Semester Project Final Presentation

Dohun Jeong

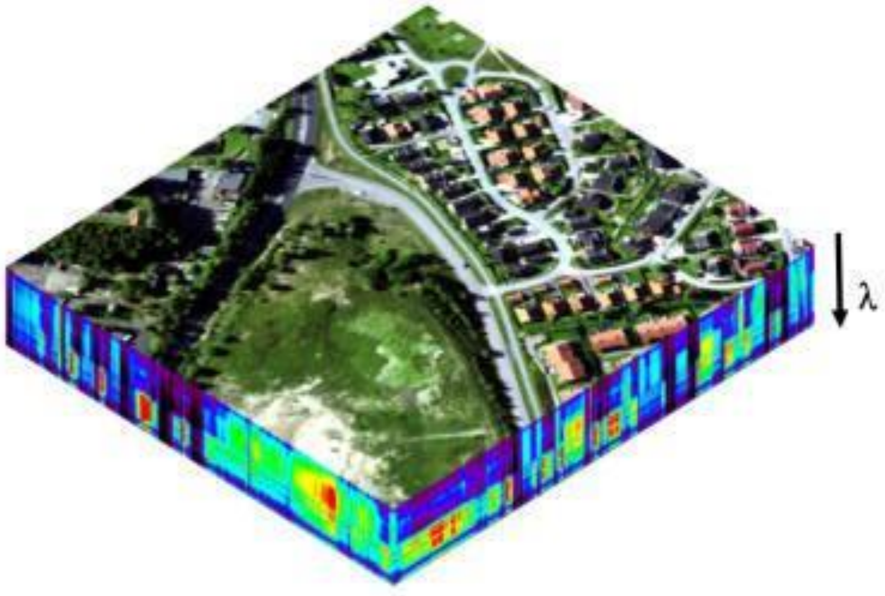
Supervisors: Adrien Hoffet, Arnaud Latty, Adam Scholefield

June 17th 2019

Accurate mirror displacement control for a new multi-spectral camera

Multispectral image

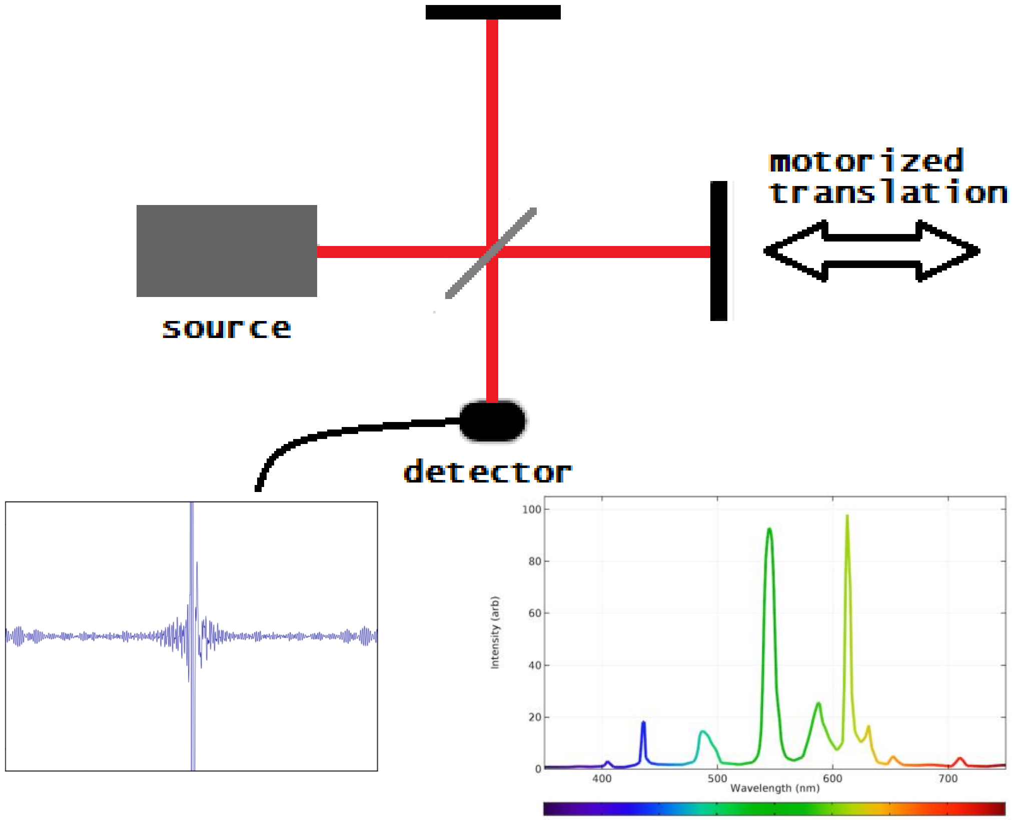
- 2 spatial axes and 1 spectral axis
- Spectral information acquired by a moving mirror Michelson interferometer



Accurate displacement control for a new multi-spectral camera

Michelson Interferometer

- The light is reflected by two mirrors. These reflections interfere with each other
- Depending on the path length difference between two reflections, constructive/destructive interference creates a wavelength-dependent pattern
- Recover wavelength information from these patterns



