MOTUS

Project Presentation and Demo

Presented By:

Jeff Priest
Roy Choi
Bill Xu
Vincent Chen

Company Profile

Jeff Priest (CEO)
- Software
  - Image processing, software interfaces

Roy Choi (COO)
- Integration
  - Motor control development, software testing

Bill Xu (CTO)
- Optics System
  - Sensor research and testing, system integration

Vincent Chen (CPO)
- Mechanical Design
  - Enclosure and testing, system integration

Outline

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Background and Motivation

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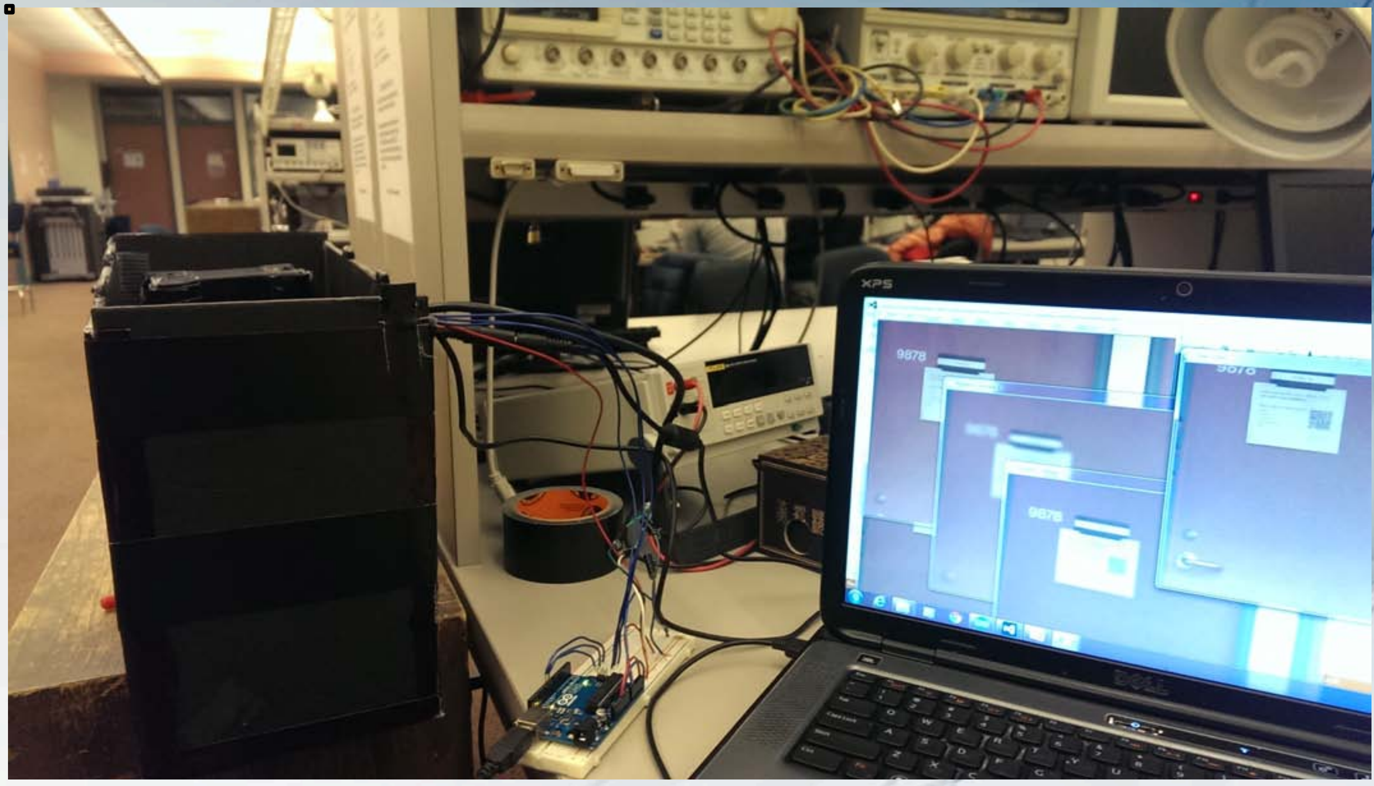
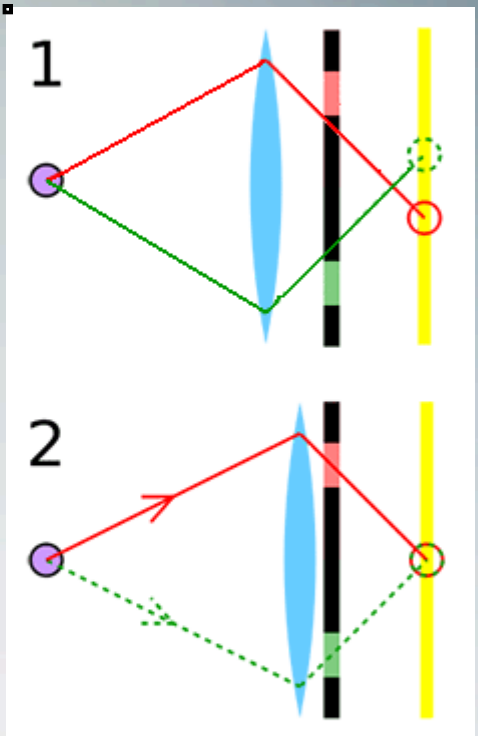
Image Sensor Shifting System (ISSS)

The ISSS is to perform auto focus feature on the camera. The basic theory is to shift the position of the image sensor in order to have it being placed within the range of depth of focus to capture the sharp and clear image of an object.

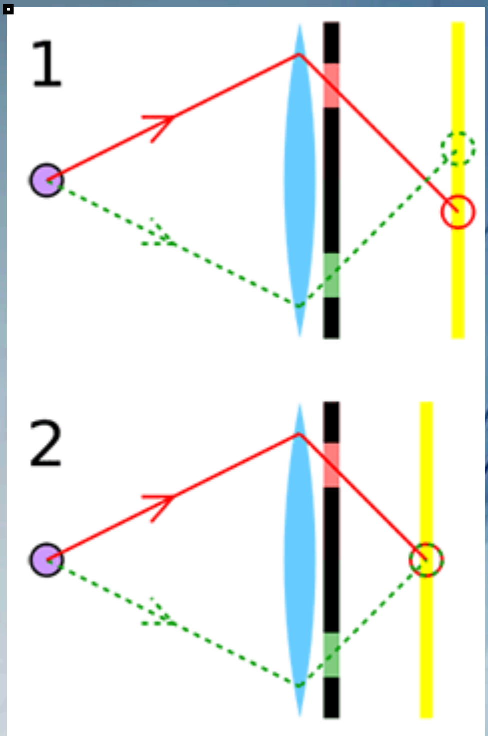


Background and Motivation

Differences between Current Focusing Systems and the ISSS



The current focusing system [1]



The image sensor shifting system

Background and Motivation

Why the ISSS is better than current focusing systems?

- The ISSS is able to adapt to many types of lens attachments
- The ISSS is able to make manual use the auto focus feature
- Macro mode can be achieved by using the ISSS

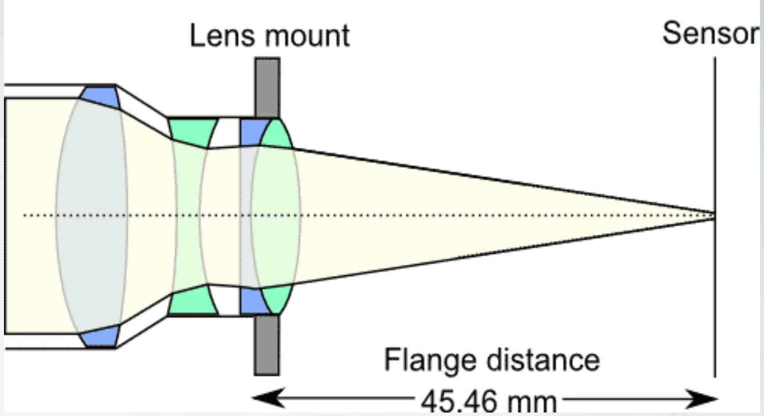
Background and Motivation

The ISSS can adapt to many types of lens attachments

The ISSS provides various flange focal distances.

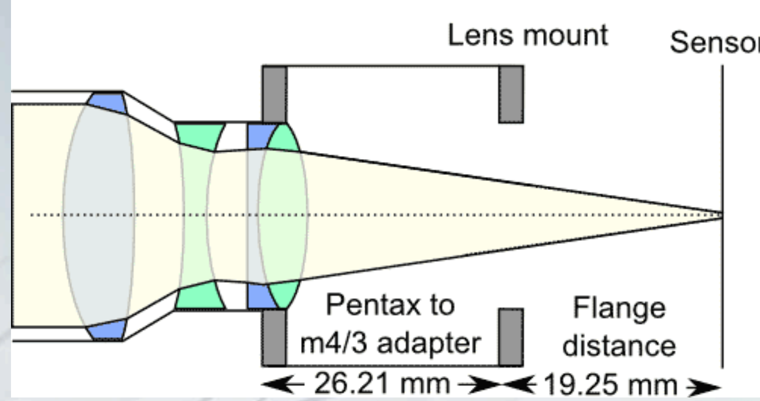
Mounting Type	Flange Focal Distance
Sony E Mount	18.00mm
Micro Four Third System	19.25mm
Canon EF Mount	44.00mm
M42 Mount	46.45mm
Pentax K Mount	45.46mm

- Pentax K mount lens on Pentax K mount camera



[2]

- Pentax K mount lens using adapter on micro four thirds mount camera



Background and Motivation

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Why do users not just buy an extension tube adapter?

Why is the ISSS better than the extension tube adapter?

- Different lenses require different adapters.
- Most adapters DO NOT have mechanical or electronic connections between the lens and the camera. No auto focusing feature.
- Some adapters DO have an electronic connection between the lens and the camera, however, they are very expensive. For example, the Metabones Canon-EF-Lens-to-Sony-NEX Smart Adapter is $399! [3]

Background and Motivation

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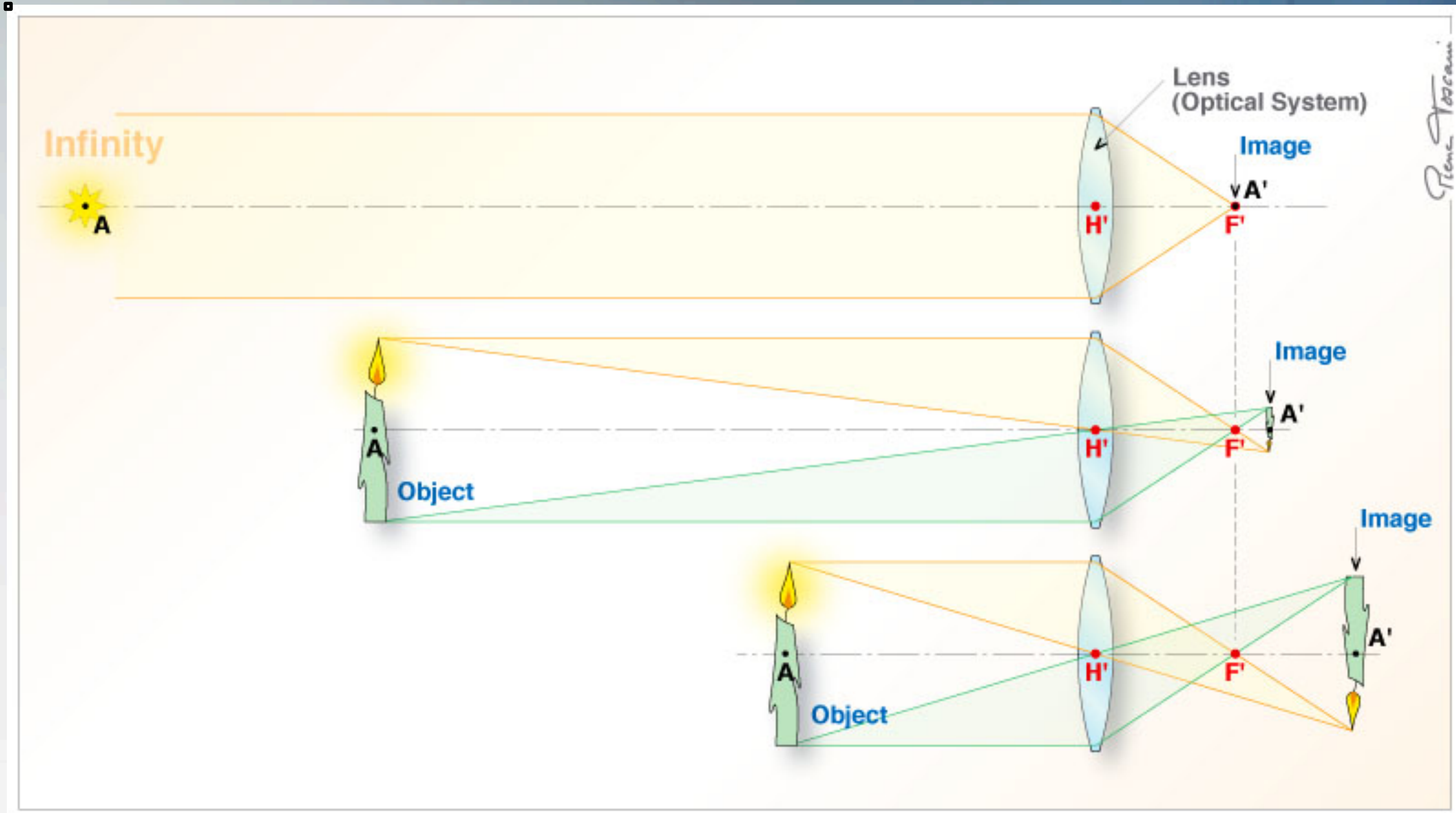
How does the ISSS allow a manual lens to perform auto focus?

