Group 3 Optical Project: Long Distance Stereo Depth Estimation

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Motivation and Background

SouthCom MiniAWACS project

- Primary function is to use Radar to track drone swarms to provide position and vector data to drone manufacturers

Optical Project

- Due to limitations and cost of optical components for SD motivation is to determine the range of an object at “long distances” using stereo vision

Goals

Basic Goals
Acquire stereo images with adequate resolution to provide range information at 100ft
Image will have adequate resolution to identify a 1m cross section object at 100ft
Determine range of object in stereo images at with less than 15% error at 100ft
Advanced Goals
Acquire stereo images with adequate resolution to provide range information at 200ft
Determine range of object in stereo images at with less than 15% error at 200ft
Stretch Goals
Acquire stereo video of scene with adequate resolution at 300ft for live depth information
Provide vector information regarding motion of object in relation to its initial position

Objectives

Basic Objectives
Use Zemax to design optical system with off the shelf lenses including an achromatic doublet lens with an appropriate focal length to allow the system to capture images with adequate resolution to range an object at 100 ft.
Determine baseline between cameras that will allow for <15% error when ranging an object at ~ 100ft
Determine alignment of cameras to allow for 1m cross section overlap of stereo images
Advanced Objectives
Improve accuracy of ranging at distances 200< ft by making necessary adjustments to system baseline to reduce ranging error at longer distances
Make necessary adjustments to lens configuration to capture images at 200ft with adequate resolution to perform depth estimation
Stretch Objectives
Develop an image processing program that can stream live video of the scene captured by the stereo cameras
Use image processing to determine objects vector information based on video processing

Engineering Requirements/Specs

Engineering Requirement	Requirement Specification	Unit
Capture stereo images of a scene	< 3	Seconds
Complete disparity calculations for features in stereo images	< 5	Seconds
Provide range of desired object	< 10	Seconds
Stepper motor will respond to commands to rotate system	<1	Seconds
Track object captured in stereo video (stretch)	<10	Seconds
Provide vector of objects in video (stretch)	<15	Seconds

Hardware (Camera)

	ELP Web camera AR0234	See3CAM_37CUG	See3CAM_24CUG
Megapixels (MP)	2	3	2
Frame Rate (fps)	90	72	120
Sensor size	1/2.6”	1/2.6”	1920x1200
Pixel size	3.5 µm x 3.5 µm	2.25 µm x 2.25 µm	3 µm x 3 µm
Cost	$91.80		$199

Hardware (Lens)

	N-BAK4/N-SF10 (Edmund Optics)	N-BK7/N-SF5 (Thorlabs)
Transmission spectra 90%< (nm)	380-1970	380-1970
AR Coating (nm)	400-700	400-1100
Cost	$186	$181.48

Final Hardware

Component	Parameter	Specification	Unit
ELP Global Shutter USB Camera	Sensor size Sensor type Speed Shutter type	1/2.6” CMOS 90 Global	Mm CMOS vs CCD Fps Global vs. Rolling
Plano Concave Lens	Diameter Effective focal length AR Coating	20 -100 425-675	mm mm nm
Achromatic Doublet Lens	Diameter Effective focal length AR Coating	50 350 425-675	mm mm nm

Optical System Hardware Design

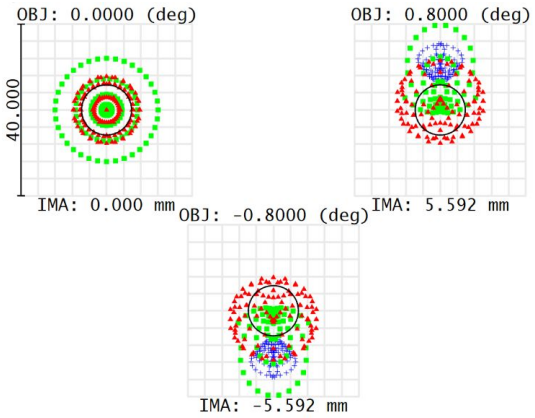
Lens

	Surface Type		Comment	Radius	Thickness		Material
0	OBJECT	Standard		Infinity	Infinity		
1	(aper)	Standard	49289	227.160	8.000		N-BAK4
2	(aper)	Standard		-174.830	4.000		N-SF10
3	(aper)	Standard		-571.490	105.888	V	
4	STOP	Standard		Infinity	225.877	V	
5	(aper)	Standard		-51.600	3.500		N-BK7
6	(aper)	Standard		Infinity	0.000	V	
7		Standard		Infinity	11.930		
8	IMAGE	Standard		Infinity	-		

