Design and Fabrication of a Stereoscopic Rear-Viewing Endoscopic TooL (MARVEL)

Andrew Strongrich*

Student Intern, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA

August 6, 2012

Abstract

The use of minimally invasive neurosurgical techniques has experienced a growing interest among patients and surgeons alike due their the numerous advantages over more traditional operations. Current methods employ the use either rigid or articulating endoscopes, both of which are inserted through a small diameter opening in the skull near the intended surgical region. Although these devices aid the surgeon in viewing the operating site, they are severely limited by their inability to provide dimensional awareness to the user. The Multi-Angle Rear-Viewing Endoscopic TooL (MARVEL) has been designed such that the compact form of existing endoscopes is maintained while also providing the user with an enhanced 3-dimensional stereo view.

The design of the alpha prototype for MARVEL was completed over the course of three months. In parallel with development, the device's optics were characterized and several software programs were generated. Once assembled, MARVEL will hold many advantages over existing endoscopic tools. It is expected that the device will greatly outperform its traditional counterparts by both increasing safety and decreasing the duration of surgical procedures. After completion, the device will be demonstrated to the project sponsors at the Skull Base Institute where it will undergo full evaluation and a feasibility analysis.

1 Introduction

Modern advances in medical technology have lead to the increasing appeal of minimally invasive surgical techniques among both medical professionals and patients alike. Although the use of such methods has many advantages, these highly sensitive procedures are often difficult to perform due to both the constrained operating environment as well as the reduced dimensional awareness imposed by the imaging systems within the equipment itself. Although not all operations allow for the use of minimally invasive techniques, they are often advantageous when operating near the fluid-filled ventricle area of the brain such as the pituitary[2].

This report serves to document and describe the design and fabrication of a Multi-Angle Rear-Viewing Endoscopic TooL (MARVEL) as well as characterize the performance of the system as a whole. Included is the tool's design process, key performance parameters of its optical system, as well as the development of the software used to operate the device itself.

2 Background

The development of MARVEL is funded by Dr. Hrayr Shahinian at the Skull Base Institute (SBI) in Los Angeles, CA. The endoscopes currently in use at his facility have fixed-angle imaging systems, unable to articulate once attached to the device. Although simple, these configurations are highly inefficient, forcing the

*Funded by the Indiana Space Grant Consortium

user to completely remove the tool to manipulate the viewing angle. Further, these endoscopes only provide the user with a standard 2-dimensional representation of the surgical site, reducing the surgeon's spatial awareness while performing surgery. Although flexible endoscopes are currently used in many neurosurgical procedures, they are often quite bulky and do not possess stereo imaging capabilities.

In order to rectify the aforementioned limitations, a stereoscopic imaging system capable of 2-dimensional planar bending was proposed. MARVEL provides the user with both a full 3-dimensional view of the target area using only a single camera and lens combination as well as the ability to articulate the distal tip via a digital servo controller. These improvements serve to improve surgical efficiency and safety through decreased operation time as well as enhanced dimensional awareness.

2.1 Stereoscopic Effect

Traditionally, the method for simulating 3-dimensional images was performed using dual camera systems, much the same as human eyes. Due to the highly constrained dimensions of MARVEL however, such a system is simply not feasible due to the incredibly tight tolerances demanded from the lens elements[1]. To avoid these complications, the 3-dimensional imaging capabilities of MARVEL are produced using a dual-aperture Conjugate Multiband Bandpass Filter (CMBF) embedded in a single lens system. These apertures each admit only half of the visible spectrum, together ideally forming an image containing all wavelengths. A illustration showing this process can be seen below.

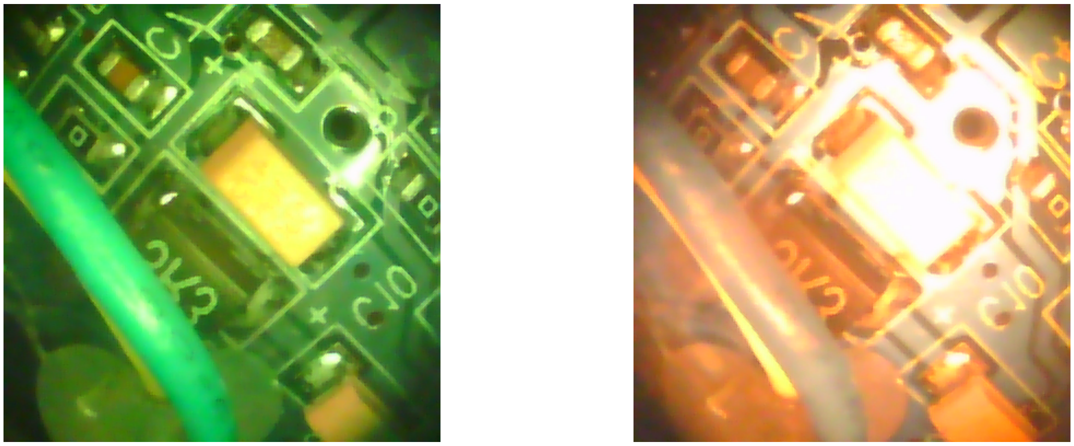
(a) Filter A

(b) Filter B

Figure 1: Dual aperture CMBFs

The wavelengths admitted by filter A fall in the ranges of 450-560 nm and 660-760 nm whereas filter B admits light between 360-450 nm and 560-660 nm. To ensure that no other wavelengths are leaking through the apertures, the fiber optic annulus which illuminates the target is attached to a DLP Light Commander that alternates between the passed wavelengths of each of the filters (i.e. within a sequence of two frames, the target will be illuminated with two different series of wavelengths. The first frame will contain wavelengths which are passed by filter A and blocked by filter B. Conversely, the second frame will contain wavelengths that are blocked by filter A and passed by filter B).

In the figure above, it can be seen that each filter only admits a portion of the visible spectrum but converges their respective light rays onto the same image plane. When the target is located precisely at the working distance of the lenses, the light passing through these apertures will completely overlap one another, forming a perfect image as though no aperture were present. As the target is moved away from the working distance (such as in the case of an object with raised features) however, the light passing through the filters will be bent in such a way that the two images are no longer aligned, producing a disparity, and ultimately, a stereo image. This feature allows 3-dimensional targets to appear in their natural dimensional state when viewed on a 2-dimensional surface such as a computer monitor. An example of such a series of images can be found below.



(a) Filter A (b) Filter B

Figure 2: Stereoscopic effect

Examining Figure 2, it can be seen that certain features of the two images are slightly offset, confirming the existence of a disparity. Overlapping these images and using a polarizer and special glasses will cause each eye to view only a single image, simulating human stereo vision and producing a 3-dimensional effect.

Although operating on principles slightly different than human vision, this method of stereoscopic depth perception has been shown by Bae et al. to produce the same effects as its dual camera counterpart without the added complexity. The use of CMBFs does not come without certain drawbacks however. In real-world applications, band-pass filters are far from ideal, admitting small amounts of unwanted light in the band-stop regions. Although this crosstalking can be minimized, to do so is often quite expensive.