Since the ISSS does not need to shift the position of the focal glass, we instead shift the position of the image sensor. We do not need to make any modifications to the lens, and it does not need to move. The shifting sensor is able to move onto the image plane within the depth of focus.

Background and Motivation

The ISSS can perform in macro mode

The ISSS is able to capture the image of an object that is very close to the lens



[4]

Background and Motivation

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Who will buy a camera with the ISSS?

- Photographers who own different mounting types of lenses. They want to use all of their lenses on one camera having the built-in ISSS.
- Photographers who have old manual focus lenses and want to perform auto focusing.
- Photographers who want to do macro photography but are not willing to pay over $1000 on a macro lens.

Background and Motivation

Sony is designing a camera with a sensor shifting system!

Quotes from an article from Sony Rumors website:

"Sony will launch an extraordinary new E-mount camera featuring a new tech: It has a sort of Contax AX system...

The sensor is mount on a tray that slide in Z direction. It allows approximately 18mm of focus adjustment. As actuator you have strong piezoelectric servo, this make for rapid movement back-forth if selected that option." [5]

CONTAX AX.mp4

Background and Motivation

269 comments on this article. Some selected comments... [5]

"Finally: 1. AF for adapted Canikon lens. 2. AF for ZEISS manual lens. 3. AF for legacy lens. 4. AF for modern but manual only e.g. Samyang lens. 5. AF for T&S lens. 6. AF for telescope."

"This is very exciting, I'm very interested to see how this will turn out. Lot's of potential with this, Macro, MF->AF, lens flexibility."

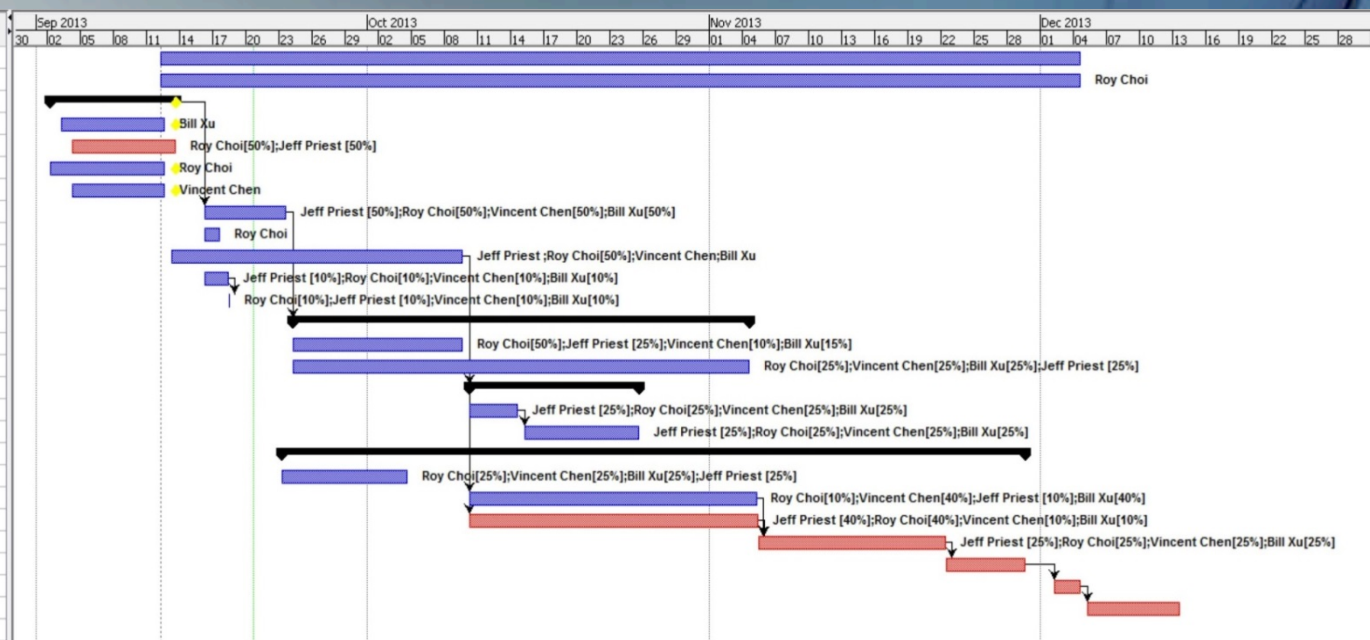
"Wow! This might be a game changer. This will make me able to autofocus with my vintage Nikon lenses, and it will probably make my lenses focus closer! I will pay for this!"

"This should work for ALL manual lenses… That is far more interesting!"

Project Management

Project schedule

	Name	Duration	Start
1	Keeping Engineering Journal	60 days?	9/12/13 8:00 AM
2	Electronic copy of Meeting M	60 days?	9/12/13 8:00 AM
3	⊟ **Project Item Discussion**	10 days?	**9/2/13 8:00 AM**
4	Camera Auto-Focus	8 days?	9/3/13 8:00 AM
5	Automatic Payment Systen	8 days?	9/4/13 8:00 AM
6	Traffic Light Timer	9 days?	9/2/13 8:00 AM
7	Auto-Leveling Wheelchair	7 days?	9/4/13 8:00 AM
8	Project Proposal	6 days?	9/16/13 8:00 AM
9	Project Scheduling	2 days?	9/16/13 8:00 AM
10	Reseach [Camera]	19 days?	9/13/13 8:00 AM
11	Project Fund [ESSEF]	2.5 days?	9/16/13 8:00 AM
12	Company Logo	0.25 days?	9/18/13 1:00 PM
13	⊟ **Design Cocument Prep**	30 days?	**9/24/13 8:00 AM**
14	Functional Spec Prep	12 days?	9/24/13 8:00 AM
15	Design Spec Prep	30 days?	9/24/13 8:00 AM
16	⊟ **Progree Report**	12 days?	**10/10/13 8:00 AM**
17	Oral Presentation	3 days?	10/10/13 8:00 AM
18	Written Progress report	9 days?	10/15/13 8:00 AM
19	⊟ **Prototype Prep**	50 days?	**9/23/13 8:00 AM**
20	Shipping hardware	10 days?	9/23/13 8:00 AM
21	Hardware implementation	18.125 days?	10/10/13 8:00 AM
22	Software Implementation	18.5 days?	10/10/13 8:00 AM
23	Integrating HW and SW	13 days?	11/5/13 1:00 PM
24	Testing fully implemented p	5.5 days?	11/22/13 1:00 PM
25	Prep for presentation	3 days?	12/2/13 8:00 AM
26	Post-Mortem	7 days?	12/5/13 8:00 AM



Schedule created at the beginning of the semester

Project Management

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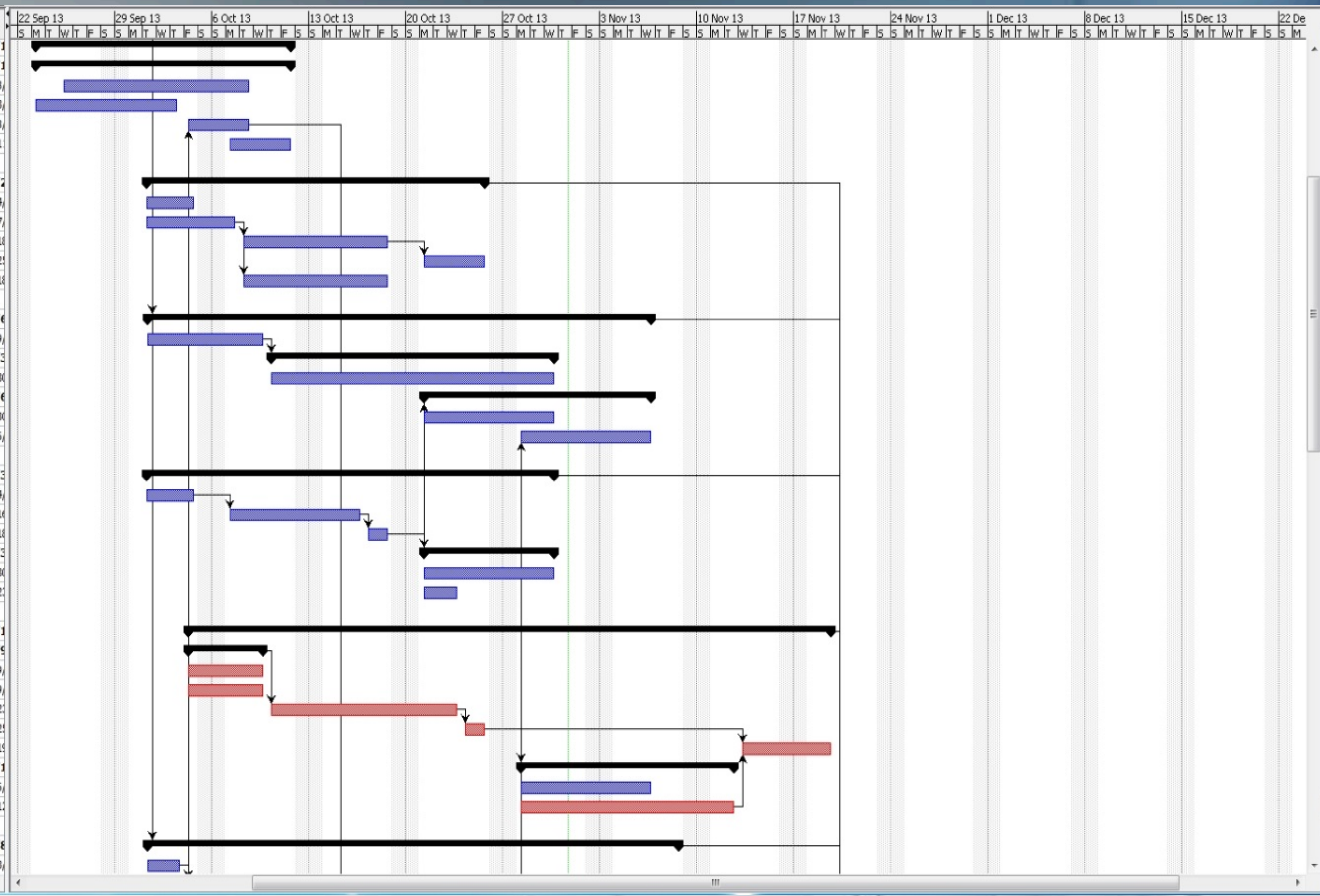
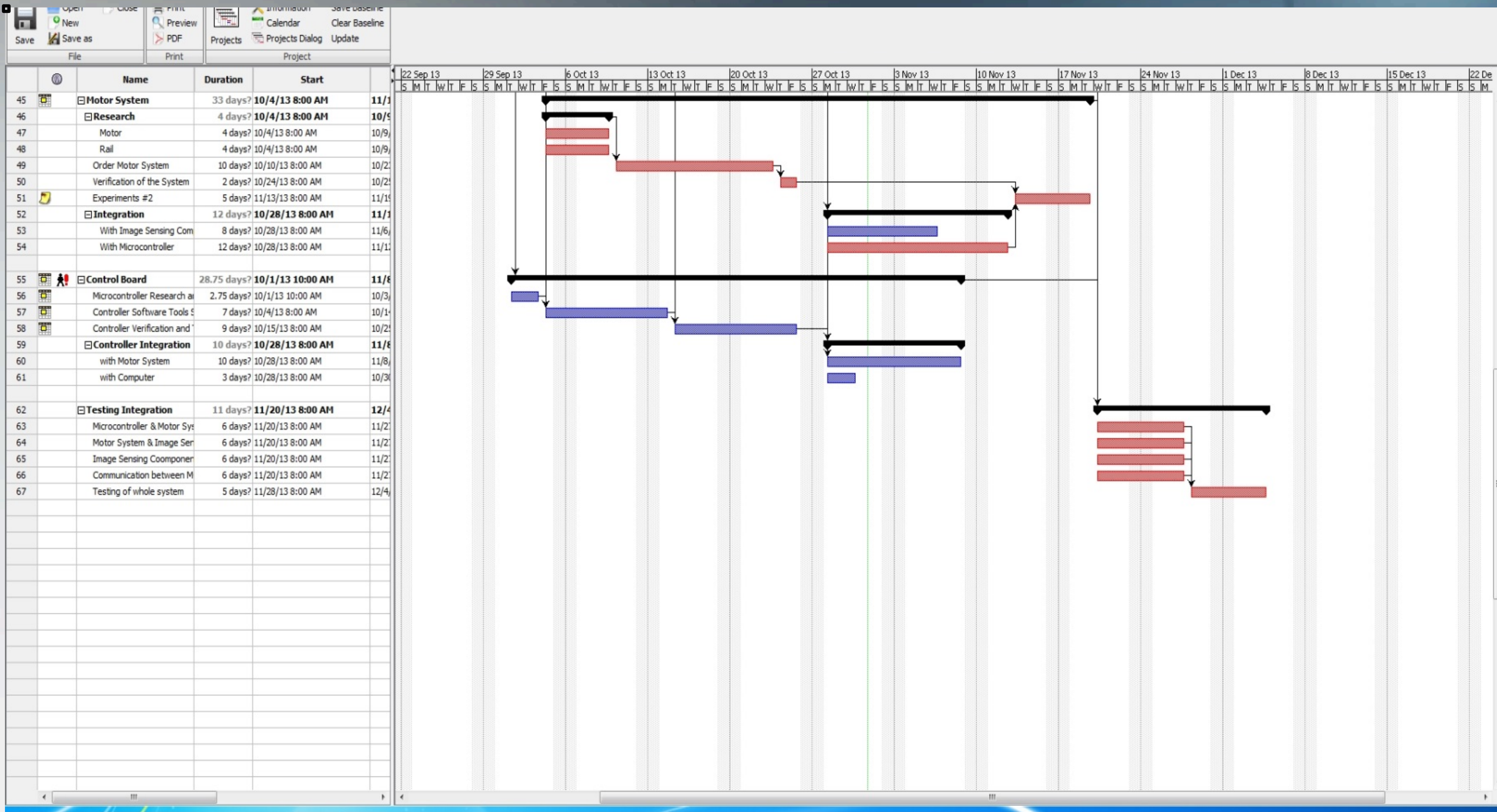
	Name	Duration	Start	
19	**Prototype Prep**	15 days?	**9/23/13 8:00 AM**	**10/1**
20	**Shipping hardware**	15 days?	**9/23/13 8:00 AM**	**10/1**
21	Motor System	10 days?	9/25/13 8:00 AM	10/8/
22	Image Sensor Componen	8.5 days?	9/23/13 8:00 AM	10/3/
23	Microcontroller	3 days?	10/4/13 8:00 AM	10/8/
24	Lens	5 days?	10/7/13 8:00 AM	10/1
25	**Optic**	19 days?	**10/1/13 8:00 AM**	**10/2**
26	Image Sensing component	4 days?	10/1/13 8:00 AM	10/4/
27	Research on Lens we are t	5 days?	10/1/13 8:00 AM	10/7/
28	Order Lens to use	9 days?	10/8/13 8:00 AM	10/1
29	Verification of the Lens	5 days?	10/21/13 8:00 AM	10/2
30	Experiments #1	9 days?	10/8/13 8:00 AM	10/1
31	**Image Processing**	26.75 days?	**10/1/13 10:00 AM**	**11/6**
32	Selection on Image process	6.75 days?	10/1/13 10:00 AM	10/9/
33	**Experiment #3**	15 days?	**10/10/13 8:00 AM**	**10/3**
34	Retrieve contrast informa	15 days?	10/10/13 8:00 AM	10/3
35	**Integration**	13 days?	**10/21/13 8:00 AM**	**11/6**
36	With Image Processing c	8 days?	10/21/13 8:00 AM	10/3
37	With Microcontroller	8 days?	10/28/13 8:00 AM	11/6/
38	**Image Sensing Compone**	22 days?	**10/1/13 8:00 AM**	**10/3**
39	Selection on Image Sensing	4 days?	10/1/13 8:00 AM	10/4/
40	Order of the component	8 days?	10/7/13 8:00 AM	10/1
41	Verification of the order	2 days?	10/17/13 8:00 AM	10/1
42	**Integration**	8 days?	**10/21/13 8:00 AM**	**10/3**
43	With Lens	8 days?	10/21/13 8:00 AM	10/3
44	With Computer	3 days?	10/21/13 8:00 AM	10/2
45	**Motor System**	33 days?	**10/4/13 8:00 AM**	**11/1**
46	**Research**	4 days?	**10/4/13 8:00 AM**	**10/9**
47	Motor	4 days?	10/4/13 8:00 AM	10/9/
48	Rail	4 days?	10/4/13 8:00 AM	10/9/
49	Order Motor System	10 days?	10/10/13 8:00 AM	10/2
50	Verification of the System	2 days?	10/24/13 8:00 AM	10/2
51	Experiments #2	5 days?	11/13/13 8:00 AM	11/1
52	**Integration**	12 days?	**10/28/13 8:00 AM**	**11/1**
53	With Image Sensing Com	8 days?	10/28/13 8:00 AM	11/6/
54	With Microcontroller	12 days?	10/28/13 8:00 AM	11/1
55	**Control Board**	28.75 days?	**10/1/13 10:00 AM**	**11/8**
56	Microcontroller Research a	2.75 days?	10/1/13 10:00 AM	10/3/