Accurate displacement control for a new multi-spectral camera

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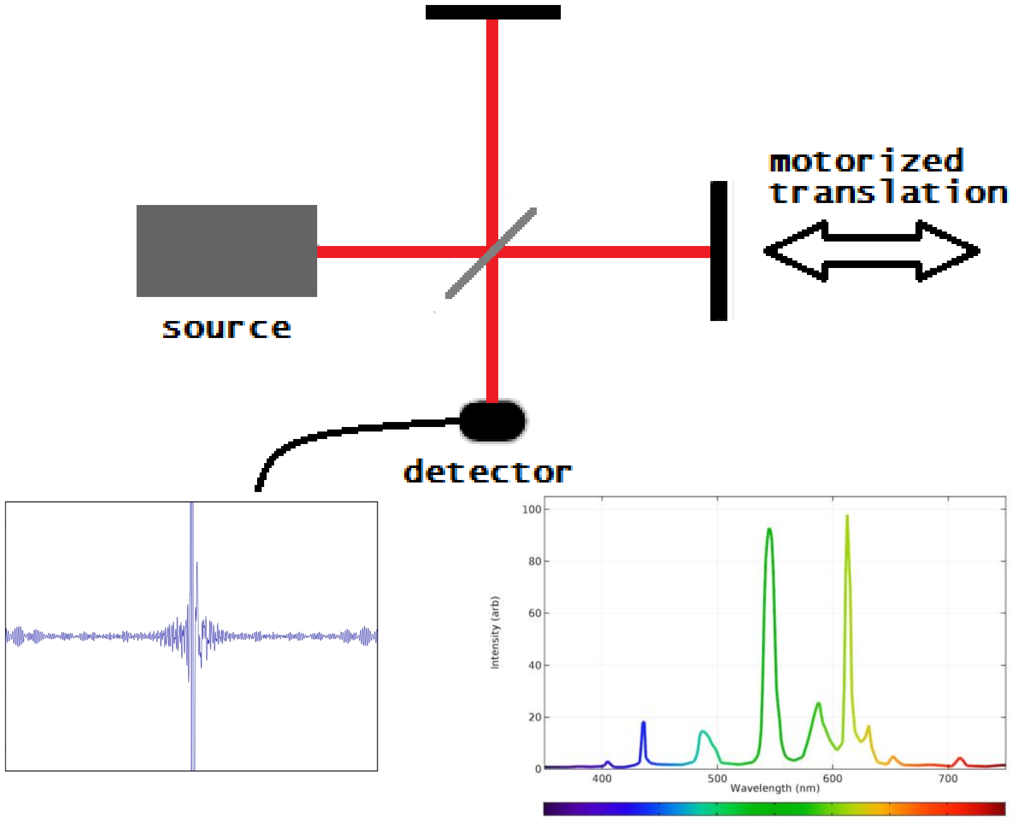
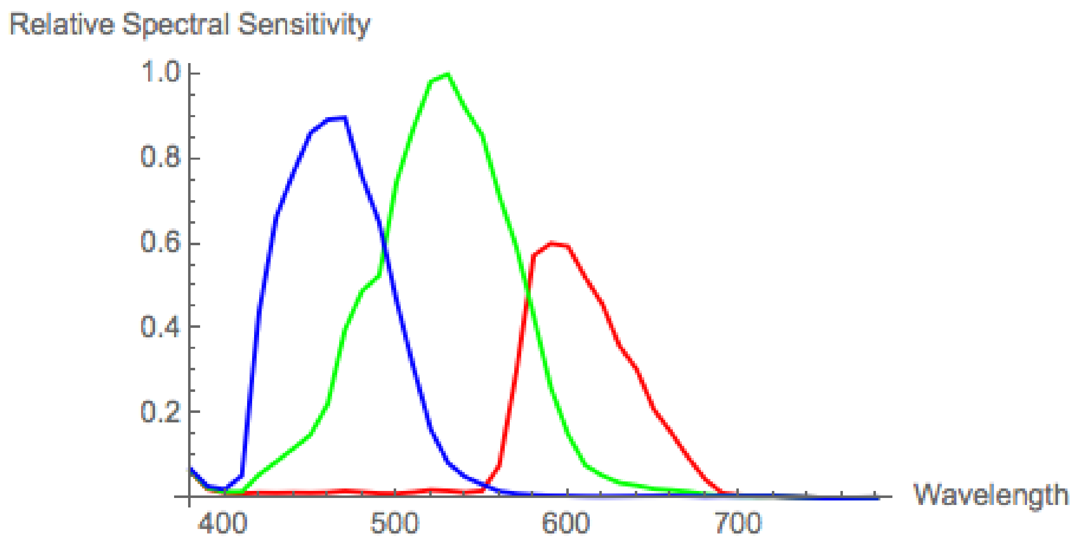
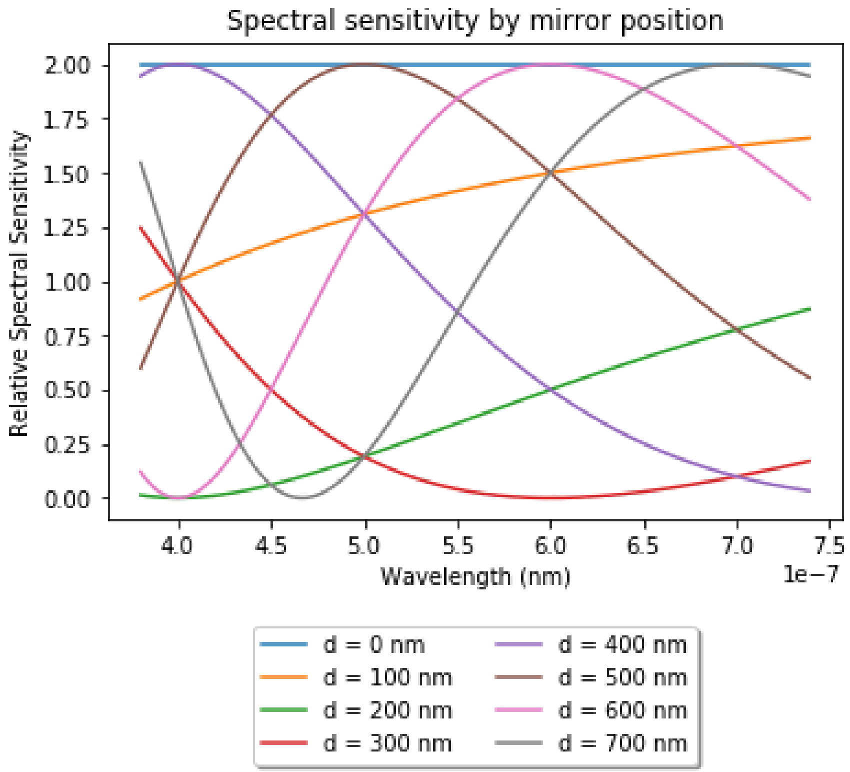


RGB camera vs. Lippmann Camera





- Measured sensitivity of an RGB camera
- Need to derive all spectral information from three curves

- Theoretical spectral sensitivity in each mirror position during capture
- Many more curves integrates to a more accurate color spectrum