Another limitation of the proposed filtering method is the requirement of apertures. In implementing this design, it was discovered that there is a tradeoff between the aperture size, which controls the amount of light passed through the lens elements, and the separation distance, the parameter responsible for the strength of the stereoscopic depth effect. For this reason, several different lens systems were constructed to determine the optimal configuration. These configurations include:

1. Dual-aperture, 600 μm diameter, 900 μm separation
2. Semicircle, 1500 μm diameter, 20 μm separation
3. Dual-aperture, 600 μm diameter, 1200 μm separation
4. Semicircle, 1500 μm diameter, 320 μm separation
5. Single-aperture 600 μm diameter

In testing all lens elements, it was expected that lens 3 would produce the greatest stereoscopic effect due to the wide aperture separation. Lens 5 (single, unfiltered aperture) will produce no stereopsis and is simply used as baseline for comparison to the lenses with CMBFs.

3 Objectives

In order to successfully demonstrate the full functionality of MARVEL and receive approval from the project's sponsor, several key objectives were required to be met. The primary objective was to design and assemble a fully functional alpha prototype. To be successful, this device must be able to:

1. Execute planar bending action up to +/- 60 degrees of the longitudinal axis.
2. Display live video in 3 dimensions
3. Provide the ability to manually adjust imaging device displacement such that optimal focus is maintained

4. Be completely handheld

Once these objectives are met, the device will be presented to SBI for evaluation. After gaining approval, the development of MARVEL will proceed into the beta prototyping phase where modifications will be made and additional performance features will be added.

The second objective was to characterize the performance of the optical system. This analysis allows the quality of the imaging components to be quantified. The primary performance metrics for the system include lens resolution and disparity. Crosstalk of the band-pass filters also plays a significant role in characterization, however the discussion of this variable will not be included in this report. To be successful, a lens resolution of around 287 line pairs/mm (lp/mm) was desired (see section 5.1). Since the stereoscopic effect is largely subjective, disparity was simply measured using a lithograph and compared to the theoretical predictions, allowing for the intensity of the stereopsis at various distances to be compared among lenses.

4 MARVEL Design

The design of MARVEL's alpha prototype and most of its components took roughly two weeks to complete. A CAD representation of this prototype can be seen below in Figure 3.

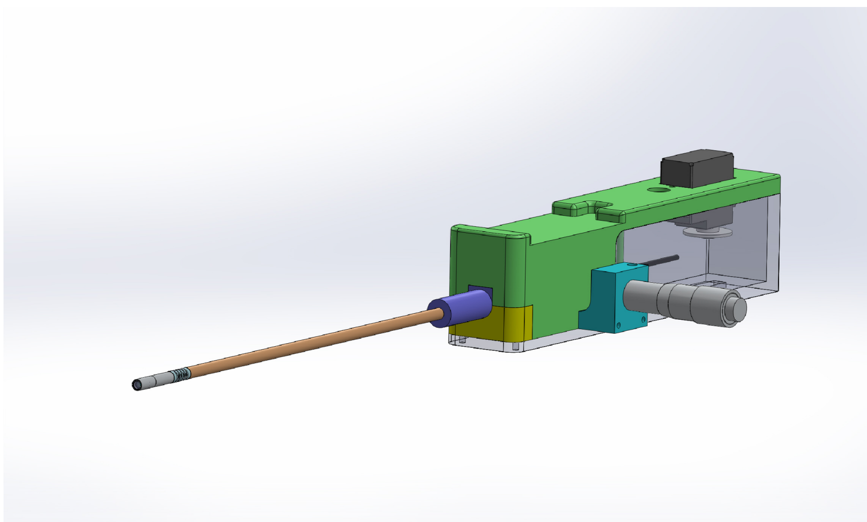


Figure 3: MARVEL assembly

Due to the nature of the device, the development was divided into two separate regions, the primary housing and the distal tip. These regions are discussed in detail in the subsequent sections.

4.1 Primary Housing

MARVEL's primary housing has several responsibilities, the most important being the primary interface to the user. Contained in this component are the digital servo for providing bending action of the tip, servo controller for commanding the servo, and linear actuating mechanism for displacing the imaging system to maintain correct focus. A figure illustrating the design of this component can be seen below.

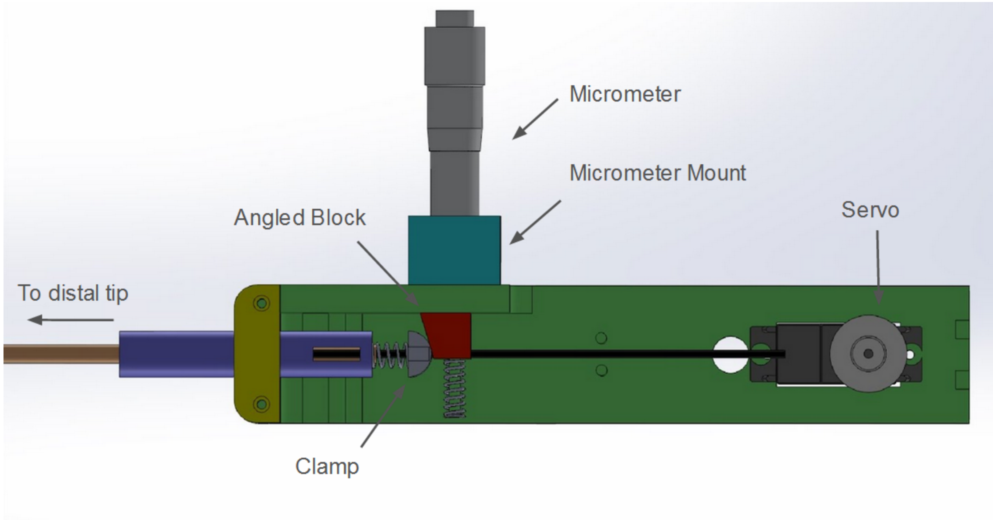


Figure 4: Primary housing

From Figure 4, several key components are visible. The purpose of the servo is to provide bending capabilities to the distal tip region. Metal guiding wires are connected to the servo's pulley system and run down the length of the shaft, through the bending section, and attach to the tip's metal outer housing. By rotating the pulley, one side of the wire is placed in tension which translates a bending moment to the joints causing the tip to actuate. This servo is controlled via a digital servo controller (not shown) which is fixed on the outside of the primary housing. This controller receives input directly from the user using a rotary potentiometer.