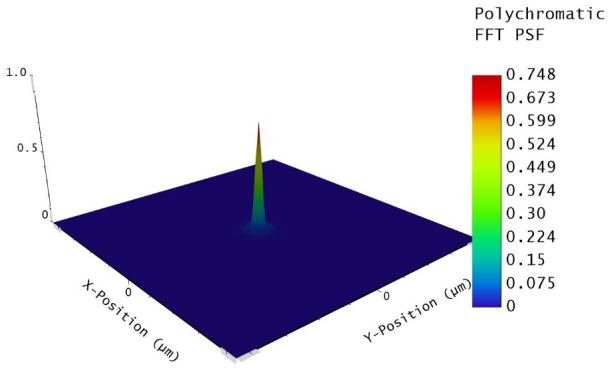
Prescription Data

```
Effective Focal Length   :        400.000X
Effective Focal Length   :        400.000X
Back Focal Length        :         11.952X
Total Track              :        359.195
Image Space F/#          :        8.163XXX
Paraxial Working F/#     :        8.163XXX
Working F/#              :        8.149XXX
Image Space NA           :      0.061XXXXX
```

Spot Diagram

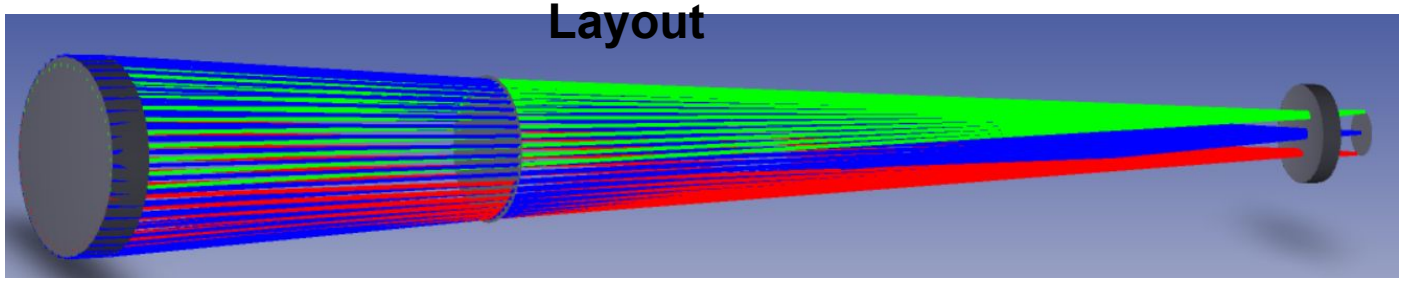


PSF



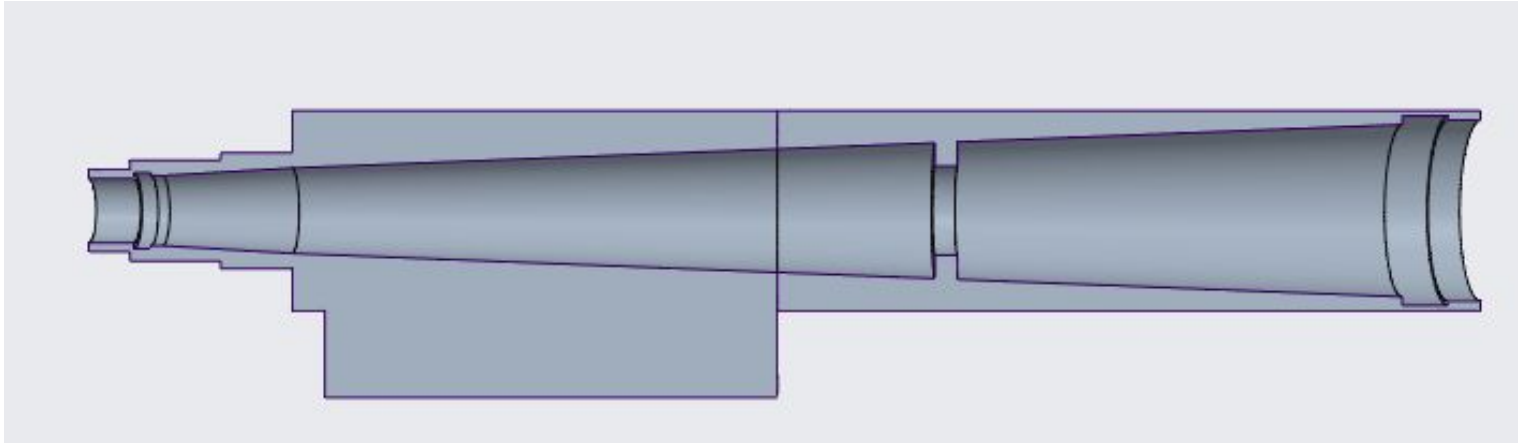
