VR/AR Camera
Design Description Document

Barry Magenya (Project Coordinator)
Mike Brunsman (Customer Liaison)
Mitch Soufleris (Scribe)

Customer: Raptor Vision LLC
Faculty Advisor: Aaron Michalko

Document Number 001

Revisions Level	Date
F	2 May 2018

This is a computer-generated document. The electronic master is the official revision. Paper copies are for

Authentication Block

reference only. Paper copies may be authenticated for specifically stated purposes in the authentication block.

Rev	Description	Date	Authorization
A	Initial DDD	January 23, 2018	All
B	Revision	February 6, 2018	All
C	Revision	February 20, 2018	All
D	Midterm Review Revision	March 1, 2018	All
E	Revision	April 9, 2018	All
F	Final Revision	May 2, 2018	All

TABLE OF CONTENTS

OVERVIEW 4
VISION 4
SYSTEM COMPONENTS 4
TRIAL AND ERROR 5
INITIAL RESULTS 6
FINAL TEST SET-UP 7
TESTING PROTOCOL 8
TEST RESULTS 9
TIMELINE 14
HAJIM DESIGN DAY 14
APPENDIX 15

OVERVIEW

The customer, Raptor Vision LLC, has provided a commercially available fisheye camera lens with 280° field of view for experimentation. While Raptor Vision has developed dewarping software to stream video from this lens rectilinearly, they still do not produce their own lenses. Various tests will be performed and will aim to provide Raptor Vision with information that will eventually contribute to the development of their own, in-house fisheye optic(s) with an even wider field of view. All resources and assistance are provided by Raptor Vision employees James Francis (Chief Executive Officer), Magnus Jansson (Chief Technologist), and Oleksandr Lysenko (Computer Vision Engineer), along with our faculty advisor, Aaron Michalko.

VISION

The project vision is for an application-specific, field-varying resolution classification of the fisheye camera lens for use in a VR/AR video streaming system. Because Raptor Vision's desired camera system will be placed in a wide variety of venues across the globe (sports, music, entertainment, etc.), each application will have its own set of resolution requirements. This information will be very helpful to the customer as they begin to design and prototype their own optic(s). Eventually, the project will hopefully include a video demonstration of these different applications and how different variations of resolution across the field can provide unique viewing experiences for the user.

SYSTEM COMPONENTS

From left to right: Entaniya fisheye lens with 280° field of view, Pixelink PL-E533CU camera and circuit board and sensor used for our setup.

The Pixelink camera was a gift from Navitar. Inside, the circuit board and sensor are easily detachable. These parts were removed and the naked circuit board was used in our eventual final set-up.

Part	Company	Product Number	Quantity	Cost
4k+ Camera	Yi	Yi Technologies	1	359.98
Backbone ribcage mod kit	Andorama Camera	BBRCY4K	1	122.53
			Total Cost	482.51

Above is a cost breakdown of the parts. The lens is not included because Raptor Vision provided it to us for free.

The camera and mod kit were bought as parts of the original set up. They did not end up working out for our experiment, so they became part of the trial and error process described below. We eventually only ended up using the lens and the Pixelink camera, which were both gifted to us. It is unfortunate the purchased pieces were not put to use in the end, but they were still a very important part of our overall scientific process.

TRIAL AND ERROR

Trial 1: Yi 4K+ Camera

Originally, the group bought a 4K camera to capture images with the lens. Unfortunately, the lens was not compatible with the camera mount, and needed a modification kit.

Trial 2: Ribcage

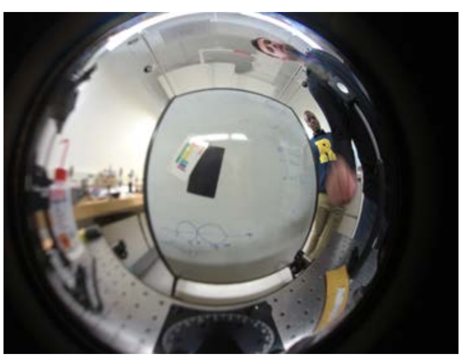
The Backbone ribcage modification kit was extremely difficult to implement. The whole camera needed to be ripped apart and put back together with a combination of backbone parts and some of the Yi parts. Eventually, we were able to get it done and see an image. However, while we were gluing the sensor back into the place, there was a slight misalignment. So, the image was blurry on one side causing an image-plane tilt, and there was no way to go back and fix it because we would not be able to see real-time images (to check if the blur was gone) while it was being taken apart.

