Frame-Twist Measurement Device
Final Design Report

PACCAR 02

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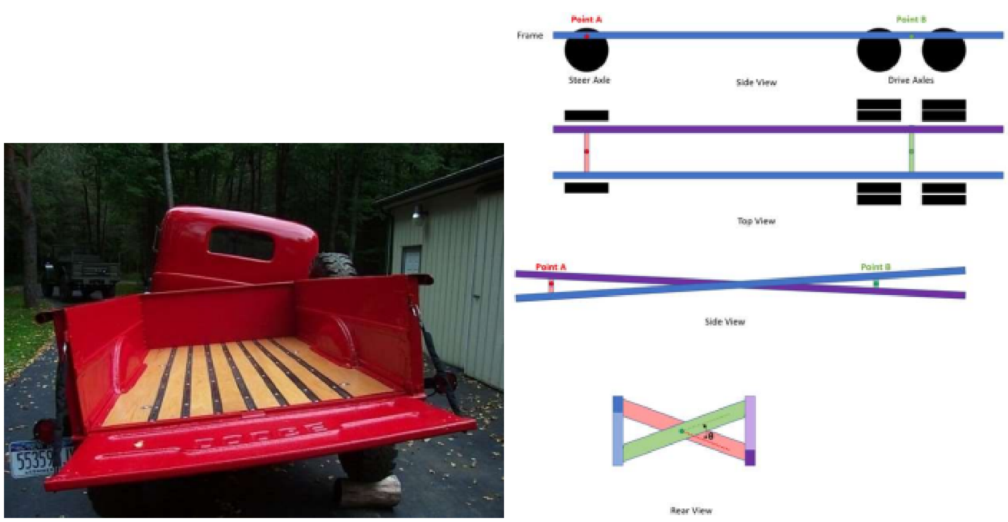
1 Introduction

PACCAR is a Pacific Northwest automotive company that manufactures trucks. These trucks range from light- to heavy-duty trucks, with most products being commercial hauling trucks.

Figure 1. Commercial hauling truck

PACCAR Technical Center is studying the validity of their vehicle model simulations with a large integrated test. Trucks sit on a rectangular frame rail that can deflect as shown in Figure 2b. One of the components under study is the effect of angular frame deflection (”frame-twist”) on the pressure applied to the wheels and thus wheel wear. PACCAR is looking for a simple method to measure tractor/trailer frame twist. They have done past research on various methods of detecting frame-twist and proposed a camera light detector method for us to investigate further.



(a) (b)

Figure 2. (a) visible effects of significant frame twist, (b) Diagram of the frame bars and relevant points

Our objective is to create a device that can precisely measure the torsional deflection of a frame and broadcast this over a CAN network interface in ”real-time”. In addition, our final deliverable must have detailed documentation about all aspects of our device so that PACCAR can easily work with our device after the project has concluded.

In this report, we will dive deeper into the specifics surrounding the scope of our project. We will also present our current design, the work behind our design, the testing that we’ve conducted, and our next steps.

2 Teams, Roles and Responsibilities

This team is comprised of two senior undergraduate Mechanical Engineers and three first-year graduate Electrical Engineers. The team roles and responsibilities broadly fall into two categories: Administrative and technical.

2.1 Administrative Roles

Each person was assigned a role as shown in Table 1 according to their organizational strengths and weaknesses.

Name	Role	Responsibilities
Eric Lee	Documentation Manager	Sets up Administrative documents and keeps track of information documentation
Jonathan Murguia	Part Manager	Part procurement and management
Sanjay Varghese	Team Manager	Ensure team is communicating and organize meetings
Ian Li	Time Manager	Makes sure that we are staying on schedule
Xin Hao Guo	Work Checker	Looks over the work of other members to double check

Table 1. Administrative Roles

2.2 Technical Roles

Members of this team were broken into technical teams as shown in Table 2 according to their knowledge.

Team	Members	Responsibilities
Electrical	Ian, Xinhao	Circuit design and optics
Computational	Sanjay, Ian	Computer Vision and Processing
Mechanical	Jonathan, Eric	Manufacturing and evaluating physical robustness
Test Rig	Jonathan, Eric, Ian	Design and construct physical test set ups

Table 2. Technical teams

2.3 Member Contributions

Jonathan has done the CAD work behind the assembly of our project including the test setup, and light housing assemblies. In addition, he also made the FOV visualizer used to easily visualize the camera FOV based on different test parameters. In relation to manufacturing, Jonathan helped to procure and produce the parts for the first test setup. As for the second and thrid iterations of the test setup, he also procured the materials and assembled them. He also has been behind the manufacturing of the light markers and was behind setting up the field tests. He also created the part inventory list for the project.

Eric has been involved the design choices surrounding the test setup and light markers. He procured some parts for the test setup and helped in the assembly of the setup. He also initiated the design for the camera housing module used for field tests. From the administrative side, Eric has regularly created document templates for weekly assignments and has been the main person behind the Gantt chart and earned value management.

Sanjay has been the main person behind computer vision research and implementation. He has taken part in the design choices and component selection for all the electronics and compute systems. He developed the camera calculation. He has developed the target acquisition code allowing the camera to detect marker patterns. He has written the code to interface the Allied Vision camera with the Jetson Orin Nano while creating the producer-consumer implementation for frame acquisition. He also wrote the algorithm to calculate the angle and co-linearity between redundant markers which would serve as a confidence parameter for angle outputs. From the administrative side Sanjay has been the main point of communication between the team, our TA Kavya, and industry mentors.

Ian has helped in the code behind controlling the stepper motor and has done most of the electrical circuitry for the project. He has also helped filling in the documentation and procurement of electronic parts.

Our industry mentors are Daniel Moreland and Shreyas Chaudhari. Our Faculty mentor is John Reece.