The angled block (red), micrometer, and clamp (gray) all compose the actuating mechanism used to displace the imaging system in the distal tip. The angled block rests on two dowel pins which act to constrain its motion. Springs are used to apply a pressure to the block such that it maintains constant contact with the micrometer. As the micrometer is adjusted, the angled block moves along the dowel pins, ultimately translating motion to the clamp which itself is in constant contact with the block via a spring. The clamp is fixed to the imaging cable and serves to displace the imaging unit in the tip. Originally, there was some concern regarding buckling when pushing the imaging cable. Although slight buckling may occur, it was determined that the dimensions of the shaft are sufficiently small for this to inhibit actuating potential.

4.2 Distal Tip

Due to the highly constrained environment, the distal tip region of MARVEL was by far the most difficult portion of the design. The lens system, fiber optic annular light, and imaging device were all required to be contained in the 4mm diameter housing, greatly restricting design possibilities. After several iterations, the most viable design was selected and can be seen below in Figure 5.

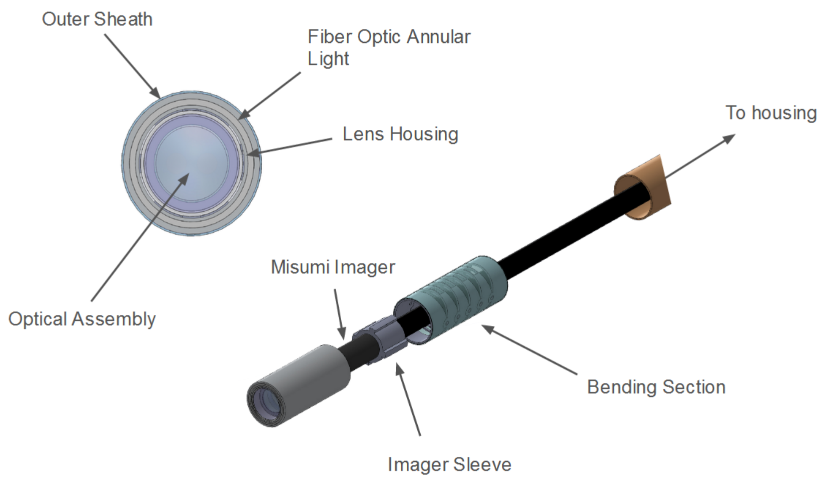


Figure 5: Distal tip

Although the inclusion of all tip elements would normally be quite simple, the additional requirement of imaging device actuation greatly increased the design's complexity. To meet this requirement, a simple sleeve element capable of being placed inside the fiber annulus was proposed. The sleeve allows for 1-dimensional freedom of the imaging system to adjust focus while still allowing all tip elements to interact as desired. This element is also used to fix the imaging element in the center of the lens's image plane.

Just behind the imaging system, the fiber from the annular light converges to form a fiber line which runs parallel to the imaging device's data cable through the bending section and down the shaft. These components must be flexible enough to allow the bending section to actuate up to +/- 60 degrees on either side of the longitudinal axis. Once through the shaft, both the fiber bundle and the imaging cable will exit the device and interface with their respective hardware.

5 Performance Characterization

Although the primary task for the fabrication of MARVEL was the design of the device itself, several of its key systems required their own separate development. These systems play an key role in the success of the project as a whole and therefore are worth discussing in this report.

5.1 Resolution of Custom Optics

The primary merit for the quality of the custom lenses used in MARVEL is their resolution. Traditionally, optical performance was measured subjectively using a standardized Air Force resolution chart. This test requires the user to evaluate the performance of the lens system by determining the finest group and element of line pairs that can be resolved (much the same as a standard eye test delivered by an optometrist).

More recently, with the added benefit of computing power, lens resolution is able to be evaluated objectively using a Modulation Transfer Function (MTF). The software chosen to analyze lens performance is produced by Imatest. By capturing an image of a standard resolution chart as well as an appropriate scale, Imatest's software is able to determine the resolving power of the lenses using the digitized image. The rig used in all lens experiments can be seen below.

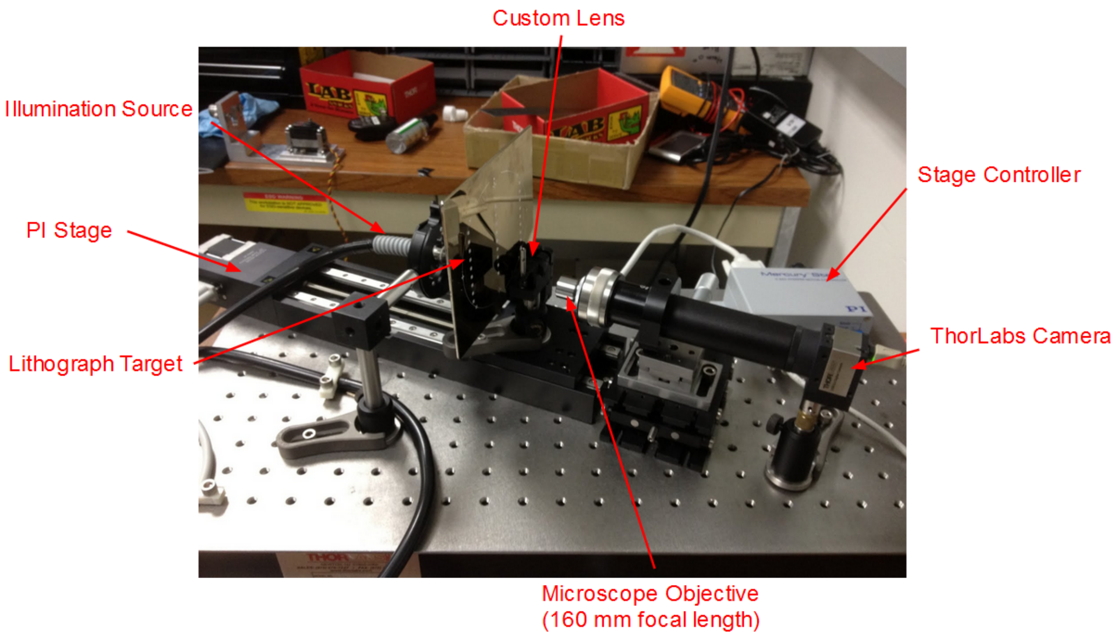


Figure 6: Test rig used for resolution testing

Figure 6 above serves to illustrate how the resolution tests were performed. First, the custom lens and resolution target are fixed to the piezoelectric stage 1 cm apart (the designed working distance of the custom lenses). Next, using a high-definition Thorlabs CCD camera in combination with a 20x/0.5NA microscope objective, the lens/target combination is moved such that the image plane from the optics lies at the working distance of the objective. This virtual image is then projected onto the imaging chip in the camera at the designed 160 mm focal distance of the objective lens. The 20x objective was chosen specifically for its large numerical aperture. It was determined that an NA of roughly 0.42 was needed to capture all incoming light from the custom lenses. An objective that does not meet this requirement will tend to capture images from only one of the two apertures, producing invalid resolution results. After capturing the image, it is evaluated twice in the Imatest software, once using a horizontal region of interest and once using a vertical region of interest. This was done to gain a more complete characterization of the lenses. An example of the typical results returned from this test can be seen below in Figure 7.

