

Video Readout for Alignment Telescope

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The Project:

Our goal is to design a video readout system for an alignment telescope to increase the ease of use with the telescope. Essentially, the readout system will consist of a CCD camera, a focusing lens, and a mounting system to attach the optical unit to the eyepiece so that the eye will not have to be used.

Background:

An alignment telescope is a device used to determine the proper alignment of lenses or mirrors. A set of reticles is placed in the alignment telescope so that a lens or mirror can be adjusted in tip and tilt to have the retro-reflected spot line up with the center of the reticles. This can become bothersome since the user must travel back and forth between the optical system and the telescope in order to properly align the system. Also, the position of the eye can be crucial since it is very easy to change the field being viewed by rotating the eye. If a camera system reads out the image from the telescope onto a computer, the user can remain at the lenses and adjust the lenses while looking at the image on a computer. This also has its advantages since the user does not always have to get behind the telescope which can also be inconvenient based on its orientation.

The Optical System:

Figure 1 shows an image of the actual alignment telescope being used. Unfortunately, we cannot disassemble the alignment telescope to measure the optical characteristics of the lens system; however, we can measure, and have measured, the optical parameters of the eyepiece that is used with the system. Using an Eidolon Lens Bench, we were able to approximately determine the FFD and the BFD to be about 12.34 mm and 17.285 mm respectively. The full field captured by the eyepiece was also measured to be about 10 mm, and with the system fully assembled, the XP was found to be about 16 mm away from the lens of the eyepiece with a diameter of about 3 mm.



Figure 1) The Alignment Telescope

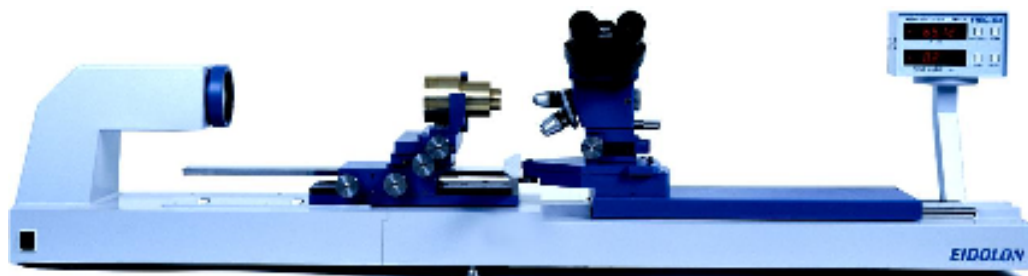


Figure 2) Eidolon Lens Bench

Using these numbers, a first order optical drawing was done to determine the appropriate parameters needed to capture the entire image. Figure 3 shows a sketch of these parameters. Since the image produced by the telescope is placed at the front focal length of the eyepiece, the rays exiting the eyepiece will be collimated; therefore, the CCD camera must be placed at the focal length of our “to be made” optical system. It should be noted that Professor Parks has loaned the project a Flea2 CCD camera module which has a 3.6 by 4.8 mm CCD array defining our imaging plane or image size. Using this knowledge, the appropriate focal length of the “to be made” system was found using the equation shown below. Since we know that the image height is constrained to be 3.6 mm, and the virtual object height (the field of the eyepiece) is 10 mm, the magnification was found to be 3.6 over 10 which is .36. Also, since we know that Z is 16 mm, the focal length of the optical system should be about 5.76 mm.

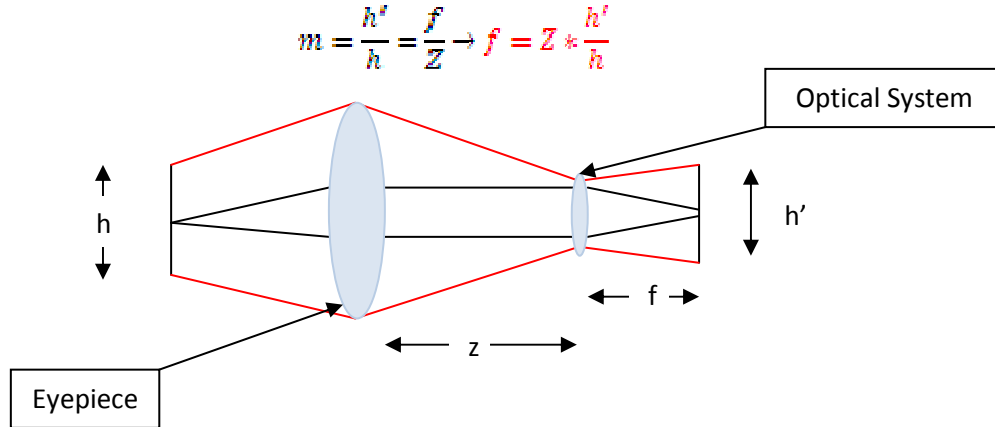


Figure 3) First Order optical Drawing (Note that this is not to scale)

Professor Parks also has available to us a set of micro imaging lenses that are all F/2.5 which are pre-mounted and can be placed into a C-mount adapter. Table 1 shows the Edmund Catalog specifications to these lenses. Using these specifications, a quick analysis was done to see how the lenses would perform in terms of the maximum field they could capture as well as how well their resolution (both spatial and angular) is. Table 2 shows the values to these results, and figures 4 and 5 show plots of these results. As it can be seen, with the higher focal length lenses available, there is less field captured, but there is a better angular resolution; however, the angular resolution is only slightly less than that achieved with the smaller focal length lenses. It should also be noted that the plots show the 5 mm focal length lens; however, professor Parks only has the 6 mm lens through the 17.5 mm lens. Therefore, we have concluded that the 6 mm lens would be the idea lens to use for this system. Though it does not capture the entire field, it is able to capture about 96% of the field and has the best spatial resolution.