3 Project Schedule

3.1 Progress

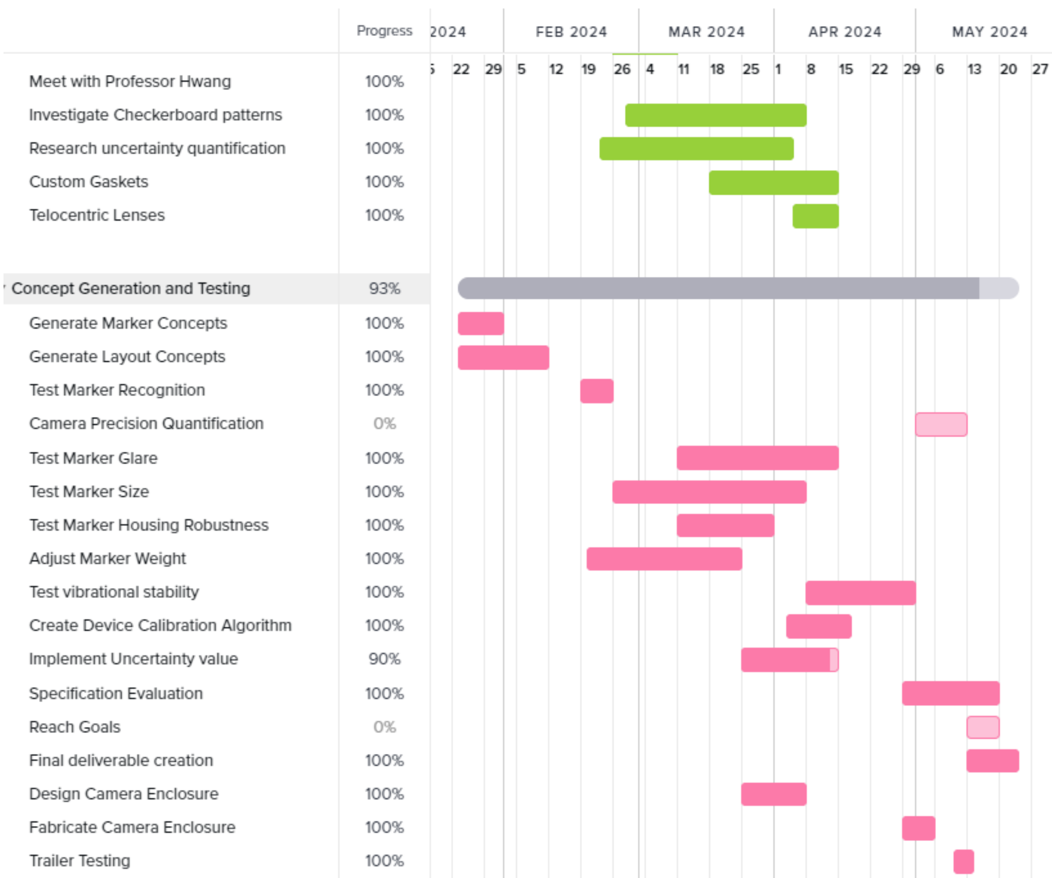


Figure 3. Major tasks for Spring Quarter

The Gantt chart for this project is shown in Figure 3. All research tasks were finished, particularly regarding feasibility, camera and lens selection, specification definition, and algorithms. Our Prototype rig was updated this quarter, and final parts such as camera and lens incorporated into a functional prototype. We did not finish the camera precision quantification nor implement the linear regression error quantification due to time constraints.

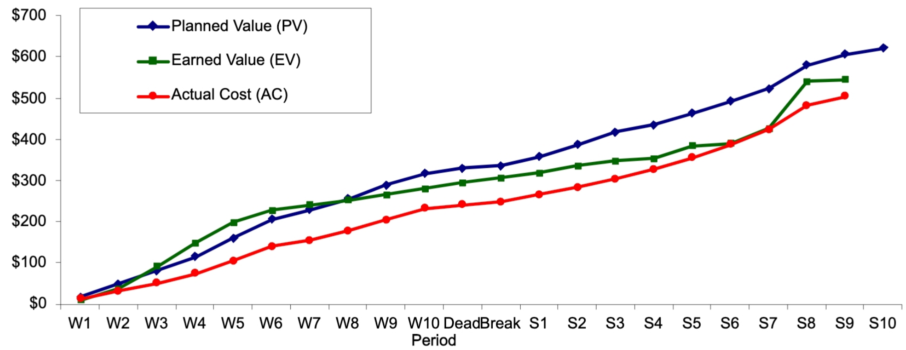


Figure 4. Earned Value tracker for hours spent on this project

As part of our project monitoring, we created the Earned Value Management (EVM) sheet as shown in Figure 4 to evaluate the hours spent on the project versus the planned hours and earned hours. In the beginning we spent half the hours we anticipated on the project yet earned more hours than planned. From week W6 to week W9 of the quarter we faced technical issues and lead time delays which hampered our progress. In response, we spent more hours working on the project, and roughly matched or exceeded the planned number of hours per week for the remaining time on the project. Our earned value lagged however due to the iteration and testing conducted throughout spring quarter running into many unexpected challenges. In week S8, we were able to conduct field tests in Mount Vernon, which led to great progress on our testing tasks. Overall, we finished roughly a week behind schedule, which was compounded by the capstone presentations being on week S9 rather than week S10 like we initially anticipated.

3.2 Work Breakdown Structure

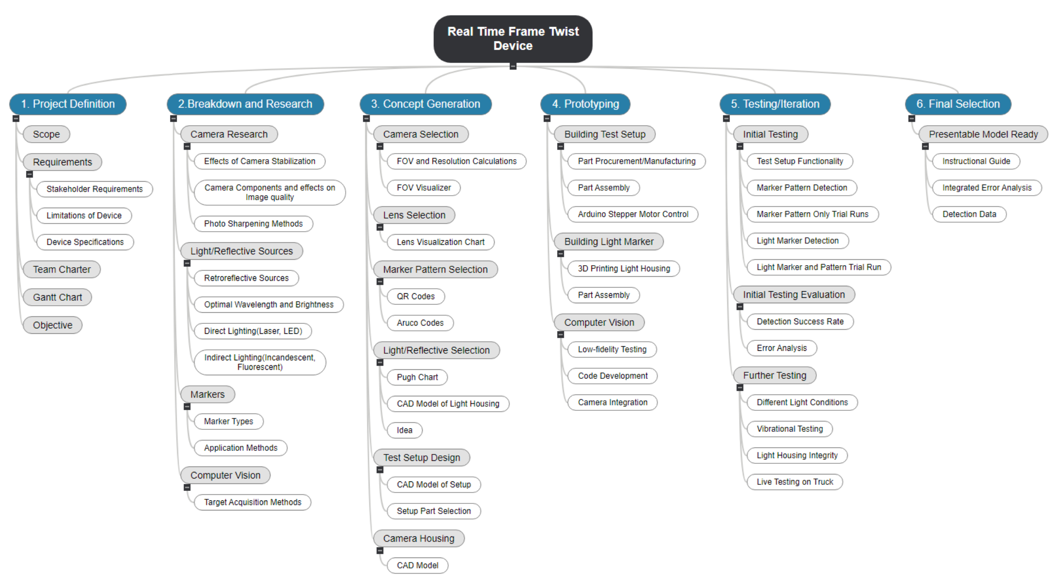


Figure 5. Work Breakdown Structure

Our Work Breakdown Structure (WBS) is shown in Figure 5. Our six major project categories were broken into subcategories and individual items for easy organization.

