Single-sensel image capture using an LCD panel

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Abstract

Compressed sensing allows reconstruction of complete image data from a sparse sampling. The sparse sampling may be done simultaneously or sequentially. The sequential method typically involves repeated use of a single sensel, each time measuring the sum of a random group of pixel locations. The random group is typically selected using a DMD (digital micromirror device) to reflect the light from the selected pixel locations into the single sensel. DMD devices provide excellent contrast, so very little light from the pixel locations not selected is sensed. However, DMDs are small and relatively expensive devices not easily scaled to larger sizes.

The current work explores the potential application of an LCD (liquid crystal display) panel as an alternative to DMD modulation. Physically large, high resolution, transmissive LCD panels have become commodity devices due to their application in consumer video projectors and 3D printers. In fact, 12K LCD panels are used in some consumer resin printers, giving control over 12,288x6,480, or approximately 79.6M, individual pixels. The large area makes it feasible to build large-format cameras, and also to use multiple individual sensels to sample potentially-overlapping regions simultaneously. However, LCDs do not have the same contrast and control properties as DMDs. The presentation will overview the KLOS (Kentucky LCD One Sensel) prototype camera and the general feasibility of using LCDs in this way.

Original (donor) LCD projector – cost under $100

KLOS 250625 prototype (with 260224 control housing)

Key Ideas

- **Spatial Light Modulation:** Single-sensel imaging is usually done using a DMD device. However, transmissive LCDs are cheaper, offer grayscale pixel control and even color modulation, and are available in large-format sizes with high resolution. This is particularly appealing in that other methods for building large-format imagers are very expensive.

- **LCD Panel and Drive Electronics:** The large-format (115x74mm) color LCD panel was extracted from a cheap video projector along with drive electronics accepting an HDMI signal. Monochrome panels up to 300x160mm and 16K (15120x6230) resolution are also available, but we have not yet prototyped using a monochrome LCD.

- **Camera Construction:** Our large-format camera, **KLOS** (**Kentucky LCD One Sensel**) is built as a tabletop device using custom 3D-printed parts. Focusing is accomplished by sliding nested rectangular sections of the camera body. Any lens of sufficient coverage may be used, but the video projector's lens was an obvious and appropriate choice.

- **Optics:** Any lens with sufficient coverage can be used, but the projector's lens is an obvious and appropriate choice. A Fresnel lens, originally used to distribute the projector's LED light over the LCD, is repurposed to focus light transmitted by the LCD panel onto the single sensel.

- **Single Sensel:** The original intent was to use a truly single-point detector, but we instead averaged over all pixels from an endoscope camera to easily get a wider dynamic range – up to approximately 18 stops.

- **Control:** A laptop is used to output the LCD pattern via HDMI. The LCD patterns are generated using **C/C++** code and the **OpenCV** library. The OpenCV library is also used to read the endoscope image data which is summed to simulate a high-quality single sensel. The code is written to execute in an Ubuntu Linux environment, but also works using WSL.

- **Image Reconstruction:** There is a large body of prior work in single-sensel image reconstruction, and we can leverage those techniques. Fundamentally, each single-sensel reading gives an equation stating that the weighted sum of the LCD pixel transmissions is equal to the value read. Thus, a sequence of readings with different patterns collects a system of linear equations which can be solved for individual pixel contributions. The catch is that the set of equations is usually grossly underspecified. We have used the KL1p library to perform **compressed sensing** reconstruction, utilizing Basis Pursuit or Orthogonal Matching Pursuit (OMP) to recover images from sub-Nyquist samples.
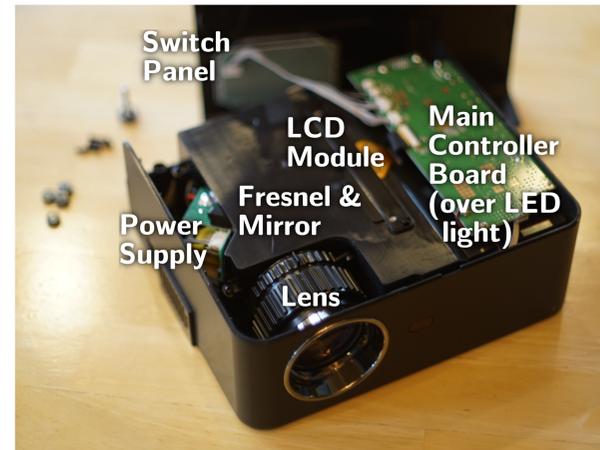
Extracted LCD panel and control circuitry

3D-printed nested camera housing parts: single sensel with USB cable, Fresnel for focusing transmitted light onto the single sensel, and main camera shell

Preliminary Results

- **Repurposing a consumer video projector's LCD and other components is proven viable**; the KLOS 250625 device works. Both random and deterministic binary (on/off) pixel patterns have been tested.

- The use of **HDMI limits sample rate**; a more direct LCD controller is need to sample faster than the NTSC video rate of 29.97 frames/s. Lag limits precision of display/sampling synchronization so that even 10 samples/s is difficult to achieve. This issue probably would be even more severe using a monochrome LCD intended for a resin printer, because the printers are designed for framerates slower than 1 frame/s. Obviously, a camera requiring many samples at these low framerates is not usable handheld, nor for scenes with moving content.

- **LCDs have a lower on/off contrast ratio than DMDs**, which means the samples have significant leakage from the sum of all off pixels. Without carefully calibrating, this effectively limits the total resolution that can be obtained. Patterns with relatively few pixels on can be dominated by leakage from off pixels.

- **Alignment of the sensel with the panel proved surprisingly critical**. Perhaps this would not be an issue if we incorporated a diffuser, but the contributions from individual pixels vary significantly with relatively minor misalignments. Our prototype was not designed to maintain precision alignment.

Future Work

- We believe the best use of this technology would be for multiplying resolution of a low-resolution sensel array (e.g., **perhaps using LEDs**), not a single sensel. Rather than Fresnel focusing all light on a single sensel, this probably would involve having multiple sensels aimed at different regions of a diffuser.

- Independently controlling pixel color channels has not been tested.

- Use of intermediate gray level pixels has not been tested.

- Smarter history-based patterning, rather then the random patterns generally used for compressed sensing, might enable significantly sparser sampling. Predicting future pixel values from previous ones proved effective in our **TDCI** (**Time Domain Continuous Imaging**) work.