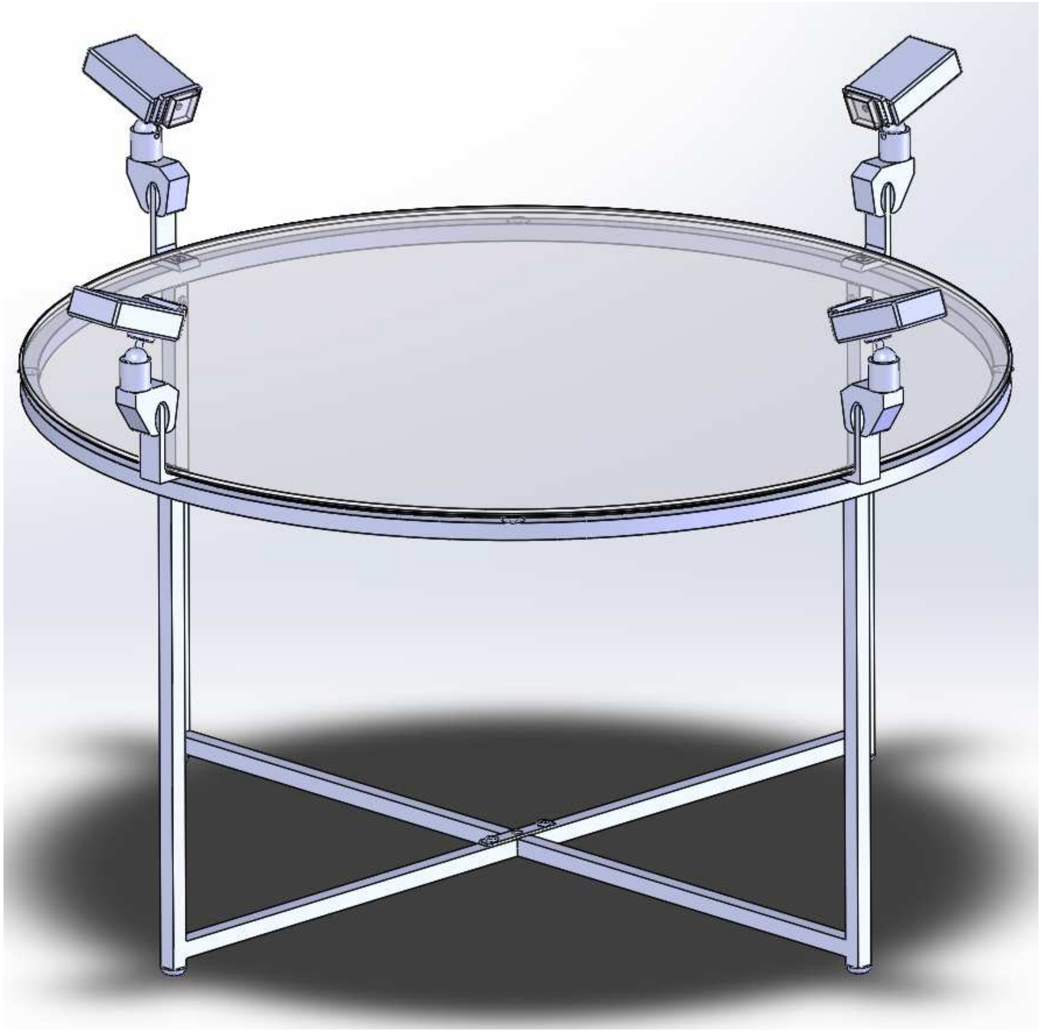
Lens Health Detection System

Client: L3Harris

April 28, 2020



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Project Goals

L3Harris designs innovative solutions to meet customer needs within the defense industry. Their designs are used in applications from night vision goggles to deep space telescopes, and require lenses of various sizes. The status of these lens surfaces play a substantial role in either mission failure or success.

Mission failure leads to the loss of time and resources. The operators of various optical systems need to have information on whether or not a lens is compromised in order to continue on the path to success. In some cases it is difficult to check the lens surface prior to operation due to the operator not being in the same vicinity of the optical system. This results in an inefficient task of someone having to physically check the lens surface prior to operation, which cannot be performed every time. The primary goal of this project was to provide the operators the necessary information to identify and correct any defects on the lens surface before they compromised mission success.