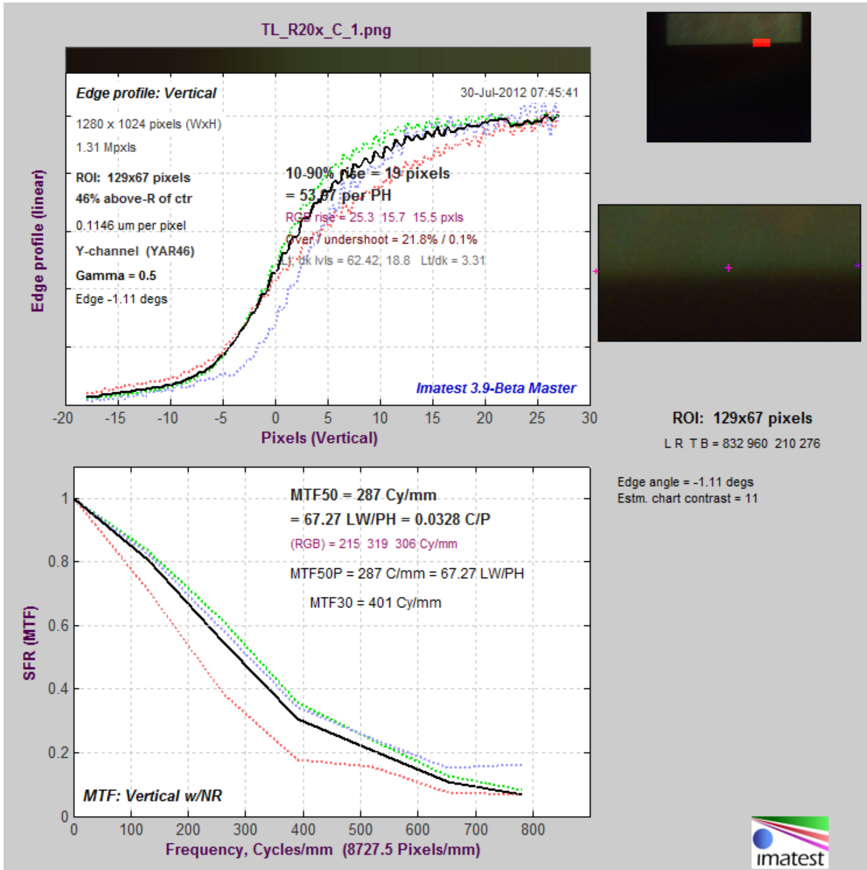


Figure 7: Typical output from resolution evaluation software

From Figure 7, it can be seen that at 50% contrast (MTF50) the custom lens system is able to resolve an average of 372 lp/mm. According to Imatest, the MTF50 is taken as the standard performance parameter since detail is diminished, but still visible, and it lies in the region where the response of cameras drops off most rapidly. A table summarizing the custom lens' performance can be seen below.

Table 1: Custom lens resolution data

Lens	Aperture Diam./Separation [microns]	Resolution (Horizontal) [lp/mm]	Resolution (Vertical) [lp/mm]
1	600/900	413	332
2	1500/20	302	320
3	600/1200	377	309
4	1500/320	347	285
5	600/NA	446	409
Baseline	NA	758	758

From Table 1 above, it can be seen that the lenses performed well, although the results were slightly unexpected. Lens resolution is defined by:

Where:

λ = Wavelength (555 nm)
f_d = Focal distance

A = Aperture diameter

Theoretically, lenses 2 and 4 should produce the lowest resolution due to their large aperture size. Given their size, the resolution should be roughly 1/3 the resolution of the 600 micron apertures. This discrepancy between the theoretical predictions and empirical data can most likely be attributed to changing environmental factors among tests (e.g. lighting) as alignment errors between the custom and objective lenses during the tests. Nevertheless, comparing lens 1 with the 287 lp/mm measurement from OTI it can be seen that the MTF measurement produces much better results. It should be noted that all resolution measurements from the lens manufacturer were based on data collected from the 400 x 400 pixel resolution Misumi imaging system used on MARVEL. Although capable of higher resolving potential, the data from OTI is limited by the low resolution camera, producing resolution measurements around 160 lp/mm on average. The 287 lp/mm benchmark was determined by viewing the Air Force resolution chart images provided by OTI and determining the smallest distinguishable group/element pattern, making accurate predictions difficult. Due to the higher resolution Thorlabs camera used in these tests (1.3 Megapixel), the resolution measurements presented here are significantly higher. Further, in Table 1, it can be seen that the resolution measurements with the custom lenses lie well below the 758 lp/mm measured in the baseline test, confirming that the Thorlabs camera is capable of resolving higher frequencies than the lenses are able to produce, revealing their true potential.

5.2 Disparity Measurements

Perhaps one of the most important features of MARVEL is the stereoscopic effect delivered by its custom lens trains. In order to quantify stereoscopic performance, image disparity was measured and compared to theoretical predictions. Disparity is theoretically defined as:

Where:

M = Magnification
SB = Stereo baseline
z = Distance from lens to target

As previously stated, the 3-dimensional imaging capabilities are derived by simulating human vision through the use of CMBFs. When in-focus, both apertures admit and focus their respective wavelengths onto the same point in the image plane. As the target is moved out of the working distance of the custom lenses, the light passing through the apertures is no longer focused onto the same point, resulting in a disparity between images.

Due to the large number of images captured during each of these tests, the disparity measurement were performed using an algorithm developed in Python. This program operates on the basis of Canny edge detection methods to find the centers of the slit images. Three slices are taken from each image and averaged to produce the most trustworthy results. In order to facilitate this process, blurring was added to all images to smooth the pixel data and eliminate unwanted edges.

In order to quantify disparity, a test rig similar to that found in Figure 6 was assembled. It should be noted that the primary difference between the two setups was simply the incorporation of the Misumi imaging system. The procedure for acquiring disparity data was as follows:

1. Calibrate linear piezoelectric stage such that the lithograph target is 10 cm from the front of the lens train
2. Manually adjust the location of the Misumi imaging device such that no disparity is seen
3. Move linear stage such that the lithograph target is 4 cm from the front of the lens train
4. Capture and save an image from the camera
5. Move the linear stage 0.3mm away from the lens train
6. Capture and save an image from the camera

7. Repeat steps 3-4 until 100 images are gathered (or the lithograph has traveled a total distance of 30 mm)

Once all images are gathered, they are then analyzed using proprietary software developed in Python. This program operates on the basis of Canny edge detection to determine the total disparity in the image. It should be noted that as a result of the often noisy images attained during the tests, digital blur was added to more easily determine the location edges. Due to the both the consistency and similarity among data, only the results from one test is provided. Graphs illustrating the behavior of the other lens systems can be found in Appendix B.

