3D Plenoptic Microscope System

Product Requirement Document

3D Team: Nightingale

Team members:

Nicholas Montifiore – Team Coordinator

Zirui Zang – Customer Liaison

Xinran Li – Technology Researcher and Scribe

Jinyu Han – Document Handler

Customer:

NAVITAR

Russ Hudyma – CTO

Dr. Ian Wallhead – Staff Scientist

Faculty Adviser:

Professor James Fienup, Institute of Opticss

Revision History:

1. Nov 7th, 2016. First draft.
2. Nov 7th, 2016.
    - Specifications for System
    - Vision
    - System Layout and Design Appearance Expectation
3. Nov 27th, 2016. Third Draft.
    - Update Specifications for Objective
    - Environmental Requirements
4. Dec 4th, 2016. Fourth Draft
    - Timeline
    - Responsibilities
    - Appendixes
5. Dec 17th, 2016. Final Draft
    - Finalize specification table
    - Finish appendix
    - Final revisions and editing

Table of Contents:

Introduction:

Light-field (plenoptic) cameras can capture both spatial and angular information, which can be reconstructed to form an image with depth information using additional software. Since a single capture is sufficient, a plenoptic camera requires less time to capture 3D images than a traditional, manual approach. This makes a plenoptic camera suitable for industrial inspection.

This senior design project is a collaboration with Navitar, Inc., a manufacturer of optical systems who focuses on designing, developing, manufacturing and distributing precision optical solutions across the globe.

Vision:

Project Nightingale is an apochromatic, plenoptic microscope with high-resolution 3D reconstruction capabilities and a long working distance. One application of this plenoptic camera is the inspection of microelectronic components on assembly lines. To serve this purpose, this plenoptic system will consist of five components: an objective lens, a tube lens, a relay stage, a micro-lens array, and a sensor, as illustrated in Figure 4.

Operating Environment:

As an industrial inspection device, the system needs to survive in -40 °C to 70 °C and operate at room temperature with no significant change in performance across normal room temperatures.

Specifications:

A. System Specifications Table:

Magnification	1x or 2x
Wavelength	450nm, 550nm, 650nm
Working distance	90 mm
Field of View	8mm diagonal object space
Total Length	415 mm
Objective F/#	10 (1x) 5 (2x)
Imager Format	1” (4K compatible)
Number of pixels	4096 x 2160
Sensor size	14.13 x 7.51 mm
Pixel size	3.45 µm
Image Circle (nominal)	16 mm diameter
Distortion	<0.25%
Relative Illumination	>85%
Design MTF	>40% across field at 72.5 lp/mm (1x) or at 145 lp/mm (2x)
Telecentricity	Yes, in sensor space
IR Filter	Included
Plenoptic Type	Plenoptic 1.0 (pupil relay type)
Plenoptic Micro Lens Array	Details in Following Content
Other Requirements	1. 2 surfaces ghost image analysis. No ghost images on image plane 2. Aperture locates 4mm after objective lens

B. Objective Lens Specifications Table:

Maximum (Preferably) Incident Angle	38° (30°)
For 1x Configuration	
Object Maximum Space Field	8mm
Object Space Aperture	f/10
Object Space Resolution	72.5 lp/mm
For 2x Configuration	
Object Maximum Space Field	4mm
Object Space Aperture	f/5
Object Space Resolution	145 lp/mm

C. Afocal Relay Specification Table:

Overall Length	100mm
Magnification	1x

D. Tube Lens Requirements:

The tube lens must be an off the shelf doublet from Edmund Optics or another appropriate vendor. The effective focal length of the tube lens is dependent on the system magnification and the effective focal length of the objective lens. If the system magnification is 1x, the focal length of the tube lens will be the same as the focal length of the objective, and if the system magnification is 2x, the focal length of the tube lens will be twice the focal length of the objective.

E. Micro Lens Array Requirements:

The micro lens array is required to be an off the shelf product from Edmund Optics or another appropriate vender.

Figure 1: An example of a micro lens array from Edmund Optics[1].

F. Potential Camera Selection:

The camera is required to be an off the shelf product from Pixelink with a Sony CMOS IMX254 or IMX255 sensor package.