Schedule created in mid-October (Part 1)

Project Management



Schedule created in mid-October (Part 2)

Project Management

Project budget estimation

Listed Item	Cost ($CAD)	Tax + Shipping
Image Sensors (2-3 Units)	$50.00	
Microcontroller	$100.00	
Motor	$50.00	
Supplies for the mounting fixture	$50.00	
Lenses (1 – 2 with different focal distance)	$50.00	
Power Supply	$20.00	
In total	$320.00	
Total Funding Applied	$350.00	
Total Funding Received	$500.00	

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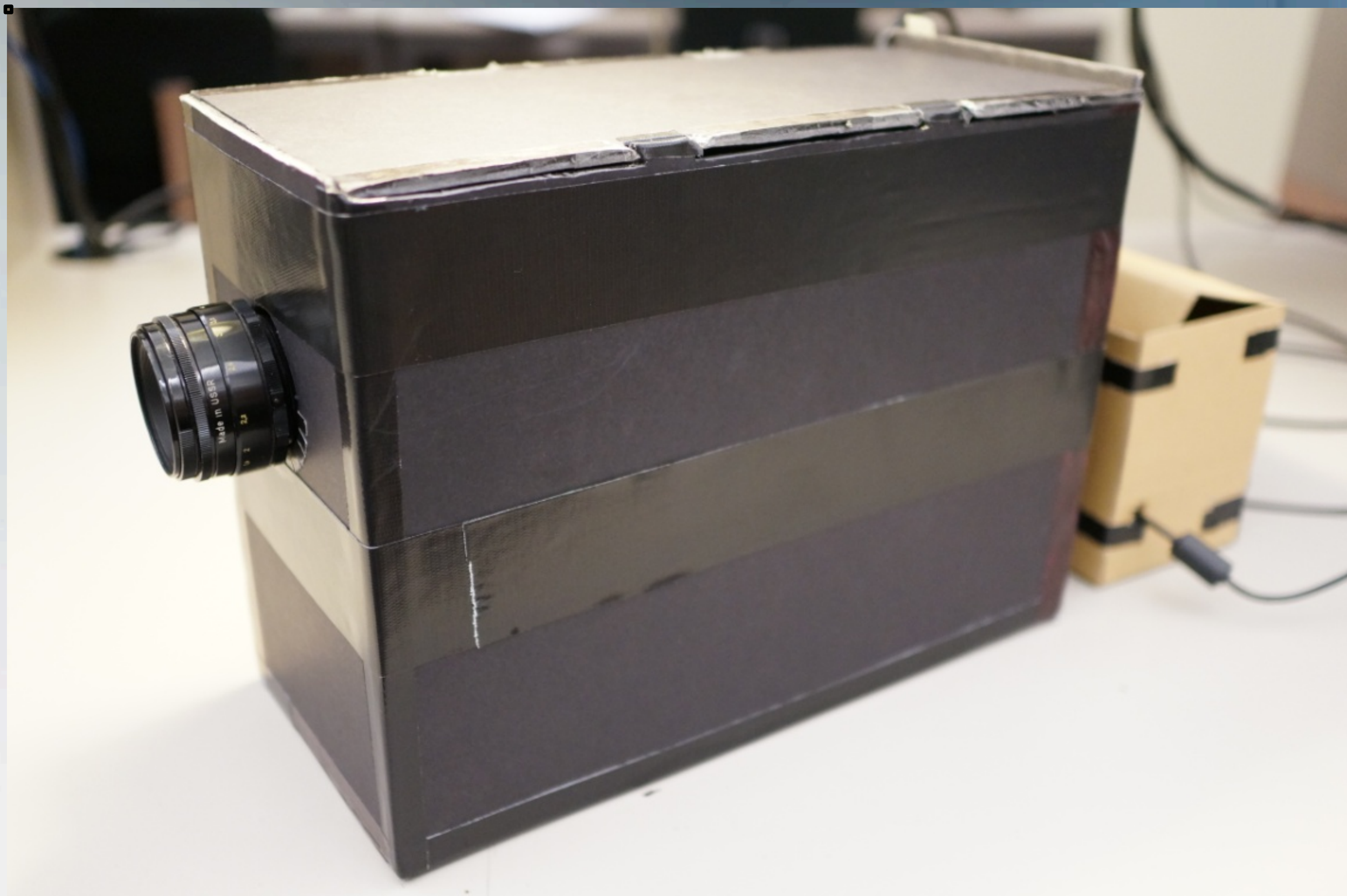
Project budget

Listed Item	Cost ($CAD)	Tax + Shipping
Total budget	$500.00	
Motor System	$157.94	$88.98
Webcam	$23.99	$0.00
Microcontroller	$33.00	$3.96
Stepper Motor Driver	$45.00	$5.40
Power Adapter (12V, 3A)	$15.00	$1.80
Lens (2 lenses with different FFD)	$110.00	$0.00
Materials for enclosure	$45.00	$5.40
Female adapter 2.1 Jack (Connection for driver and PSU)	$1.50	$0.70
Total	$537.67	
Remaining Funds	$0.00	

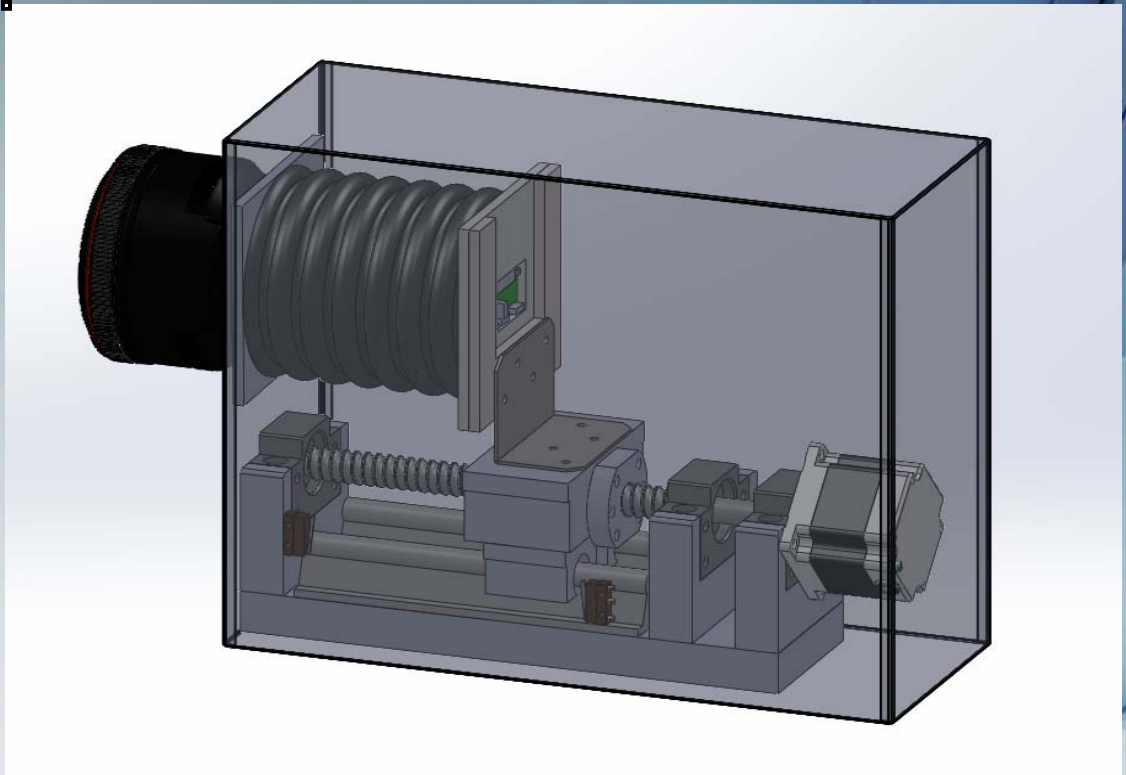
Design – System Overview



Design – System Overview

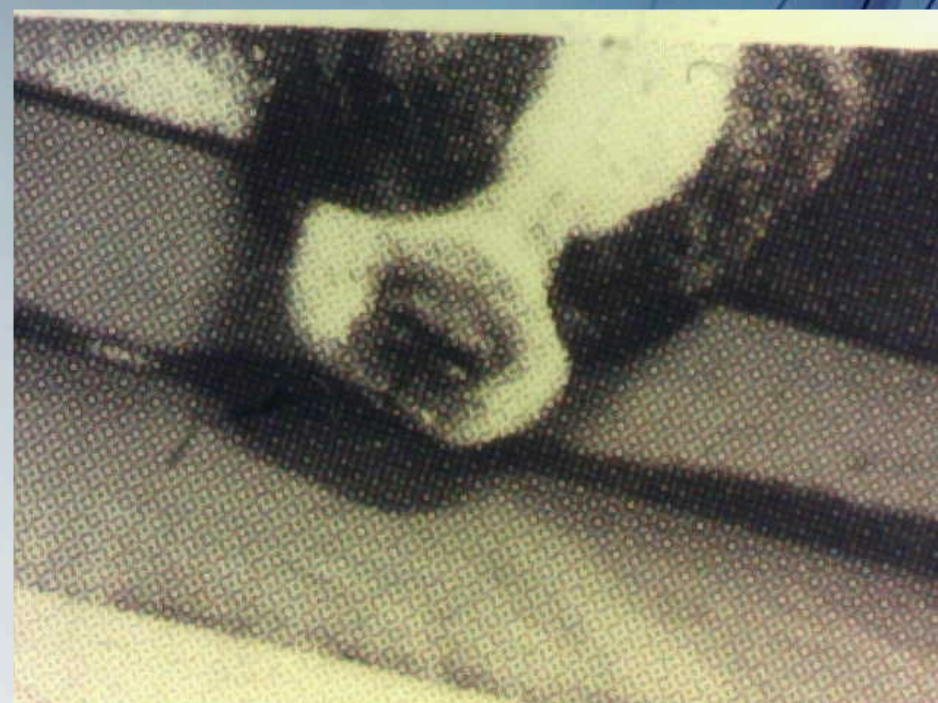
The system design can be broken down into the following sub-sections:

- Optics
- Image Sensor
- Shifting System
- Motor Control
- Image Processing



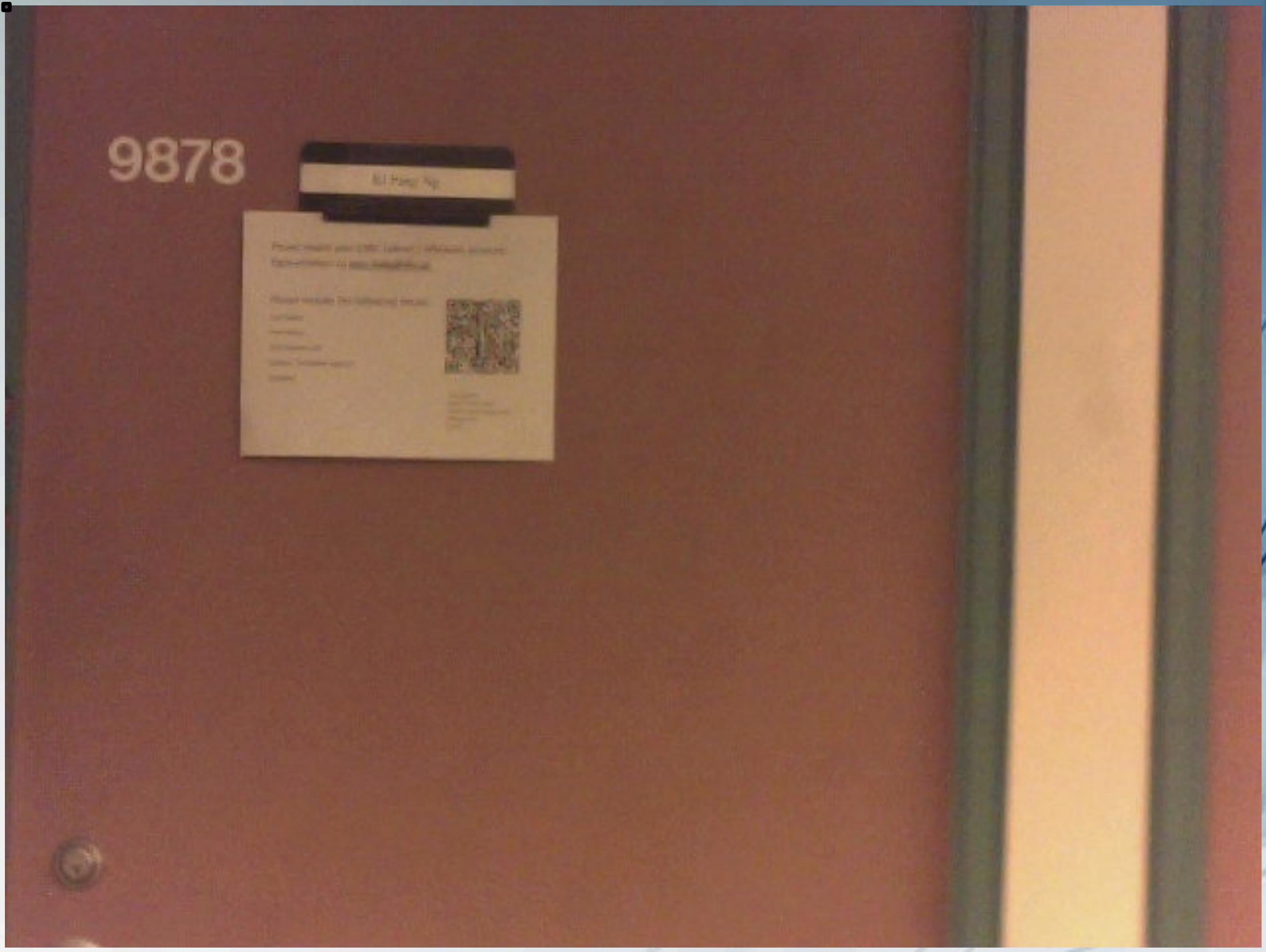
Design – System Overview

Sample output image of the ISSS (distance ≈ 20cm)



Design – System Overview

Sample output image of the ISSS (distance ≈ 30m)



Design – Optics

Helios 58mm F2 Lens

- Prime Lens
- F2 to F16 aperture values
- Flange focal distance: 45.46mm
- Produce 36mm x 24mm image

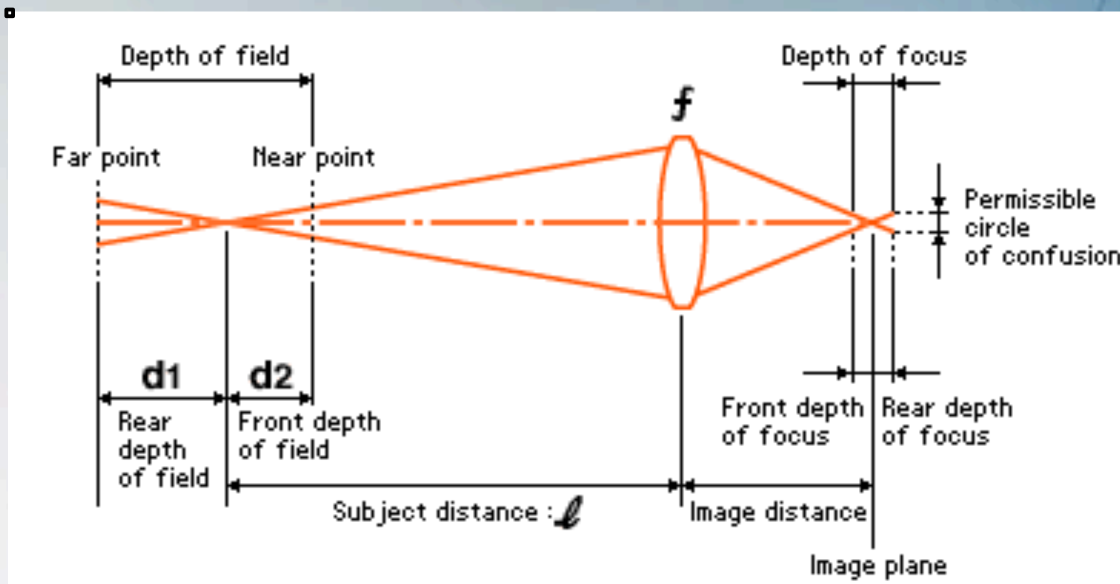
[6]

Design – Optics

Depth of field and depth of focus

Depth of Field: the range between the nearest and farthest objects in a scene that appear acceptably sharp in an image

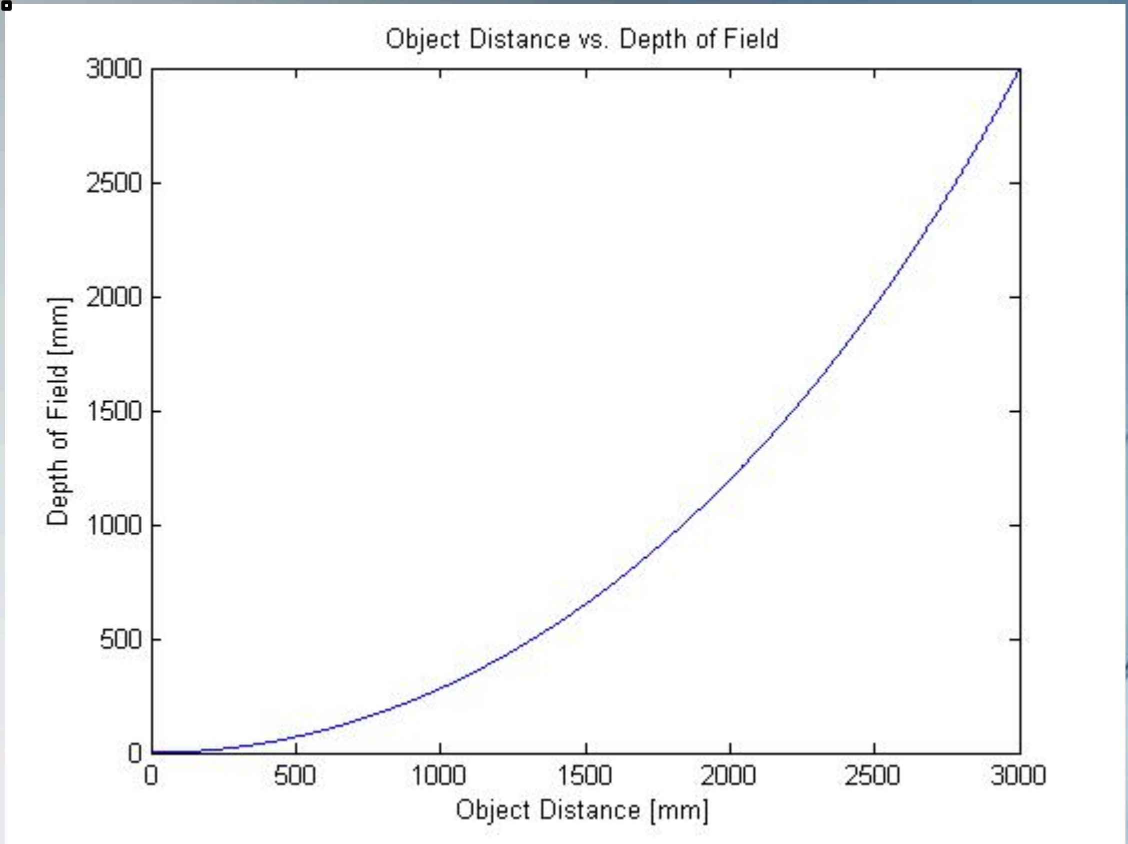
Depth of Focus: the range of the tolerance of placement of the image plane in relation to the lens



[7]

Design – Optics

Depth of field



$$\mathrm{DOF} \approx \frac{2Ncf^2s^2}{f^4 - N^2c^2s^2}$$

Design – Optics

Depth of focus

Aperture F Number	Depth of Focus
F16	0.928mm
F8.0	0.464mm
F5.6	0.325mm
F4.0	0.232mm
F2.8	0.162mm
F2.0	0.116mm

$$t \approx 2Nc$$

Design – Optics

Object distance and image distance relationship

Nearest focus distance: 13.8 cm

$$\frac{1}{S_1}+\frac{1}{S_2}=\frac{1}{f}$$

Design – Image sensor

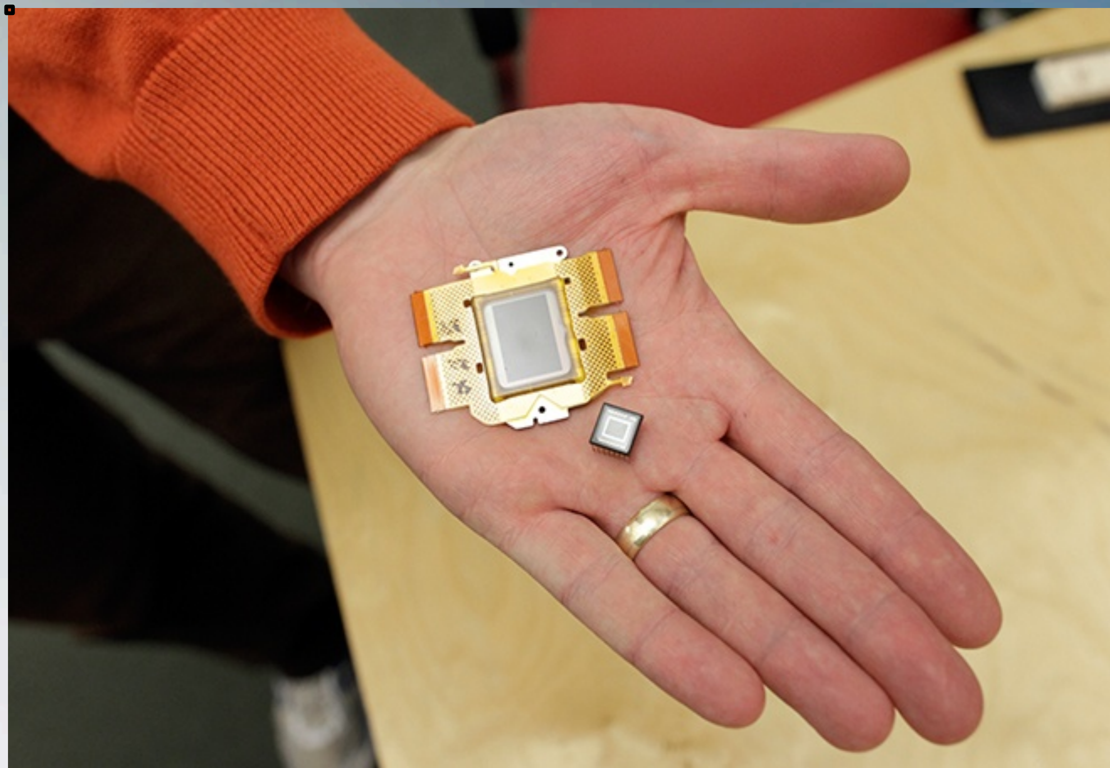
¼ Inch CMOS Image Sensor

- 1.3 Megapixel still image
- Dimensional size: 3.6 x 2.7mm

[8]

Design – Image sensor

¼ Inch CMOS Image Sensor vs. Full Frame Image Sensor



[9]

Design – Image sensor

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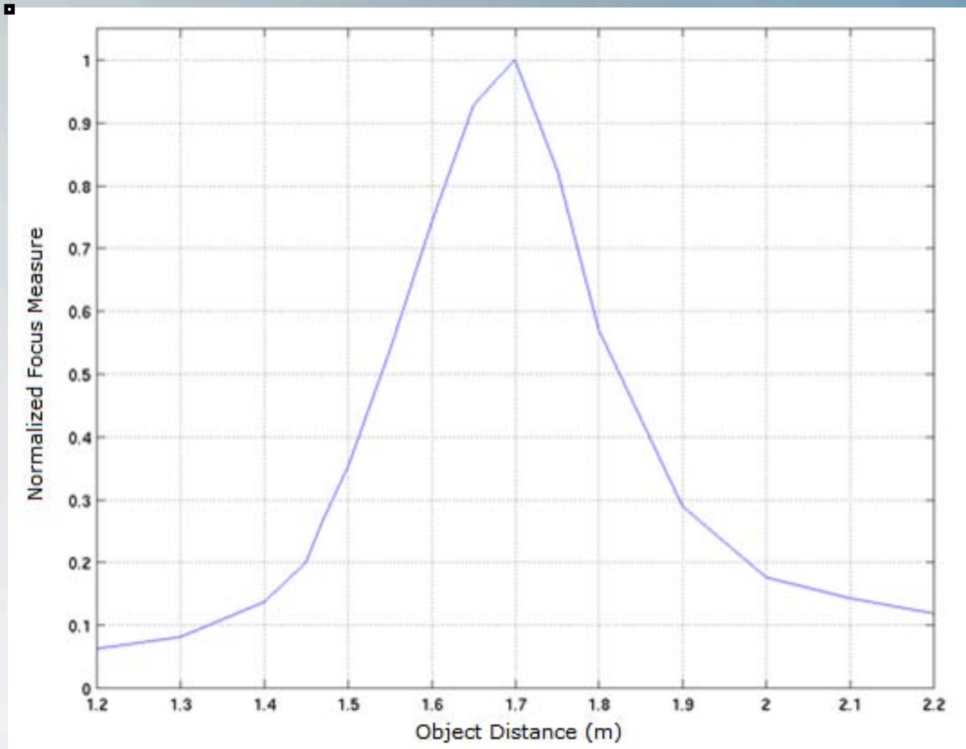
¼ Inch CMOS Image Sensor vs. Full Frame Image Sensor

¼ Inch CMOS Image Sensor has 9.26 crop factor.