Table 1) the lens specifications

Focal Length	Max. Sensor Format	f/#	Primary Mag	Field of View*	Working Distance	Resolution** (megapixel)	A (mm)	B (mm)	C# (mm)	D (mm)
5.0mm	1/3"	2.5	0.033-0.020X	224-372mm	150-250mm	1.35	14.0	14.6	4.0-3.9	3.7
6.0mm	1/3"	2.5	0.040-0.024X	177-294mm	150-250mm	1.35	14.0	14.1	6.9-6.8	4.5
8.0mm	1/3"	2.5	0.053-0.032X	118-196mm	150-250mm	1.35	14.0	12.3	8.8-8.6	3.7
10.0mm	1/3"	2.5	0.068-0.040X	90-150mm	150-250mm	1.35	14.0	17.0	6.6-6.3	3.7
12.5mm	1/2"	2.5	0.084-0.050X	95-159mm	150-250mm	2.41	15.0	22.9	10.1-9.7	4.8
17.5mm	1/2"	2.5	0.130-0.076X	60-104mm	150-250mm	2.41	14.0	20.7	5.8-4.9	7.6
25.0mm	1/2"	2.5	0.190-0.110X	42-74mm	150-250mm	2.41	18.0	30.0	8.5-6.5	11.5

Table 2) Analysis of lenses

Focal length	Aperture	EP	F/#	spatial resolution (microns)	Angular resolution (arc-minutes)	m	Field captured (mm)
5	2	2	2.5	3.355	1.153364063	0.3125	11.52
6	2.4	2.4	2.5	3.355	0.961136714	0.375	9.6
8	3.2	3	2.666667	3.578666667	0.768909367	0.5	7.2
10	4	3	3.333333	4.473333333	0.768909367	0.625	5.76
12.5	5	3	4.166667	5.591666667	0.768909367	0.78125	4.608
17.5	7	3	5.833333	7.828333333	0.768909367	1.09375	3.291429