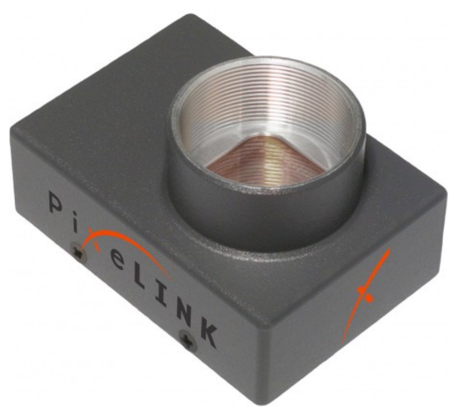


Figure 2: An example of a camera from Pixelink[2]

[1] Source: http://www.edmundoptics.com/optics/optical-lenses/fresnel-lenses/lenticular-arrays/2045/

[2] Source: http://www.pixelink.com/

Design Responsibilities:

We are responsible for:

1. Designing the lens system, as suggested by customer, consisting of an objective, a relay stage, and a tube lens.
    - Infinity corrected, apochromatic microscope objective with a working distance of 90mm.
    - A 1x afocal stage of 75-100mm length. This could be replaced with a zoom stage in future upgrades.
    - A telecentric tube lens system of approx. 200mm focal length. The actual focal length will need to be determined to achieve 2x magnification.
    - The above 3 sub-systems together form a stand-alone microscope inspection system.
2. Designing the plenoptical system, including selecting a suitable micro lens array and camera.

Desirable:

1. Testing the prototype
2. Generating 3D images using prototype
3. Analyzing the noise propagation through the system onto the reconstructed images

Not Responsible for:

1. Satisfying any mechanical design requirement. e.g. (3 ft. drop test)
2. Prototyping, including system alignment, enclosure design, system assembly etc.
3. Survival of humidity ranging from 0 to 100%

System Layout:

Figure 3. System Illustration. A current product that has a similar layout and dimensions as the product we are designing.

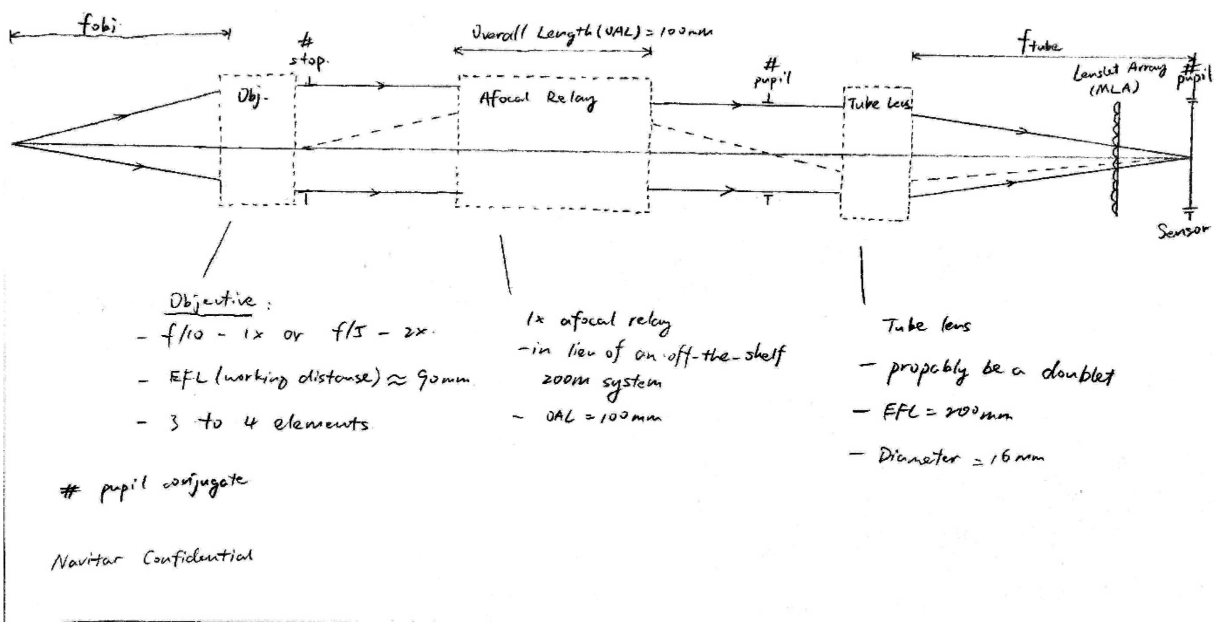


Figure 4. Plenoptic System Sketch.

