Final Project Report
Autonomous Navigation on Road

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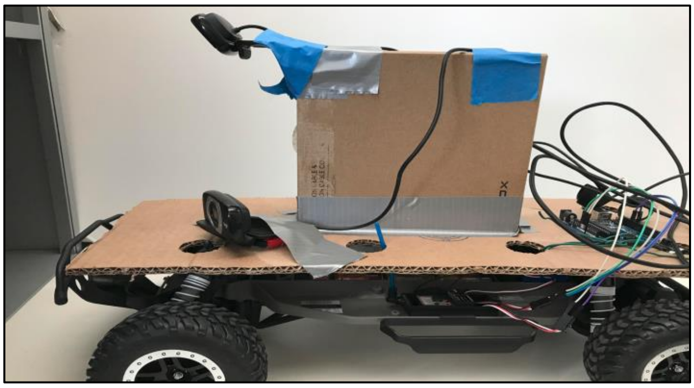

Acknowledgments

The course AuE 8240 Autonomous Driving Technologies gives the hands-on experience of learning, interacting with peer teammates effectively. We would like to express our sincere gratitude for the guidance, inspiration, motivation and encouragement to our course instructor **Dr. Yunyi Jia** and familiarizing us for the effective class communication environment which extremely solved our issues faced by everyone in hardware or software aspects easily.

We would also indebted to our teaching assistants **Haotian Su** and **Yuchen Yan** for the reviews, suggestions and for giving us valuable support in guiding us whenever required. This project could not have been completed without the assistance and familiarizing us with every task in the course work and also assisted us from their past experiences and provided us enough information required for the successful completion.

We would greatly thank for their effort and giving us the assistance in troubleshooting area and giving us further ideas for the successful completion of tasks in the project.

Our humble thanks **Dr. Yunyi Jia, Haotian Su, Yuchen Yan** for giving us great opportunity to learn and take time in each team at various stages for our successful completion and providing us all the facility that was required till end of the Project.

DATE: -Siddharth Thorat
05-06-2022

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1. Introduction:

Autonomous vehicles are vehicles (but also trucks, buses, and others…) where human drivers are not required to take control to safely operate the vehicle, combining sensors and software to control, navigate, and drive the vehicle.

To allow self-driving vehicles to take over the streets, there is a trend by automakers to gradually add technologies that collaborate with drivers both in driving and maintaining the car itself, such as:

- cruise speed control;
- driving and parking assistance;
- braking management;
- obstacle detection system and road users;
- proximity alerts with other vehicles and driving adaptations;
- monitoring of operating conditions;
- speed adjustment according to path conditions.

These are some of the systems already present in specific models. To better understand how integration occurs, let's get to know the technology behind vehicle automation in the following topic.

Currently, there are no legally operational and fully autonomous vehicles in the world. However, partially autonomous vehicles, such as cars and trucks with varying amounts of automation, from assistance for braking to aid changing lanes and parking, with some models even having a certain degree of automatic steering.

Although it is still in its infancy, autonomous driving technology is becoming increasingly common and could radically transform our transport system.

Few advantages on autonomous driving vehicles:

:

a. There will be 90% reduction in the traffic deaths: The driving technologies are designed in such a way that to reduce the error by replacing the human perception and the decision with sensors and all computer systems like LiDAR, GPS, Camera's, Intelligence used in the vehicle.

b. We can observe 60% drop in harmful emissions: Nowadays in most of the states there are frequent traffic jams which creates the big problem as vehicles create emissions in a congested highway. So, if there is less traffic on these busy roads the CO2 emissions will drop. The autonomous cars will help the environment in smart way.
c. Lower fuel consumption: The fuel consumption can be improved by self-driving vehicles by 4 to 10 percent by accelerating de-accelerating the vehicle smoothly than a human driver. It also lowers the vehicles peak speed to conserve the fuel.
d. Due to introducing of autonomous vehicles there could be 500% increase in lane capacity. The ability to continuously monitor neighboring traffic and respond with finely altered braking and acceleration changes should enable autonomous vehicles to travel safely at higher speeds and with reduced headway between each vehicle.
e. It could reduce 40% travel time and also reduce the transportation costs. The autonomous vehicles can reduce the poor decision making.

The project resembles the autonomous vehicle RC vehicle in the real time through the cameras and navigating using controllers and detecting the signs for pedestrian safety. The project requires concepts learnt from the beginning of course and implement on the RC vehicle for successful completion of the project.

1.1 Problem Statement

The autonomous navigation on road project is divided into four tasks and finally, integration of all the tasks is done to navigate the RC vehicle with detection of road signs.

