Maritime Domain Awareness System: Optical Setup

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***Abstract* — This paper presents the optical subsystem of the Maritime Domain Awareness System. It will go into the selection of components, as well as how the overall system will work. This paper will also show some of the simulations and testing results, as well as the calculations used to determine the efficiency of the system.**

***Index Terms* — CMOS Image Sensors, Image Sensors, Imaging, Lenses, Optics**

I. Introduction

As an additional component to the Maritime Domain Awareness System (MDAS), we developed an imaging system to assist with the close-range identification of neighboring ships that the radar system picks up. This imaging system, like the rest of MDAS, is made of entirely commercially available materials. The camera system consists of a CMOS sensor with an added lens system for increased magnification and image quality. The goal of this system is to provide more visual context for the data collected on the radar, so that investigating vessels have an easier time finding the unmarked ships.

II. System Components

This system is a relatively standard imaging system, comprised of a CMOS sensor, lens tubes, and a lens, which are mounted on a three-axis gimbal. These components all fit the criteria of "off-the-shelf", which fits the consumer-friendly model that we are trying to construct. This section provides a semi-technical breakdown of each component and why it was chosen.

A. CMOS Sensor

The key imaging component of this system is an Allied Vision Alvium 1800 U-050c CMOS sensor. This sensor has a 0.5 MP resolution and is a popular machine vision sensor. This is a C-Mount sensor with a 4.8 x 4.8 um pixel size. The model we have selected is a color model, with a fast frame rate and global shutter. This sensor can connect straight to the NUC, or to any other USB connected device.

B. Lens

The lens that we chose for this imaging system is a Ø1" achromatic doublet lens. This lens type helps to decrease the spot size, which results in a sharper image being projected onto the sensor. This lens is made of NBK-7 material, has an anti-reflective coating, and a 300 mm focal length to achieve long distance imaging. Originally, we investigated using a Galilean telescope system for long-distance imaging, but this doesn't focus properly onto the sensor's flat surface.

C. Lens Tubes

The lens tubes that we implemented are standard C-mount lens tubes. They help eliminate external light from affecting the system, as the CMOS sensor is very sensitive to light. The total length of the lens tubes adds up to 303 mm, taking into account the focal length of the doublet lens, and the sensor's lens mount.

D. Gimbal

The gimbal that we selected is a three-axis gimbal, which provides horizontal rotation, vertical tilt, and roll to maneuver the camera. Choosing a gimbal with a wide range of rotation is important for the surveillance aspect of our project. The selected gimbal model is a FeiyuTech SCORP-C, which is a high-quality gimbal made for DSLR cameras. This model simulates a professional integrated gimbal system, and lets us precisely move the camera to the targeted area.

III. Simulations and Testing

Before any components were put together, simulations were done in Zemax to verify the feasibility of the selected components. Multiple lens systems were tested out to see which had the smallest spot size, the clearest image simulation, as well as the shortest feasible axial length. Due to the sensor's flat image plane, the typical telescope lens system does not work well with this setup. Therefore, an achromatic doublet lens was selected, since it can effectively decrease the spot size, and focus directly onto the camera plane.

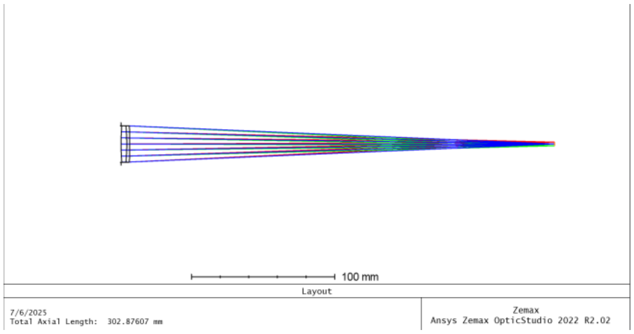

Fig. 1. Final lens design Zemax simulation

The distance between the Ø1" aspheric doublet lens and the sensor must be 303 mm, in order to properly focus the image onto the CMOS sensor. This is due to the effective focal length (EFL) of the system being 300 mm, found from the achromatic doublet lens [1]. This EFL was realized using three separate 100 mm long lens tubes, as well as 1 mm spacers to get the distances as precise as possible. Looking at Figure 1, the three different fields are the represented field of view (FOV), based on the calculations represented in section IV. The blue is at the incident angle, while the green and red are at ±.25° to get the full simulated FOV. This lens setup produced the following simulated spot sizes:

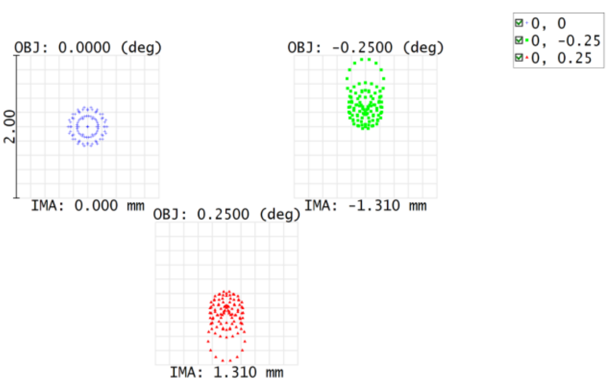

Fig. 2. Simulated Zemax spot size

This spot size is important to the quality of the image produced, because the smaller the spot size the finer detail that can be produced by the imaging system [2]. The smaller spot size also produces sharper boundaries and increases the contrast between different objects in the picture. Looking at Figure 2, the color of the spot size corresponds to the fields specified in Figure 1. The spot size at the incident angle has a radius of .183 um, while the spot size at ±25° are both 0.403 um. Since the spot size that was simulated is quite small (less than one millimeter) this means the produced image will be of higher quality.

When put into practice, the system first produced clear images at four meters, with mild pixel discrepancies (due to the high resolution of the CMOS sensor). These pixel discrepancies needed to be manually filtered through and fixed using a code implemented into sensor's software development kit (SDK), VimbaX. The initial tests for this system were done without the gimbal, with the imaging system mounted on a tripod.

The resulting initial testing image is shown below:

Fig. 3. Initial testing image at four meters

IV. Calculations

In order to properly understand the efficiency of the system, a few calculations were done, both by hand and by using MATLAB. We needed to find the field of view (FOV) as well as the angular resolution of the imaging system. The equations are as follows:

$$FOV_{angle} = 2 * \tan^{-1}\left(\frac{sensor\ dimension}{2f}\right) \quad [1]$$

$$FOV_{object} = \frac{Sensor\ Dimension * Working\ Distance}{f} \quad [2]$$

$$\propto = \frac{physical\ seperation\ (m)}{distance\ to\ object\ (m)} \quad [3]$$

$$\propto_{sensor\ limited} = \frac{2 * pixel\ size}{focal\ length} \quad [4]$$

$$M = \frac{Image\ size\ (sensor)}{FoV\ Dimension} \quad [5]$$

Here are the three angular FOV values calculated:

$$FOV_{Horizontal} = 2 * \tan^{-1}\left(\frac{3.8784\ mm}{2 * 300\ mm}\right) = 0.741°$$

$$FOV_{Vertical} = 2 * \tan^{-1}\left(\frac{2.9184\ mm}{2 * 300\ mm}\right) = 0.557°$$

$$FOV_{Diagonal} = 2 * \tan^{-1}\left(\frac{4.8538\ mm}{2 * 300\ mm}\right) = 0.927°$$

Here are the two object FOV values calculated:

$$HFOV = \frac{3.8784\ mm * 3048\ mm}{300\ mm} = 39.40$$

$$VFOV = \frac{2.9184 * 3048\ mm}{300\ mm} = 29.65$$

Therefore, the magnification is:

$$M = \frac{3.8784}{39.405} = \frac{2.9184}{29.651} = 0.09\ x$$

We calculated the angular resolution using a MATLAB script, uploading the image to find the pixel separation using the intensity profile of the image. For the image in Figure 3, the angular resolution is 0.002°. The sensor limited angular resolution for the 0.3 mm image distance is 0.00004°.

VII. Conclusion

All of the previous content comprises the imaging system of the Maritime Domain Awareness System. This imaging system provides additional visual information to benefit a complex radar system, and everything is made of entirely off the shelf components. MDAS hopes to improve our nation's security in international waters, and this paper outlines just one of the pieces of the entire impressive system.

Biography

Gianna Montevago is a 22-year-old graduating Optical Engineer. She hopes to pursue a job in fiber optics, either in fabrication or as a technician.

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References

[1] Edmund Optics. "Understanding Focal Length and Field of View." Accessed 2 July. 2025. https://www.edmundoptics.com/knowledge-center/application-notes/imaging/understanding-focal-length-and-field-of-view/

[2] Micro X-Ray, "X-Ray Sources 101: What is Focal Spot Size and Why Does it Matter?," *Micro X-Ray*, Nov. 22, 2022. Accessed 2 July. 2025. https://microxray.com/x-ray-sources-101-what-is-spot-size-and-why-does-it-matter/