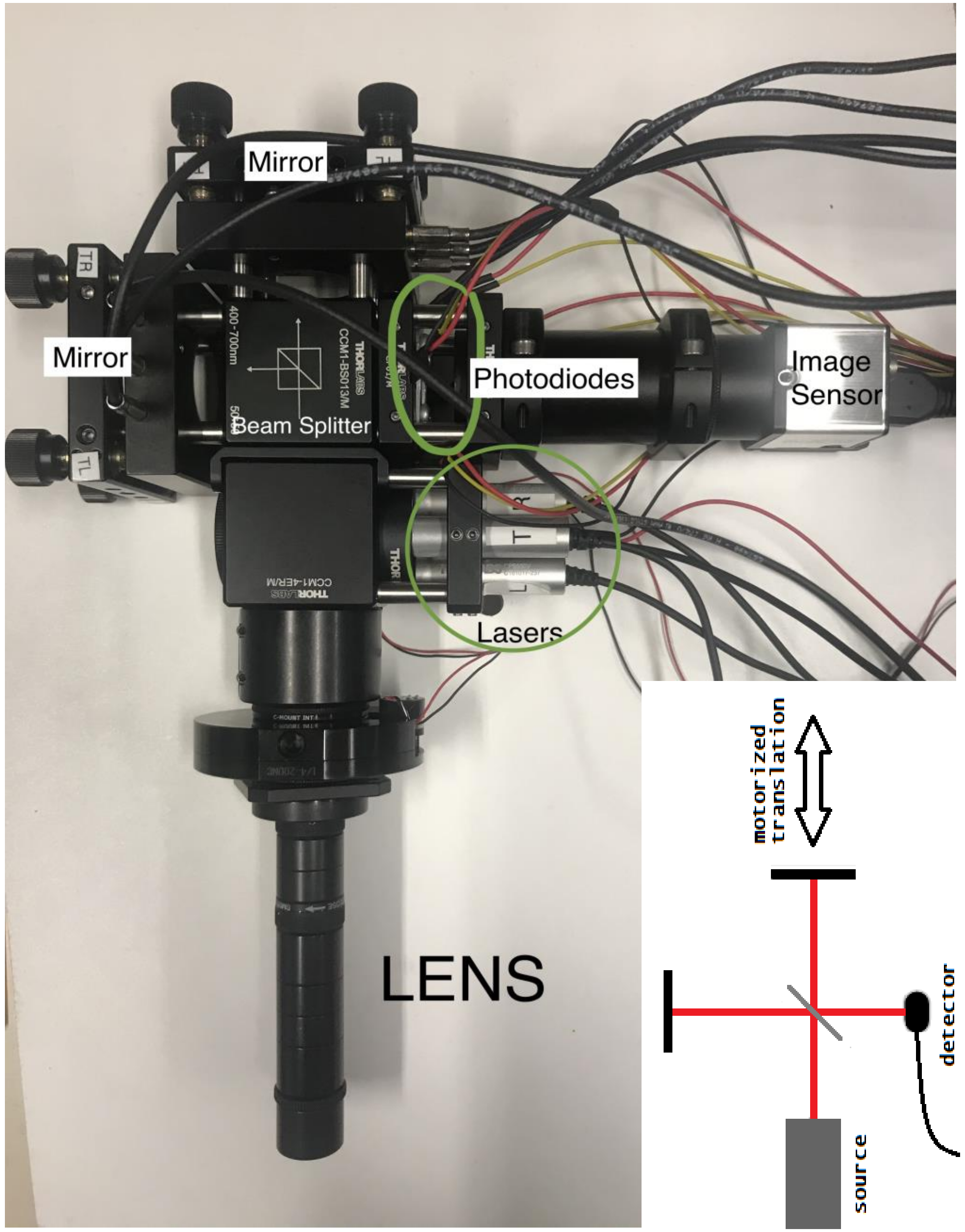
Hardware implementation

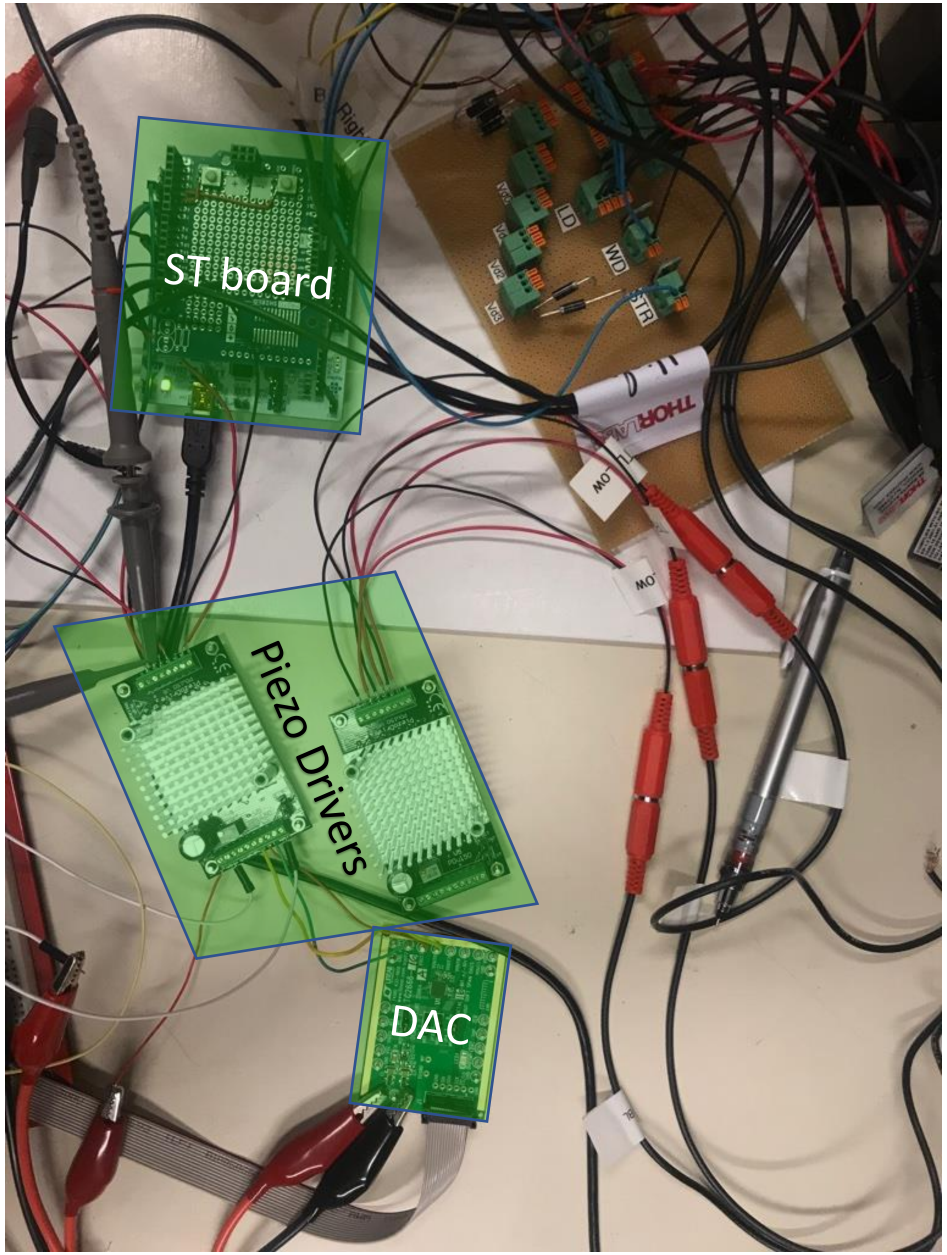
Piezo Actuators for motorized mirror translation

- Exhibits hysteresis
  - Depends on the previous state
  - Can’t have a lookup table of voltage vs. displacement characteristics
  - Feedback necessary

Measuring accurate displacement

- Use laser interference pattern
- 4 IR lasers put along the same optical path to measure the relative path length difference from the two mirrors.
  - Intensity of the interference pattern measured by photodiodes on the same plane as the image sensor.