[10]

Design – Shifting System

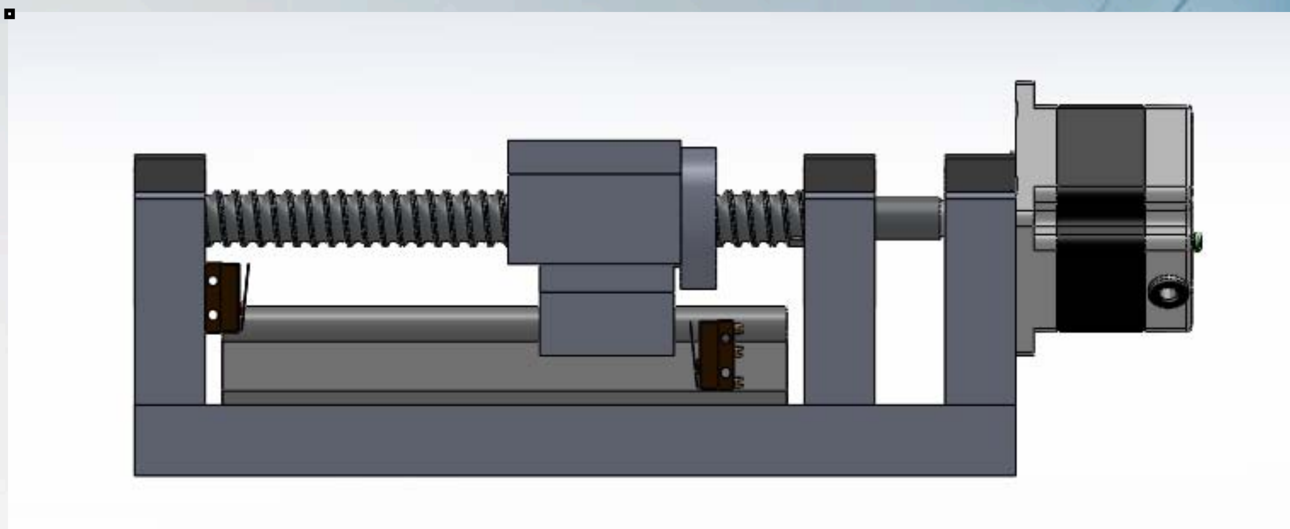
- Focus value reaches a peak when the sensor is located at certain position
- Small perturbations near the peak results in large changes in sharpness
- The motor requires a large delay, resulting in a slower movement speed in order to give the image processing algorithm time to 'catch' all of the sharpness values



Design – Shifting System

Rail Assembly

- Components: stepper motor, supporting blocks, supporting rails, ball screw and nut, image sensor carriage and micro switches.
- Aluminum material for all blocks
- Advantage of this rail system: high precision, stable image sensor motion



Design – Shifting System

<u>Stepper Motor</u>

- Model: 57BYGH56-401A Nema23 Stepper Motor
- Step angle: 1.8 Degree
- Rated current: 2.8A
- Lead wire: 4
- Speed: rotation 360 degree every 0.2 second while step delay is 1ms.

Design – Shifting System

Micro Switch

- 3 Connector
- Max Voltage: 6 volt
- Max Current: 5 amp
- Normally Open or Normally Closed Mode
- Normally Closed Mode is selected in ISSS

Design – Shifting System

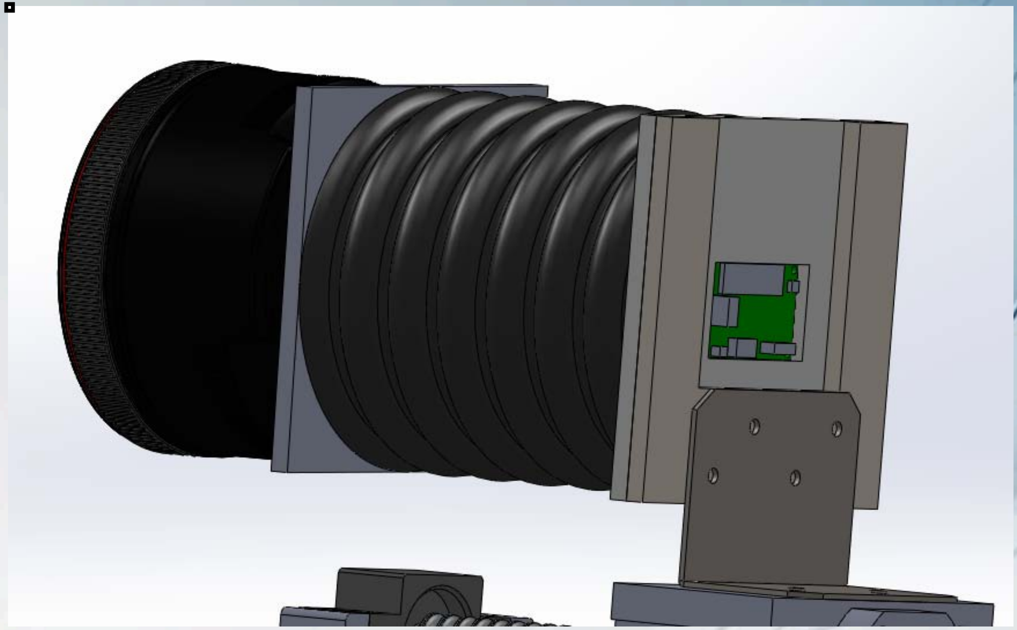
Ball Screw and nut

- Screw pitch (lead): 5mm
- Screw diameter: 16mm
- Length: 200 mm
- Each step of motor rotate, the image sensor carriage will be shift 25 um.
- Can shift image sensor carriage with speed up to 25mm/s with 1ms motor step delay

Design – Shifting System

Image sensor mount

- Two 10mm x 10mm foam boards
- sheet metal bracket
- U shape aluminum bracket
- Bellow
- The sensor should be aligned at the center of lens



Design – Camera Bellow

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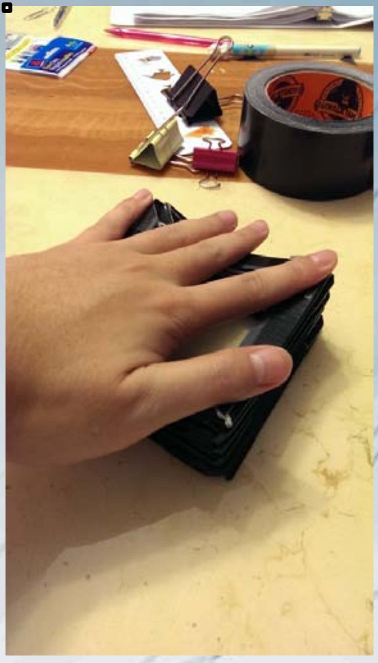
Camera Bellow

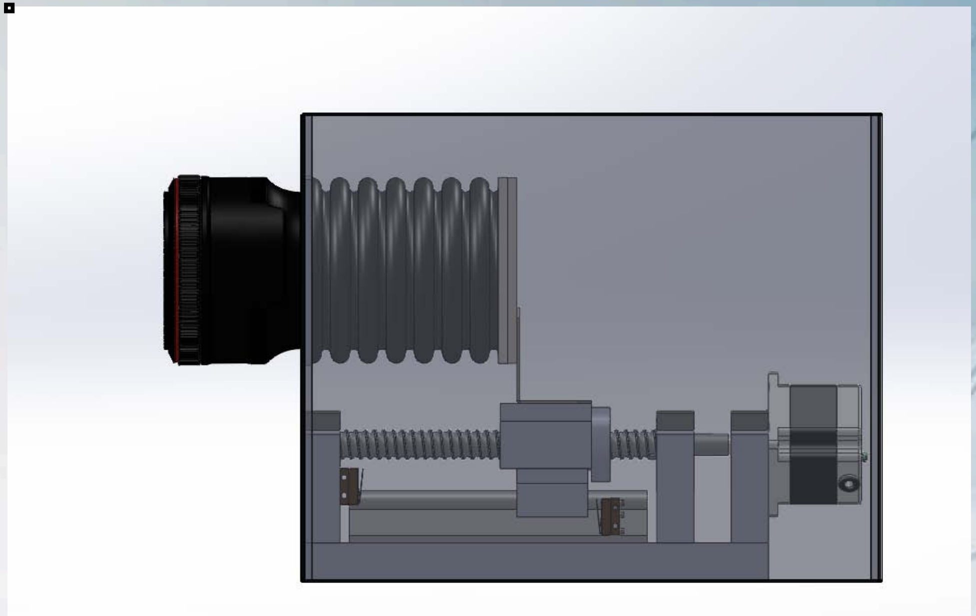
- Provides light proof environment
- Constructed by poster paper and black tape
- Compressed to 4cm thin; expanded to 15cm thick



Design – Shifting System

Enclosure and final assembly

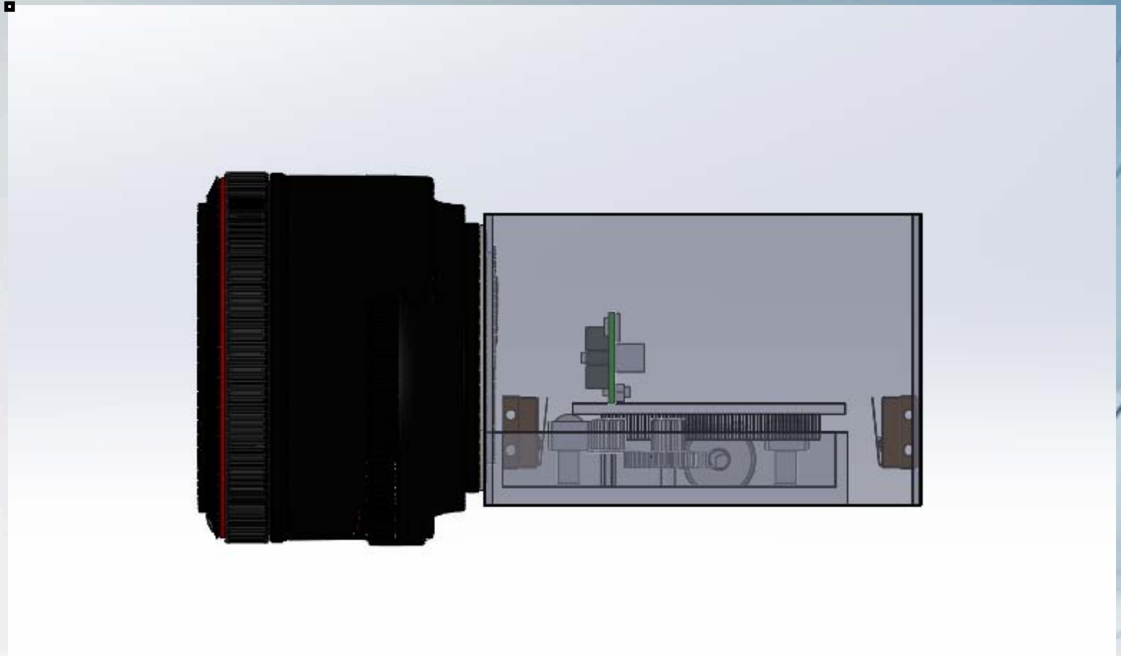
- Lens mounted out side the enclosure
- All mechanical moving part are secured inside the enclosure
- Material of enclosure is foam board



Design – Shifting System

Alternative shifting mechanism

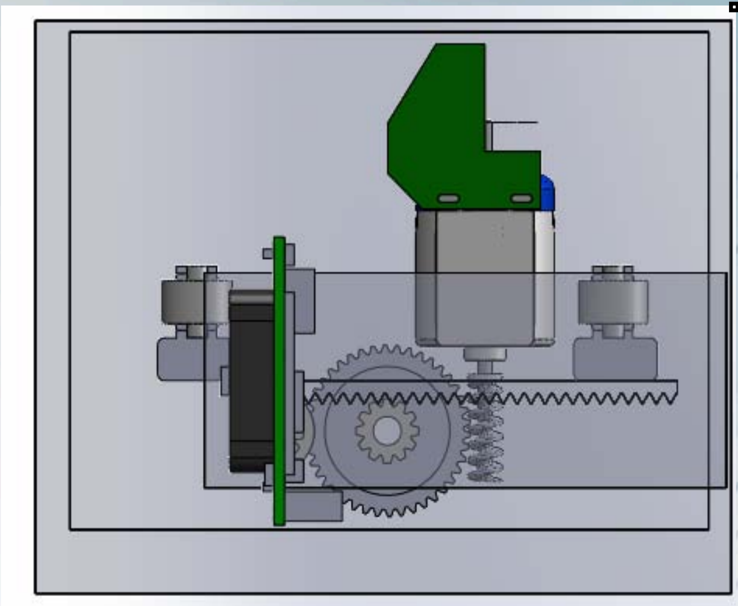
- Use gear train instead of ball screw mechanism
- Use DC motor with rotary encoder instead of stepper motor