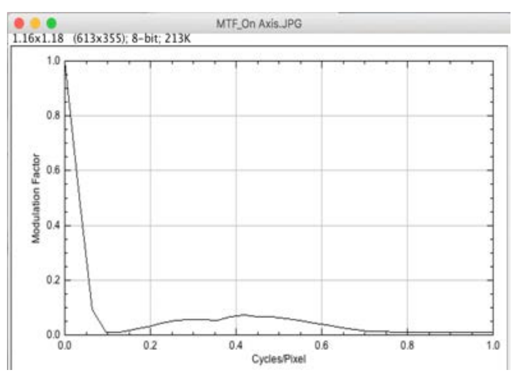
Examples of failed experimental set-ups. On the right is an image of the group implementing the BACKBONE Ribcage. On the right is the camera and lens together once the Ribcage was implemented.

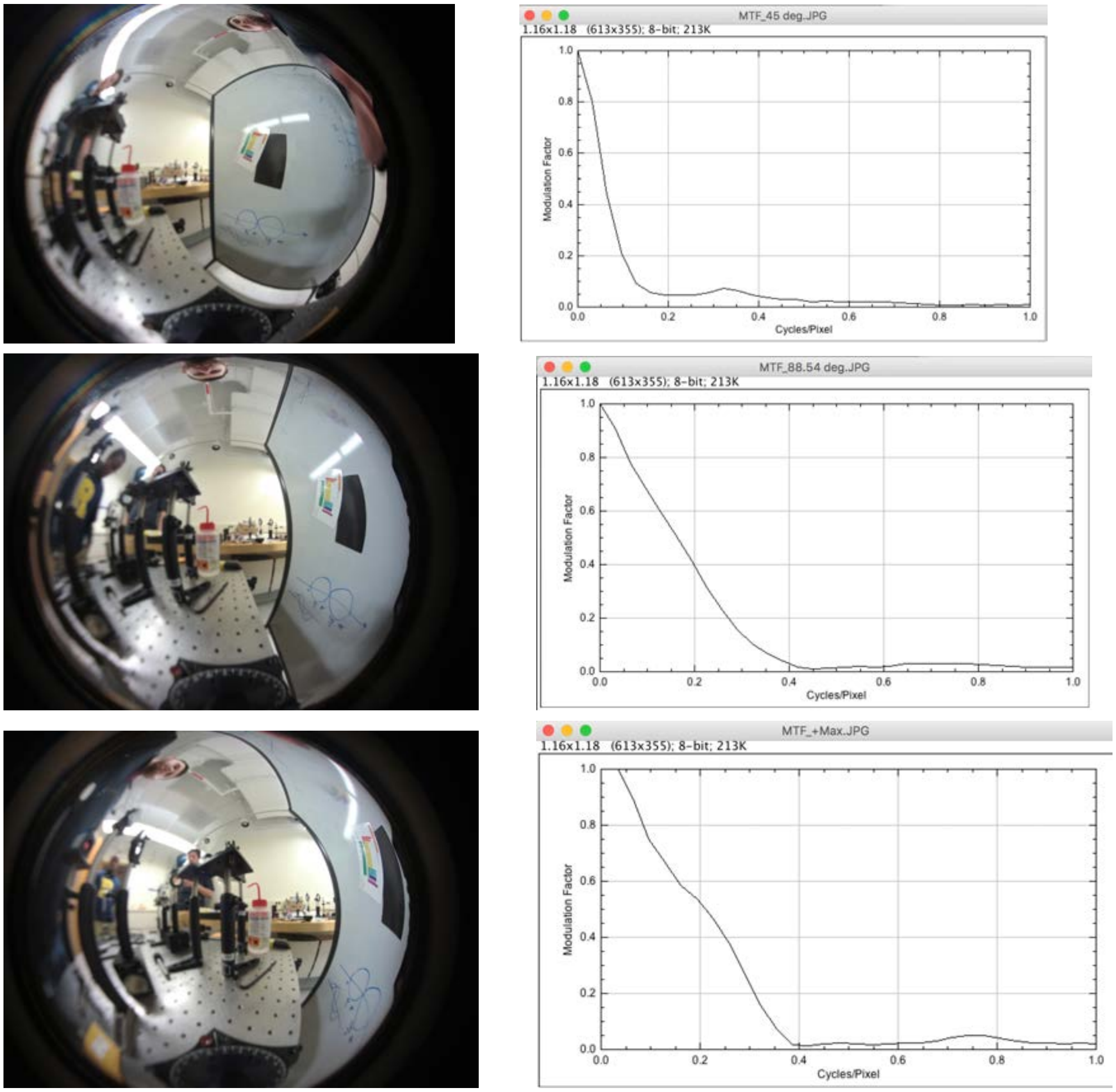
Trial 3: Tip/Tilt Stages

In order to attempt to align the lens and sensor manually, they were placed on separate tip/tilt stages. The hope was that by stripping away some of the plastic on the camera, the lens could be moved close enough to the sensor to “simulate” being screwed in. But, this time, we could tilt the lens to offset the effect of the misaligned sensor. Unfortunately (once again) the lens could still not get close enough to the sensor to form usable images.