The team understood the importance of making an impact and completing a project corresponding with L3Harris' design standards. The mission was to design, prototype, and test a Lens Health Detection System to be adapted for future use in L3Harris optical systems. Due to the large variations in lens sizes and applications, the team aimed to produce a design which could easily be adapted for use on many different optical systems.

The changes made due to COVID-19 provided unprecedented challenges for the team. Hardware was unable to be passed between hands, and all remaining software development and testing was completed using two Raspberry Pis rather than four. The team also required devices on-campus to complete testing which were unable to be used, most importantly an Environmental Chamber. Software development and testing was modified due to the mandated stay at home order.

Background

L3Harris holds many important roles within the defense industry, one of the most significant being developing optical systems These systems are designed to perform on many different fronts, and have applications in everything from warfighter effectiveness to intelligence. One of the most crucial aspects defining optical system efficiency is the status of the surface of the optical lens. It is critical the lenses on L3Harris optical systems are completely unblemished to accurately relay data and achieve mission success.

Currently, the only way to identify defects on the lens surface is merely by looking at it. This requires the operator physically check each lens before use, a greatly inefficient process. In some applications, these blemishes may not be found until images are returned from the optical system and abnormalities are observed. In this case, the data collected cannot be used and the initial mission would be considered a failure.

The Lens Health Detection System (LHDS) was designed as the solution to identifying defects on the lens surface. The LHDS increases the efficiency of optical systems by processing and outputting an image of the lens surface with all defects clearly displayed. It includes hardware that can be adapted for use in multiple optical systems, focusing on lenses between 1 and 2.4 meters in diameter. The optical systems on which the LHDS can be placed vary in size and movement. The LHDS was designed to minimize the moment added to the optical system to ensure the system will calibrate accurately with the LHDS connected. It was crucial to guarantee the LHDS would not interfere with the operation of the optical systems in any way.

One of the most crucial requirements was for the LHDS to detect defects greater than or equal to 0.2 square inches. The LHDS achieves this requirement using four Raspberry Pi 4 Model B, Raspberry Pi camera modules, and other lightweight COTS products paired with Python software. Once installed, the optical system operator will easily be able to execute the system using a straightforward GUI on the system's computer. The software relays an image of the lens and identifies the presence of any defects that could compromise operations.

System Functionality

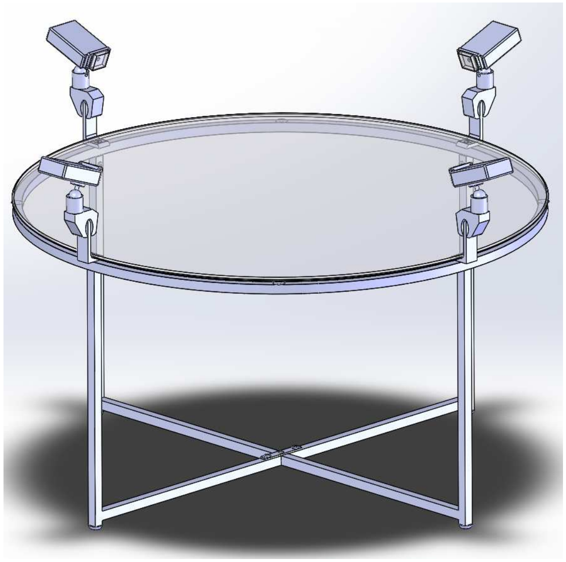
Software Breakdown

The current Lens Health Detection System utilizes four Raspberry Pis and four Raspberry Pi Camera Module V2 cameras to capture multiple images of the lens surface. One Raspberry Pi acts as the master Pi and the other three as the slave Pis. The master Pi orders the other three slave Pis to capture and send the images back to the master for processing. The master Pi then stitches the images together and processes them using Python and OpenCV software.