Design – Shifting System

Gear Train

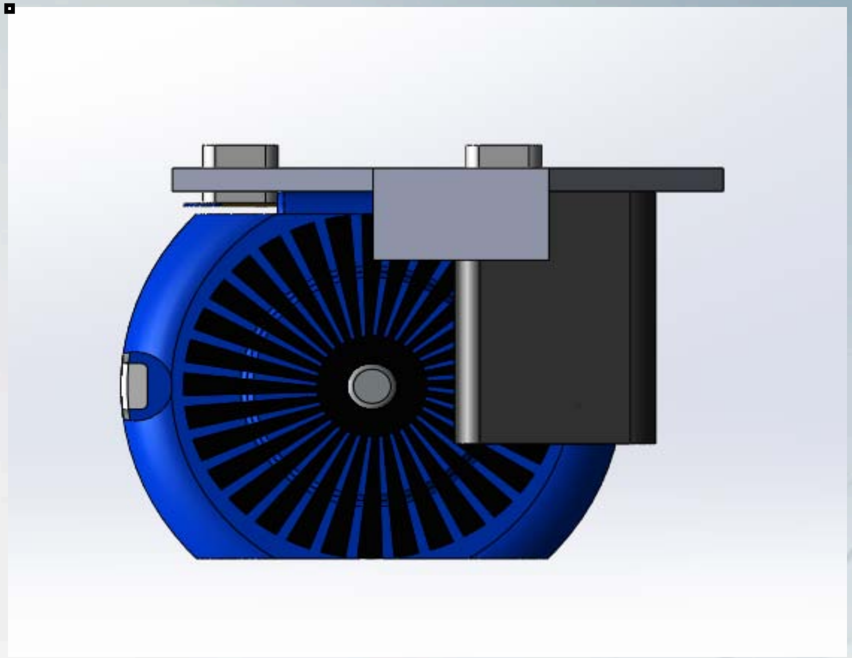
- Two sets of gear system
- Set 1: worm and worm gear
- Set 2: pinion and rack
- Two supporting wheel
- Image sensor carriage will be secured to rack gear

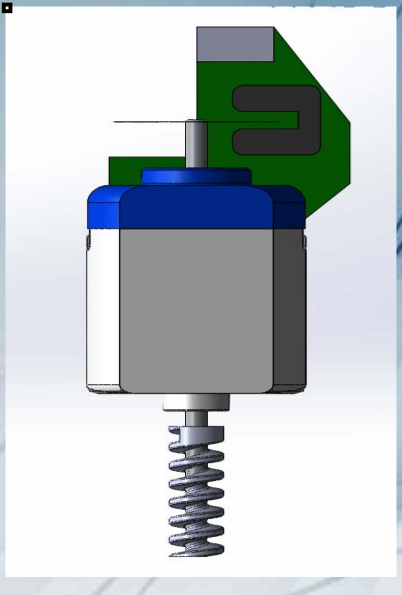


Design – Shifting System

DC motor with rotary encoder

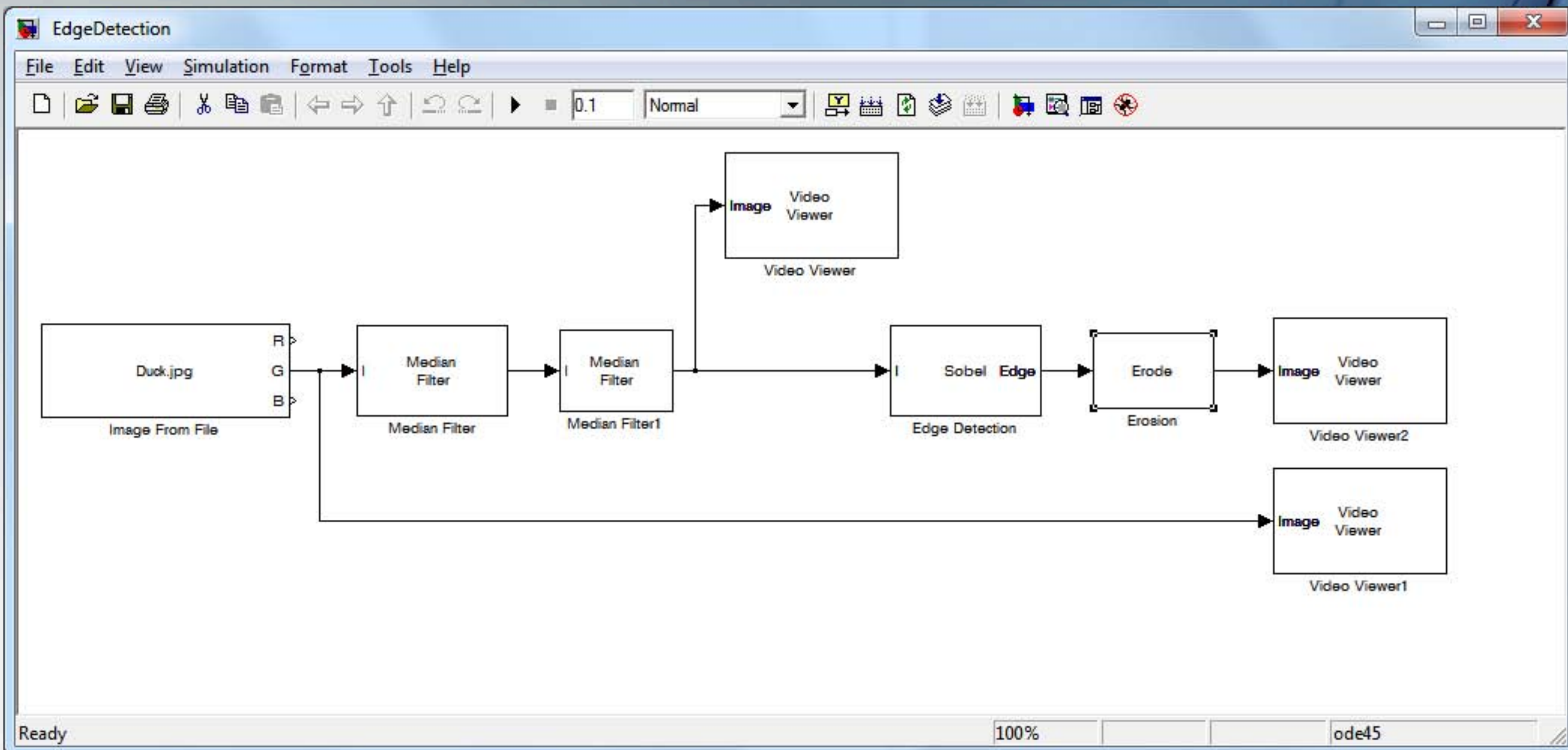
- A photo sensor will be triggered once each 11.25 degree that motor rotate
- Minimum detecting step size is 18 um





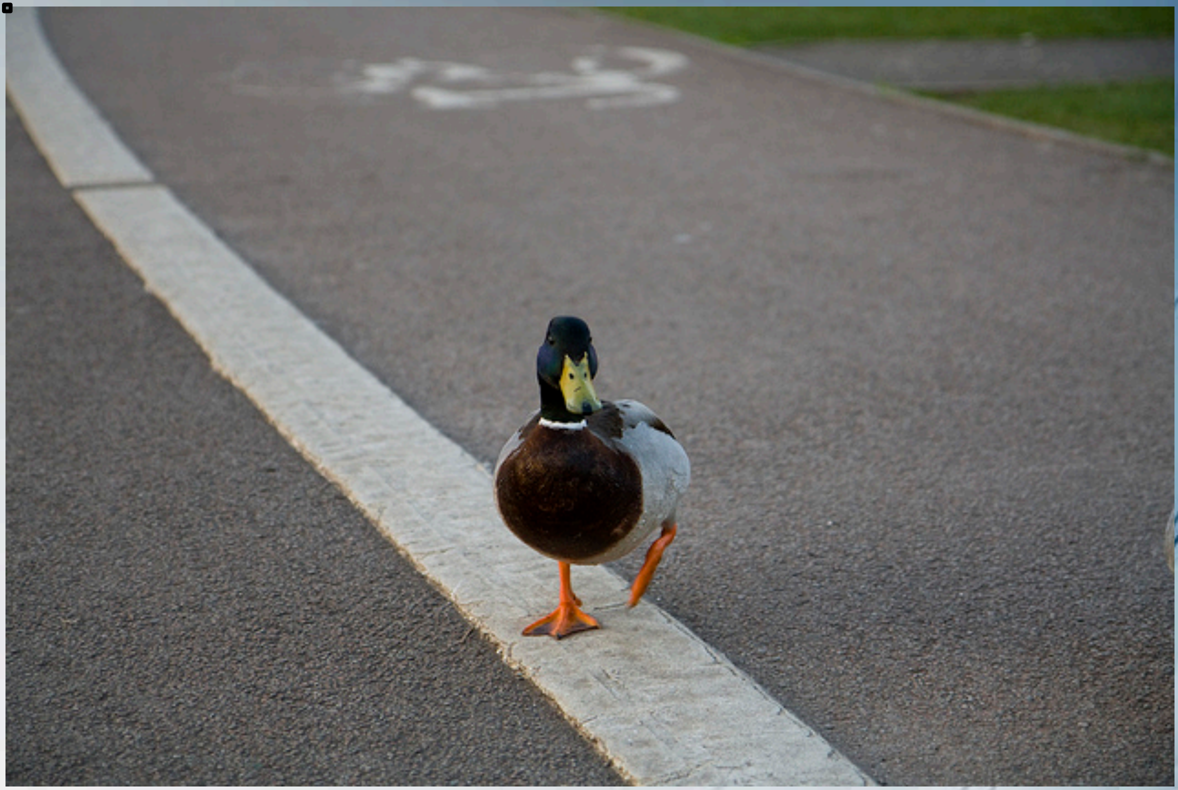
Design – Image Processing (early attempts)

MATLAB and Simulink Model



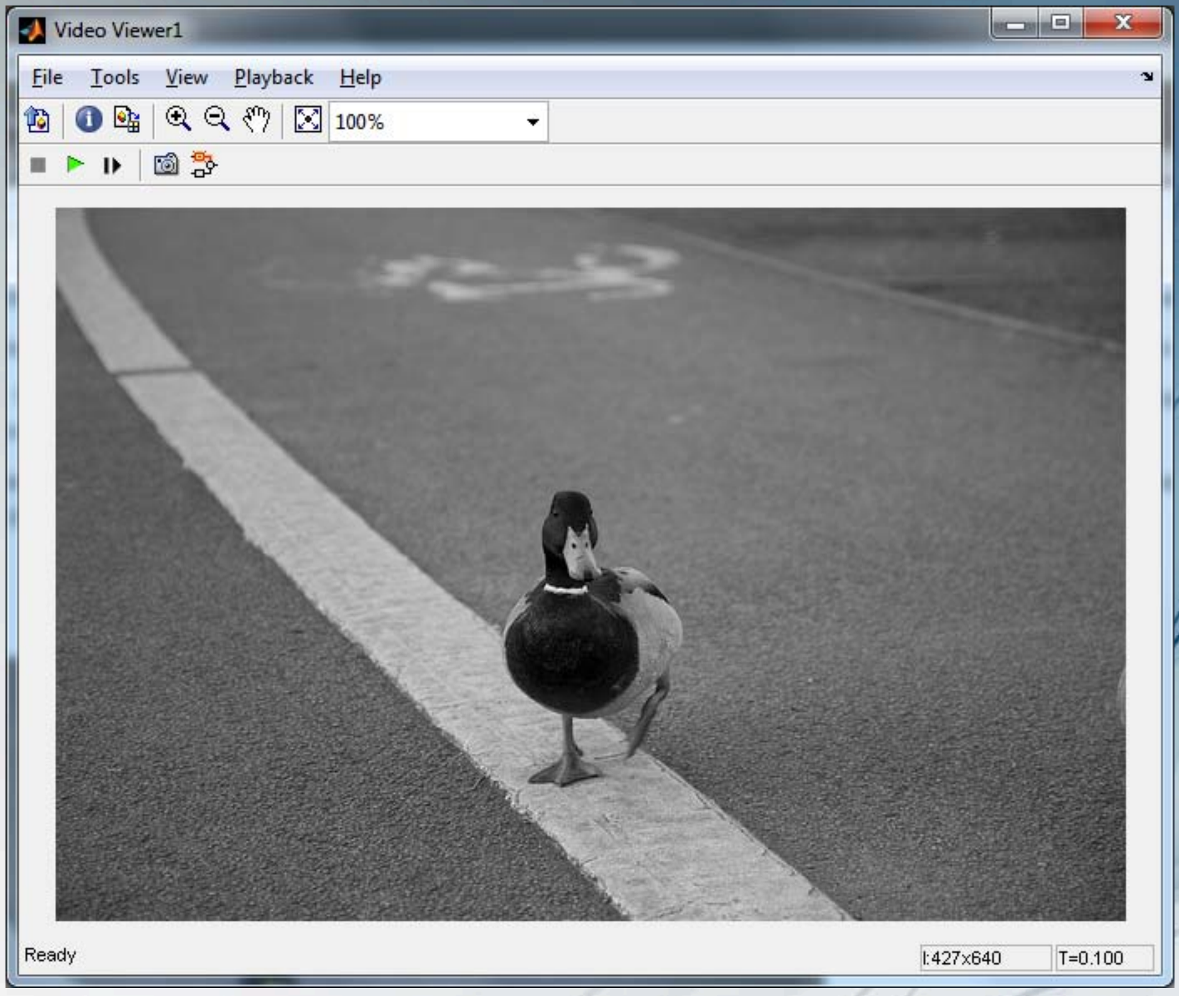
Design – Image Processing (early attempts)