INITIAL RESULTS



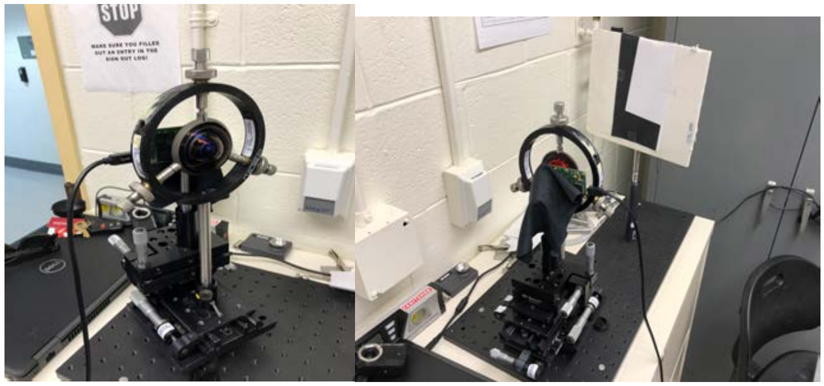




Images and slanted-edge MTF results for angles of (top to bottom): On axis, 45°, 88.54°, and 132° with camera and lens attached.

These images were taken when the camera and lens were screwed together with the Ribcage. As you can see, there is an extreme blur on the left side of all of the images. This was very disappointing, because we actually got some very good results on the right side. But, we eventually had to move on to another set up in order to see the entire field without any blur.

FINAL TEST SET-UP



Front and Back views of final test set-up

Above is the test set-up that is being used. The Entaniya fisheye lens is mounted in a 3-jaw mount, with Teflon tape on each jaw so it can safely be in contact with the metal rim of the lens. The sensor is mounted on a clamp upon a stage that can tilt and move in the y and z directions. The lens will be rotated in the "theta" dimension by hand within this mount. This lens structure is stemming from the stage that can move in the Z direction. The height was adjusted by manually moving the sensor or the lens. The target was in the shape of an L which was rotated by 10 degrees. A black cloth was placed around the sensor in order to minimize stray light.

TEST PROTOCOL

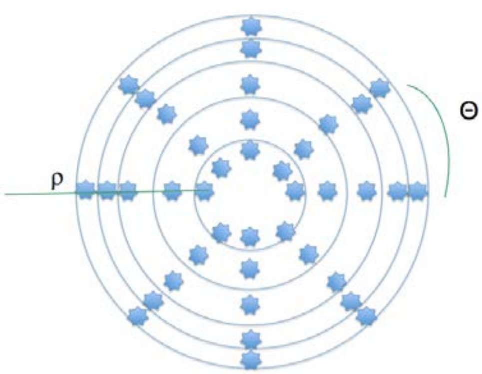
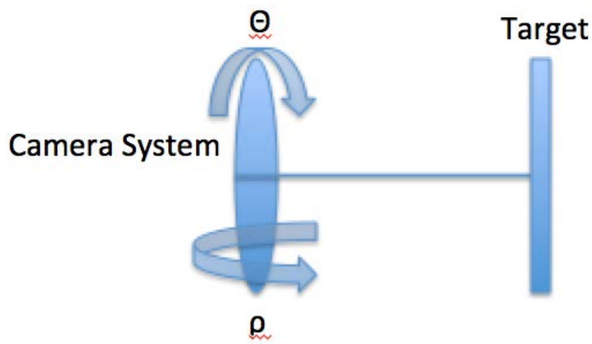


Diagram of measurements across field and angles at which measurements will be taken

r_1	0
r_2	45
r_3	54
r_4	75
r_5	87
r_6	120



A basic visualization of the two rotations that will be made during test

To test the optic, the team must investigate the entire FOV. We will rotate the lens around an L shaped target and carry out slanted edge MTF tests at various points in the field. The team plans on recording resolution data across the entire FOV at specific locations. These locations will not be placed linearly, but rather in equally weighted circles around the field, which will allow for an equally weighted view of the field. We plan to take 11 rho rotation measurements at the angles defined in the table below across 8 symmetrical theta rotations every 45° as seen in the figure below. This calls for 88 total measurements.