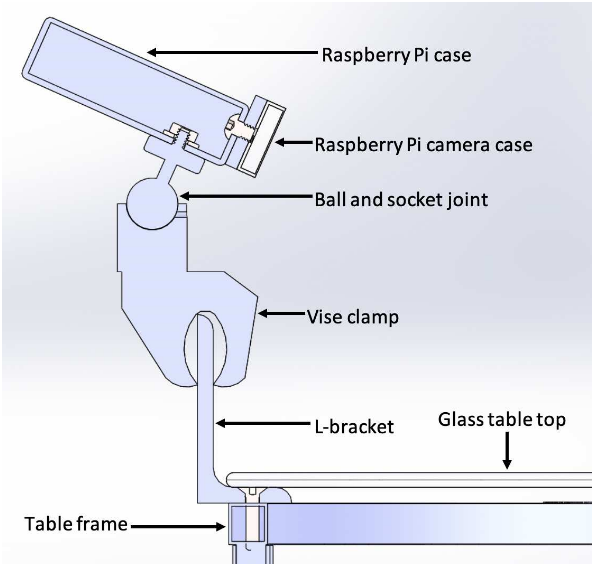
A base image of the lens without defects is used as a reference point to which other images are compared. The LHDS checks for defects by comparing the new stitched test image of the lens to the reference image and finds the difference in pixels between each image. The resulting image depicts the differences between the reference and test image. The software then outlines and calculates the size and location of each defect within the resulting image. All reference, test, and resulting images are automatically stored in individual files on the master Pi where the user can access them. The program is initiated on a graphic user interface (GUI) with multiple buttons for the user to take the images and process them in a simple and easy format.

Model Breakdown

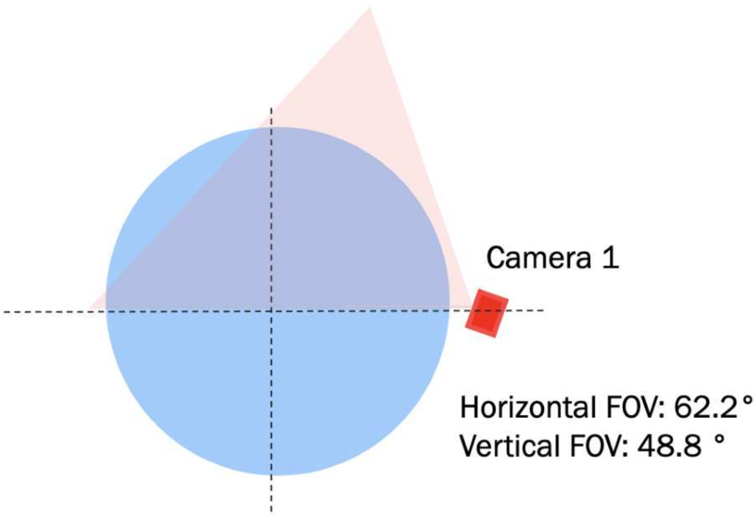
To model a large optical lens without going over budget, a meter sized glass table top has been used. The table included a circular metal frame as shown in the top image. Through several design iterations, a mounting mechanism was designed using a combination of off the shelf parts. The system is optimized so each Raspberry Pi camera captures over one quarter the lens. It is critical for the mechanism to not obstruct the top planar view of the glass table in any way as to not interfere with the field of view on real optical systems.



The mechanism was designed to be clamped to the side of the table with minimal overlap. A detailed view of this mechanism is shown in the image to the right. Aluminum L-brackets are mounted to the top of the table frame and they represent the retaining ring of the optical system. The vice clamp is critical part to the mechanism because it is adjustable and non-damaging to the L-brackets. The adjustable clamp allows the mechanism to be mounted to different sized retaining rings smaller then four inches. This is key when changing optical systems to survey. It is also key that the clamp has rubber pads where it interfaces the retaining ring so it does not indent or scratch the retaining ring. Another critical component is the ball and socket joint on the clamp. This ball joint allows the camera to be adjusted to the most optimal field of view with three degrees of motion. Once in place, a set screw is tightened to secure its position.