- Task -1 Autonomous Lane keeping
- Task -2 Road Sign Recognition
- Task-3 Communication
- Task-4 Control of vehicle

2. Task -1 Autonomous Lane keeping

- Implementation of Lane keeping:

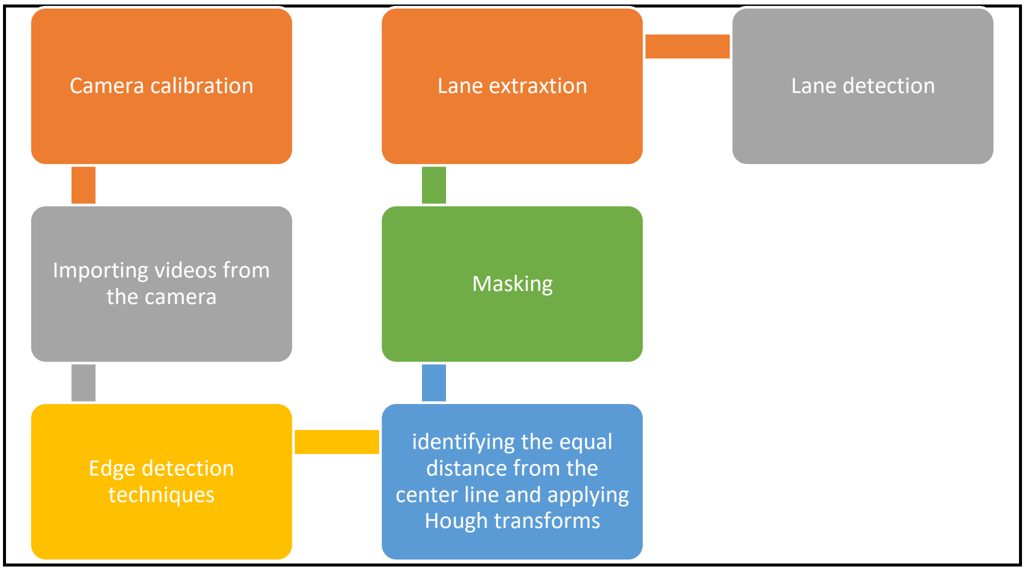


Figure 1(Implementation of Lane Keeping)

2.1 Camera calibration:

- The camera calibration is the process of estimating the intrinsic and extrinsic camera parameters by dealing with focal length, changing the exposure and distortions. By knowing the extrinsic and intrinsic parameters we can set the orientation and position in real time. In addition to that it allows us to estimate the image structure in the view of Euclidean space and the distortion lens is removed which may affect the accuracy at the end.

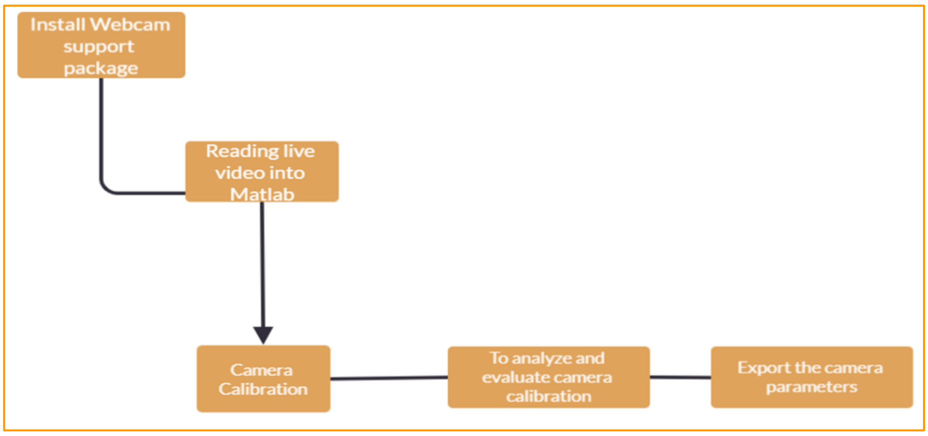


Figure 2(Steps for camera calibration)

- We need to install the MATLAB webcam package which is available on add-ons section. In addition, after installing the package we need to open the camera calibration app and setup for calibration. We need to checkerboard pattern image is attached on a flat surface. During calibrating, the camera angle is placed in twenty different positions so that we ensure that the camera calibration is done accurately.

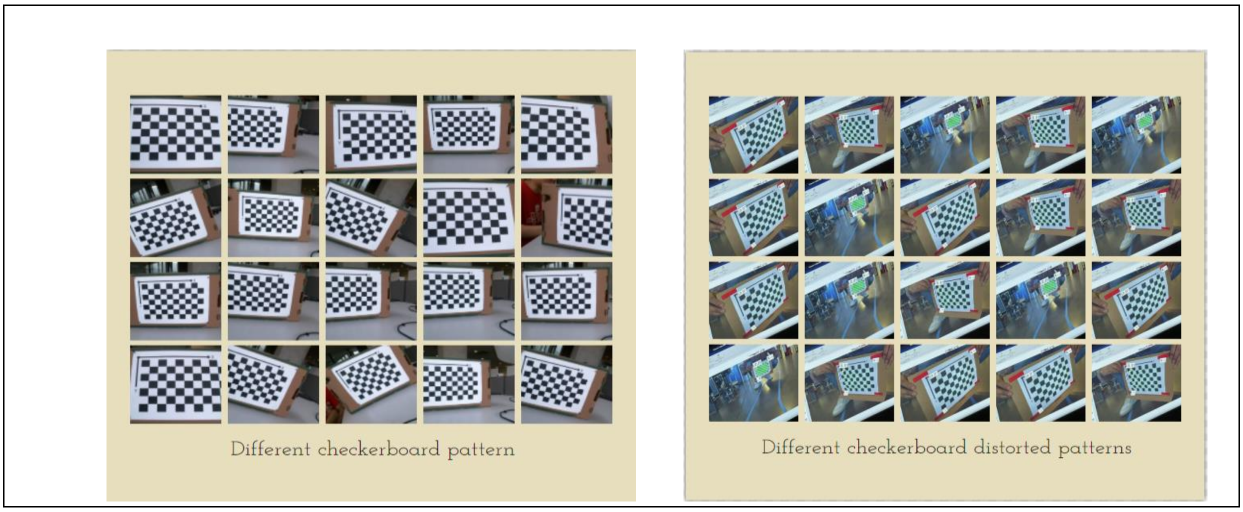


Figure 3(Different checkerboard images)