Timeline:

Fall Semester:

December:

Finish Product Requirement Document.

Start preliminary design for objective lens, tube lens and relay stage.

Spring Semester:

January:

Continue working on preliminary design:

- Determine whether the system functions optimally at 1x or 2x.
- Work on reducing color aberrations.
- Put the entire system together and begin to optimize.

February:

Optimize the optical system.

Study the micro-lens array.

March:

Choose the proper micro-lens array.

Optimize the design of system as a whole with: objective lens, tube lens, relay stage, micro-lens array and sensor.

Tolerance and possible redesign if necessary.

April:

Prepare for final presentation for the class and to the customer.

Note:

If our team can finish the design of the system ahead of schedule, we will send the design to Navitar's rapid prototyping team, who will build the system in 2-5 weeks. During that time, we will work on designing an experiment to conduct with the finished product.

Appendix:

A. Lytro: A Study

Abstract

System designers, like Newton, stand on the shoulders of giants. As we were completing our designs for Nightingale objective and relay, we began to search for design references for the light-field part. Thanks to a generous loan of a Lytro from Professor Fienup, we decided to investigate the consumer light-field camera. We set up several experiments to evaluate its performance and read a few papers and patents related to its design. This report documents our findings with Lytro and suggests some possible starting points for our micro lens array design.

Background

Lytro is a consumer light-field camera that grew from Ren Ng's doctoral dissertation. We tested the first generation version released in 2012.

Figure A-1: Lytro Camera (First Generation)

Specifications[3]

Table A-1: Selected specifications of Lytro First Generation.

Name	Value
Focal Length	43 mm -- 344 mm
Zoom	8x optical
Aperture	Constant f/2.0
Sensor Type	CMOS
Light Field Resolution	11 megaray
Active Area	4.6 mm x 4.6 mm
2D Image Resolution	1080 px x 1080 px

Tests

Table A-2: The distances of the USAF-1951 targets. Target -2,1 is 14 mm wide.

Target	Distance (m)	Smallest Resolvable Target	Spatial Resolution (lp/mm)
1	0.60	0, 1	0.71
2	0.80	-1, 5	0.57
3	1.06	-1, 4	0.51
4	1.34	-1, 3	0.45