4 Project Budget

Our project was allocated a budget of \$3000. We have made six purchase requests for a total of \$1922.95. We have \$1077.05 left in our budget. A detailed expense summary is shown in Table 3.

Item Description	Item cost	Quantity	Total Cost	Reimburse?
Motor Shaft Collar	2.17	2	4.34	Y
NEMA23 Mounting Brace	12.99	1	12.99	Y
1/2ft Aluminum Extrusion	16.33	1	16.33	Y
Red and White Reflective Tape	22.99	1	22.99	Y
Red Tape	3.94	1	3.94	Y
Light Difusing Film	15.98	1	15.98	Y
Jetson Orin Nano	499.00	1	499.00	
Micro HDMI cable adapter for Rpi 4	8.99	1	8.99	Y
Sandisk 64GB memory card	13.24	1	13.24	Y
Amazon basics Tripod 50in	20.70	1	20.70	Y
RPI HQ camera Varifocal Lens	64.99	1	64.99	Y
M2.5 Female to Male Standoff	2.37	4	9.48	
RPI 4 Camera Mounting Plate	6.95	1	6.95	
RPI HQ Camera	50.00	1	50.00	
Allied Vision Alvium 1800 C-510M	645.77	1	645.77	
TechSpec 25mm lens	260.00	1	260.00	
Tamron M118FM25 25mm lens	149.95	1	149.95	
CSI-2 camera adapter for allied vision camera	33.75	1	33.75	
MCP2515 CAN Bus Module	10.59	1	10.59	
SN65HVD230 CAN Board	9.99	1	9.99	
Wire Coneectors	9.95	1	9.95	
1 by 4 Fir Board	5.98	1	5.98	
Mounted M25.5 x 0.5 Threaded - Red Filter	47.5	1	47.5	
Total			1922.95	

Table 3. Budget Summary

5 Realistic Constraints

1. **Budget**
   - While the provided budget is sizeable, the cost of high resolution high frame-rate cameras imposes a limit on the achievable precision and sampling rate achievable in this project.
2. **Environmental Conditions**
   - This device is mounted on the outside of a truck. Though its position under the truck gives it some protection from the elements, some degree of waterproofing must be implemented to protect it from rain.
3. **Interoperability:**
   - The device must interoperate with existing electronic systems on the CAN bus. Compatibility with standard CAN addresses which is well documented ensures seamless integration with other electronic control units.
4. **Maintenance:**
   - Minimizing maintenance requirements is essential for continuous operation or repeatable testing conditions. The system should be designed for easy troubleshooting with accessibility of ports and ease of mounting options, reducing downtime.
5. **Scalability:**
   - Tractors and trailers vary in size and complexity. The system should be scalable to adapt to different tractors and trailers, accommodating diverse vehicle layouts.

6 System Requirements

The device should be ”real-time”, as defined by a sampling rate of at least 60 Hz, with 120 Hz as the reach goal. This is to satisfy the Nyquist sampling criteria and avoid aliasing when analyzing the data.

Due to the length of the vehicle tests, the device must run for at least 30 seconds, and preferably much longer to allow for more complex testing.

The range of measurable relative angular deflection should be ±20° with a reach goal of ±30°. This is the anticipated range of movement for the frame beam and thus must be captured.

Maximizing the precision and thus resolution is essential for simulation verification. This device must have a confirmed level of precision of at least 0.25° with a goal of 0.1°.

The device must be flexible and function on a variety of trucks with wheelbases between 120-350”, with the target wheelbase of 235”. Due to the mounting constraints the distance between the camera and the markers will be 160” ±10”. The marker separation can be a maximum of 35” ± 1”. This is necessary to be a useful diagnostic tool for many vehicles.

Since this device will be mounted on a truck and experience rigorous vehicle tests the device must be physically robust to prevent breakage. It must withstand operation without damage or displacement, survive vibrational accelerations under 2g, and angular velocities up to 360 deg/s. The device setup and components should be physically robust

This device must also be operationally robust. This means having forms of redundancy and data checking built in so it can operate under non-ideal conditions and reports its quality of data.

For ease of data collection, the device data must be outputted as CAN packages onto the truck’s CAN Bus. Diagnostic data such as confidence level and jitter must be reported. Error messages, such as if the reported angular velocity is greater than PACCAR estimations should be displayed for diagnosis. Due to the confidential nature of truck specifications video should not be recorded and the device should not use excess memory.

6.1 Operating Hazards and Requirements

1. **Precision and Accuracy Requirements:** The device must achieve a minimum precision of 0.25° with a goal of 0.1°, measuring angular deflections within ±20° . Sampling rates must be at least 60 Hz, with a target of 120 Hz.

2. **Electromagnetic Compatibility Requirements:** The device must comply with automotive EMC standards to prevent interference with and from other electronic systems, ensuring reliable CAN bus data transmission.

3. **Safety Requirements:** The device must be securely mounted, free of hazards, and incorporate fail-safes to shut down during critical errors, ensuring it does not pose any risk to operators or vehicle components.

4. **Standards Requirements:** Compliance with ISO 26262 (functional safety), ISO 11898 (CAN communications), and ISO 16750 (environmental testing for automotive electronics) is required to ensure reliability, safety, and interoperability within the automotive ecosystem.

7 System Specifications

For our design, we decided to stick with the camera-based approach that PACCAR initially suggested we investigate for we think in terms of flexibility it has potential.

Our design in regards to frame rate could only obtain a maximum frame rate of 45Hz which is lower than the requirement of at least 60Hz. This is due to a technical issue with our camera's drivers still not being up to date which limits performance.

In regards to the length of our testing runtimes, the device can operate in tests exceeding the minimum runtime of 30 seconds.

In our tests, our device has measured up to ±30° which means we've met our reach goal. The device could likely measure beyond this, however, 30° is already an extreme angle for a truck frame and so we've stuck closer to the angle range of ±20° for most of our testing.

With our current methods of testing our device has reached the required accuracy of 0.25° and has had success in reaching an accuracy of 0.1° . However, we can't fully validate the accuracy for we have doubts in the sophistication of our testing setup which we discuss later in the report (make sure to include a bit about this in testing methods).