- The camera parameters taken for the detection was

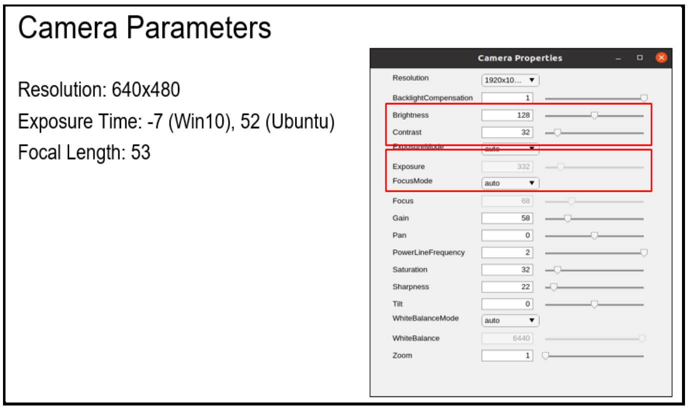


Figure 4(Camera parameters)

- The camera position for detecting the lane:

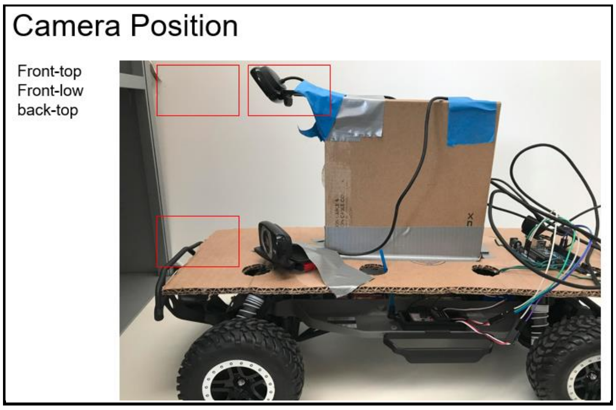


Figure 5(Camera position)

2.2 Approaches for Lane Keeping

➢ We used six approaches for the accurate detection of lanes in the track-

- Edge detection method (Canny edge detection and Sobel)
- RGB merge
- Image Rescale
- Denoise
- Gamma correction
- Histogram equalization

Edge detection method (Canny edge detection and Sobel operator):

- The Edge detection is the image processing method for finding the boundaries of objects within images. It works by detecting discontinuities in brightness. It is used for image segmentation and data extraction in areas such as image processing, machine vision and the computer vision.

Canny Edge Detection:

- Apply Gaussian filter to smooth the image in order to remove the noise
- Find the intensity gradients of the image
- Apply gradient magnitude thresholding or lower bound cut-off suppression to get rid of spurious response to edge detection
- Apply double threshold to determine potential edges
- Track edge by hysteresis: Finalize the detection of edges by suppressing all the other edges that are weak and not connected to strong edges.

Sobel Operator:

- The Sobel operator performs a 2-dimensional spatial gradient measurement on image and highlights regions of high spatial frequency that correspond to edges. They are typically used to find the approximate absolute gradient magnitude at each point in an input grayscale image.

RGB Merge:

- An alternative to the normal Red-Green merge is to merge the images based upon the colors Cyan and Magenta, or Cyan-Yellow or any other color combination. This leads to visualization of colocalization due to our poor perception of red and green colors.

Image Rescale:

- The image rescaling is to change the dimensions of an image file or its output.

Denoising:

- The general denoising procedure involves three steps-

- Decompose: we need to choose a wavelet, a level N. Then, compute the wavelet decomposition of the signal at the N level.

- Threshold detail coefficients: From level 1 to level N, select a threshold and apply soft thresholding to the detail coefficients.

- Reconstruct: Compute wavelet reconstruction using the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

Gamma Correction:

- In Gamma Correction, the block accepts the pixel stream and also the bus containing five synchronization signals from the frame block to pixels block.

- It goes from the same set of signals to the downstream pixels block to frame block.

- For such signals the maintenance and bundling are necessary for pixel-stream processing.

Histogram Equalization:

- Histogram equalization involves about the converting the intensity values so that the histogram of the output image approximately equal to a definite histogram.

Hough transforms:

What is meant by Hough transform?

- The Hough transform is a popular feature extraction technique that converts an image from Cartesian to polar coordinates.
- Any point within the image space is represented by a sinusoidal curve in the Hough space.
- It can also be used to detect lines, circles or other parametric curves.

Challenges:

- During the camera calibration we need to calibrate from every angle for accuracy.
- We found challenging part in lane detection due to exposure fluctuation of blue tape which is used for track.
- The most challenging part was about the camera detecting the edges during turnings.