[3] Source: https://support.lytro.com/hc/en-us/articles/200863400

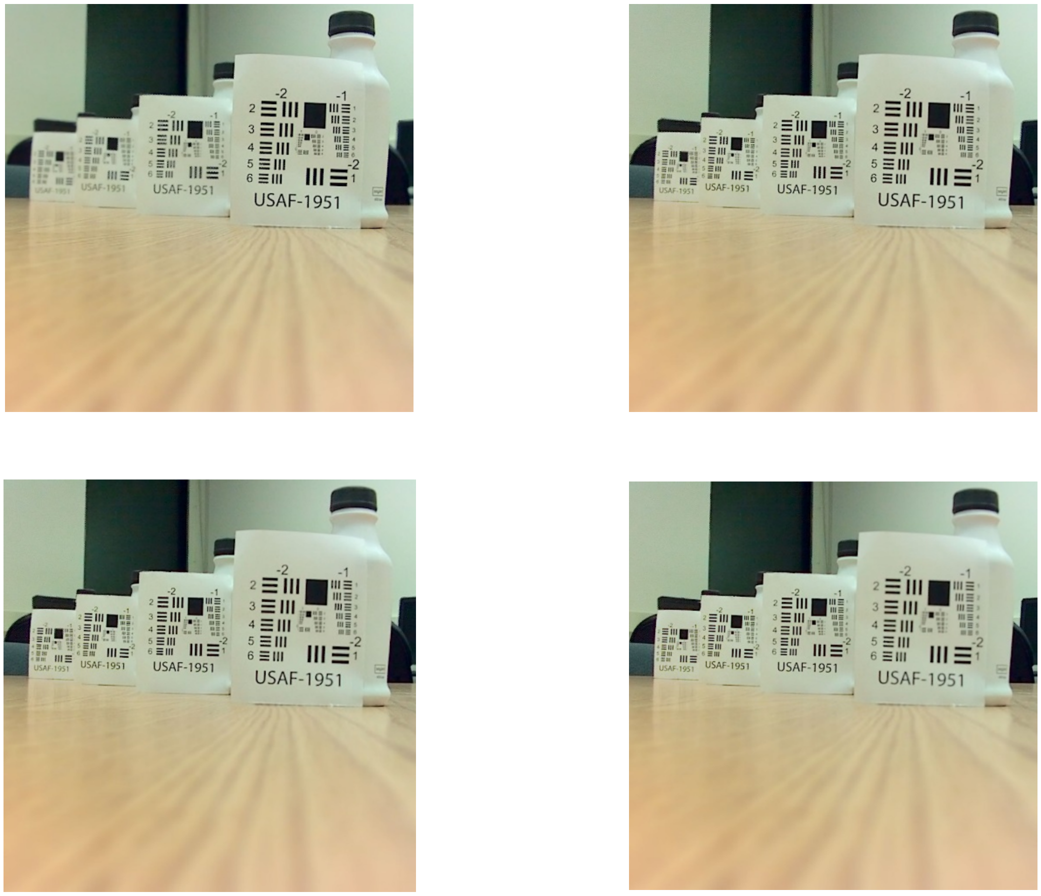


Figure A-2: Four 2D images generated from the light-field image. Each 2D image is focused on one of the four targets. The generated images simulate an aperture of f/2.0.

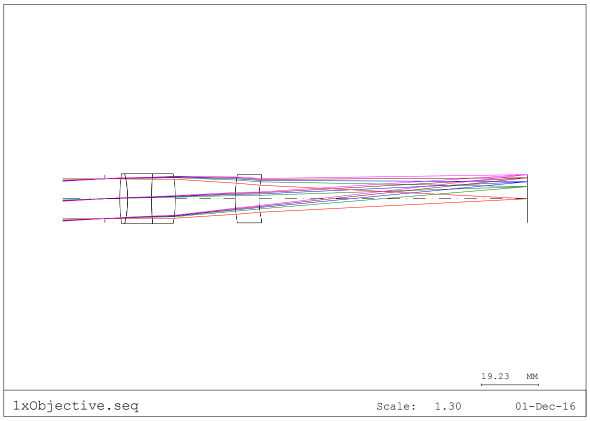
Figure A-3: Two 2D images generated with f/2.0 (left) and f/16.0 (right).

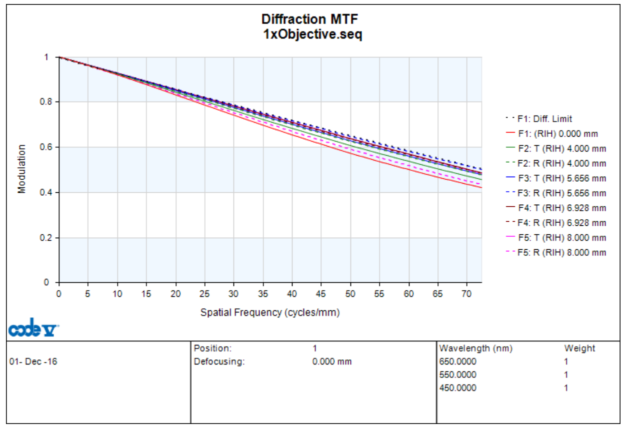
We tested the camera by capturing a scene with four USAF-1951 targets at various distances. With the 3D light-field image, the Lytro software generated five 2D images. Four of them were generated under f/2.0 configuration, each with focus on one target. The fifth image was generated under f/16.0.