The camera angle is determined based on the diameter of the optical lens. The ball joint has a male screw end and a circular platform to fasten and stabilize the Raspberry Pi. The Raspberry Pi camera is in a plastic case, and this cased is fastened to the Raspberry Pi plastic case. The Raspberry Pi camera is connected to the Raspberry Pi with a ribbon cable. There are four camera systems mounted around the lens to accurately capture the total surface area of the lens. The image below depicts in red the specified area one camera captures. The other three cameras are mounted 90 degrees apart from each other on the table in the same orientation as the first camera for their given quadrant. As specified in the image below, the horizontal and vertical field of view (FOV) ranges the cameras have enable them to cover enough area to capture the entire lens in this orientation.



Testing and Analysis

The main goal of testing was to certify our system will hold up for real-world use, and meet the client deliverables regarding minimum defect size detectability. The test protocols put in place to achieve this goal involved running multiple trials using defects of different origins and sizes. The team wished to add other facets into the testing protocols to certify our project against different temperature and weather conditions, physical durability, and longevity of special paint applications specified by the client. However due to the pandemic, these facets had to be scrapped and our focus placed on the overarching client deliverable of defect size and 100% efficiency under ideal conditions. This was completed using two Raspberry Pis rather than the four initially planned and was carried out at a private location off campus. During this test, a base backdrop and consistent lighting were used throughout the testing process to prevent any outside factors from interfering.

There were five overall system-wide tests with varying numbers, sizes, and types of defects placed. The types of defects placed ranged from simple pieces of paper to dirt and oil marks. The defects were also placed by someone other than the system operator searching for defects on the lens. This prevented the operator from knowing the number of defects and locations of the defects to look for prior to testing.

The results were then taken into account for all false positives and false negatives to measure how accurate the system was. A false positive for this test means the system detects a defect where there is no physical defect. A false negative in this context means the system did not find a defect where there is a physical defect on the lens. During testing there was only one false negative that occurred throughout the entire test and it was concluded that it was due to human error.

Challenges

Some technical challenges in developing the LHDS included learning a new programming language, Python, as well as integrating the hardware components which required a great deal of troubleshooting to figure out how the components interact. The plan was initially to use MATLAB because the team all had experience in this language, but because Raspberry Pi is more compatible with Python the team eventually pivoted to that language for the software. The long-term benefits of using Python outweighed the challenge of learning Python. The team did not have access to any optical systems so a model was created using COTS components and the LHDS was developed and tested using this physical model.

This was the first year-long engineering project for most of the team, so members had to work through all problems rather than ignoring them until the end of the project. The team worked well together and established open communication with the director and the professors. There were many aspects of the LHDS project that required creative problem solving. The onset of COVID-19 in the middle of the second semester required the team to work remotely for the remainder of the project. This was a beneficial learning experience because many real-world engineering projects are done remotely.

Our goal was to provide L3Harris with a LHDS design that they can implement on their optical systems in the future to reduce the time operators spend checking the lenses and reduce the optical system data lost due to damaged or blemished lenses. We have provided a functional prototype that is ready for testing.

Meet the Team

From left to right:

Zachary Aldrich – Test Engineer
My role was to create a dynamic and inclusive testing plan to certify that our design would perform to professional standards in the real world and meet all client specifications. I also aided in the aesthetic design of the final system in preparation for expo.

Frederick Austin – CAD/Manufacturing Engineer
I made sure the mechanical design and the assembly of all components functioned effectively and efficiently, meeting project requirements. I worked with the systems engineer to implement python OpenCV tools to accurately detect defects on the lens surface.

Rosalina LaBarba – Logistics Manager
I managed the team's communications with the client, director, and professors and set up the team's meetings throughout the project. I worked on the aesthetics of the design as well.

Sarah Carter – Project Manager
As project manager, I ensured the project stayed on track by organizing and running all project meetings. In addition to this role, I contributed to the testing of some critical components as well as to the overall design of the project.

Julia Sakiewicz – Financial Manager
My primary role was to manage the project budget and procure all necessary materials. I connected the team with various university and local resources throughout the project.

Sean Wilson – Systems Engineer
I ensured all software for the system was fully functional and capable of detecting defects on the surface of the with accuracy. This included integrating open source code using Python and OpenCV to create a GUI to process images from the raspberry pi's.