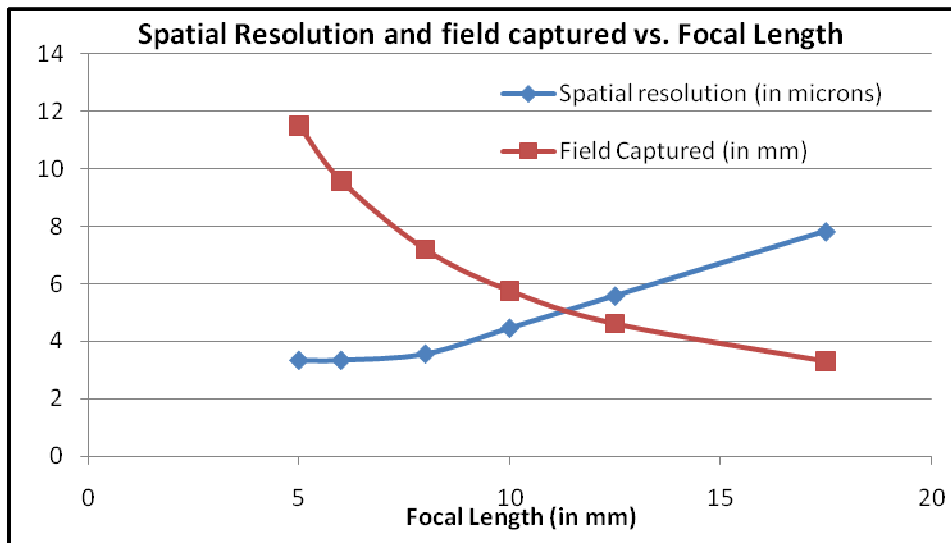


Figure 4) a plot of the spatial resolution and field captured vs. Focal Length

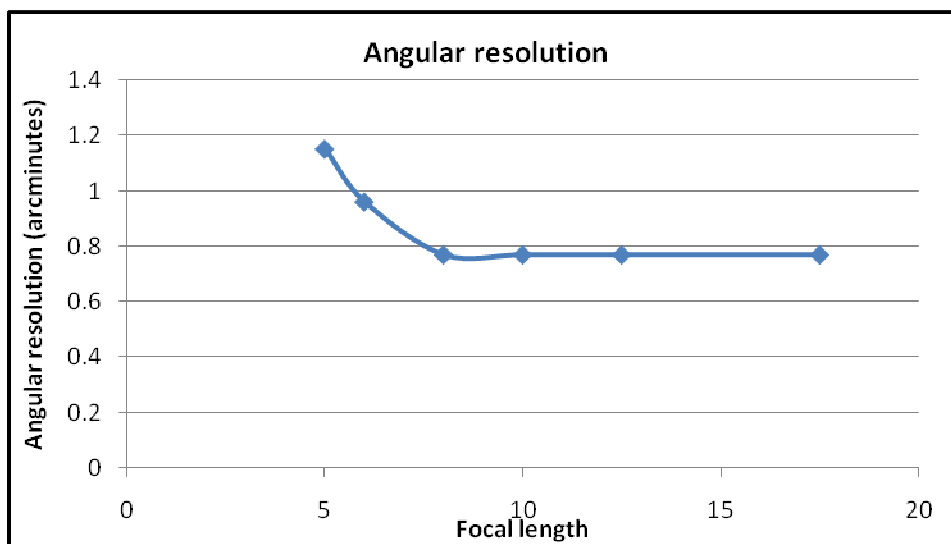


Figure 5) a plot of the angular resolution vs. Focal length

Mechanical Mount for Lens

Since the micro imaging lenses were going to be used, the mechanical design became fairly straightforward. Figure 6 and 7 below show the mechanical housing for the lens and its C-mount adaptor which will be able to screw into our CCD camera. The lens was threaded into the mount such that it was focused at infinity.

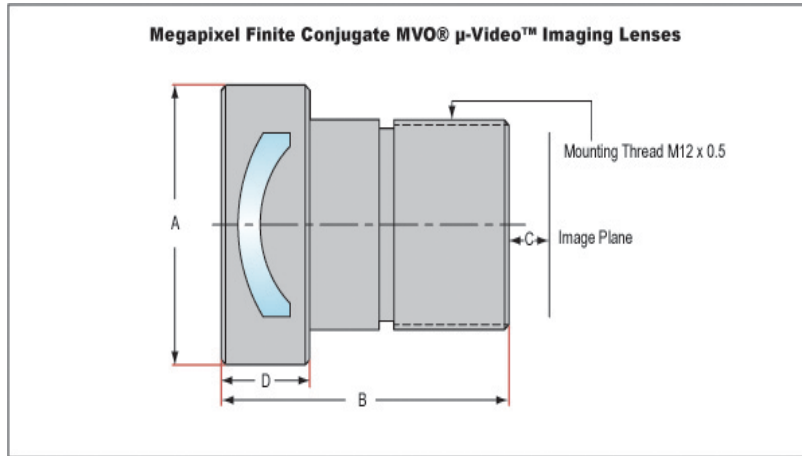


Figure 6) Mechanical housing of the lens

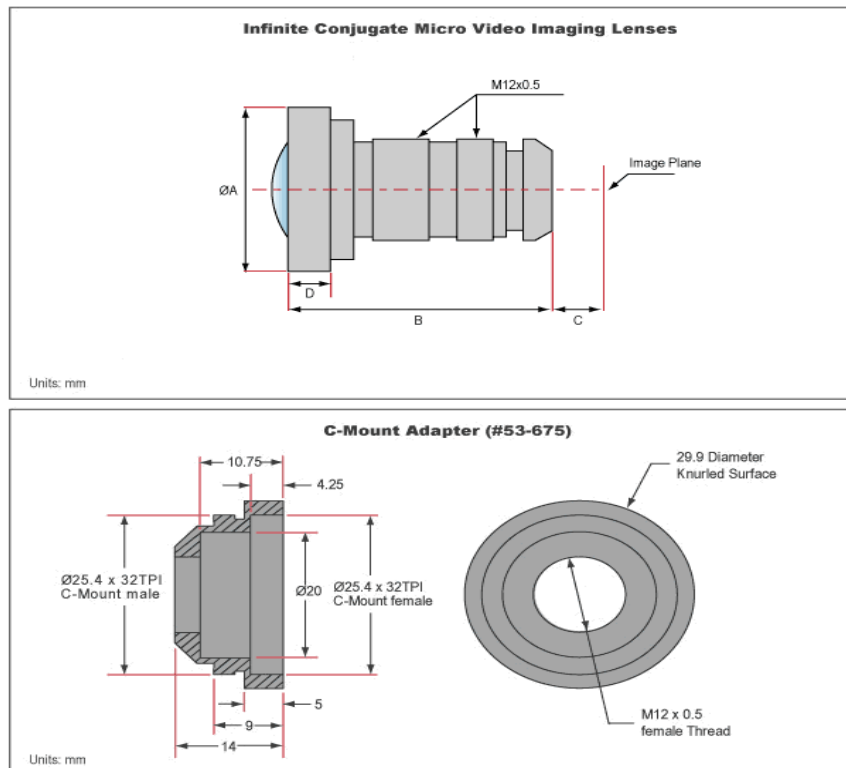


Figure 7) C-Mount Adapter for the lens

The housing to adapt the CCD camera to the eyepiece can be seen in figure 8. The housing has the ability to slide over the eyepiece and can then be tightened down using a hose clamp or something similar. The two slits put into the mount were created so that it could be easily deformed to fit onto the eyepiece. On the back ring of the tube (the smallest ring) 32 threads per inch were placed along the outside edge of the ring so that the C-mount adapter could be screwed onto to mounting tube. Figure 9 shows a Solidworks model of the system. Also note, attached to the end of this document is the drawing of the mechanical mount with specifications.