MATLAB and Simulink model – Source image



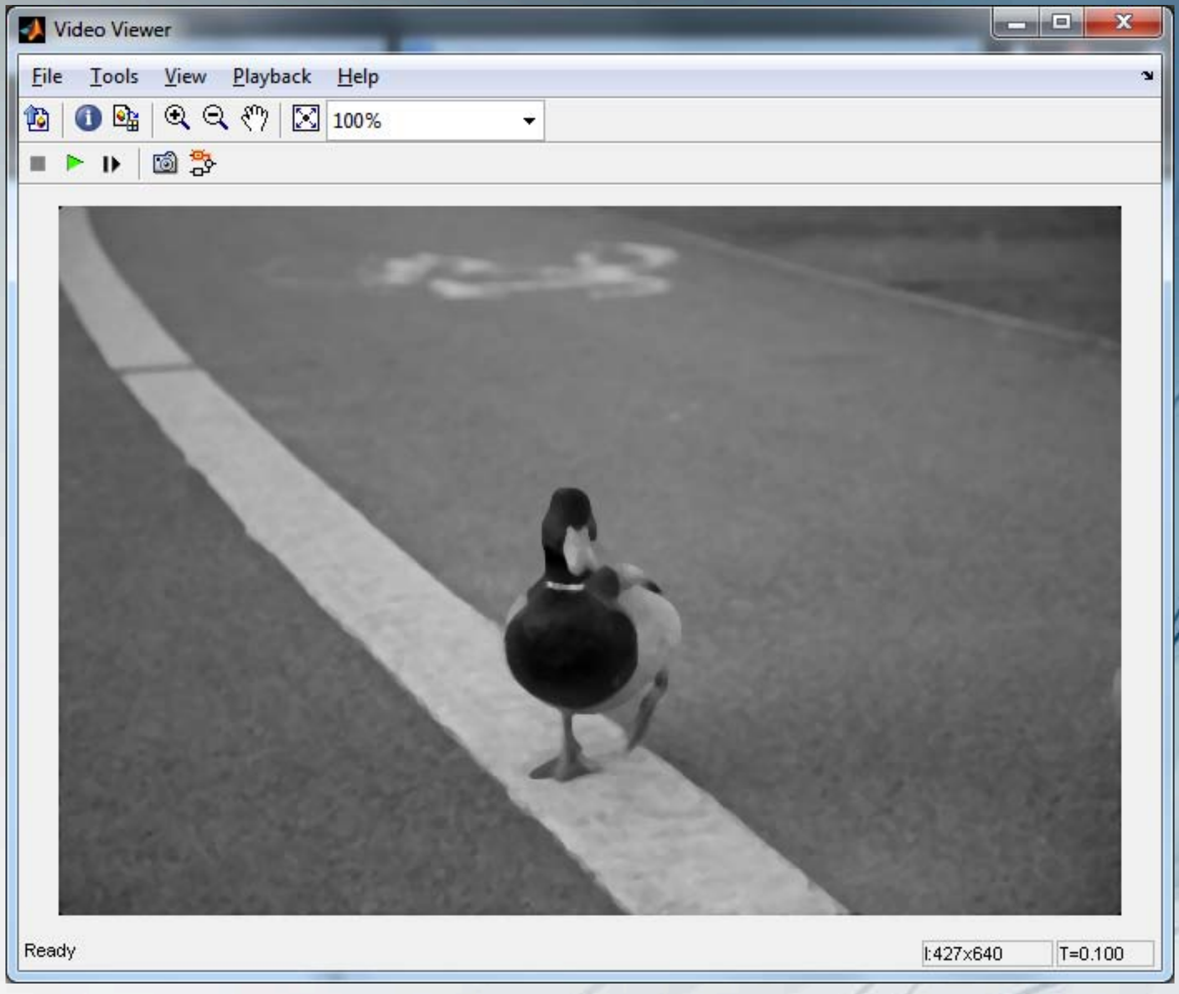
Design – Image Processing (early attempts)

MATLAB and Simulink model – Green channel



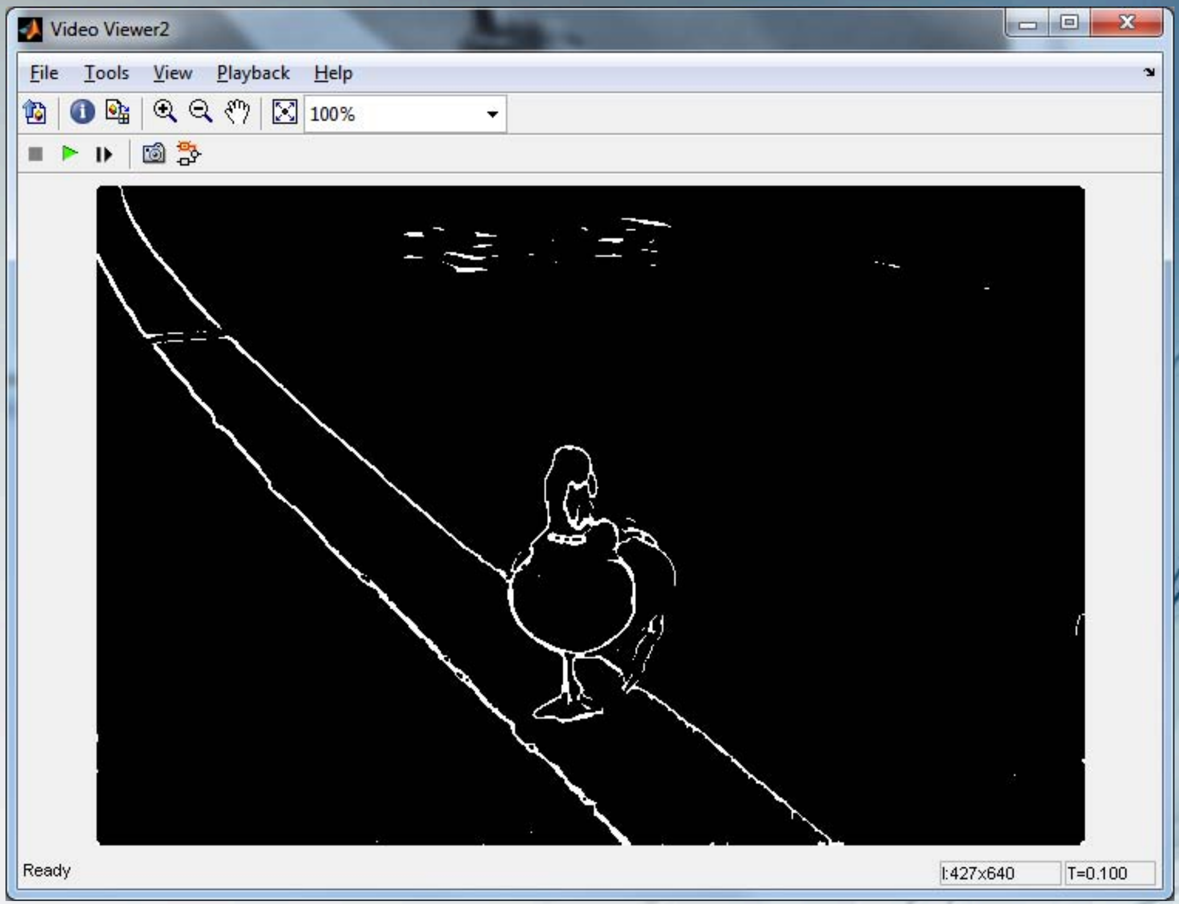
Design – Image Processing (early attempts)

MATLAB and Simulink model – Median filter (x2) results



Design – Image Processing (early attempts)

MATLAB and Simulink model – Sobel edge and erode results



Design – Image Processing (early attempts)

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Problems with using MATLAB / Simulink

- Lack of control over certain parameters
- Speed / Optimization
- Less familiar with MATLAB than with C++

Design – Image Processing

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Another Option: OpenCV

OpenCV

- Highly controllable – Open source C++ library
- Optimized for real-time video processing
- Very well documented
- Widely used in both academia and industry

Design – Image Processing Algorithm

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The General Idea (Theory)

- The image sensor sends data to the local workstation, which processes the real-time video data.

- The algorithm decides how much to move the motor, and in which direction based on the current image focus.

Design – Image Processing Algorithm

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The general idea (Actual)

- The process is started with a key-press event from the user
- The key-press event is registered by the image processing application, and a "START" command is sent to the microcontroller via serial communication
- The microcontroller receives the "START" command and sets the appropriate control parameters for the motor driver
- The motor travels the length of the rail, before hitting the safety switch, at which point it reverses direction and returns to the initial position.
- Throughout this process, the image processing algorithm is analyzing the video feed in real-time and computing a sharpness value for each frame

Design – Image Processing Algorithm

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The image processing algorithm

Two common methods:

1. Frequency analysis
   - Accurate
   - Sensitive to scene changes

2. Sharpness / Edge detection
   - Accurate
   - Sensitive to scene changes, but less so than with frequency analysis

Design – Image Processing Algorithm

The image processing algorithm

Laplace Kernel

```
0  1  0
1 -4  1   *
0  1  0
```

[10]
=>

The next (and final) step is to search the resulting image for the highest value, and take that to be a representation of the overall sharpness for the image.

Works in practice!

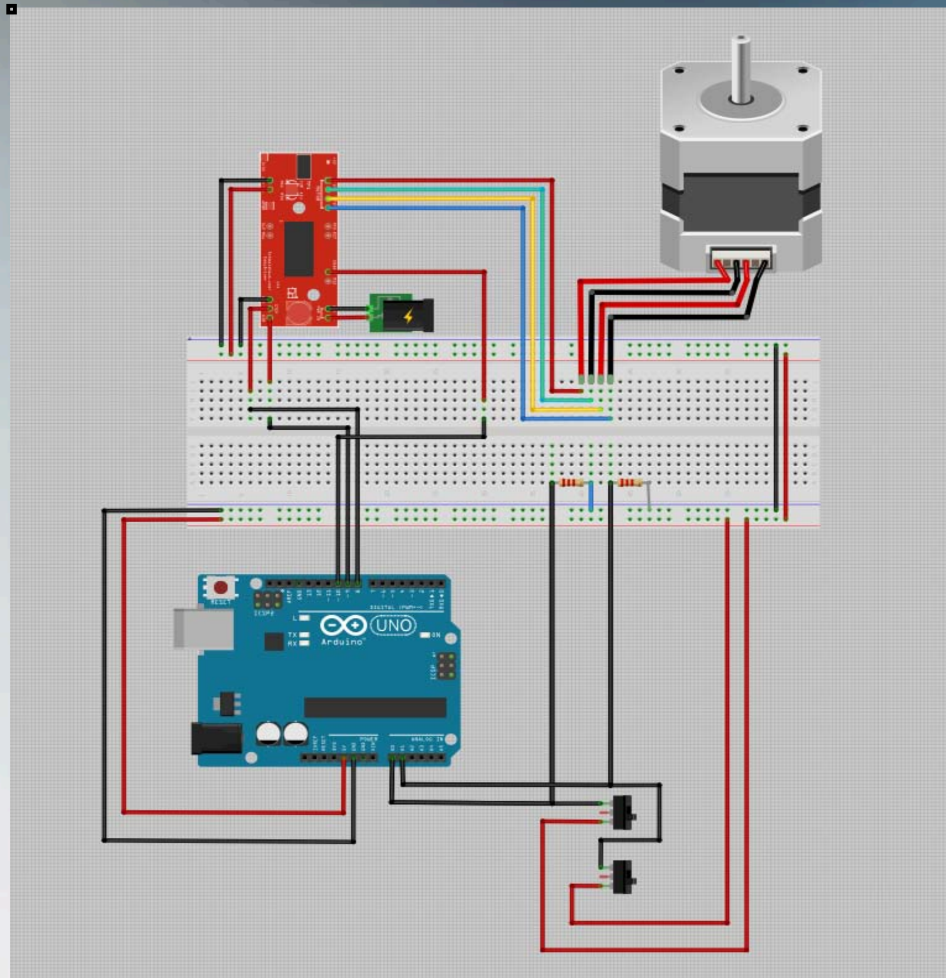
Design – Image Processing Algorithm

The image processing algorithm

The output of the Laplace Filter for the previously shown example

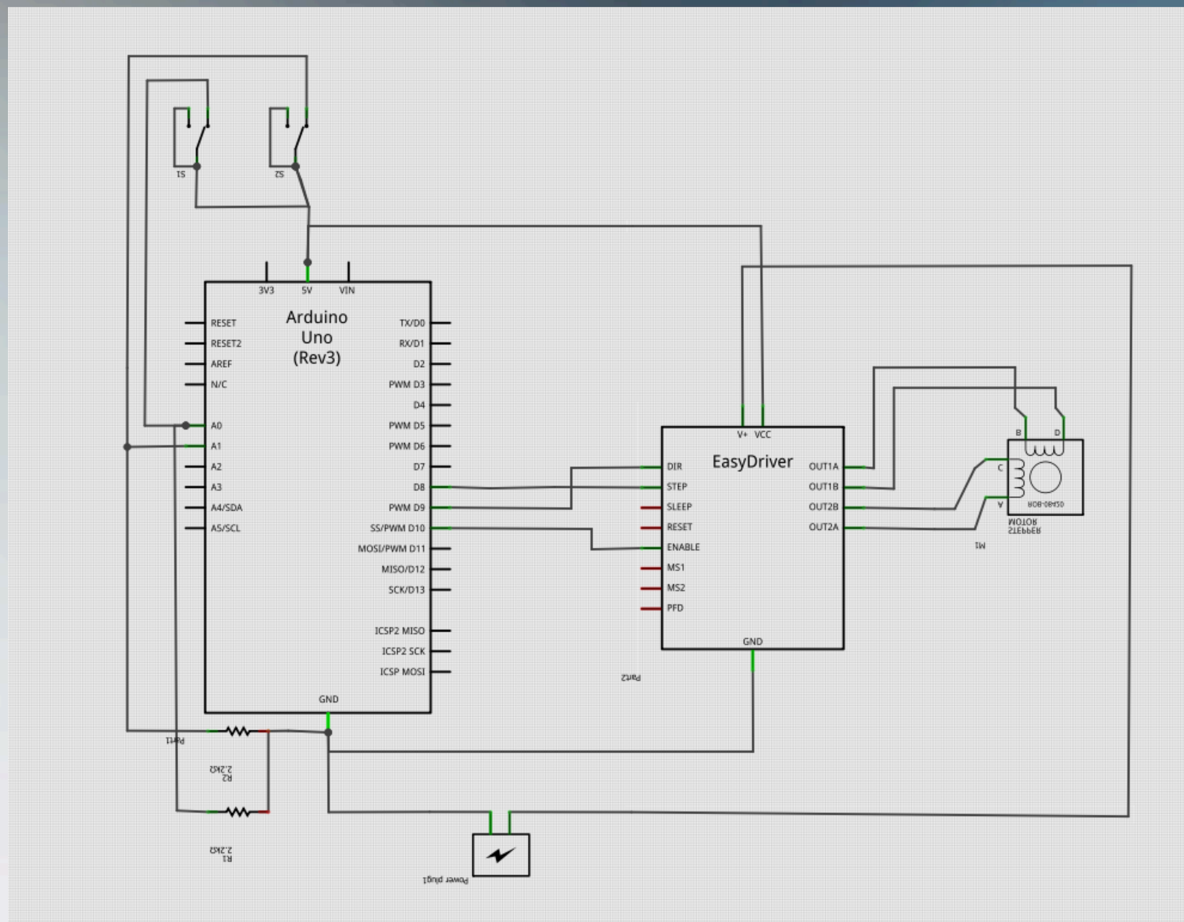
(Aperture = 5, levels adjusted)

Design – Motor Control



To rotate the stepper motor, multiple pulses (based on the step number) must be provided to the motor, and the Arduino is used to pass pulses.