Optical System Hardware Design

3D Lens Layout



Lens Housing Design

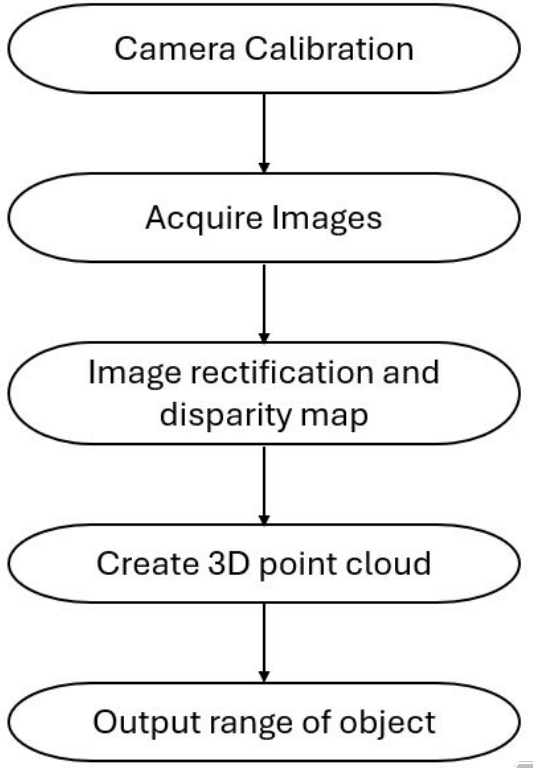
Total track from front of 1st surface to image



Field Stop
~118mm

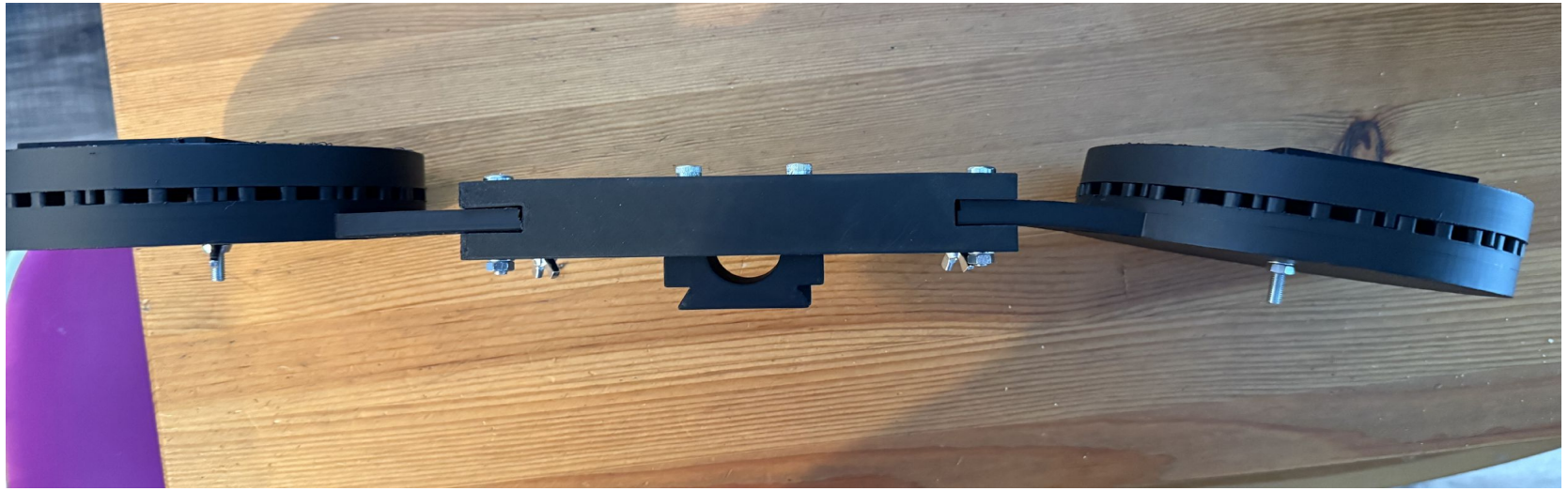
Software: Initial Design

- MATLAB Stereo Camera Calibrator App
  - Provides necessary intrinsic properties of stereo camera system
  - Allows for use of stereo vision-based functions in MATLAB for desired image processing
- MATLAB stereo image acquisition
- MATLAB Image processing using stereo camera intrinsic parameters