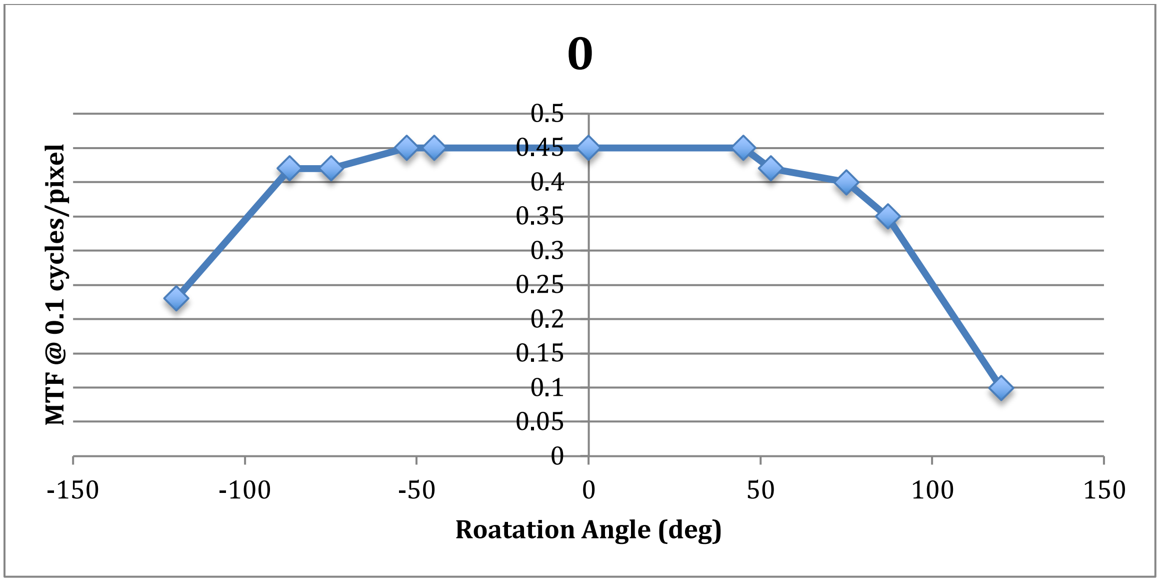
TEST RESULTS

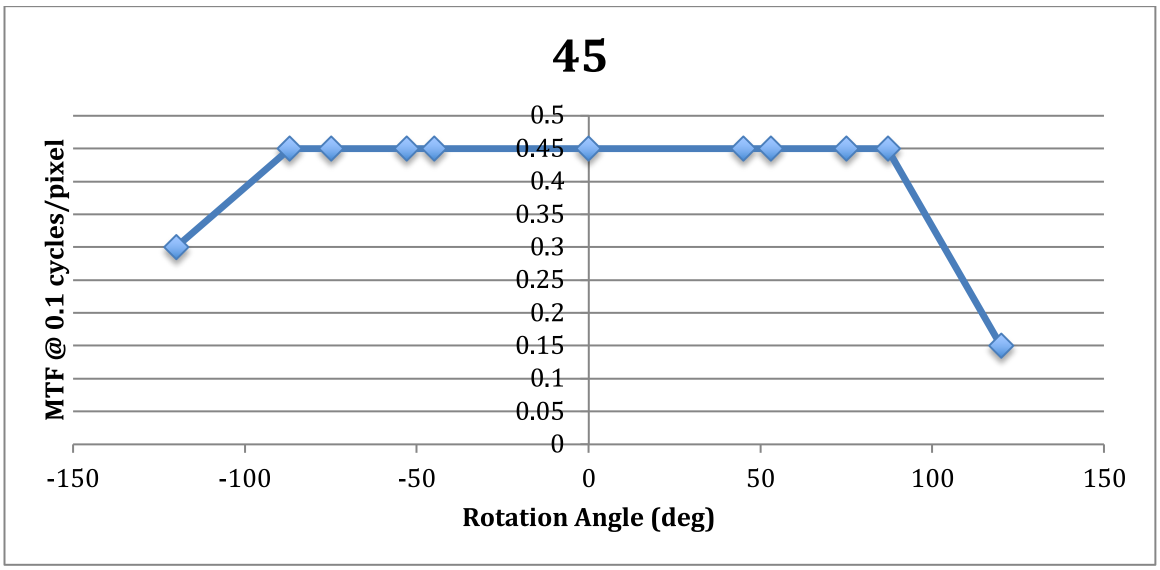
After all of the photos had been taken and the MTF's run, each MTF chart was read at 0.1 cycles/pixel. This allowed the team to get a good understanding of the performance of the lens where the customer may be imaging an object.