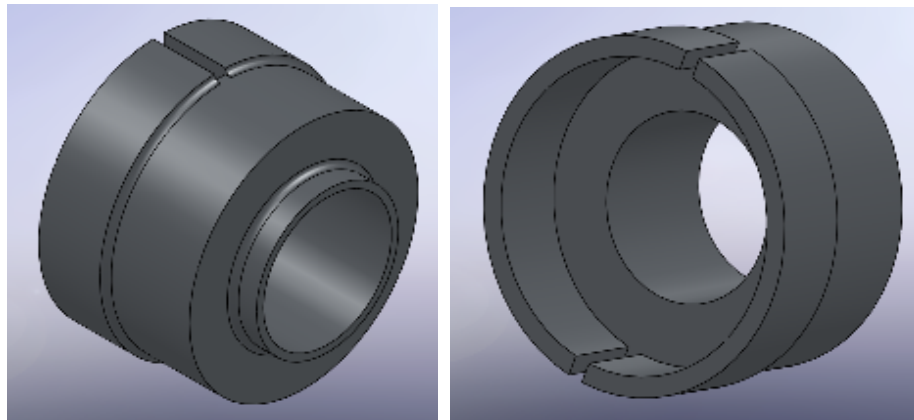


Figure 9) The mounting tube design

Mounting Tube

C-Mount

Eyepiece

FLEA2 Camera system

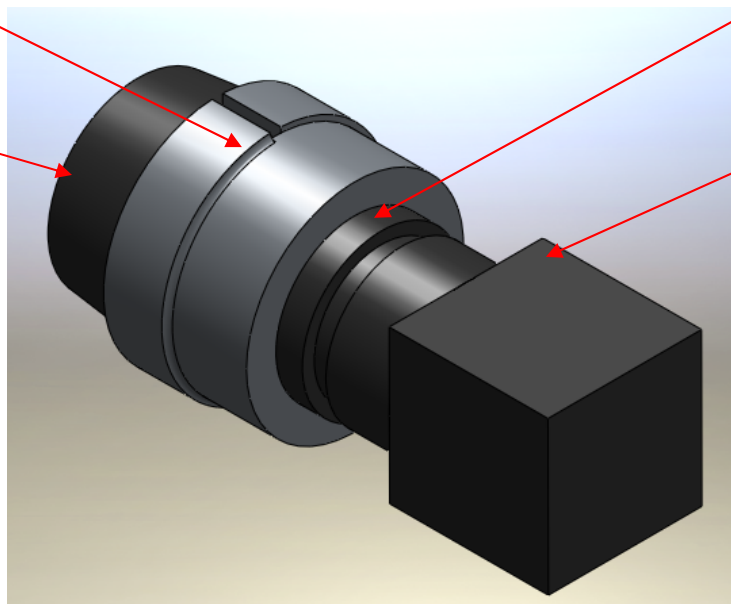


Figure 10) the final design

Integration with LabVIEW

The camera system was integrated with LabVIEW to create a continuous feed from the alignment telescope. Although software already exists to operate the Flea2 camera (PSMalign.vi), it was beneficial to learn the program and get the camera working from the ground up

The primary objective of the programming in Labview was to create a user-friendly display of the Flea2 camera, with a real-time video feed and some ability to alter the camera characteristics, mainly the exposure/integration time. The most efficient solution for this was using the Image Acquisition package within Labview. This conducts the initialization of the 1394 Firewire camera and makes it easier to modify attributes as well as view the output. The program is entitled Flea_Cam.vi.

A schematic of the program is attached, showing the block diagrams and front panel of the software. The entire program is placed in a while-loop, allowing the video feed to run continuously until the user indicates to stop. Within the program there is an additional true/false condition to switch between continuous video and a still shot. The default for the program is to run in video mode, while there is a toggle switch to end this session, resulting in a still frame. This makes it possible to stop the video feed and resume when desired. The other two features that have been introduced into the program are the camera control: changing the exposure time as well as adjusting for brightness. These controls are done using a slider and can also have a value inputted. The exposure setting is manual along with an automatic adjustment, allowing the operator to give then general range for the desired brightness with the software automatically performing fine adjustment. The two levels for the camera have default settings which can be reached using the 'Reset' buttons below each.

The following is a picture showing the camera software in use. The front panel to the left is running the camera and applying the specific settings, while the window to the right displays the resulting image from the camera.