Design – Motor Control



Schematics for motor control system

Design – Motor Control

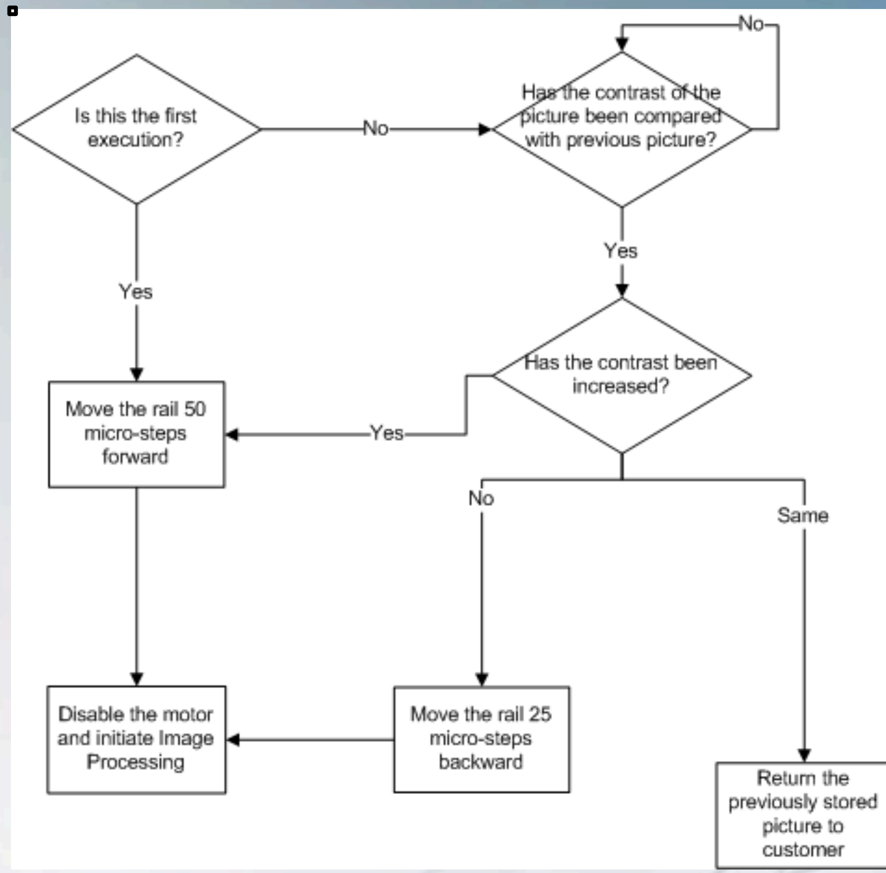
MOTUS

Advantages of using an Arduino

- Open-source software is easy to use, resulting in quick prototyping
- Widely used; lots of support and documentation
- Provides constant analog output voltage: 3.3 and 5V
- Re-programmable chip

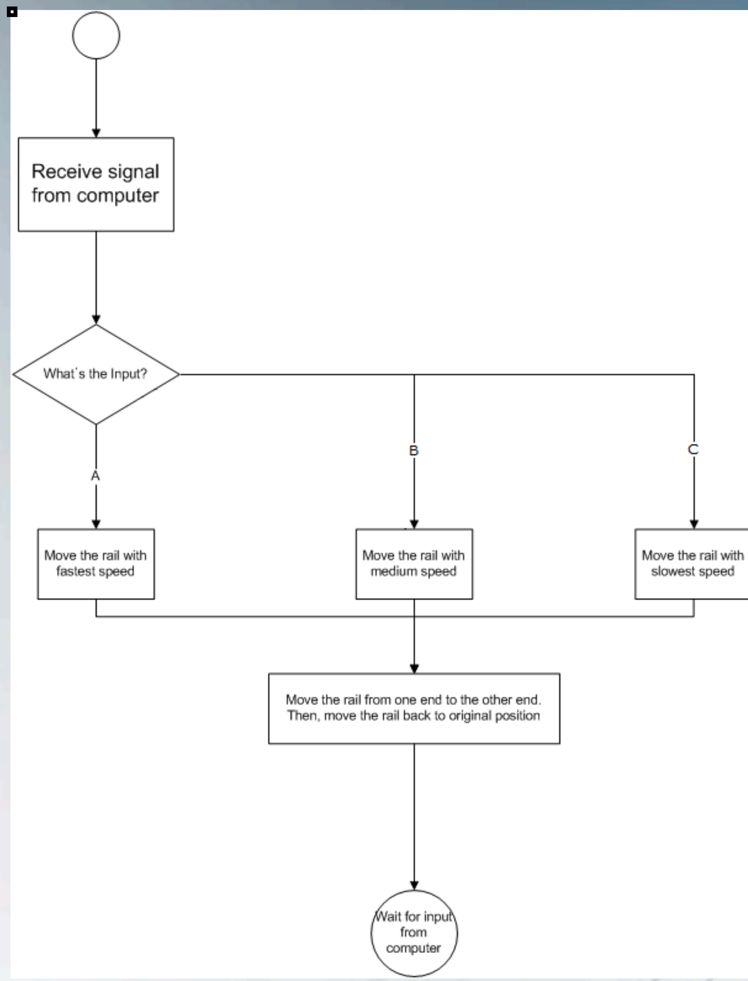
Arduino

With the bi-directional communication between computer and Arduino established, our project would've been developed with below algorithm.



Design – Motor Control

Arduino control logic



Reliability

MOTUS

Cycle tests

The ISSS has been run 10 times on each speed setting.

Each test was set up to capture the same object.

Speed Setting	Number of sharp images captured	Time taken per run
Fast	6	~ 21 seconds
Medium	7	~ 41 seconds
Slow	8	~ 61 seconds

Looking Ahead (Performance)

MOTUS

Problem: Selected image isn't always the most focused

Reason 1:

While the image sensor in the depth of focus, the CPU is still computing the previous frame and misses the current focused image.

How to fix:

While the image is being processed, slow down the motor's speed.

Reason 2

The image sensor cannot adjust to changes in brightness (no auto ISO control). If lighting conditions are too bright or too dim, the contrast is too low.

How to fix:

Use the image sensor with auto ISO control feature.

Reason 3

Improper alignment.

How to fix:

Use proper alignment tools to align the lens and the image sensor in proper positions.

Looking Ahead (System Size)

MOTUS

Problem: The ISSS's size is bulky.

Reason 1:

Rails are too long; motor is too big.

How to fix:

Replace with shorter rails and less powerful motor. However, shorter rails will shorten the nearest focus distance.

Reason 2

Camera bellow exists.

How to fix:

Remove the bellow. However, the ISSS's enclosure cannot currently provide a completely darkened environment.

Reason 3

The ISSS requires a local workstation to run the image processing algorithm.

How to fix:

Load the OpenCV libraries on an embedded device that has a processor powerful enough to run the image processing algorithm at a reasonable rate (approximately 20 frames analyzed per second).

Looking Ahead (Focusing Speed)

Problem: The ISSS's focusing speed is slow.

Reason 1:

Contrast detection auto focusing.

How to fix:

Replace with the on-chip phase detection image sensor.

Looking Ahead (Portability)

Problem: The ISSS is not portable.

Reason 2

Images have to be shown on computer's monitor.

How to fix:

Attach a LCD display.

Looking Ahead (Power Source)

Problem: The ISSS's motor requires to plug in 110V 60Hz.

Reason :

Motor requires too much current.

How to fix:

Replace with a smaller motor.

Looking Ahead (Usability)

MOTUS

Problem: The ISSS is not easy to operate.

Reason :

In the current prototype version of the ISSS, there is no easy interface for a non-experienced user to focus an image. It requires a person who is proficient in C++ to make adjustments to the image processing algorithm.

How to fix:

Invest more time developing a robust user interface that gives full control over the algorithm's parameters and image output.

Looking Ahead (Lenses Adaptability)

MOTUS

Problem: The ISSS cannot use different mounting type of lens.

Reason :

While the ISSS provides variable flange focal distances, the physical shape of the mounting mechanism is not able to have other types of lenses attached.

How to fix:

Replace the mounting mechanism with a hybrid mounting ring as shown below.

Hybrid mounting ring [12]

Looking Ahead (Focus Points)

Problem: Only images with flat surfaces can be processed

Reason :

The image processing algorithm processes entire image's sharpness value. When the object is not perpendicular to the camera's lens, certain areas of the image may be out of focus.

How to fix:

Set up multiple focus points/zones on the image. The image processing will only calculate sharpness values within those points/zones.

An image showing several points that create a focus region [13]

Acknowledgements

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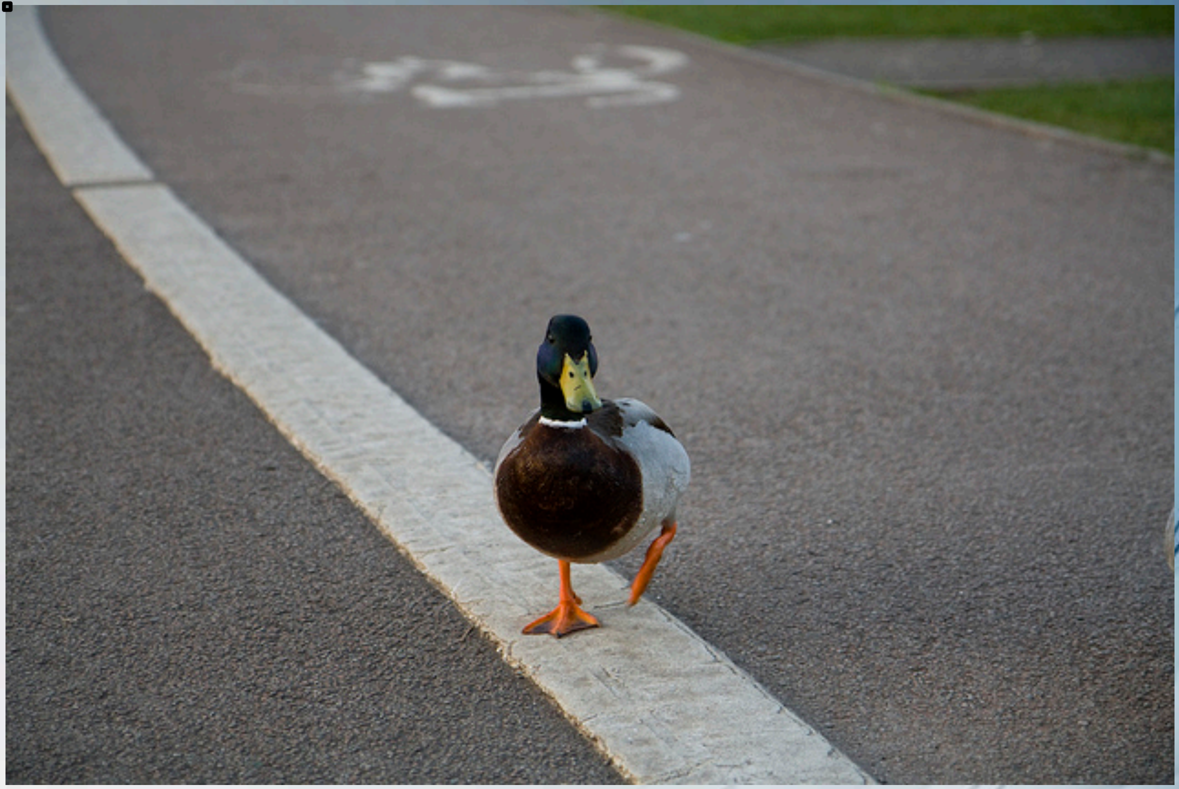
- Mike Sjoerdsma
- Lukas Mehri
- Jamal Bahari
- Mona Rahbar
- Alireza Rahbar
- Gary Houghton

- http://www.ensc.sfu.ca/~whitmore/courses/ensc305/ [14]

Q&A

Questions?



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