8 Design Implementation

8.1 Alternative Proposals

Various alternate proposals were evaluated by our client PACCAR. An accelerometer solution was deemed unsuitable due to the long runtime requirement creating enormous tolerance stack ups. A torsion bar proposal was infeasible due to the complex routing required to install such a bar. Strain gauges were also proposed however since the other dynamical effects such as beam bending also contribute to the gauge outputs, the analysis and filtering out other contributions was deemed too complex.

8.2 Design Overview

The proposed solution our team investigated consists of a camera module and light marker modules. The camera module is attached to the front end of a truck frame and is positioned facing the back end where the light marker modules are mounted which can be seen in Figure 6. The camera module uses computer vision to recognize the light markers, extract a coordinate location, and determine the angle relative to a reference 0° line.

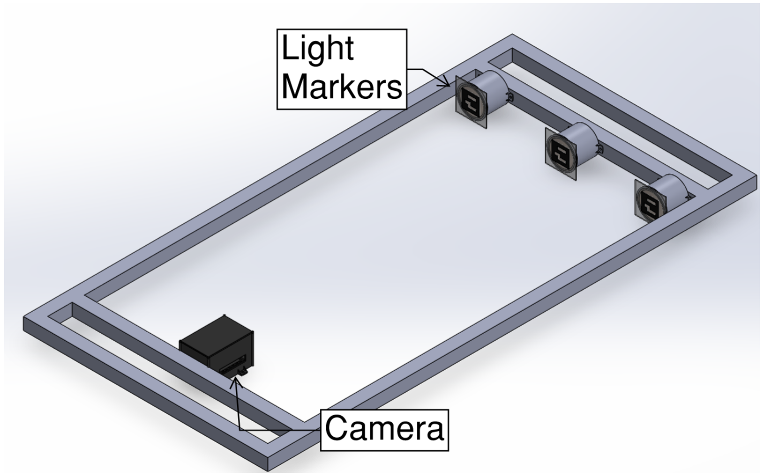


Figure 6. Concept of our solution on a truck frame

8.3 Hardware Design

8.3.1 Light Marker Design

A major concern at the beginning of this project was the influence of environmental lighting conditions on the performance of the camera. Low-light conditions could reduce marker distinctiveness while bright conditions could create glare artifacts which could distort the image and prevent marker detection. Thus, we designed a light marker module to address those concerns

The light markers consist of a 3D-printed housing which encases the light source. Attached to the housing is a red filter, acrylic diffuser, and the ArUco marker pattern.

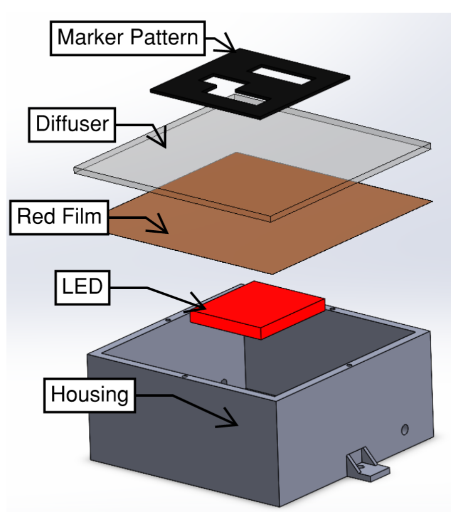


Figure 7. Exploded view of light marker assembly

Light emitted from the light source is focused by the reflector cone before being diffused to create a uniform back lighting for the marker, allowing sharp marker pattern contrast independent of the environment. The markers are constructed from a matte material to mitigate glare artifacts caused by external light sources.

Figure 8. Illuminated Light Marker

8.3.2 Camera Module Design

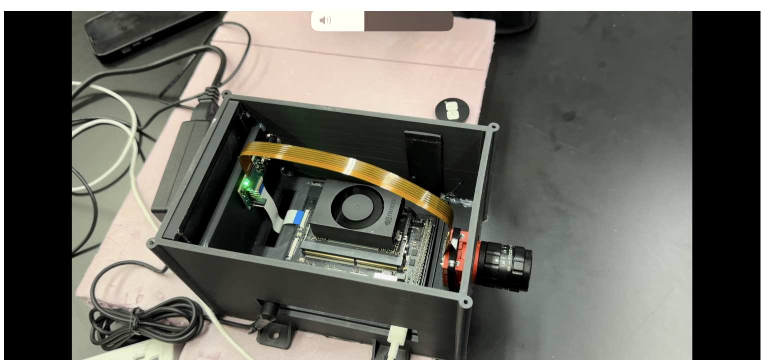


Figure 9. Top view of camera module

The electrical hardware consists of a high speed 81 FPS 5.1 MegaPixel camera which is connected to a Jetson Orin Nano through a CSI-2 interface, ensuring rapid image acquisition and processing capabilities for real-time marker detection and angle calculations. The monochrome camera was selected for its higher light sensitivity and faster data readout rate, essential for achieving high-speed performance and accurate detection. A 25mm focal length lens was chosen based on the wheelbase specifications to optimize the field of view, and a red lens filter was incorporated to enhance the contrast for the red-illuminated marker patterns, further improving the accuracy of marker detection. These components are encased in an enclosure to protect the electronics from water and dust. Special care was taken to ensure the CSI-2 cable could be connected in the correct orientation with the adapter and the Jetson Orin Nano.

8.4 Software Design

The software design for the system is split in 4 main sections.

1. **Image Preprocessing:** The system, being placed underneath the truck, is expected to encounter various lighting conditions, foggy climates, dust, and other external factors. These conditions can cause the captured images to differ significantly from the reference images. Therefore, initial preprocessing of the image is necessary to enhance and correct the images, bringing them closer to the reference before any identification process is run. This step includes enhancing the image, correcting lens distortion, and thresholding to sharpen the ArUco codes.

2. **Marker Identification and Detection:** The current candidate for the markers is ArUco codes, which are computationally simple and consist of 4x4 blocks of monochrome checker patterns unique to each code. These codes also allow for the determination of orientation with respect to the camera. Once the ArUco codes are identified, their positions in the frame are estimated to calculate the centroids of all relevant markers. This data is fed to the ROI estimator block which dynamically crops the actual frame of the camera to a reduced image for faster ArUco detection. This is the primary means of having a faster computation while detecting ArUco markers and calculating the angle out of it all within the predetermined time frame.