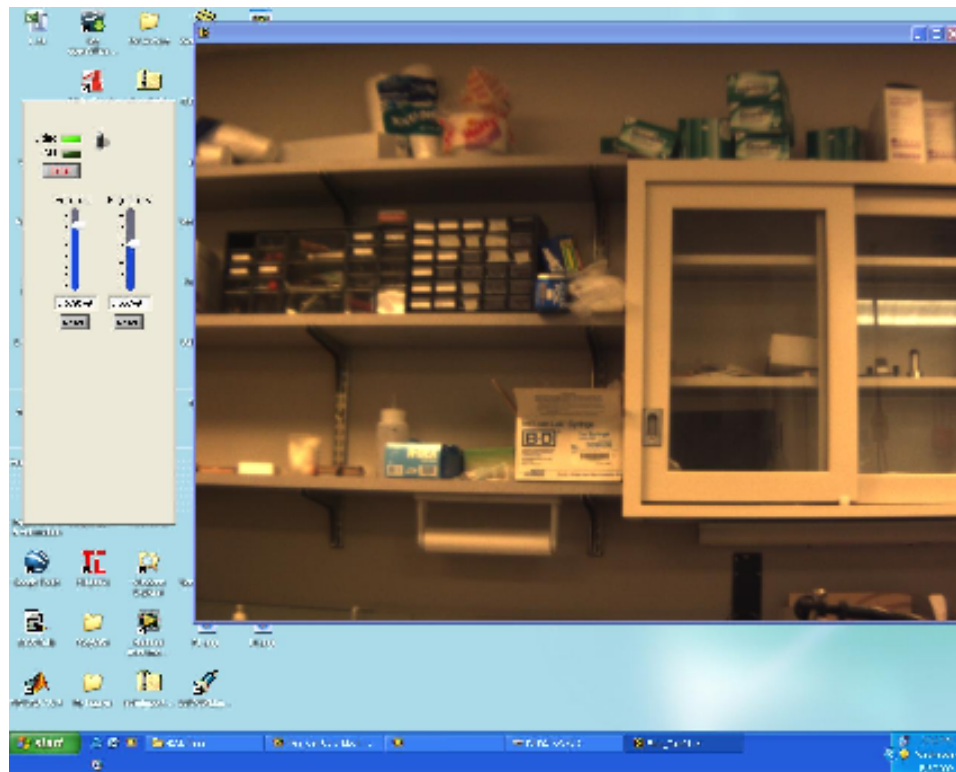


Figure 11) Flea_Cam.vi in use

The following picture shows a zoomed-in view of the front panel and controls the operator will be using to run the camera.

Mode Indicators

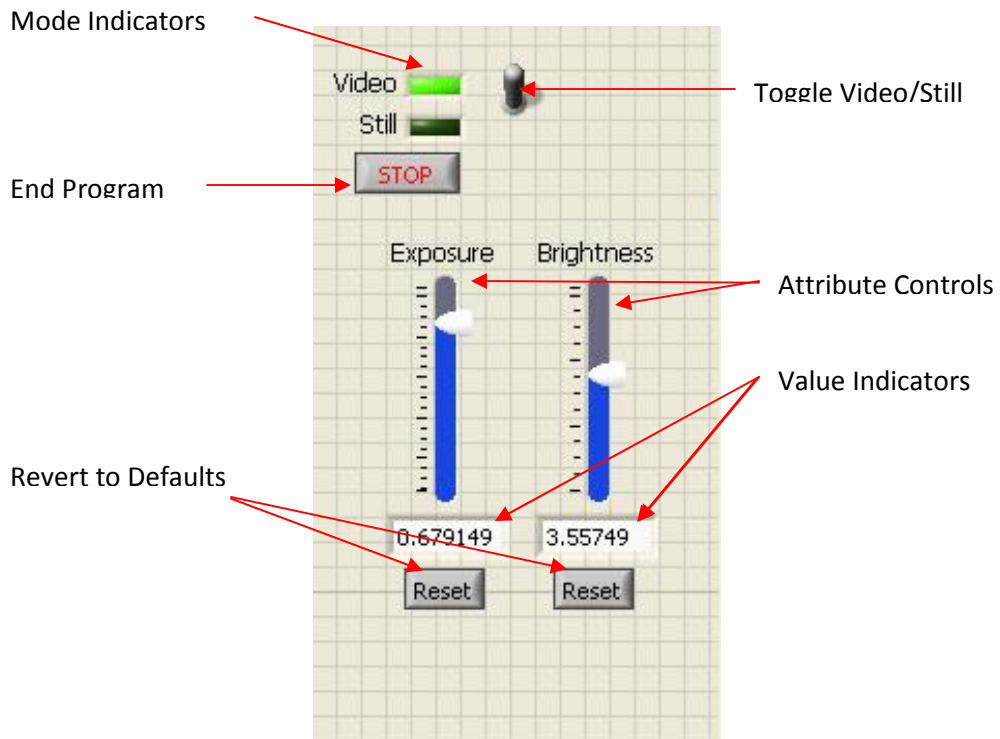


Figure 12) Front Panel

The following images are of the block diagram running the program. It shows the conditional portions of the program and how the various buttons and switch will alternate between different events.

