Optical Theremin

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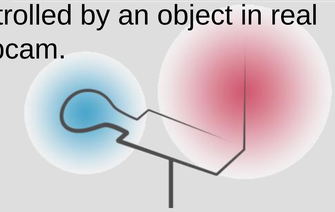
RICE

videlectriX

What is a Theremin?

- A theremin is an electronic instrument controlled by two antennae which sense the relative position of hands.
- Project goal: Create a virtual theremin instrument controlled by an object in real time with a webcam.

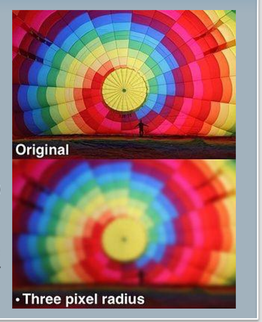


Blue – volume
Red – pitch

Gaussian Blur

- Convert RGB video stream into Hue Saturation Value color space.
- Convolve HSV image with Gaussian kernel to eliminate noise

$$G_0(x,y) = Ae^{\frac{-(x-\mu_x)^2}{2\sigma_x^2}+\frac{-(y-\mu_y)^2}{2\sigma_y^2}}$$

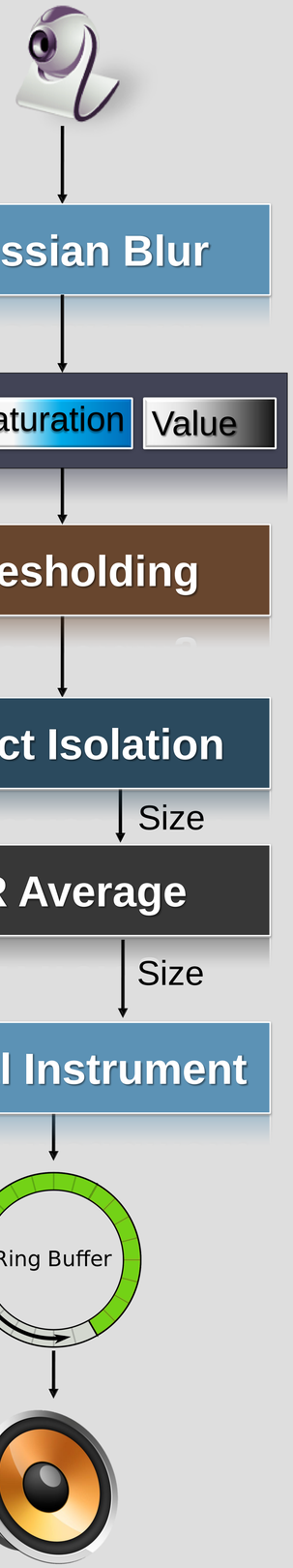


FIR Average

- Angle and Size inputs averaged in real time to smooth values
- Reduces effect of noise, motion blur
- Length 5 FIR optimizes tradeoff between smoothness and latency

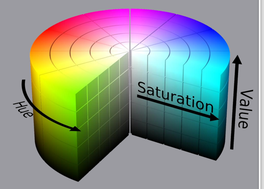
Virtual Instrument

- Instrument provides real-time output via callback routine that periodically writes samples to a ring buffer which then writes to the host's audio hardware.



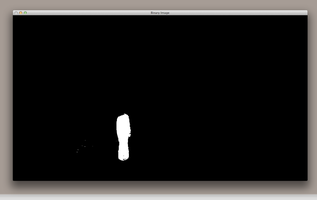
Color Window Selection

- Hue selects color
- Saturation selects neutrality/boldness
- Value selects lightness or darkness
- We determine a narrow window of (H,S,V) to track chosen object in any lighting



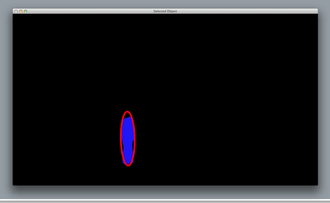
Thresholding

- Only pixels with HSV values in the selection window are enabled, the rest are disabled



Object Isolation

- Isolate the contour enclosing the largest area of enabled pixels as object
- Fill in object mass and fit ellipse to determine position and angle
- Flexible controls (angle, size, position)



Audio Synthesis

- Wavetable synthesis – repitch periodic audio sample
- Digital waveguide – delay line and filter-based physical model
- Subtractive synthesis – filter waveforms to modify sound

Performance

- Object tracking accuracy*:
  - Angle: +/- .05%
  - Size: +/- 5%
  - Y-Position: +/- 1%
- Program speed:
  - 11 Frames per second

*Stationary pool noodle, 1000 samples

Conclusions

- Optical Theremin design is fast enough to be responsive with several tones and modes of control.
- Design decisions optimized usage and display of Digital Signal Processing techniques

References

OpenCV Computer Vision Library opencv.org

Synthesis ToolKit ccrma.stanford.edu/software/stk/

Smith, Julius, *Physical Modeling using Digital Waveguides* Physical Modeling of Musical Instruments, Part I, Volume 16, no. 4. 1992.

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