3. **Angle Estimation and Error Handling:** The positions of the markers are used to calculate the angle between them, taking into account any jitter or random noise that might affect the data. This step ensures accurate angle estimation and includes error analysis and confidence calculation. Having more than 2 markers adds redundancy to the error analysis which is beneficial in estimating confidence over the measured angle. For this calculation, the adjacent marker distances can be verified and used for deducing confidence parametrics.

4. **CAN Data Broadcast:** The final angle value, along with additional helpful data like the distance between adjacent markers, number of detected markers, collinearity between makers and likewise, is broadcast over the CAN bus. This allows the next system to derive further information from the test.

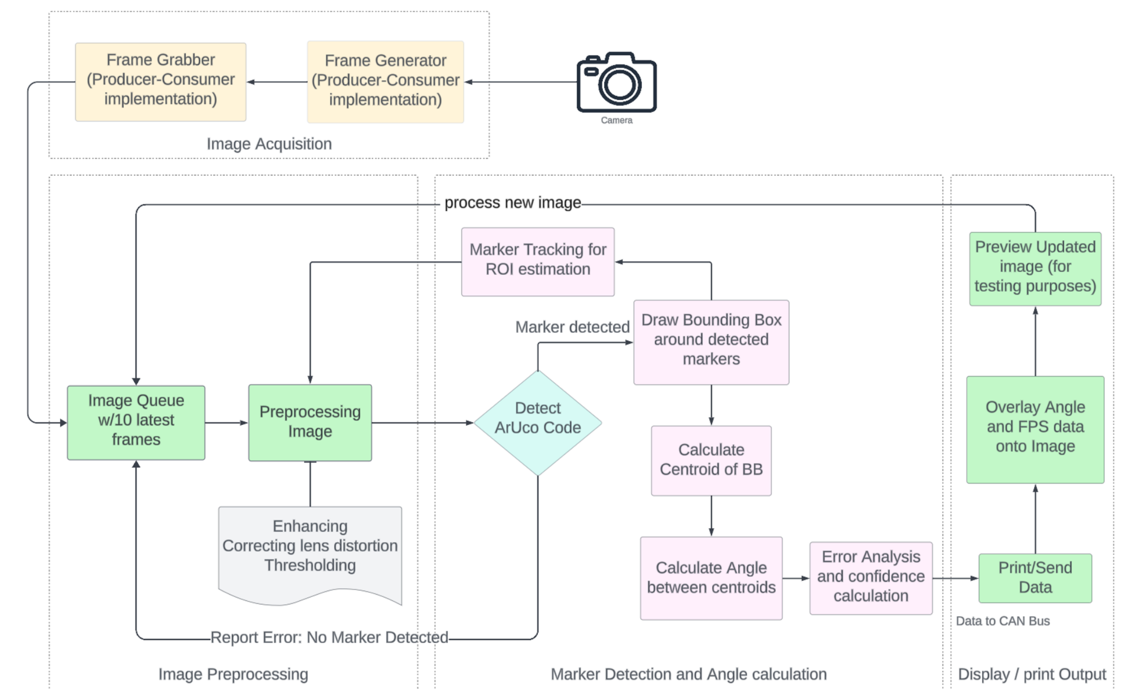


Figure 10. Device Software UML Diagram

A Unified Modeling Language (UML) Diagram of the entire process is shown in Figure 10.

9 Design Methods

9.1 Design Selection

9.1.1 Camera Selection

The ability to recognize the marker pattern while covering the entire range of beam motion while incorporating buffer space was our main priority. The beam length combined with the ±30° range of motion requirement thus drove our calculated Field of View (FOV) size. This lead us to selecting a 38”×21” dimensional FOV. Our 0.1° pecision requirement was the driving factor in selecting a pixel FOV. We needed to select a Pixels Per Inch (PPI) value which allowed us to resolve the marker clearly, which we decided 68 PPI was a good value. This gave us our final FOV value of 2584×1428 Px. Another requirement was that we need to output a minimum of 60Hz data-rate. The closest camera that would fit this requirement was the Allied vision Alvium 1800 C-510M which has a 5.1MP (2464x2064 pixels) and 81 FPS output. The global shutter was also beneficial to prevent truck vibrational movement from distorting the image during capture. The MIPI CSI-2 interface works directly our choice of edge computer (Jetson Orin nano) so processing time is saved relative to using a USB interface version.

In addition, to better visualize the FOV of the camera we developed the CAD Visualization model shown in Figure 11. This model takes in differing parameters such as focal length of the camera and outputs the projected FOV of the camera.

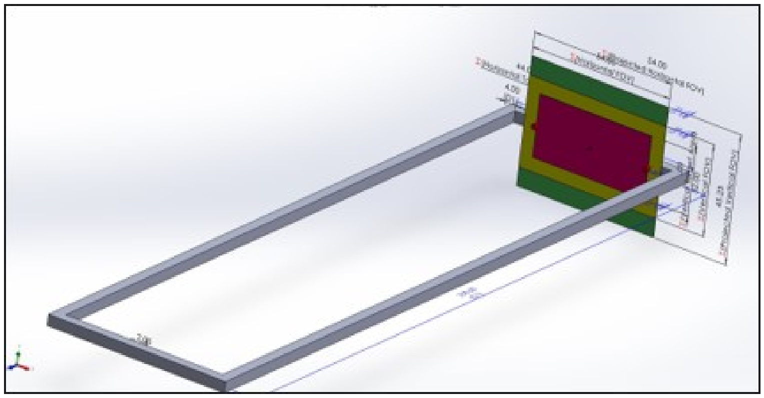


Figure 11. FOV Visualizer. The red indicates the expected frame range of motion, yellow as buffer for translational movement, and green as regions which can be neglected.

9.1.2 Camera Lens Selection

The range of wheelbase values (120 - 350”) is too broad to be captured by a single lens. Thus, we created a method of identifying what distances a lens diameter would work for. We established the lower limit of a lens’ range as the minimum distance needed to ensure the FOV was fully captured. The maximum limit was where 5% lens distortion occurred. We then created a visualization chart as shown in Figure 12.

We chose to focus on the typical 235” wheelbase truck, and using the visualizer guide chose the 25mm lens diameter. After being informed that the actual marker-camera distance was 160”, we were relieved to see that the 25mm still worked, and as a bonus would have less distortion. Our final lens selection was the TechSpec 25mm lens.