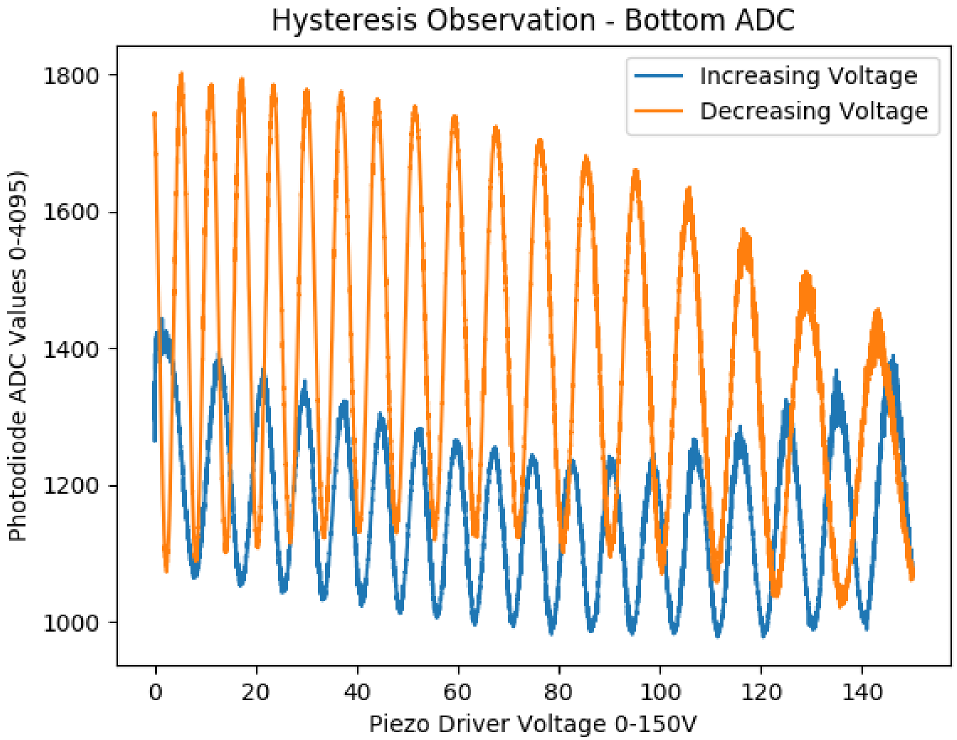

Mirror
Mirror
Beam Splitter
Photodiodes
Image
Sensor
Lasers
LENS
motorized
translation
detector
source


ST board
Piezo Drivers
DAC

Previously on the Digital Lippmann Camera…

Problems identified during the experiments:

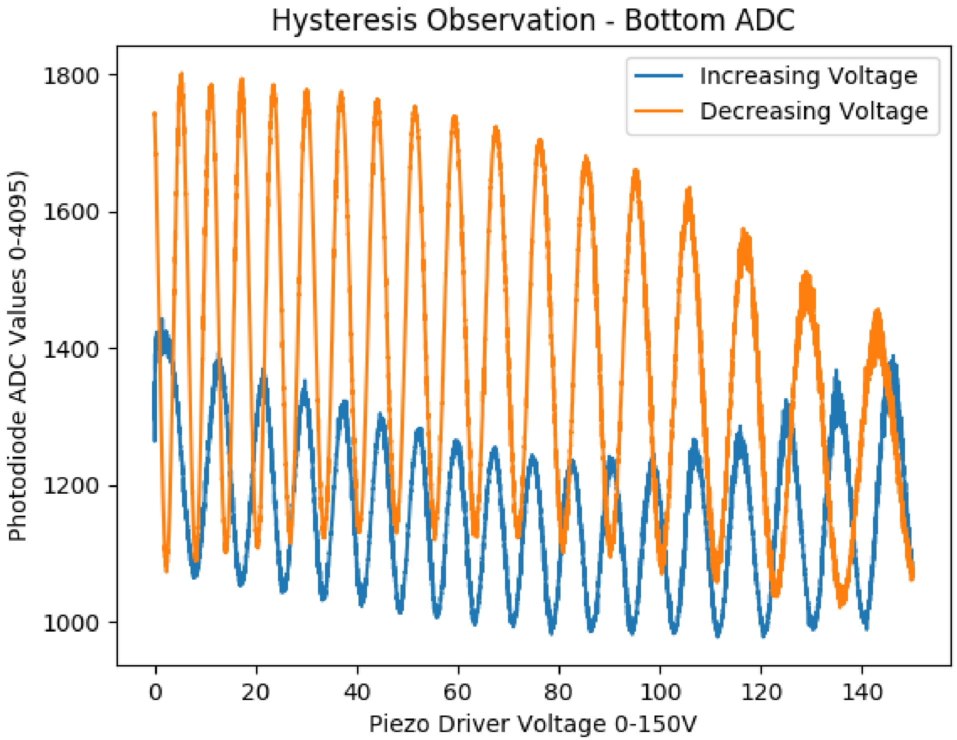
- The intensity captured by the photodiode depends not only on the position along the interference pattern, but also on the alignment of the laser to the photodiode.



Previously on the Digital Lippmann Camera…

Problems identified during the experiments:

- Hysteresis and the necessity of a smoothing filter prevents mirrors from moving in both directions.