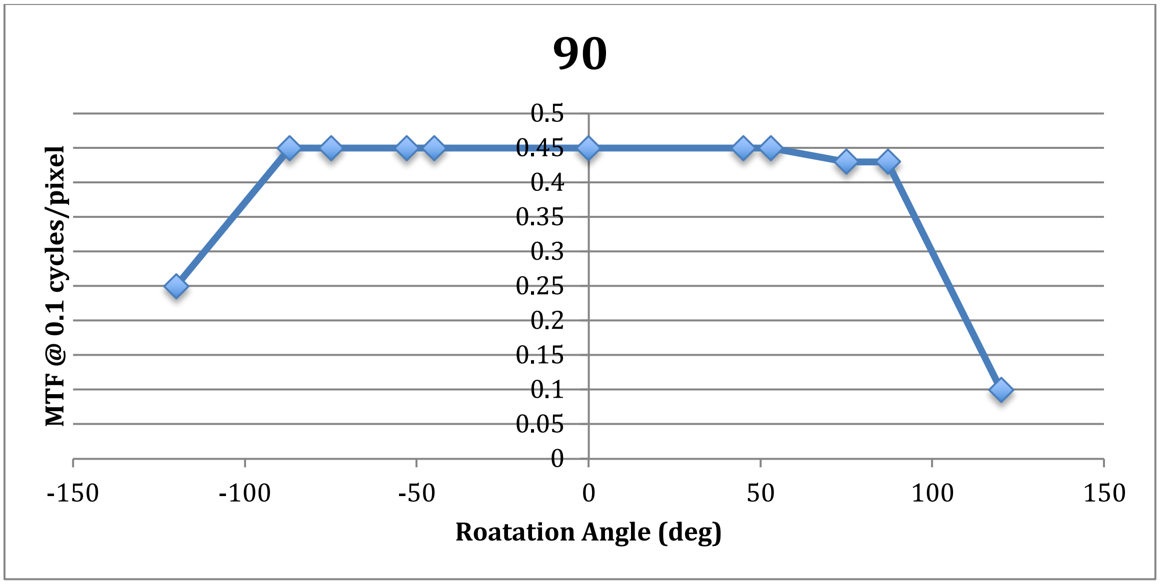
0	**MTF @ 0.1 cycles/pixel**	**45**	**MTF @ 0.1 cycles/pixel**	**90**	**MTF @ 0.1 cycles/pixel**	**135**	**MTF @ 0.1 cycles/pixel**
-120	0.23	**-120**	0.3	**-120**	0.25	**-120**	0.25
-87	0.42	**-87**	0.45	**-87**	0.45	**-87**	0.5
-75	0.42	**-75**	0.45	**-75**	0.45	**-75**	0.45
-53	0.45	**-53**	0.45	**-53**	0.45	**-53**	0.45
-45	0.45	**-45**	0.45	**-45**	0.45	**-45**	0.45
0	0.45	**0**	0.45	**0**	0.45	**0**	0.45
45	0.45	**45**	0.45	**45**	0.45	**45**	0.45
53	0.42	**53**	0.45	**53**	0.45	**53**	0.45

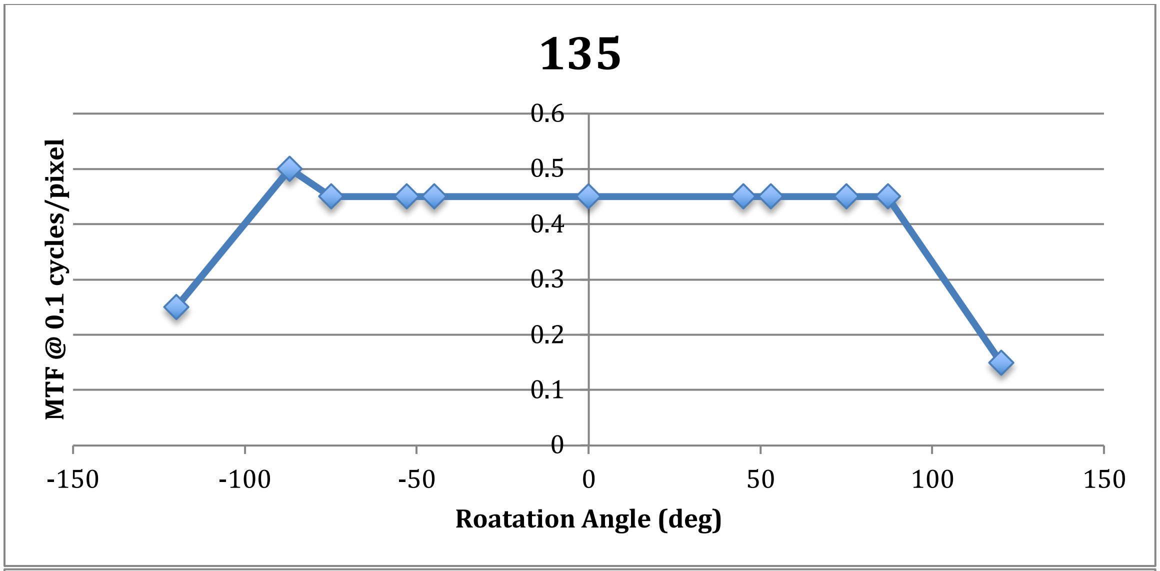
75	0.4	**75**	0.45	**75**	0.43	**75**	0.45
87	0.35	**87**	0.45	**87**	0.43	**87**	0.45
120	0.1	**120**	0.15	**120**	0.1	**120**	0.15
180	**MTF @ 0.1 cycles/pixel**	**225**	**MTF @ 0.1 cycles/pixel**	**270**	**MTF @ 0.1 cycles/pixel**	**360**	**MTF @ 0.1 cycles/pixel**
-120	0.25	**-120**	0.2	**-120**	0.25	**-120**	0.2
-87	0.48	**-87**	0.45	**-87**	0.45	**-87**	0.45
-75	0.45	**-75**	0.45	**-75**	0.45	**-75**	0.45
-53	0.45	**-53**	0.45	**-53**	0.45	**-53**	0.45
-45	0.45	**-45**	0.45	**-45**	0.45	**-45**	0.45
0	0.45	**0**	0.45	**0**	0.45	**0**	0.45
45	0.45	**45**	0.45	**45**	0.45	**45**	0.45
53	0.45	**53**	0.45	**53**	0.45	**53**	0.45
75	0.45	**75**	0.45	**75**	0.45	**75**	0.45
87	0.45	**87**	0.42	**87**	0.45	**87**	0.43
120	0.15	**120**	0.15	**120**	0.15	**120**	0.1