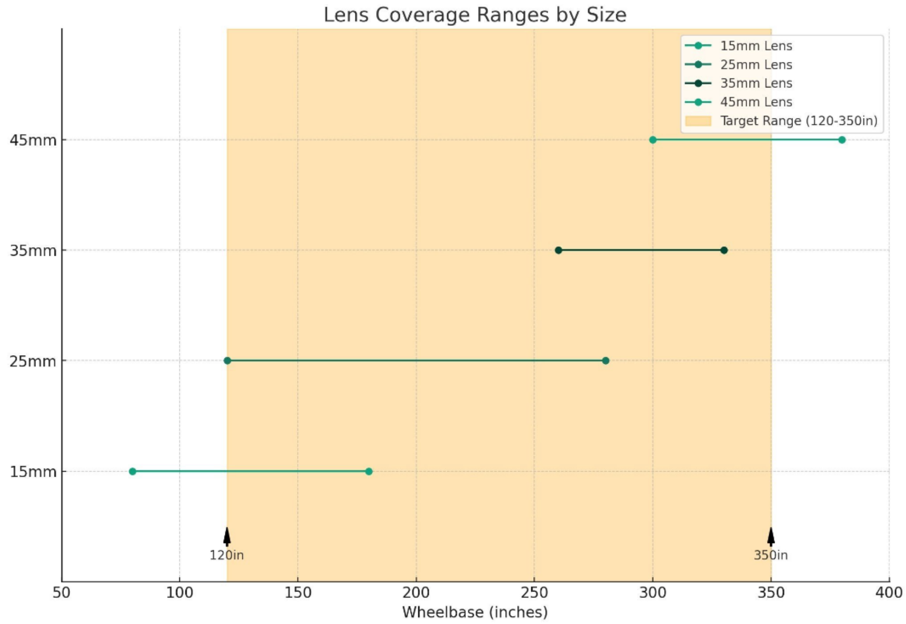


Figure 12. Lens Selection Visualizer

9.1.3 Marker Selection

For determining what marker design to use in our project we used a Pugh Chart. We used compared candidates on their brightness, potential glare, consistent visibility, identifiable, robustness, and cost. We based our analysis off of what we knew about how these marker types would work with our current camera setup and assigned values accordingly. Using this chart, shown in Figure 13, we decided to go with the Light Markers.

Problem/Situation: Frame marker Type Selection

Criteria	Baseline (Reflective Markers)	Light Sources	Retro-Reflective Markers	Light Markers		Totals	Rank
Brightness	3	+	–	+	–	-1	5
Potential Glare	2	0	–	0	–	-3	7
Consistent Visibility	3	+	0	+	–	0	4
Identifiability	4	–	+	+	–	-1	5
Robustness	2	0	–	0	–	-3	7
Cost	1	0	–	0	–	-3	7
Totals		1	-3	3	#		
Rank		2	3	1	4		

Figure 13. Marker selection Pugh Chart

As for the actual design of the Light Marker in Figure 8, we chose to incorporate the red-tinted film, diffusion film, reflector cone, incandescent light bulb, and 3D-printed housing. The red-tinted film makes the light red which is a comparably distinct color, making detection easier. The diffusion film makes the light spread more consistent so there are no bright spots. The reflector cone allows the light to be focused in a particular direction, making the light brighter at a farther distance. The incandescent light bulbs are simple to install, have adequate brightness, and have a known light spectrum.

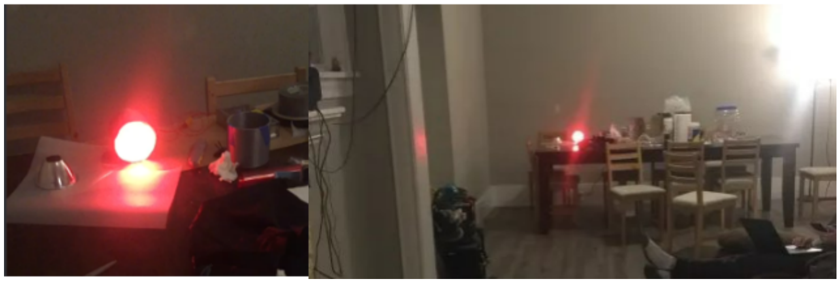


Figure 14. Light Markers in action

For the marker material, we initially used designs printed on printer paper for low fidelity testing. During testing we found that while they were identifiable, there was noticeable distortion during image processing. We attributed this distortion to the lack of straight defined edges and the bleed through.

We then tested sticker paper due to its transparency allowing much stronger contrast. The adhesive backing minimized distortion from marker curvature however its glossy surface created extreme glare artifacts from reflecting external light as shown in Figure 15.

These markers will be mounted underneath a truck, so direct sources of high intensity external light are minimized, however situations may arise where incoming vehicles may create such glare. Thus, we tested a matte black vinyl sticker whose surface eliminated the glare artifact issue.

Figure 15. Left: Sticker Markers, Right: Glare on Markers

10 Test Design

10.1 Test Setup Design

The test setup is to allow us a way to test how effectively the camera can detect the angle of twist and to what accuracy.

For this, we used a long aluminum extrusion beam to attach the light markers at set distances from the center. The beam is attached to a stepper motor that controls the angle the beam is set to. This whole beam setup is set a certain distance away from the camera.

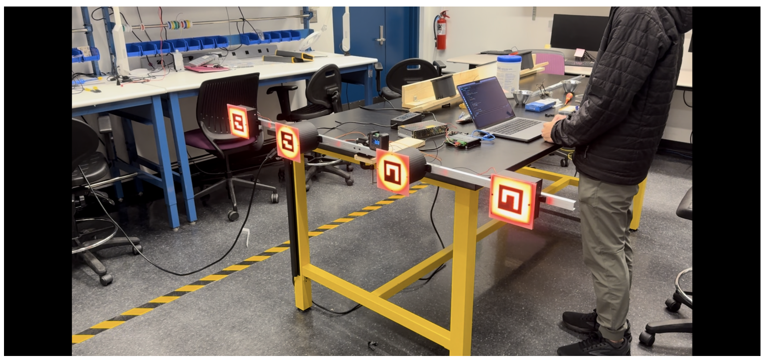


Figure 16. Test Setup ready for testing

We also have Demo Video to show a demonstration of our testing process for our prototype.

10.2 Completed Testing

We have done tests on environmental glare and found that the glare was significant and switched to a matte marker surface. From testing QR code marker designs we concluded that they were too detailed and switched to ArUco codes.

Vibrational testing using a vibrator table did not generate amplitudes high enough to indicate clear camera distortion.