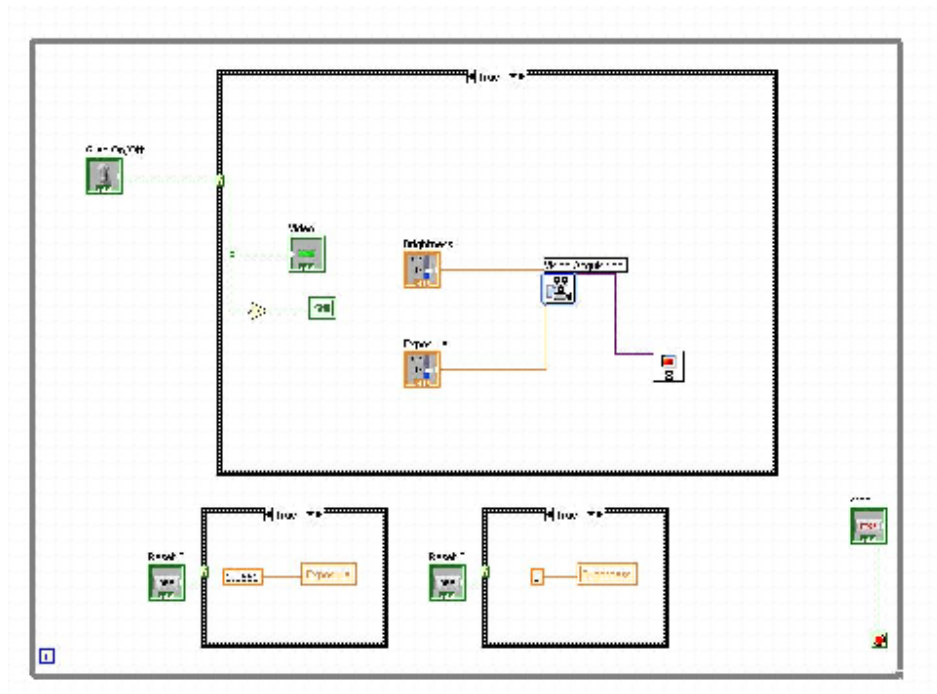


Figure 13) Block Diagram, True Case

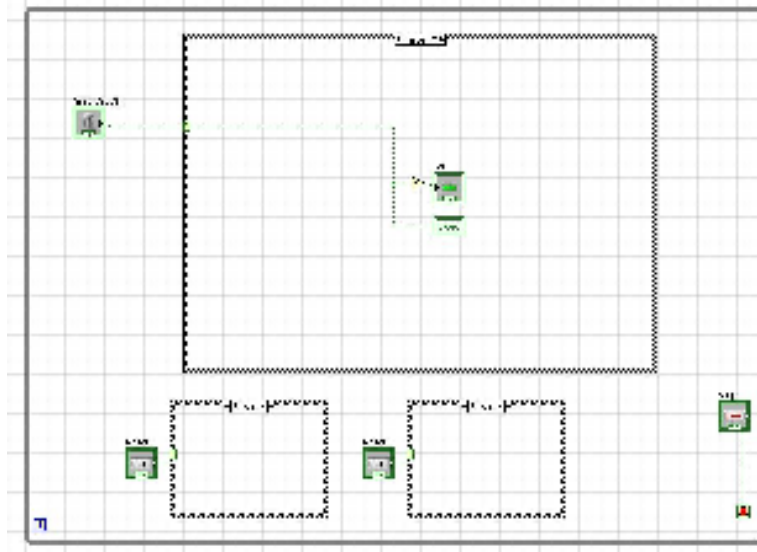


Figure 14) Block Diagram, False Case

Overall, the use of LabView in this project was effective and made testing of our system possible. It was a learning experience as well, understanding a new programming environment and how to achieve our objectives within it. Future development of the system could incorporate functionality of the camera currently not included, as well as some image analysis to aid in the alignment process.

Results

After constructing the LabView program and machining the mounting tube, the entire system was integrated together and tests were done on the functionality of the system as well as its performance. The first test done with the system was to just to make sure it could see the object the telescope was focusing on, and to make sure the eyepiece reticles appear consistently in the same spot on the video feed. Figure 15 below shows the system use without a hose clamp to fix the mount to the eyepiece and with a hose clamp. Both images have the reticles centered on the 21.3 mm mark of the ruler; however, without the hose clamp as compared to with the hose clamp, the reticles are shifted to the left and less marks on the ruler can be seen. In other words, the image is tilted across the vertical and horizontal axis of the image plane. As it can be seen, the hose clamp reduces the tilt in the image, which means that without the clamp, the camera is not securely fixed in one plane.



Figure 15) Comparison of image without and without hose clamp (left-without, right -with)

The second test performed on the system was to test its field of view. Four different focal positions (relative to the front of the telescope) were tested and the amount of marks seen on the ruler was recorded at those positions. The results are shown in Table 3 below. The full field of view (FFOV) was found by taking the arctangent of the difference in heights over the difference in axial (focal) position. Since 4 measurements were taken, 6 different fields of view were determinable. Therefore the average full field of view found was 0.825 degrees or 49.5 arcminutes. Figure 16 shows the images captured at these focal positions.