Previously on the Digital Lippmann Camera…

Challenges in mirror control:

- Phase unwrapping
- Reducing photodiode measurement noise

Methods

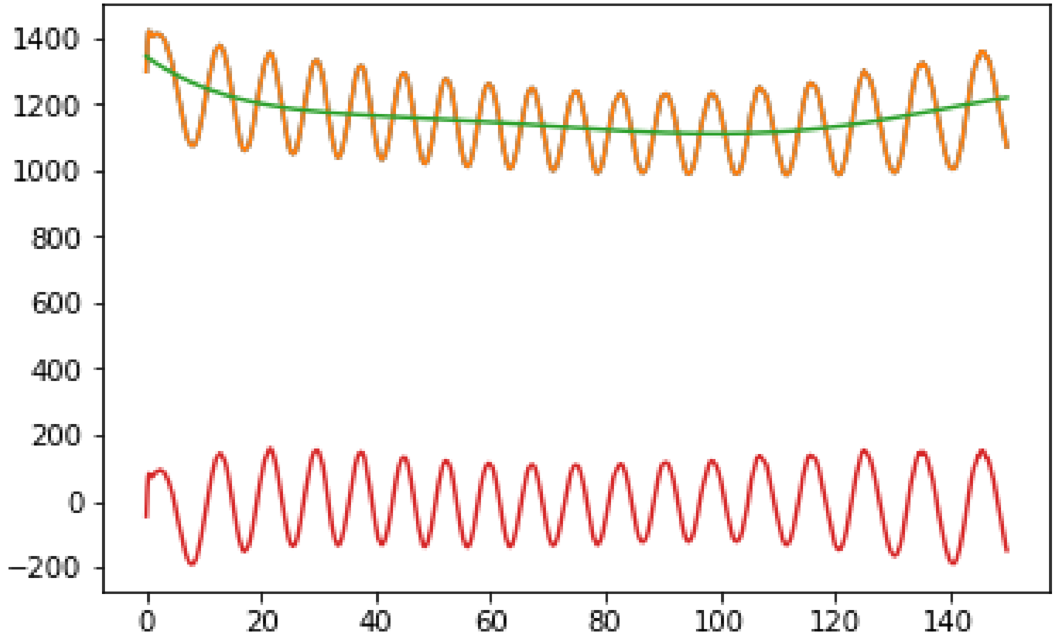
A posteriori

1. Smooth the function using Savitzky-Golay filter

Methods

A posteriori

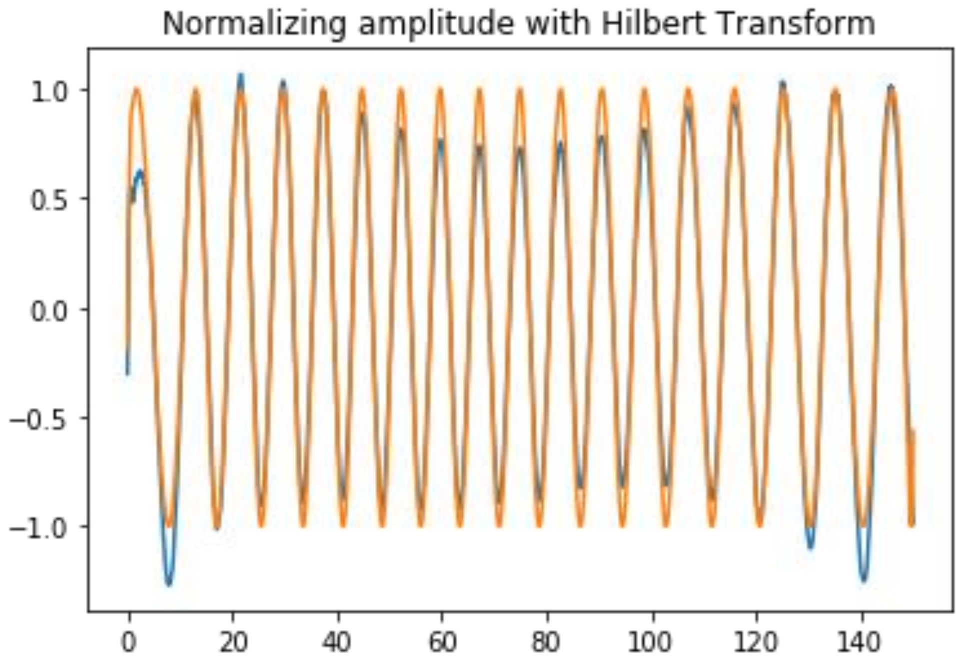
1. Smooth the function using Savitzky-Golay filter
2. Center the interference pattern to zero with low-degree polynomial fitting



Methods

A posteriori

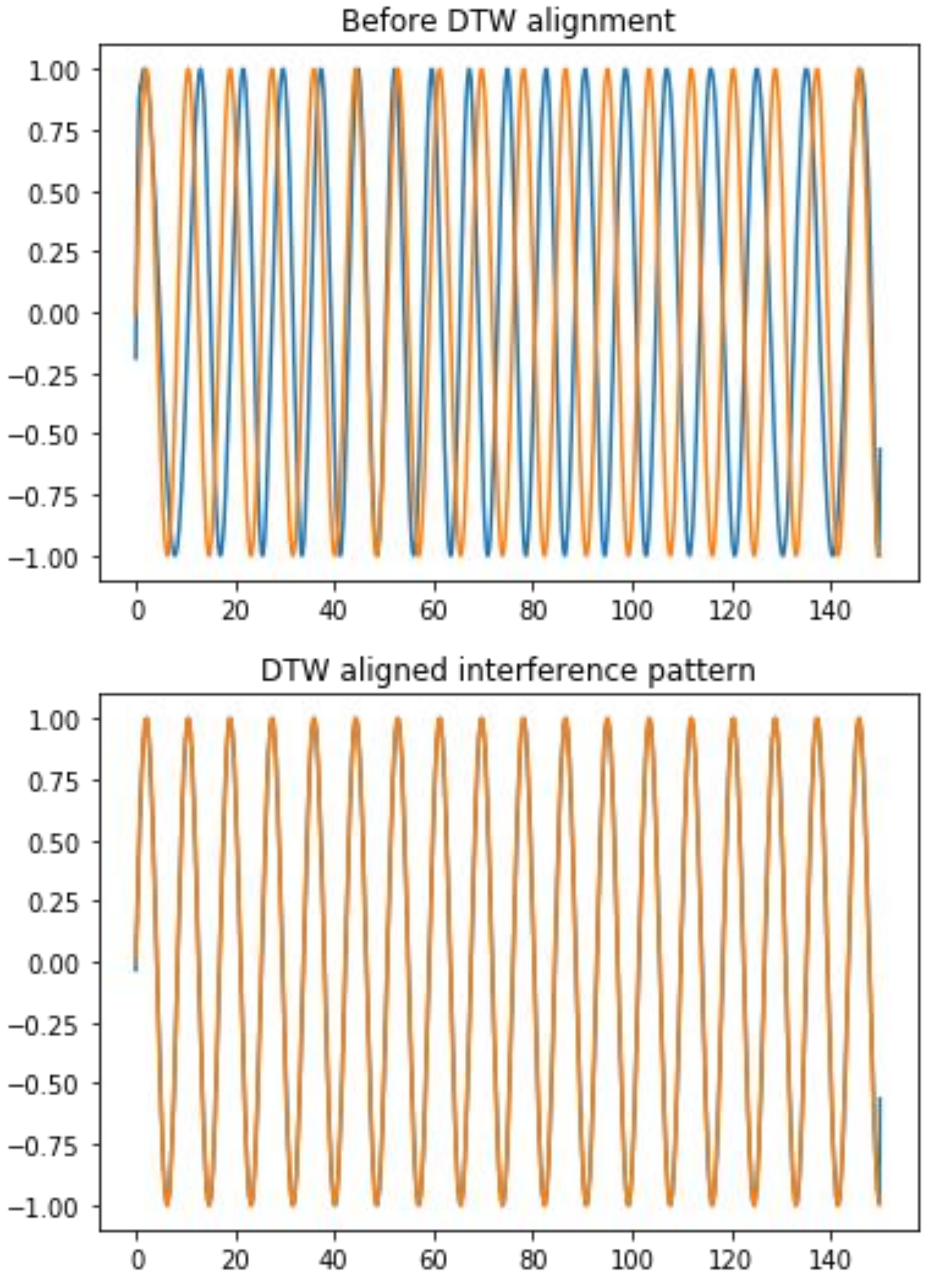
1. Smooth the function using Savitzky-Golay filter
2. Center the interference pattern to zero with low-degree polynomial fitting
3. Normalize the amplitude to 1 with enveloping