Experimental Results:

Canny Edge vs Sobel Operator:

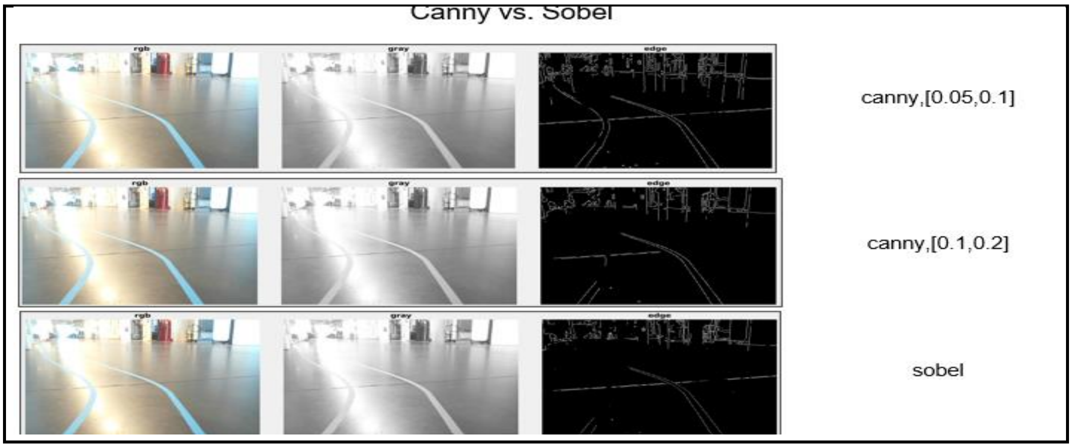


Figure 6(Experimental results for canny vs Sobel)

Type	Time [s]	FPS
Sobel	0.001264	791
Canny [0.05,0.1]	0.007790	128
Canny [0.1,0.2]	0.007525	132

Figure 7(Table representing Sobel vs canny edge detection experimental results)

RGB Merge:

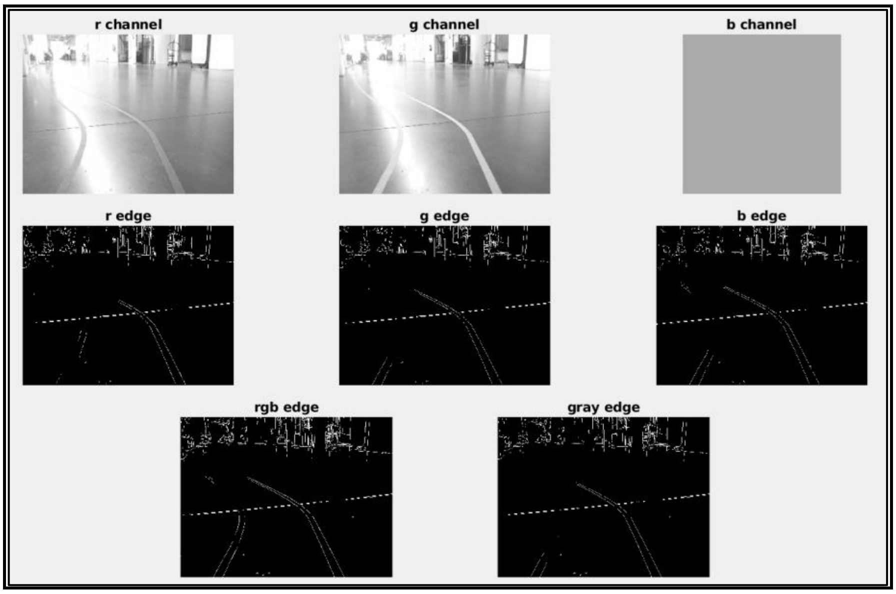


Figure 8 (Experimental results for RGB merge)

Image Rescale:

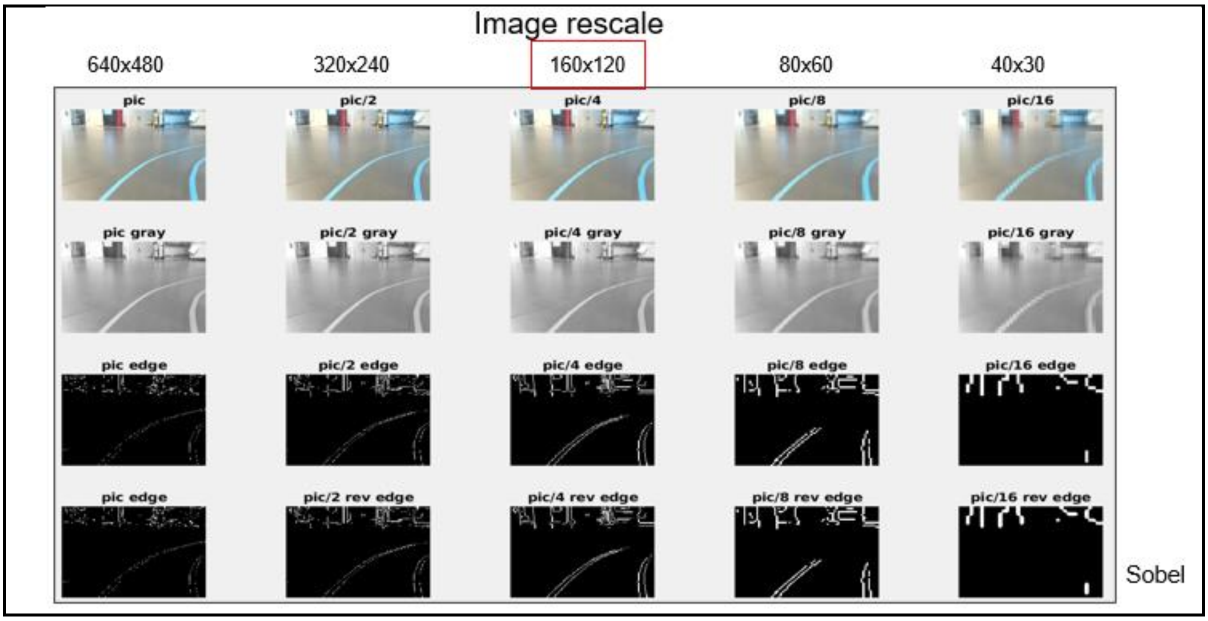


Figure 9(Experimental results for Image Rescale)