The strength of Lytro appears to be its ability to generate images with various focuses with only one capture. This ability significantly reduces the time it takes to capture the scene. In an industrial setting, a faster camera with depth-mapping ability may increase its productivity.

B. Early Stage Design

Objective Design - F/10, System Mag: 1x

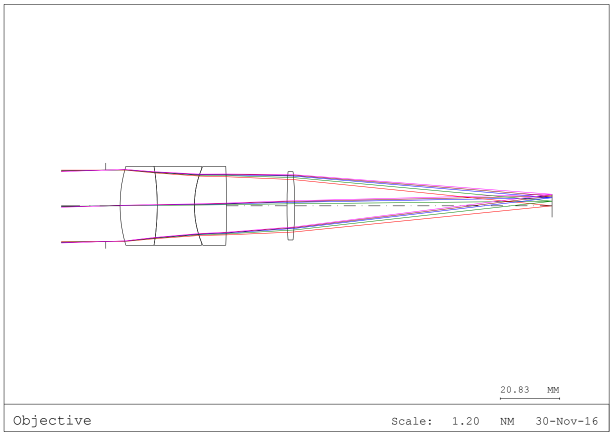


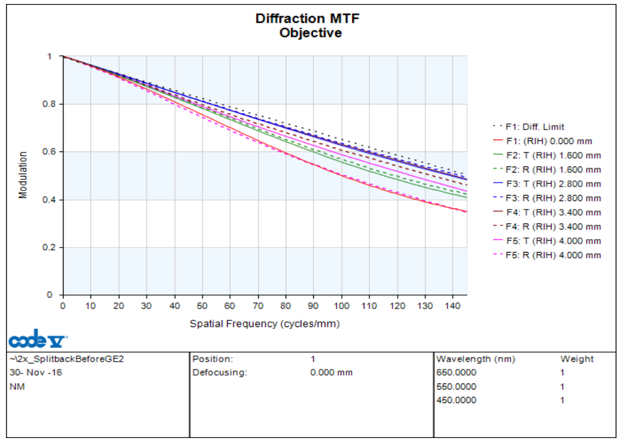


Surface #	Surface Name	Surface Type	Y Radius	Thickness	Glass	Refract Mode	Y Semi-Aperture
Object		Sphere	Infinity	Infinity		Refract	O
Stop		Sphere	Infinity	5.0000		Refract	6.6121 O
2		Sphere	53.6916	2.6544	K7_SCHOTT	Refract	6.9416 O
3		Sphere	-34.5198	8.0000	NLAK33B_S	Refract	6.9349 O
4		Sphere	87.1941	8.0000	NPK52A_SC	Refract	7.1571 O
5		Sphere	-48.6689	20.0811		Refract	7.4661 O
6		Sphere	43.0276	8.0000	NFK58_SCH	Refract	7.2048 O
7		Sphere	30.0531	90.0000		Refract	6.7035 O
Image		Sphere	Infinity	0.0000		Refract	8.0008 O

This is an example of a preliminary objective design for a system with a system magnification of 1x. The design meets the image quality requirements defined in the specification section of this document.

Objective Design - F/5, System mag: 2x





Surface #	Surface Name	Surface Type	Y Radius	Thickness	Glass	Refract Mode	Y Semi-Aperture
Object		Sphere	Infinity	Infinity		Refract	O
Stop		Sphere	Infinity	5.0000		Refract	12.3845 O
2		Sphere	47.5076 V	13.0000 V	NBAK2_SCH	Refract	12.6011 O
3		Sphere	-83.9881 V	13.0000 V	NLAK8_SCH	Refract	11.8136 O
4		Sphere	33.6644 V	11.2295 V	CAFL_SPEC	Refract	10.9834 O
5		Sphere	-383.4872 V	21.1711 V		Refract	11.0184 O
6		Sphere	202.4601 V	2.7037 V	NFK58_SCH	Refract	10.8658 O
7		Sphere	-114.7029 V	90.0000		Refract	10.8246 O
Image		Sphere	Infinity	0.0000		Refract	4.0013 O

This is an example of a preliminary objective design for a system with a system magnification of 2x. The design nearly meets the image quality requirements defined in the specification section of this document.