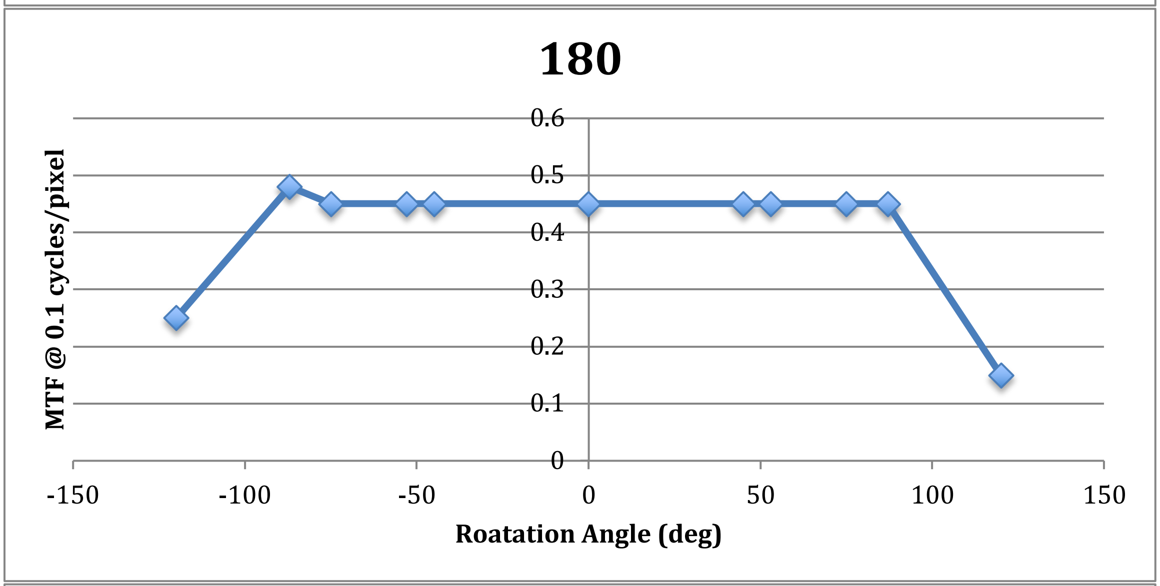
After these measurements had been read, a plot was created to understand the resolution as a function of the place in the FOV. These plots can be seen below for each theta measurement of the lens.