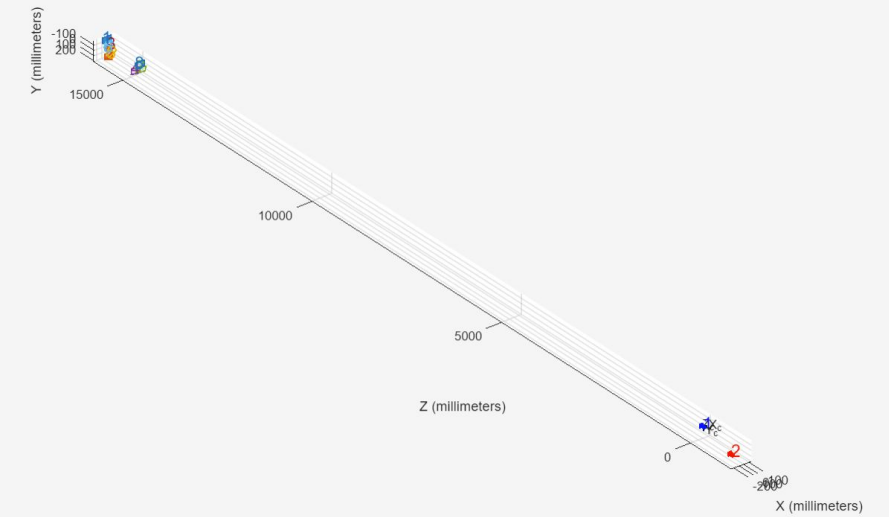
Prototyping and Testing (Failures)

Original Camera Mount



- 3D Printed plastics and Florida summer heat do not mix
- Required fundamental redesign and shortening of baseline distance between cameras

Prototyping and Testing (Failures)



- MATLAB Stereo Camera Calibration App was not able to create a usable calibration file the extrinsic and intrinsic parameters of the stereo camera system to use computer vision algorithms for depth sensing
- Calibration files introduced distortion and could not map calibration images accurately to create calibration file

Distorted Disparity Image

Prototyping and Testing (Software)

- MATLAB was unable to communicate and stream video for image capture and would frequently freeze
- OpenCV was used instead for video streaming to aim system on target and acquire stereo images. OpenCV was able to stream and acquire images in VGA and 720p resolutions
- MATLAB was then used to complete image processing using disparity using calculations vs. computer vision algorithms

Prototyping and Testing (Imaging)

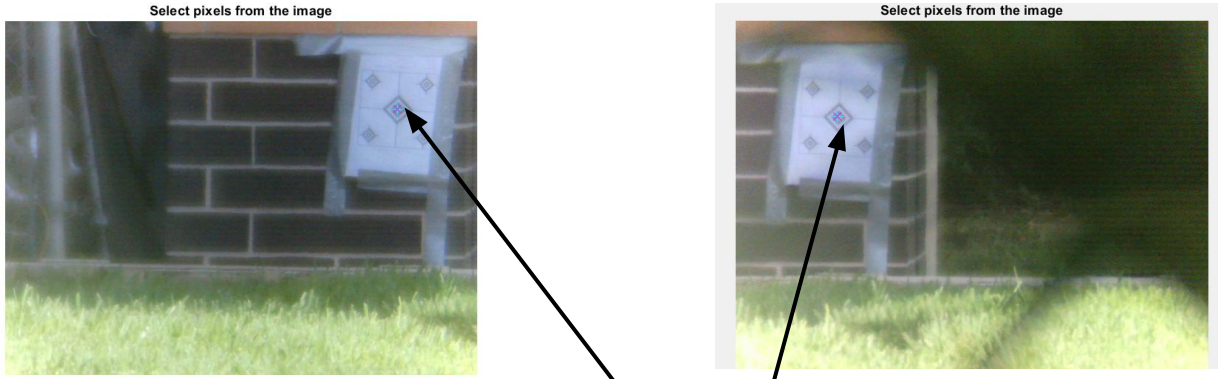
Stereo Images at ~ 110m

Stereo Images at ~ 100m

Image Resolution 640x480 (VGA)

Prototyping and Testing (Depth Estimation)

- Disparity determined using manual selection of pixel in image



$Disparity = xL - xR$ (pixel location on x axis)

Depth Estimation calculation

$$z = \frac{focal\ length * baseline}{disparity}$$

Final Testing

Actual distance to target (meters)	Estimated depth via calculation using disparity determined by manual pixel selection (meters)
110	27m
110	27.07
110	27.1
110	27.05
110	27
110	27.06
110	27.08
110	27.02
110	27.11
110	27.07

Budget

Item	Number	Cost per item	Total cost
ELP Camera	x2	$91.80	$183.60
350mm focal length Achromatic doublet lens	x2	$186	$372
-100mm focal length lens	x2	$45	$90
Manual Focuser	X2	$25	$50
Focuser to camera mount	x2	$10	$20
ABS/PETG plastic filament	x4	$20	$80
		Total Cost	$795.60