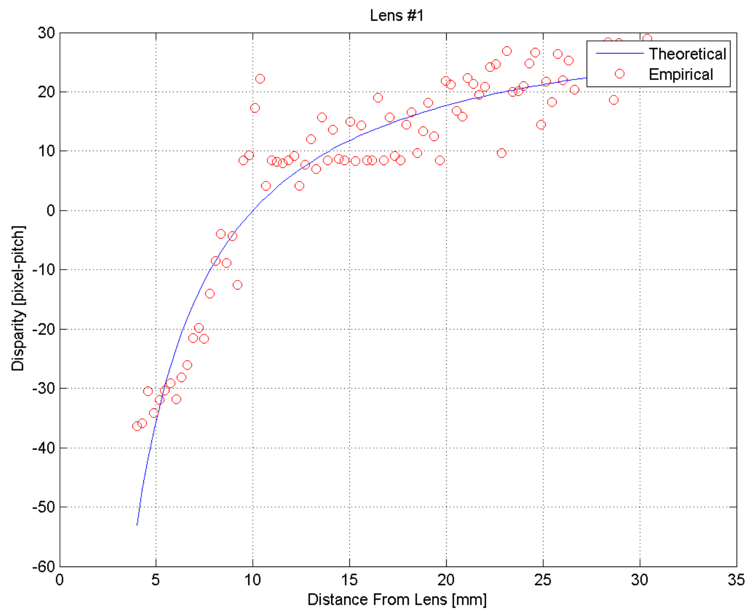


Figure 8: Lens #1 disparity measurements

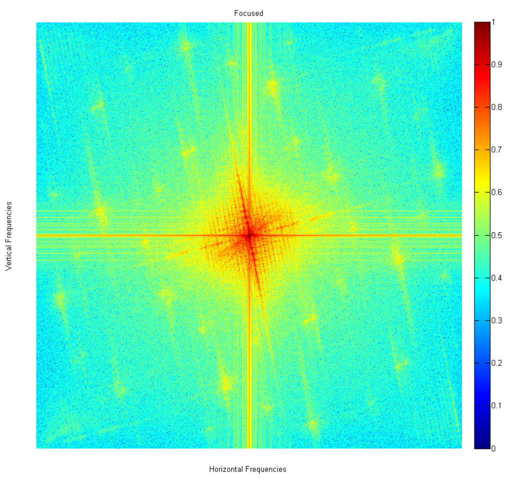
Observing Figure 8, it can be seen that the experimental data fits the theoretical predictions rather well, especially in regions near the working distance of the lens. Further, examining the behavior of the graphs and looking at equation **??** it can be seen that disparity is more sensitive to changes in separation distance on the near side of the working distance as opposed to the far side. This result suggests that the best stereoscopic effect is achieved when the rearmost point of a target is placed just beyond the working distance of the lens, allowing its 3-dimensional features to become most pronounced.

Although correlating nicely with theoretical predictions, it should be noted that all disparity measurements falling outside of 1 standard deviation were discarded and this method of measurement does not perform particularly well when the disparity is small such that no discernible edge is present between slit images. Alternative methods may have to be explored in the future to receive consistently reliable measurements.

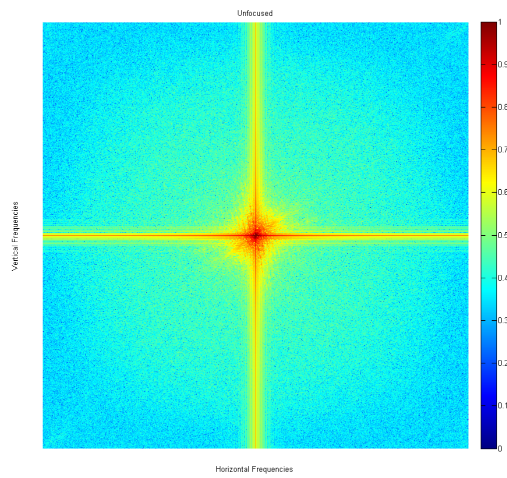
5.3 Autofocusing Algorithm

Although not an explicit requirement, the incorporation of autofocusing software could potentially provide a substantial benefit to the surgeon while operating MARVEL. By eliminating the need to manually adjust the location of the imaging device, the workload on the operator is significantly reduced, allowing for complete concentration on the task at hand.

Several methods for determining the optimal focus level of an image currently exist. These include: image derivatives, variance, autocorrelation, histograms, and Fourier transforms[3]. The proposed technique for MARVEL operates using a Fast Fourier Transform (FFT), saving images and converting them from the spatial domain to the frequency domain. Once in the frequency domain, the power spectrum is computed, normalized using the DC frequency value, and logarithmically scaled to better reveal data behavior. In processing the image using an FFT, it is assumed that a high contrast, and hence in-focus, image will generally contain more power in the high frequency regions of the spectrum. This conclusion was reached by acknowledging the fact that higher frequencies will tend to possess better resolving power (i.e. be capable of capturing finer detail) than their counterparts. To demonstrate this, the power spectrum for both an in-focus and out-of-focus image can be seen below in Figure 9.



(a) Focused image



(b) Unfocused image

Figure 9: Logarithmically scaled power spectrum

Examining Figure 9 closely, it can be seen that near the outer regions of the image (the area where high frequencies are present) the in-focus image has slightly more power than the out-of-focus image. To quantify the resolving power, only the top 90% of all frequencies are preserved via a high-pass filter. These values are then averaged and stored for comparison to other images. Taking a series of images at various distances from the lens system, the power spectrum data can be seen below in Figure 10.