Methods

A posteriori

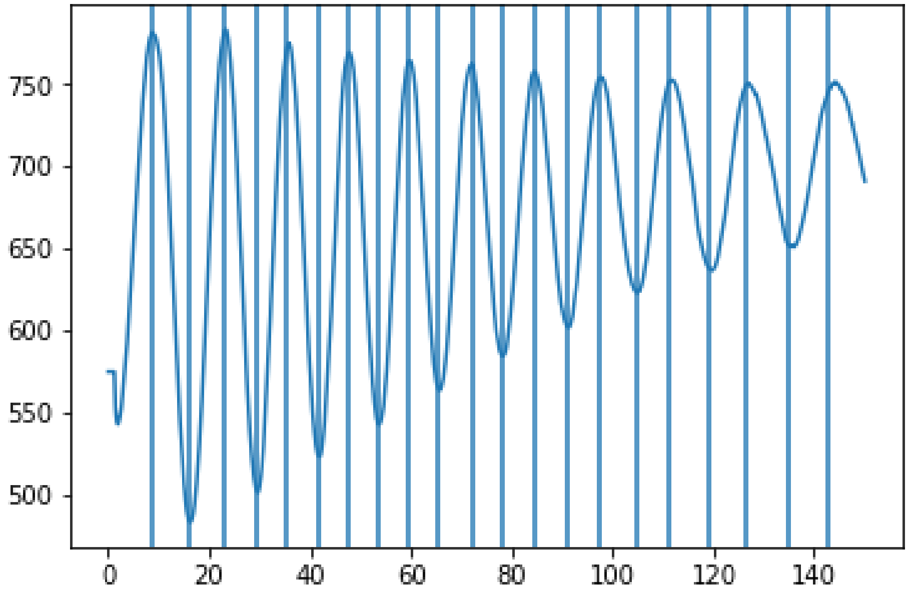
1. Smooth the function using Savitzky-Golay filter
2. Center the interference pattern to zero with low-degree polynomial fitting
3. Normalize the amplitude to 1 with enveloping
4. Perform Dynamic Time Warping to get sub-wavelength resolution of displacement measurements



Methods

Rudimentary Real time

1. Smooth the function with Moving Average Filter
2. Identify the peaks (maximum interference, minimum interference, maximum slope, minimum slope)



Methods

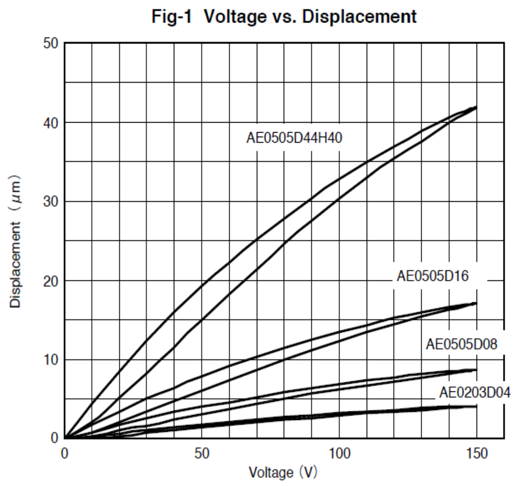
Rudimentary Real time

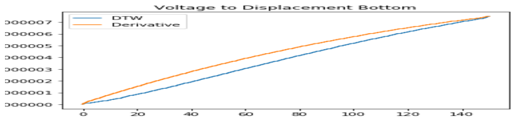
1. Smooth the function with Moving Average Filter
2. Identify the peaks (maximum interference, minimum interference, maximum slope, minimum slope)
3. Increment the displacement by an eighth of the wavelength