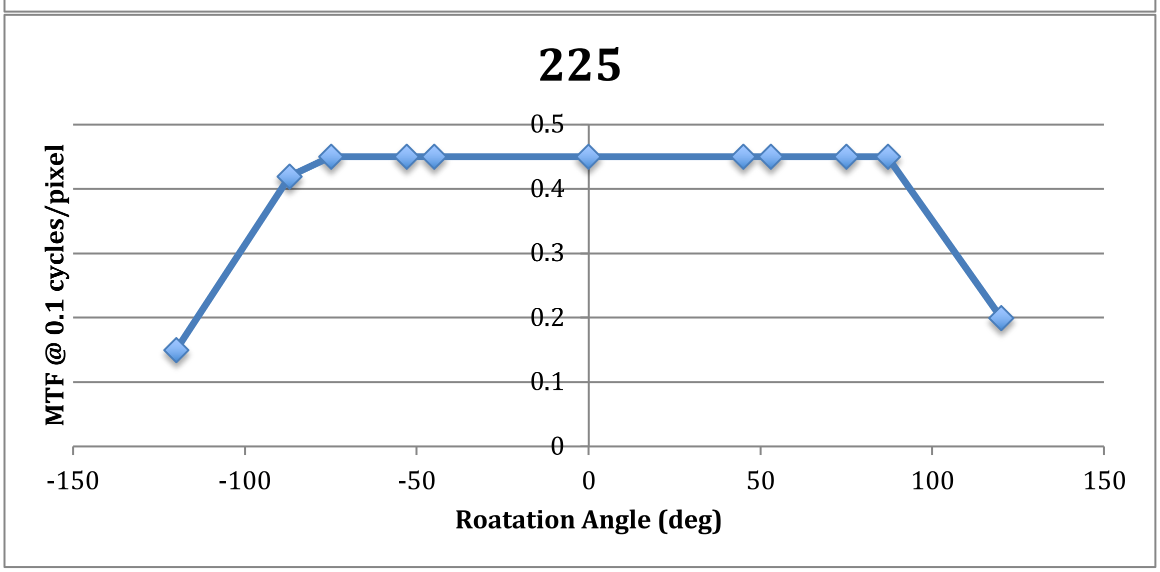

0
MTF @ 0.1 cycles/pixel
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-150
-100
-50
0
50
100
150
Roatation Angle (deg)

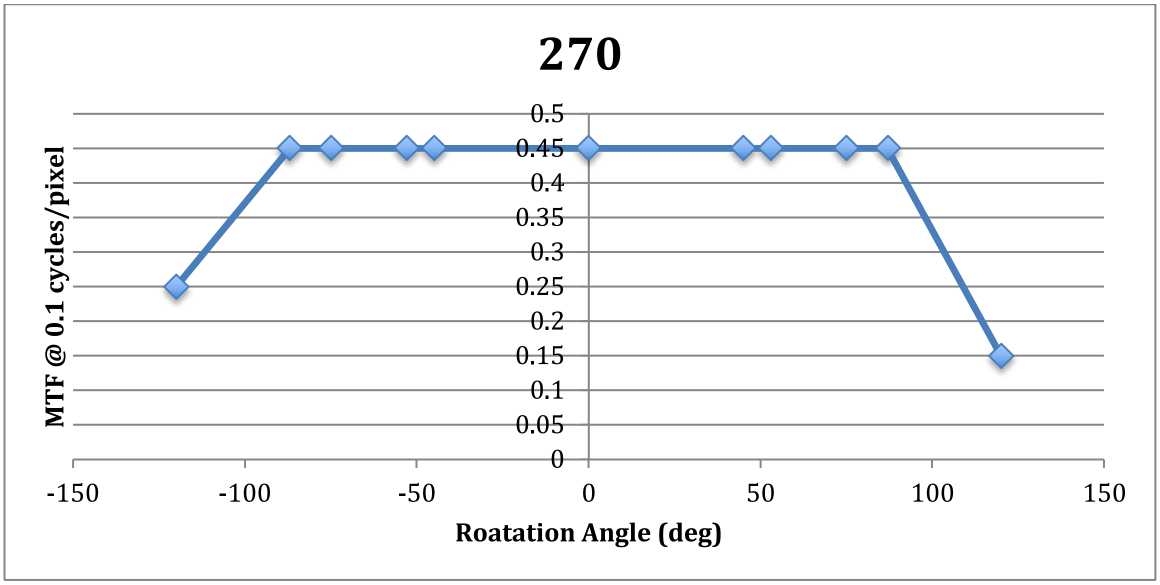

45
MTF @ 0.1 cycles/pixel
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-150
-100
-50
0
50
100
150
Rotation Angle (deg)

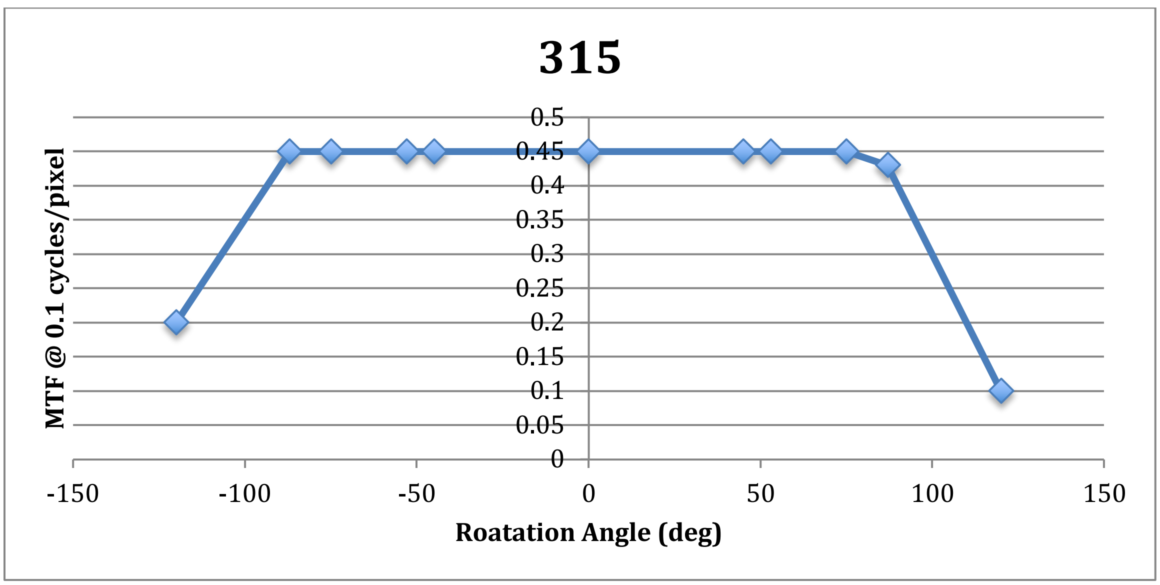

90
MTF @ 0.1 cycles/pixel
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-150
-100
-50
0
50
100
150
Roatation Angle (deg)