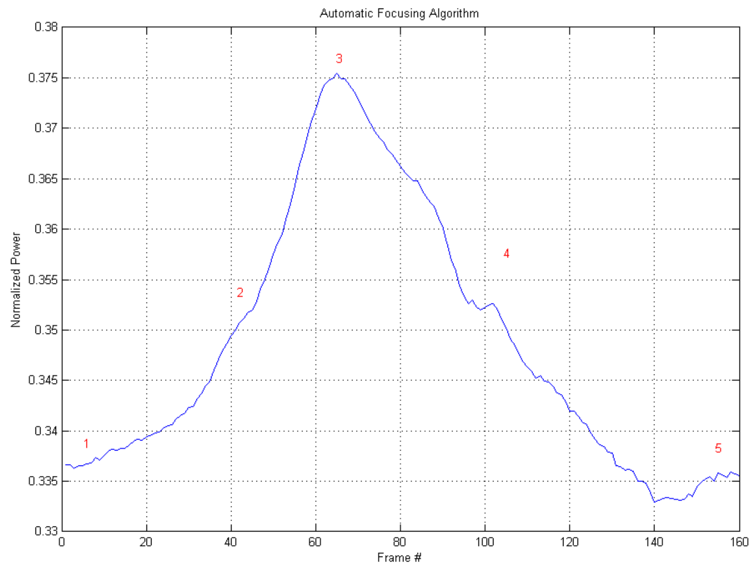
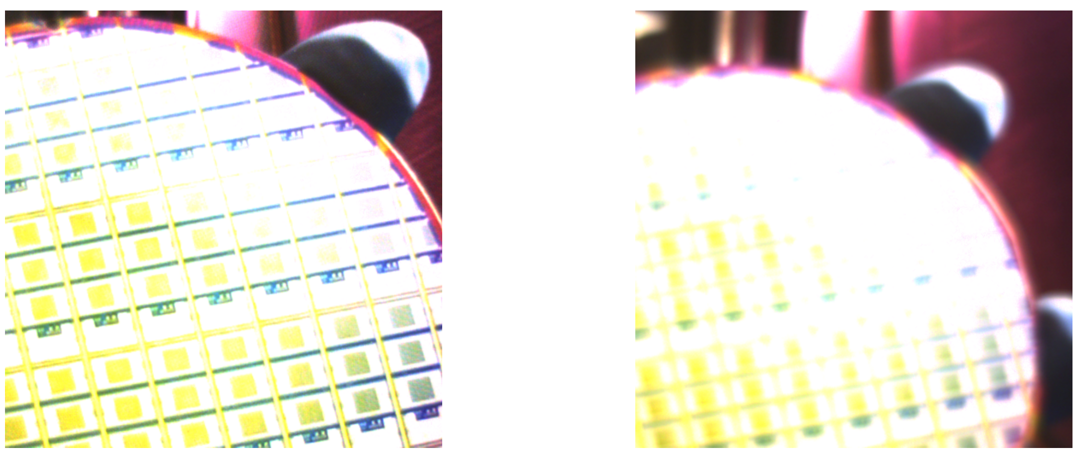


Figure 10: Average power of top 90% of frequencies

Two images associated with an in-focus and-out-of-focus scenario (points 1 and 3 from Figure 10 can be seen below in Figure 11 below.



(a) Focused image (3)

(b) Unfocused image (1)

Figure 11: Images from autofocus test

From Figure 10, it can be seen that there clearly exists a maximum value (point 3) where the highest average power is present in the high frequency region of the Fourier transformed images. Subjectively analyzing the images associated with Figure 10, the most highly focused image indeed corresponds to the highest average power as expected. For a more in-depth analysis of focus determining using Fourier techniques, the reader is referred to [4]

With a method for quantitatively determining the focus level of an image, an algorithm for adjusting the displacement of the imaging system must be developed. This task will most likely be accomplished using a commercially available linear actuator such that adjusting the focus level will be completely automated, requiring little or no user input.

6 Conclusion

Reflecting on the development of MARVEL, it can safely be stated that nearly all objectives have been successfully completed. With the design of the alpha prototype finished, the team is currently awaiting the arrival of the fiber light, shaft, and bending section. Once these pieces are received, the device can be fully assembled and its performance evaluated. Since all subsystems have been validated, this process is expected to go smoothly. Possible complications that may arise will most likely involve incorrect tolerances, forcing the team to modify parts in the laboratory. After gaining approval from the project sponsor at SBI, MARVEL will proceed into the beta prototyping stage. In this phase, adjustments will be made based on suggestions received from the sponsor. Other features, such as the inclusion of a Field Programmable Gate Array (FPGA) (see below) and automatic focusing, may also be implemented.

Regarding MARVEL's display software, it was noticed that the system produces frame rates which are slightly less than ideal. In performing various tests and demonstrations for visitors, rates of roughly 10 frames per second were observed. Ideally, rates of roughly 20 frames per second per eye are desired, corresponding to a total rate of 40 frames per second. Not only does a slow frame rate make viewing the video feed frustrating, it also places a strain on the viewer due to the large disparities between the left and right images when the target is moving. In an attempt to rectify this issue, the software was rewritten to incorporate multi-threading. Unfortunately, after profiling performance, it was discovered that the low frame rates could be attributed to an issue intrinsic to the camera developer's software, leaving the team unable to improve performance. After consulting with experts, it was suggested that the entire system be redeveloped using an FPGA board. Given the time constraint and inexperience of the author with hardware programming however, this solution could not be successfully implemented.

In reference to the characterization of the optical system, all performance metrics were successfully measured. In gathering the resolution data from the lenses, the results were as expected. The resolution of lens 1 as specified by the manufacturer was 287 lp/mm. The laboratory measurement produced a average resolution of roughly 373 lp/mm, much better than the expected results overall. In performing these tests, there was some discrepancy between the measured data and theoretical predictions. The large aperture lenses (2 and 4) should produce roughly 1/3 the resolution of the smaller 600 micron aperture lenses. Clearly, this result was not seen and can most likely be attributed to changing environmental factors during the tests. To achieve better results, a rig specifically designed for performing resolution tests is highly recommended.

Image disparity was also measured, producing results that agreed rather nicely with theoretical predictions. This correlation confirms the prediction that objects falling closer to the lens system than the working distance tend to produce a stronger sense of depth than those further away. Fortunately, this is the region where the surgeon will most likely use their tools, allowing for a more natural viewing experience. In the future, software could also be developed to track the location of the tool itself and adjust the location of the imaging system such that optimal focus is maintained specifically on these devices.

Finally, the most recent development to the project was the automatic focusing software. Although several methods exist for determining the focus level of an image, given the current expertise of the author as well as the time available to develop the logic, the FFT method offered the most logical path. With the measurement technique completed, all that remains is the logic development associated with moving the imaging device such that the optimal focus level is achieved. This algorithm would operate by displacing the target in the direction of increasing power, storing the maximum value with its respective location, and comparing this value with other measurements until an absolute maximum is achieved. It is expected that this process would take roughly 1-2 weeks of development time.

Acknowledgments

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the Indiana Space Grant Consortium and the National Aeronautics and Space Administration.

References

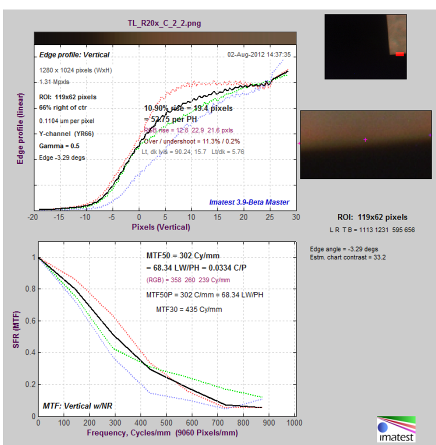
[1] Bae, S.Y., Korniski, R.J., Choi, J., Shearn, M., Bahrami, P., Shahininan, H., Manoharha, H.M., "Stereoscopic Depth Effect of a Dual-aperture Stereoscopic Imaging System". Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. 2012. (unpublished)

[2] Jones, M.D., Mark. Personal Interview. 11 May 2012.