Results

Voltage vs. Displacement characteristics from a posteriori method

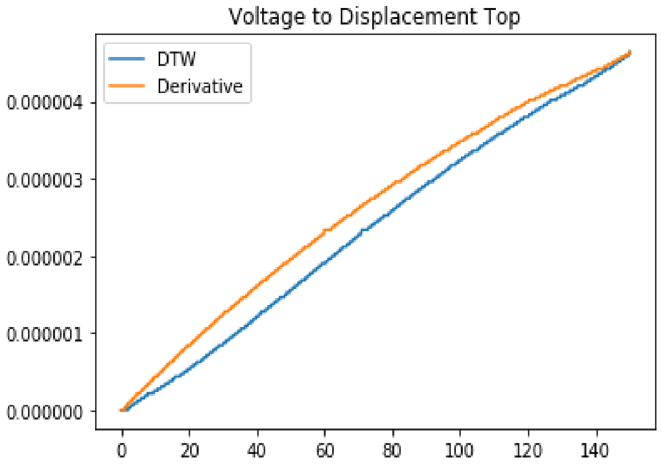
- Datasheet plot matches

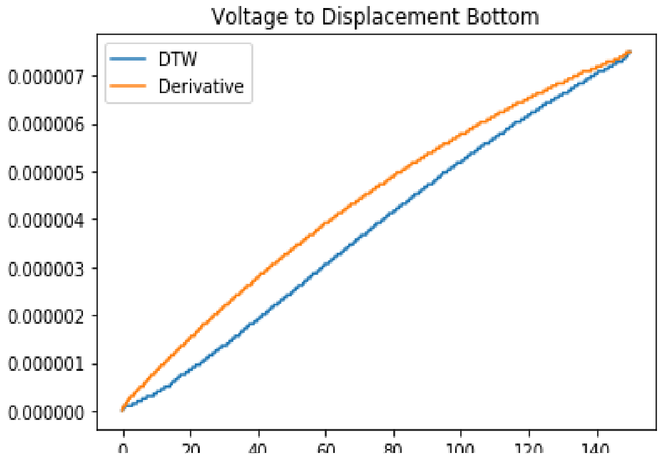


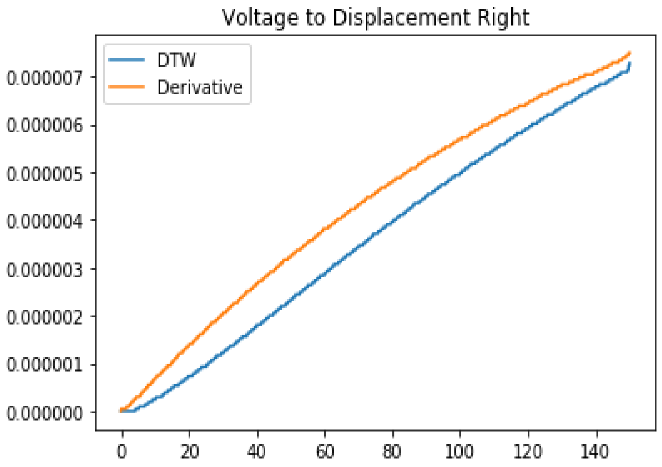


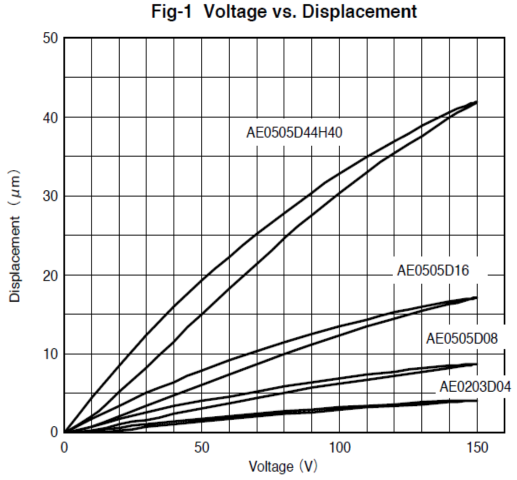
Results

- Can log photodiode information and real time displacement estimate, then compare the a posteriori calculation to test accuracy of real-time estimate
- Displacement in one of the actuators not normal





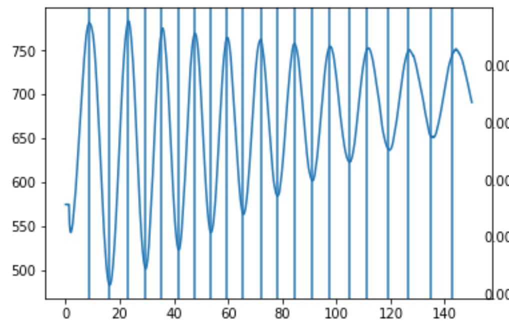


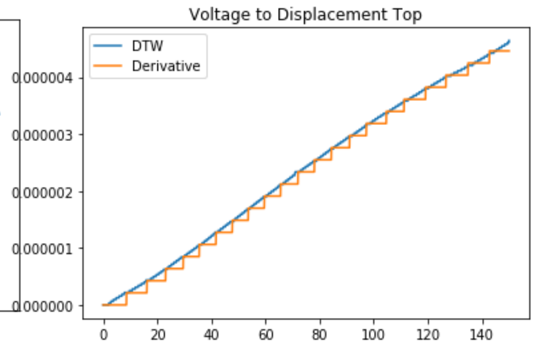


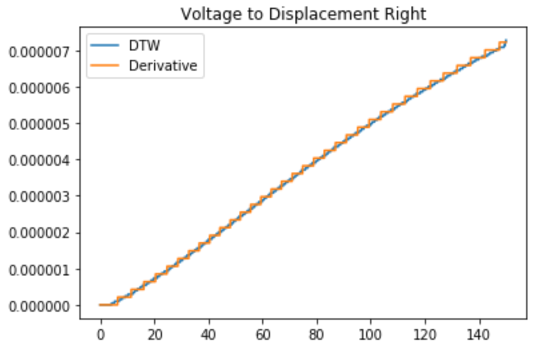
Results

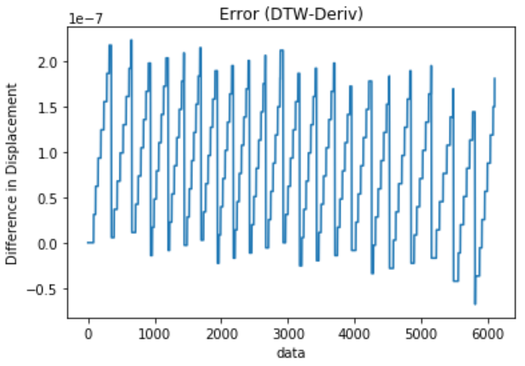
Using the same data to find displacement in "real-time"

Using the same datapoints, displacement is derived from past data only.