Table 3) Field of view measurements and results

Position #	Focal position	Height of image	Position Difference	FFOV (radians)	FFOV (degrees)	FFOV (arcminutes)
1	1168.4 mm	26 mm	2 and 1	0.013122606	0.751869956	45.11219736
2	1473.2 mm	30 mm	3 and 1	0.014762707	0.845840804	50.75044827
3	1778 mm	35 mm	4 and 1	0.014216015	0.814517669	48.87106014
4	2082.8 mm	39 mm	3 and 2	0.016402728	0.939807102	56.38842614
			4 and 2	0.014762707	0.845840804	50.75044827
			4 and 3	0.013122606	0.751869956	45.11219736

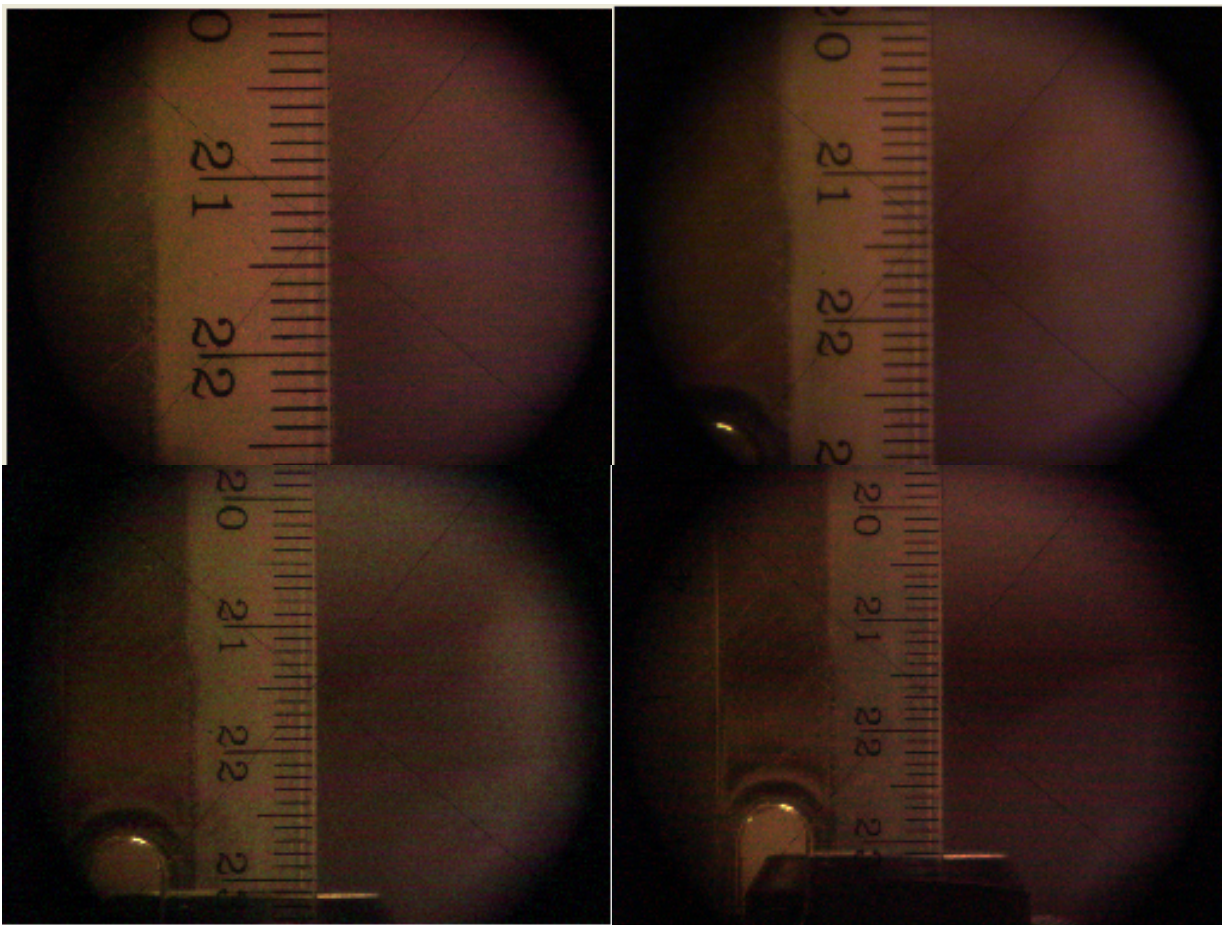


Figure 16) the four images captured at the different focal positions (position 1 - top left; position 2 - top right; position 3 - bottom left; position 4 - bottom right)

The third test performed was to simply see the depth of focus of the system using the camera. Figure 17 shows the image of the ruler between ± 2 inches from position 1. As it can be seen, if the object is within 1 inch of the focus it can be resolved; however, if it is at 2 inches or beyond focus, it is poorly resolved. It was found that at 12 inches away, the object cannot be resolved at all. Prior to 12 inches, the object can at least be seen, though the resolution may be very bad.