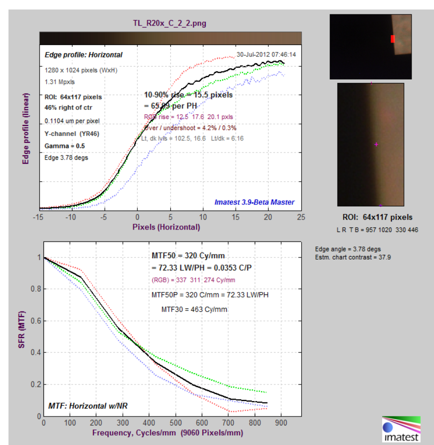
[3] Rudnaya, M., Mattheij, R., Maubach, J., Morsche, H., "Gradient-based Sharpness Function". *World Congress on Engineering*. Vol. 1, London, U.K., 2011.

[4] Welch, P., "The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method Based on Time Averaging Over Short, Modified Periodograms". *IEE Transactions On Audio and Electroacoustics*. Vol AU-15. No. 2, 1967.

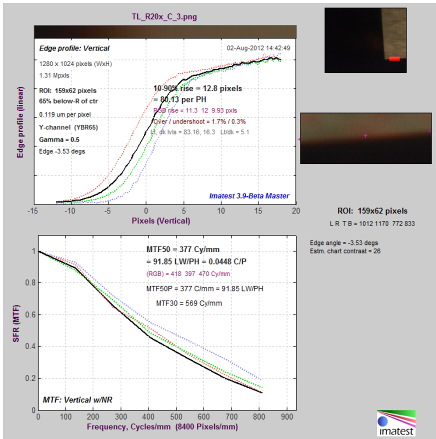
Appendix A: Resolution Measurements



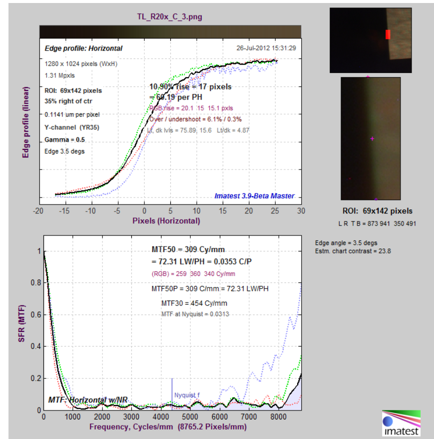
(a) Focused image (3)



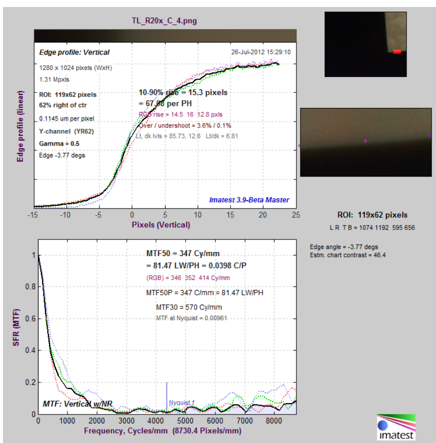
(b) Unfocused image (1)



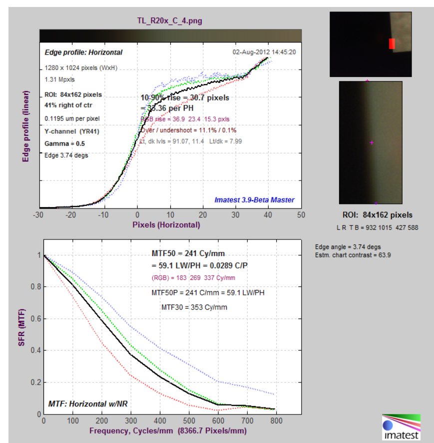
(c) Focused image (3)



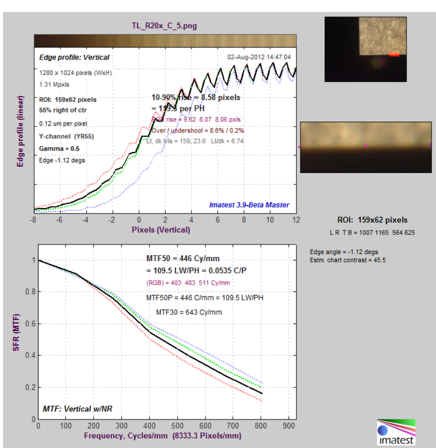
(d) Unfocused image (1)



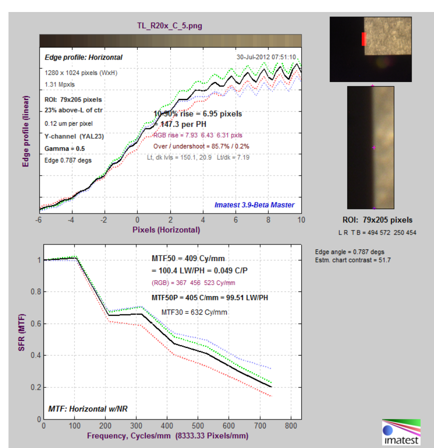
(e) Focused image (3)



(f) Unfocused image (1)



(g) Focused image (3)



(h) Unfocused image (1)