Figure 17. Field Testing Setup

Field testing revealed that our light marker modules did not experience glare artifacts and had clear pattern contrasts. Interestingly, the reflector cones introduced distortion to the pattern, leading to our recommendation to remove the reflector cones. Due to the high temperatures during field testing and the black module housing, the PLA which composed the marker began to warp as it reached its glass transition temperature. We recommend switching to a high temperature plastic such as ABS or to a metallic module material to prevent this.

11 Results and Recommendations

Listed below are the graphs that we plotted to compare our system to a standard digital guage. For a reference, we relied on the fundamental working principle of stepper motors since each step of a stepper motor moves by a fixed rotational value. As shown, most of our calculated angle values were under the accuracy threshold requirement. The drawback of the digital gauge is the error accumulation overtime due to vibrations which is overcome by our instrument.

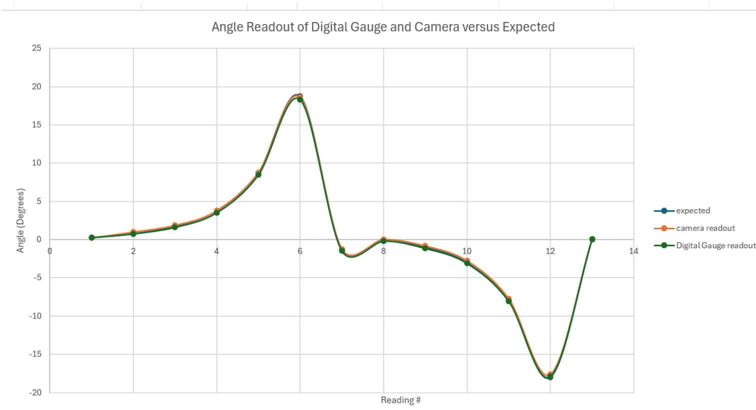


Figure 18. Angle Readout of Digital Gauge and Camera versus Expected

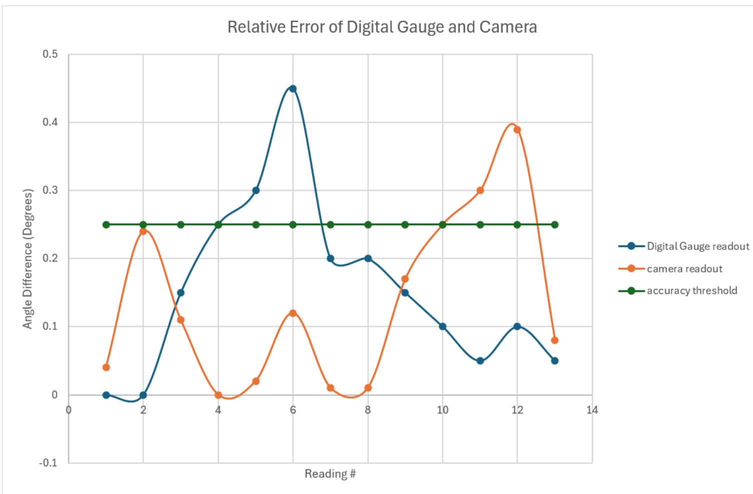


Figure 19. Relative Error of Digital Gauge and Camera

Our selected camera has a frame rate of 80 FPS. Dr. Hwang has indicated that computer vision computations should be quick and not interfere with the 60 FPS goal. Unfortunately, due to the recent release of this camera, optimized drivers have not been released for the Jetson Orin Nano, thus limiting the device performance to 45 FPS.

A ±20° range of motion was achieved and due to our feasibility calculations utilizing a ±30° specification, that range of motion should be easily achieved. Our prototype can achieve the specified 0.2° precision at our target 160” camera-marker distance.

The light marker performs as intended, preventing image quality from being affected by the environmental conditions.

The lens selection guide presents a convenient method of quickly switching lenses to use on trucks with other wheelbase lengths.

12 Future Steps

- Interfacing with the CAN network was nonviatal to the function of the prototype and thus not implemented due to time constraints. Interfacing with the CAN network is a task that will need to be implemented by PACCAR in the future.
- Converting the 3DP parts from PLA to ABS plastic would increase the thermal resistance of the enclosures which is a necessity even now considering the mounting point of these enclosures. Metal enclosures could also be explored which would provide even more ruggedness. This would open up the possibilities of making the electronics IP rated.
- The current implementation doesn't account for lens distortion which could be significant for wide angle lenses. So distortion correction using checkerboard patterns could be an important requirement to flatten out the image correctly.
- We use the ArUco marker detection method from OpenCV. While it is good at detecting all the markers, we don't know what strategies it utilizes to perform the detection. This leaves little room for improvement in the software because the major contributor to the time consumption in computation is the ArUco detection method. An important future step would be to develop custom marker detection algorithm for more transparency.
- A proposed idea which we could pursue was utilizing a telescopic lens. These lenses eliminate parallax error, allowing a single lens to be used for an arbitrary wheelbase lengths instead of using a family of lenses. A major drawback of this type of lens is the small field of view due to the parallel incoming light requirement. Due to budget constraints, we opted not to go with this choice.

  The telescopic lens is an ideal choice for using a checkerboard marker pattern and edge detection algorithm as Dr. Hwang has suggested. This pattern was unfeasible in our project due to the multitude of edges from the truck itself, however with a telescopic lens where the field of view is restricted to completely within a checkerboard marker or with an additional blank buffer region, it is a god option ad the multitude of corners create ample reference points for analysis.

  Such a vision would have the camera mounted on one end of the frame with a single checkerboard marker collinear with it on the other end. Translational vibration amplitude must be analyzed to determine the marker size to remain in the FOV. This design may encounter the line of sight requirements which prevented a torsional bar or polarized laser solutions from being utilized, however this idea must be explored further.

13 Project Success Criteria

Our current ArUco code system allows us to select different marker patterns for each position so marker differentiation is built-in. We have been using multiple markers in our tests which means we have implemented redundancy to further the operational robustness. This gives us the ability to identify all the markers to the right as well as the left side from the center. Having redundant markers also gives us more information like the collinearity between markers and the distance between adjacent markers which are the potential reasons behind the confidence parameter of our angle calculation

Our current set-up achieves under 0.2° precision which is expected according to our feasibility analysis. This was verified by using a stepper motor to rotate the marker beam at fixed intermittent steps.

Our device can be used for the typical 235” wheelbase truck (T680), however since the full range is too broad for one fixed focal lens and our budget prevents us from purchasing lenses to cover the full range. By including the lens visualizer we intend to give PACCAR a reference for selecting other lenses when need arises.