Denoise:

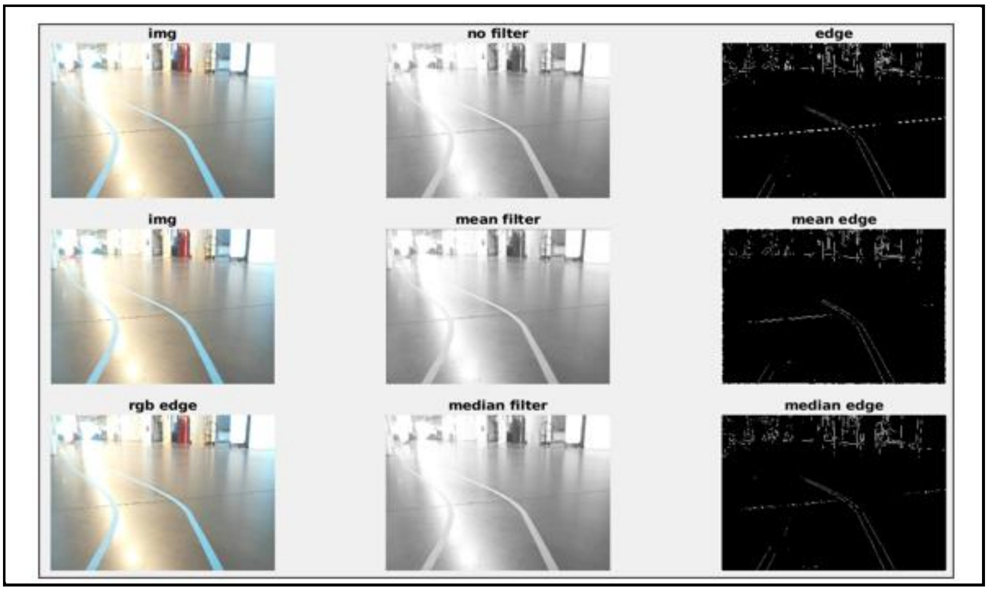


Figure 10(Experimental results for denoising)

Gamma Correction:

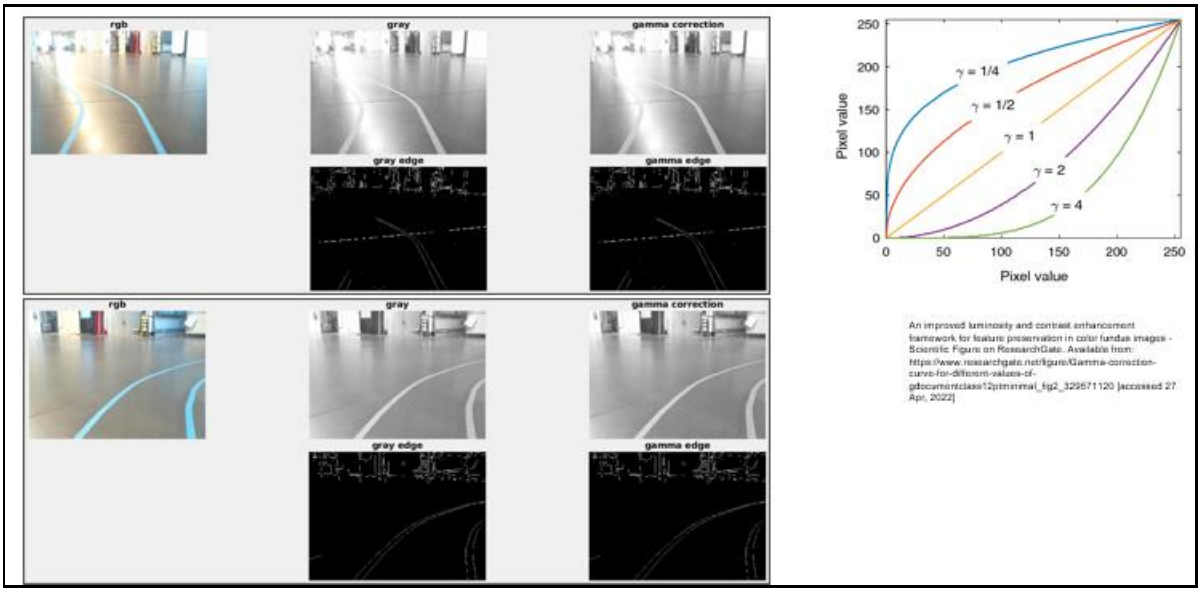


Figure 11(Experimental results for Gamma Correction)

Histogram Equalization:

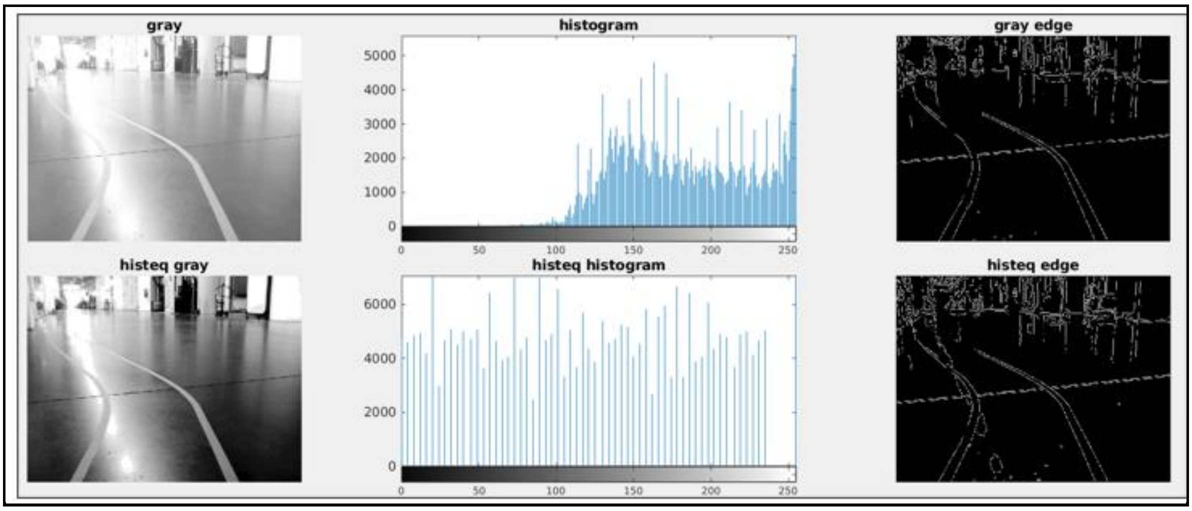


Figure 12(Experimental results for histogram equalization)

Summary for parameters:

Camera Position	Exposure time	Edge detection	Rgb merge	Image rescale	denoise	Gamma correction	Histogram equalization
Top-back	80	sobel	✓	160x120	Median filter	?	✗

Hough Lines:

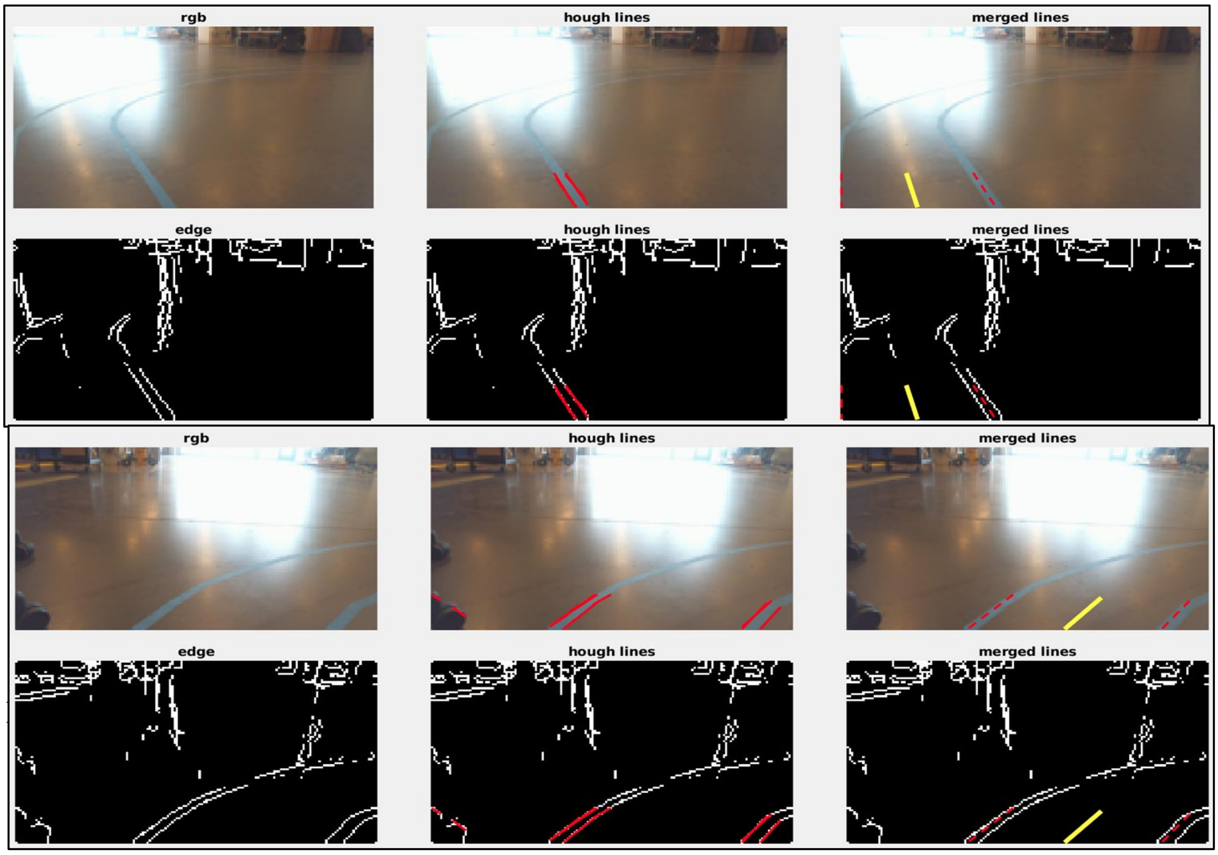


Figure 13(Experimental results of Hough lines)

2.3 Stanley Controller:

- We used Stanley controller for the RC vehicle to navigate between the lanes.
- The Stanley controller is the path tracking approach which consists of non-linear feedback function of cross track error measures from the center of front axle of the RC vehicle to nearest point.
- The Stanley controller considers the front axle point as the control point.