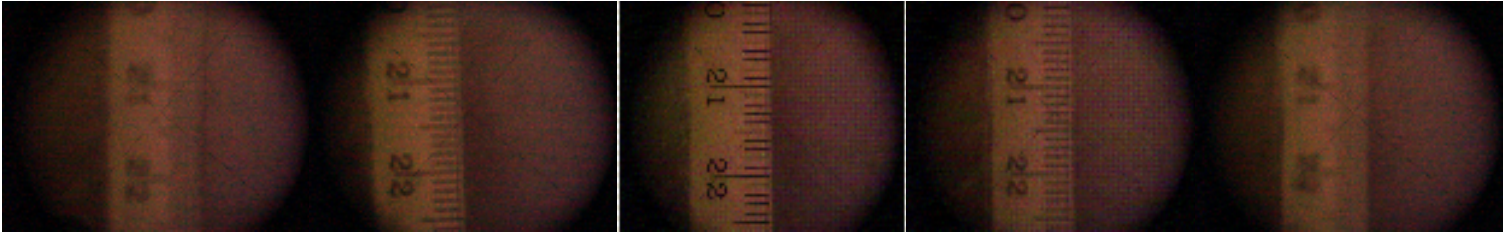


Figure 17) Depth of focus test; from left to right, the object is placed (relative to the focus position) -2 inches \rightarrow -1 inches \rightarrow 0 inches \rightarrow + 1 inches \rightarrow + 2 inches

The last test done with the system was to use it for its purpose of aligning an optic. For this experiment, a mirror with reticles drawn on it was placed some distance away. The telescope was then focused on the mirror and a flash light was inserted into the telescope. When turned on, the flash light would illuminate the eyepiece reticles and show the retro-reflected spot coming off of the mirror. The idea is to adjust the tip and tilt of the mirror so that the retro reflected spot would center itself on the alignment telescope. Figure 18 shows an image seen when aligning. As it can be seen, there is a bright spot at the center of the eyepiece reticles as well as the mirror reticles (the faint black circle). Having this system made it much easier and faster to align the mirror since it was approximately 50 inches away from the telescope. There was no need to travel back to the telescope to check the alignment while adjusting the mirror.

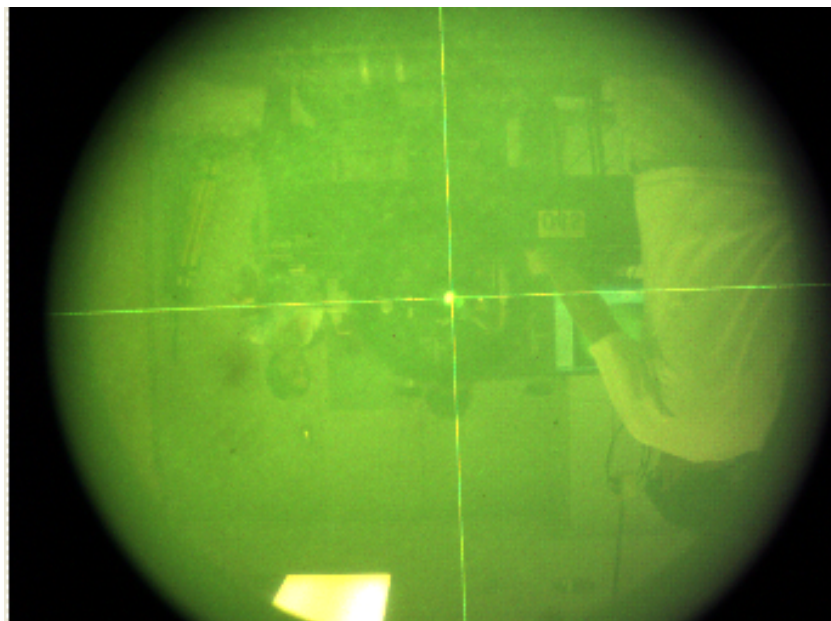


Figure 18) Alignment testing with the system

Conclusion/ Recommendations

Presented in this report was the process of creating a video readout system for an alignment telescope using commercially available parts. An “off the shelf” lens was chosen based off an analysis of the alignment telescope’s eyepiece and a provided CCD camera. A simple mounting tube was machined to support the lens camera system and software was written to display the output of the camera using LabView.

The overall system was capable of capturing 96% of the full field imaged by the eyepiece producing an average full field of view of 0.825 degrees or 49.5 arcminutes. A resolvable depth of focus measured with the system was found to be just short of ± 2 inches from focus, and the system did provide ease of alignment since there was no need to travel back and forth between the telescope and the lens system.

If any modifications were to be made to the system, it would be recommended to replace the 6 mm lens with a lens that 3 mm in diameter along with a focal length of 5.76 mm. This would create optimal results on the current image plane since it would fit in the exit pupil of the eyepiece while capturing the entire field of the eyepiece.