135
MTF @ 0.1 cycles/pixel
0.6
0.5
0.4
0.3
0.2
0.1
0
-150
-100
-50
0
50
100
150
Roatation Angle (deg)


180
MTF @ 0.1 cycles/pixel
0.6
0.5
0.4
0.3
0.2
0.1
0
-150
-100
-50
0
50
100
150
Roatation Angle (deg)


225
MTF @ 0.1 cycles/pixel
0.5
0.4
0.3
0.2
0.1
0
-150
-100
-50
0
50
100
150
Roatation Angle (deg)





As expected, the lens performed worse at the edges of the field than towards the middle. Overall, the lens had consistent performance out until 87 deg. Unfortunately, due to the constraints of the mount of the lens, no information was available from 87-120 deg. This eliminated a valuable location where we could have further understood the decay of the resolution.

TIMELINE

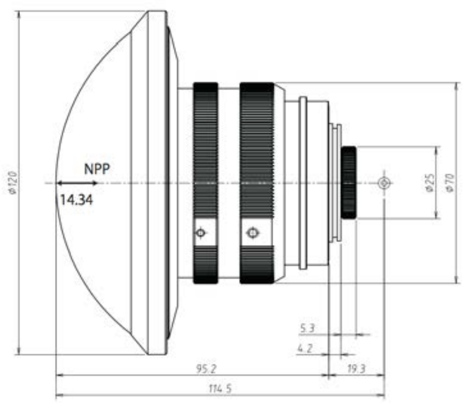
Month	February				March				April				May
Task / Week	1	2	3	4	1	2	3	4	1	2	3	4	1
Prepare Setup	■	■	■	■	■								
Record Images				■	■	■							
Process data					■	■	■	■					
Create data map						■	■	■	■				
Examine details in regions of interest							■	■	■	■			
Relate results to real-life applications								■	■	■			
Make video representations of data									■	■	■		
Make videos of applications									■	■	■	■	
Create conclusive Report											■	■	
Design day													■

HAJIM DESIGN DAY

For Design Day, the group will have the camera and lens on display for people to see. Resolution plots across the field of the camera will be shown. The images and videos we take will be shown on a screen, both with and without the de-warping software. We are coordinating with Magnus to get the images dewarped.

APPENDIX

Entaniya fisheye lens specifications



Field of view	280 degrees
Focal length	1.07 mm
Aperature ratio	F/2.8
Lenses	12 Element Glass
Lens	ED x 1 SHR x 3
Projections	Equisolid angle
Mechanical back	2.42 mm
Image circle (h x v)	diameter：4.2mm： （280°×280°） 1/2.3-inch sensor：280°× 280°
Weight	175g

Image height

Angle of view in degrees	Image height in mm	Angle of view in degrees	Image height in mm
0.00	0.0000	77.00	1.33
7.00	0.13	84.00	1.43
14.00	0.25	91.00	1.54
21.00	0.385	98.00	1.63
28.00	0.50	105.00	1.73
35.00	0.63	112.00	1.81
42.00	0.75	119.00	1.89
49.00	0.87	126.00	1.95
56.00	0.99	133.00	2.01
63.00	1.10	140.00	2.04
70.00	1.22		

Yi 4K+ camera specifications

Stills	12 MP
Sensor	IMX377
chipset	**Ambarella H2**
waterproof	with case
4K max FPS	**60fps**
2.7K max FPS	60fps
1080 max FPS	120fps
720 max FPS	240fps

Bitrate	**max. 120 Mbps**
stills format	RAW
Display	2.19"
Battery	1400 mAh
Image Stabilization:	**up to 4K 30fps**

Also includes: Wi-Fi, Bluetooth, SD card(max 128GB) and voice control

Pixelink Camera Specifications

Specifications

Interface	USB 2.0
Sensor Model	Aptina MT9T001
Color Space	Color
Resolution (MP)	2048 x 1536 (3.0MP)
Bit Depth	10-bit, 8-bit
Pixel Pitch (μm)	3.2μm
Optical Format	1/2"
Sensor Diagonal	8.19 mm
Lens Mount	C-Mount, CS-Mount
Frame Rate (FPS at Full Resolution)	12
Sensor Type	CMOS

Shutter Type	Rolling