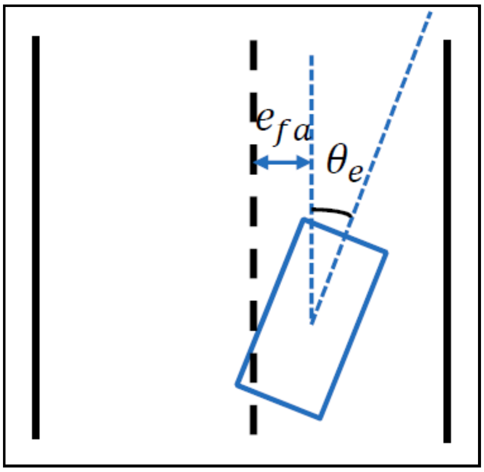


Figure 14(Implementation of Stanley Controller)

<u>Stanley controller approach:</u>

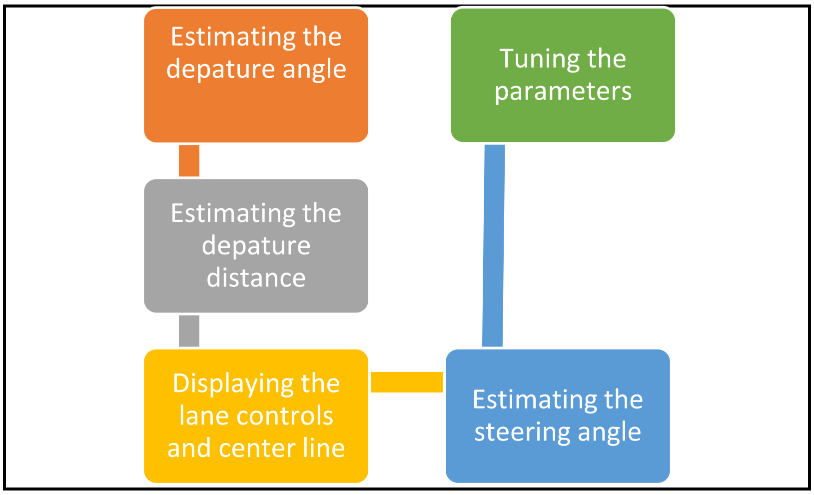


Figure 15(Implementation of Stanley controller)

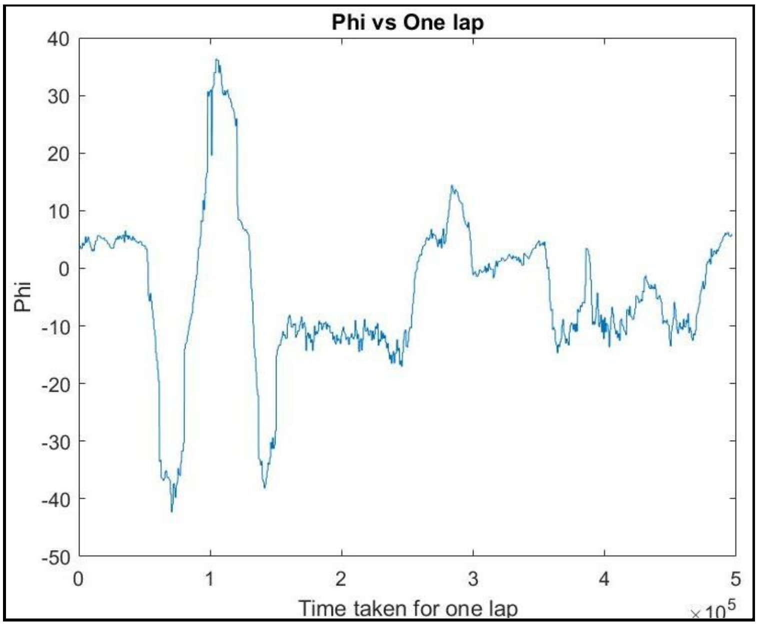
Simplified Version

$$\boxed{\varphi(t) = -k_1 \cdot \theta_e - k_2 \cdot e_{fa}}$$

```
kscale=0.5;
k1=0.70*kscale; k2=0.3*kscale;
angleScaleVal=1.6;
```