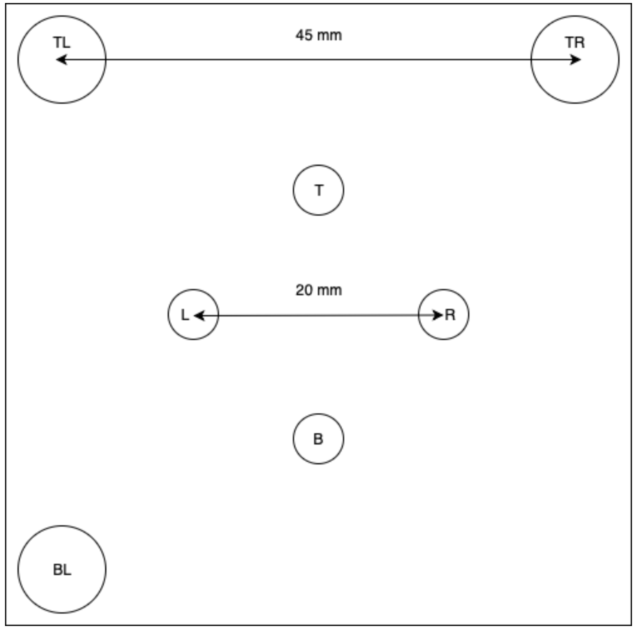


Discussion

Control algorithms

Displacement in all four ADCs are converted to displacement of the actuators.

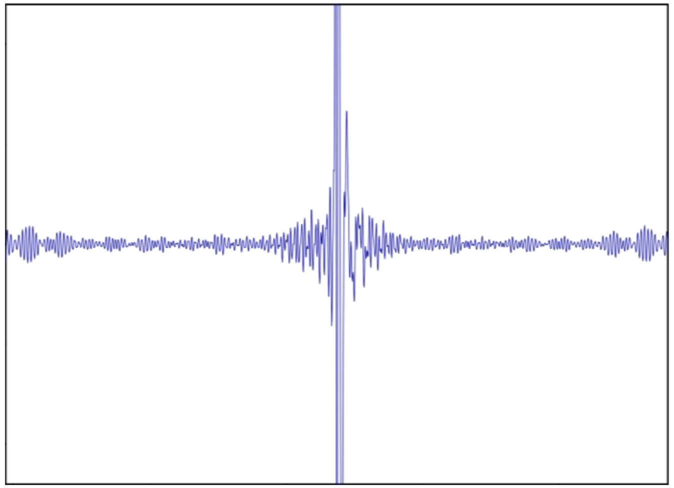
$$\begin{pmatrix} x_{TL} \\ x_{TR} \\ x_{BL} \end{pmatrix} = \frac{1}{8} \begin{pmatrix} 11 & -7 & 11 & -7 \\ 11 & -7 & -7 & 11 \\ -7 & 11 & 11 & -7 \end{pmatrix} \cdot \begin{pmatrix} x_{top} \\ x_{bottom} \\ x_{left} \\ x_{right} \end{pmatrix}$$



Discussion

Initialization

- Goal: Set the reference position of the mirror to where the two optical paths are of the same length.
- ManualInit
  - With the GUI on the Raspberry Pi, control top/bottom or left/right angle, or translate the mirror
- AutoInit
  - The microcontroller automatically finds the peak with finer control



Discussion

AutoInit algorithm

- Suggested: Move actuators one by one
- Minimize this cost function:

$$\theta(I) = -min([I_{top}, I_{bottom}, I_{left}, I_{right}])$$

$$I = \begin{pmatrix} I_{top} \\ I_{bottom} \\ I_{left} \\ I_{right} \end{pmatrix}$$

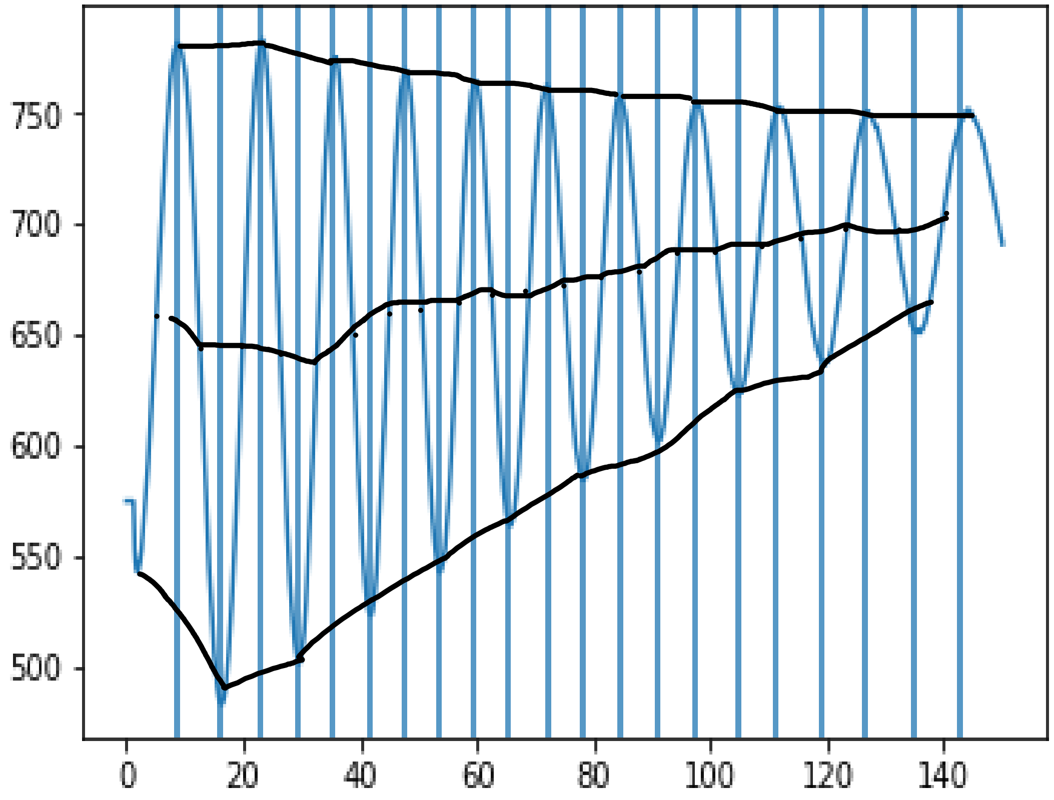
- Reduce measurement noise of the intensity by taking multiple samples at the same position

Discussion

Move "Real time"

Goal: Translate the mirrors without distorting the angle. Capture images when mirrors are translated to the desired positions

1. Smooth the function with Moving Average Filter
2. Normalize the amplitude to 1 and center the interference pattern to zero with previous peak measurement
3. Find the derivative to find the sinusoidal phase of the interference.



Conclusion

Adaptive control for portability

- Working prototype of this camera was built on the optics table
- Feedback from the laser provides accurate angle adjustment in a less stable environment.

Challenges involved

- Need to investigate if amplitudes vary less when
- Controlling the laser light from leaking into the image – turn off during capture?

Future work

- PCB will also contain MOSFETs for LED, shutter, and laser diodes.
- Final electronics can occupy as little space as 25cm*10cm*4cm