Appendix B: Disparity

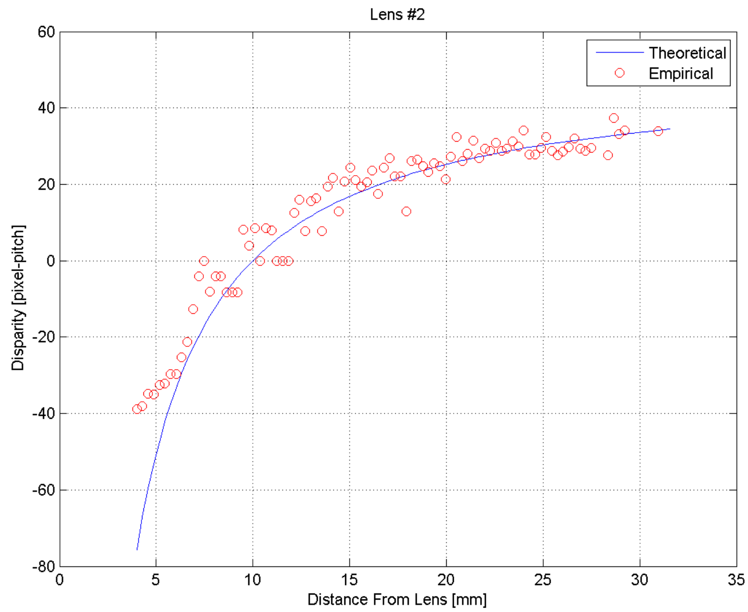


Figure 12: Lens 2

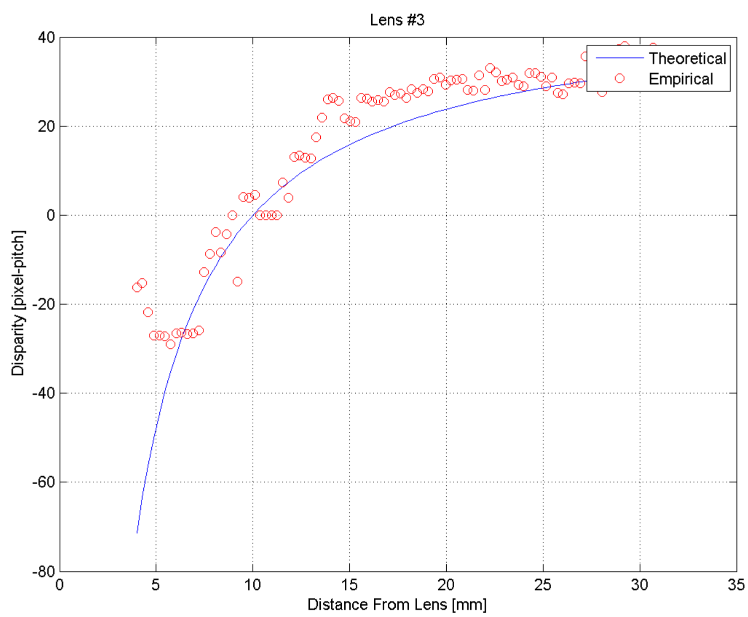


Figure 13: Lens 3

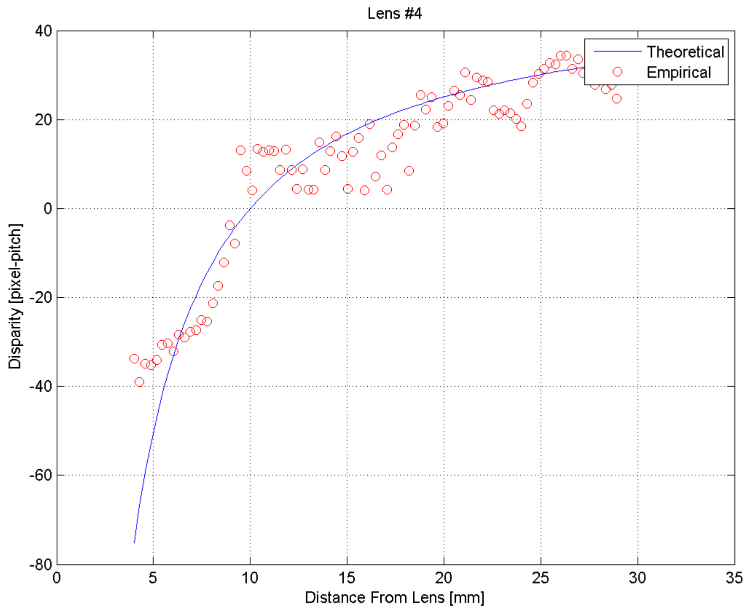


Figure 14: Lens 4

Appendix C: Automatic Focus

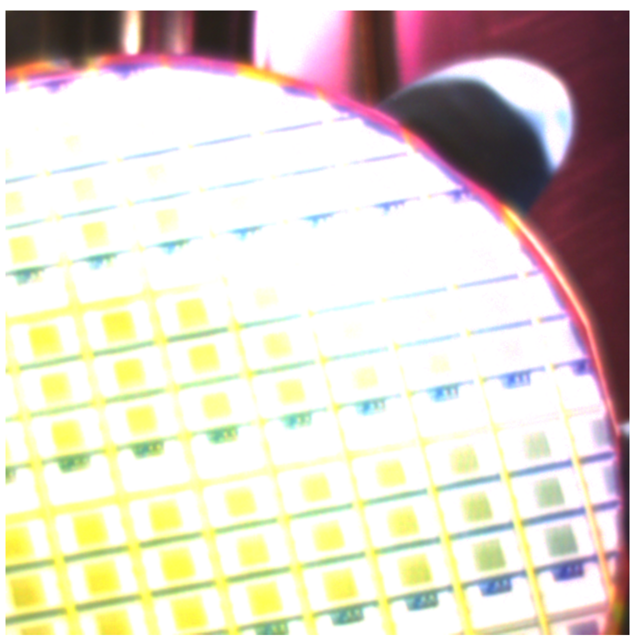


Figure 15: Position 2

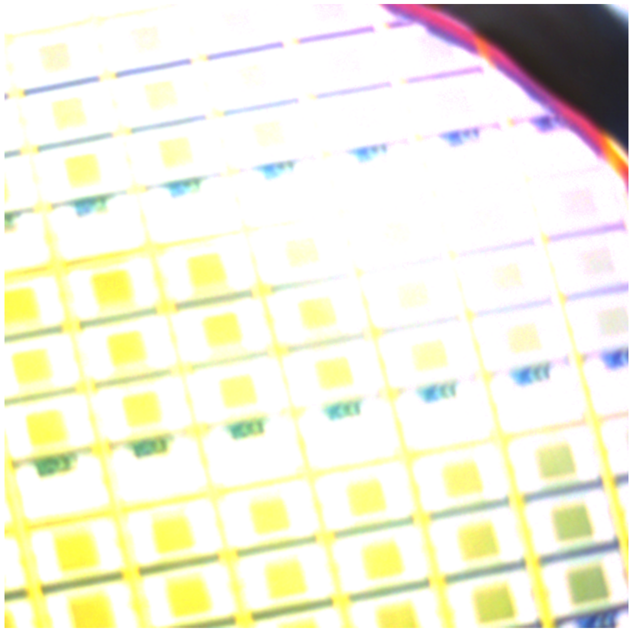


Figure 16: Position 4

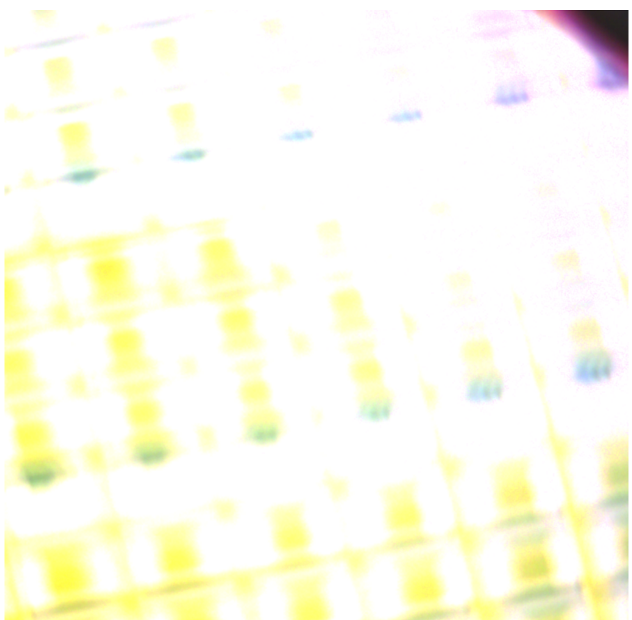


Figure 17: Position 5