While Physical interfacing with the vehicle CAN network could be done with some efforts, we could not work on it due to time and manpower constraints.

14 Impact and Consequences

14.1 Environmental

- For our project we use a significant amount of PLA in making our structural components. PLA is relatively environmentally friendly due to using organic precursors and recyclable, however if not recycled properly, it can take years to break down and introduce microplastics. A solution to this issue is to either use materials that require less maintenance in regard to recycling or require more attentiveness on its disposal. A mindful choice that we can make during the design process can be to design parts that don’t require much in terms of supports.
- Supports is ultimately material that becomes waste after the print is finished so designing parts that don’t require supports minimizes the waste produced through the printing process. How we would go about this is to either change the print orientation/direction or change aspects of the design to include less severe overhangs.

14.2 Ethical

- Privacy concerns: Recording potentially sensitive footage without consent can infringe on an individual’s privacy. Additionally, trucks tested at PTC can contain confidential information for clients. To prevent this, the device only reports angular and uncertainty data. Thus, video frames are deleted so confidential information cannot be shared

14.3 Safety

- A safety concern is the possibility of the product becoming a road hazard if the mounting for our equipment failed and it fell onto the road. An obvious solution to this is to use stronger materials or to make the design more reliable in terms of determining its predicted life expectancy. However, to do this we would need to conduct fatigue and stress testing to determine cycles and stress amplitude.
- The lights used to illuminate the marker face forwards and can blind the onlookers, disorienting them and increasing risk of collision which can lead to serious injury or death. To remedy this, diffusers can be added to reduce the brightness while testing in varied conditions can verify that the lights are not disorienting
- Messages from our device can saturate the CAN network and prevent more vital messages from reaching other systems/the driver. To remedy this, our messages will be given a low priority code so vital messages can override and bypass our messages

15 Conclusions and Recommendations

- Better tracking algorithm for the detection of the Aruco Markers could help in getting lesser compute time out of the system. This would help to create more room for future image processing additions which would also be time consuming.
- The current implementation works on a static threshold value that is predetermined during calibration and manually entered into the program. This could be improved by understanding the intensity of the illuminated markers and dynamically updating the threshold value so that we get the best crop out of the thresholded images. This would prove beneficial in hazy weather to get the maximum contrast and sharpness out of the image.
- Another possible improvement would be to try and utilize the GPU in Jetson Orin Nano for image processing. This would offload the matrix heavy tasks to the GPU which would greatly improve performance while leaving the CPU free for handling I/O communications and other tasks in the future.

16 References, Acknowledgements, and Intellectual Property

16.1 Relevant Engineering Standards

1. **IEEE 1016-2017 Standard for Information Technology—Systems Design—Software Design Descriptions:**

- IEEE 1016-2017 standard encourages the use of architectural and design patterns to describe the software system's overall structure. This standard suggests use of the producer-consumer approach to handle the frame grabber implementation for the CSI camera. This way, a multi-threaded design can be implemented to parallelize IO and compute operations. By decoupling producers and consumers, changes to one component can be made with minimal impact on others, promoting software maintainability and scalability. The producer in our case impacts the system calls to initialize the camera and start grabbing images, whereas the consumer works on preprocessing the images and to work on the computation for detections.

2. **IEEE/ISO/IEC 29148 - Systems and software engineering – Life cycle processes:**

   - This standard is crucial for systems engineering as it offers a framework for maintaining software and systems. It will guide the establishment and execution of life cycle processes, which will be documented in process descriptions and integrated into the quality management system. To maximize effectiveness, it's important to seamlessly integrate the standard's processes with existing organizational processes, ensuring they complement rather than conflict with each other.

3. **SAE J1939-11 - For CAN Bus Protocol:**

   - SAE J1939-11 will serve as the foundation for implementing the physical layer of the CAN bus communication system in our project. This standard will help us to determine the data rate of CAN communication and understand the electrical characteristics of the hardware (physical layer). Since we are developing a system that needs to be integrated within the truck, adhering to J1939 standard will ensure the interoperability and compatibility with existing systems.

4. **IEEE 829 - Software Test Documentation:**

   - Adhering to IEEE 829 ensures systematic software testing, including test planning, design, execution, and reporting. This is crucial for verifying the reliability and functionality of embedded software.

5. **IEEE 12207 - Software Life Cycle Processes:**

   - Following these standard guides the software development life cycle, covering processes such as requirements, design, implementation, testing, and maintenance. It ensures a structured approach to software development.

6. **IEEE 1547 - Standard for Interconnecting Distributed Resources with Electric Power Systems:**

   - If the system includes electrical components, compliance with IEEE 1547 ensures safe integration with electric power systems, emphasizing safety and reliability.

7. **IEEE 802.3 - Ethernet Standards:**

- Compliance with IEEE 802.3 ensures compatibility and reliability in networking components, especially if the system involves wired communication.

8. **IEEE 830 - Software Requirements Specification:**

    - IEEE 830 provides guidelines for creating clear and comprehensive software requirements specifications. A well-defined specification is critical for successful system development.

9. **IEEE 1471 - Recommended Practice for Architectural Description of Software-Intensive Systems:**

    - This standard aids in documenting and communicating the architecture of software-intensive systems, ensuring a clear understanding of system components and interactions.

10. **IEEE 1451 - Addresses wireless communication interfaces for sensors and actuators:**

    - This standard is a set of standardized interfaces that aim to enable the communication between different sensors, actuators, and control devices regardless of the manufacturer.

17 Appendix

All relevant files have been uploaded to a zip file in the team sharepoint. The zip file is in the final deliverables folder.

18 References

[1] Customized Car Instrument Cluster Gauge Face (accessed Feb. 8. 2024)

[2] Edmund Optics - Optics Manufacturer & Supplier — Imaging Lens (accessed Feb. 9. 2024)

[3] Detection and Identification Techniques for Markers Used in Computer Vision (accessed Feb. 14, 2024)

[4] An evaluation of artificial fiducial markers in underwater environments (accessed Feb. 20, 2024)

[5] Github, how_do_drones_work/opencv (access Feb 27, 2024)

[6] automatic generation an detection of highly reliable fiducial markers (accessed Feb. 10. 2024)

[7] Github, Allied Vision NVIDIA Jetson driver

[8] Github, Allied Vision VmbPy

[9] NVM Express® Base Specification

[10] MIPI CSI-2®

[11] Github, OpenCV