - Add the increment to the phase accumulator
4. Use the top N bits of the phase as a lookup index
   - index = phase >> (32 - 8)
   - 8-bit index, 256-entry sine table
5. Fetch the corresponding sine sample at the index
6. Scale the sample by amplitude
7. Send the sample to the DAC
8. Repeat at the sample rate so the output becomes a smooth sine wave
9. frequency → increment,   loudness → amplitude multiplier

Interactive Color Mapping Success

- Color-to-sound mapping provides a new sensory pathway, enabling users to access visual information through hearing
- Allows user to successfully distinguishes between different colors and different shades of color
- Real-time audio feedback transforms art exploration from a passive experience into an interactive one
- Demonstrates that complex visual details like color can be encoded into sound
- Personalizes accessibility, allowing individuals to interpret and experience visual content in ways that resonate with them

Impacts Interactions with the Environment

Uses:

- Find a certain color / navigate to a certain color
- Object identification / detection
- Finding shapes or tracing outlines to get information about drawings and figures
- Encoding color information (HSV) in sound

Where It Can Go in the Future:

- Test in different scenario to obtain a new experience using sound
- Discover more use cases
- Developed into final PCB hardware implementation like below:

** Image created using https://chatgpt.com/

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