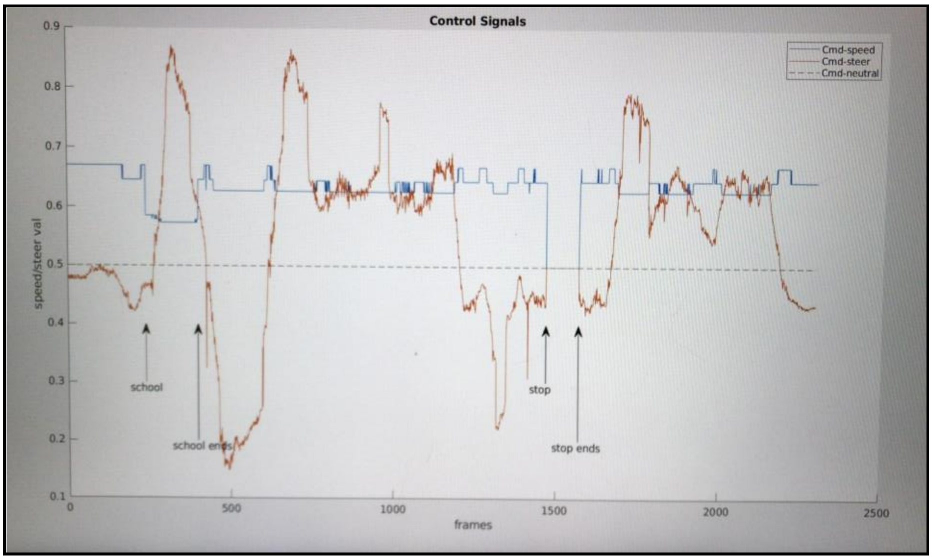
```
phi = k1*dirTheta + k2*distTheta;
phi = phi * angleScale;
phi = max(min(phi,45),-45);
```

Experimental results:



Plot 1 (Phi vs Time Taken)

- The above graph represents about the time taken for the RC vehicle navigating through an entire one lap in the test track. If we observe, whenever there are turnings the speed is reducing and rapidly increasing when the RC vehicle is navigating in the straight path.



Plot 2 (Speed/steering vs frames)

<u>Description:</u>

- The above graph represents about the RC vehicle's speed, steering and when it is in neutral.
- The blue line represents about the speed of the RC vehicle, During the turnings the speed of the vehicle is decreasing and also during the road signs too.
- The orange line in the plot represents about the steering behavior of the vehicle during the straight path, the turnings and also during the sign boards in the test track.
- The green dotted line in the plot represents about the RC vehicle in neutral position.

3. Task -2 Road Sign recognition:

- RC vehicle is made to recognize the stop sign and school sign for safety. The RC vehicle need to stop near the stop sign for 3seconds and slow the vehicle near school zone sign then navigate through the track.
- We used both the approaches cascade object detector – the traditional machine learning and Deep learning RCNN model.

3.1 Methodology:

<u>Approach -1:</u>
Cascade Object detector – Traditional Machine Learning

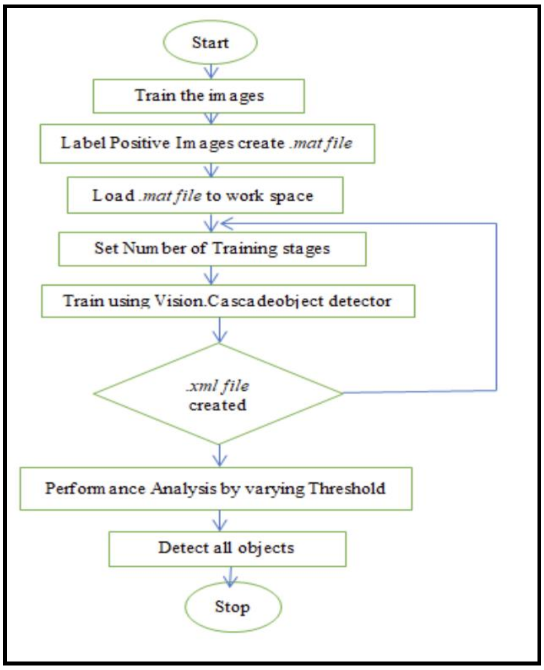


Figure 16 (Flowchart of Cascade object detector)

Steps:

- The cascade object detector has two stages, each stage of classifier is defined by present area of positive or negative images.
- Here, positive represents that the image is found and if negative there is no image found.
- In the detection, if it is detecting as positive the region in the classifier moves to next stage and similarly if it's detecting as negative then it thinks the region in classifier is complete and navigates through the next area.
- Finally, it reports in the window at the final stage when the region in classifier is detected as positive.
- The main reason to train every orientation in cascade object detector is due to it's sensitive aspect ratio in most of the 3D objects.

1. Stop: 0.3, 10, accuracy = 72%

neg: 943, pos: 311, time: 0.049687, FPS: 20

	Confusion Matrix		
		Actual	
		Positive	Negative
Predicted	Positive	191	231
	Negative	120	712

neg: 943, pos: 311, time: 0.048755, FPS: 20

	Confusion Matrix		
		Actual	
		Positive	Negative
Predicted	Positive	176	92
	Negative	135	851

1. Stop: 0.1, 10, accuracy = 81.89%

neg: 943, pos: 311, time: 0.049569, FPS: 20

	Confusion Matrix		
		Actual	
		Positive	Negative
Predicted	Positive	176	92
	Negative	135	851

4. Stop-0.1, 20, stop at stage 7, accuracy = 80.54

neg: 943, pos: 311, time: 0.049497, FPS: 20

	Confusion Matrix		
		Actual	
		Positive	Negative
Predicted	Positive	175	108
	Negative	136	835

Figure 17 (Training the model using traditional approach)

Challenges:

- During training the dataset, the camera was detecting other color images present in the background as stop and school signs.
- In addition, it requires the set of negative images apart from the positive images and the number of images needed is high as compared to other approach we used.
- There was no delay in the detection but there was no accuracy compared to other

approach we used for detecting the signs.

- Depending upon the challenges faced we discussed to use the other approach deep learning CIFAR 10

Approach-2: Deep-Learning using CIFAR10:

Steps:

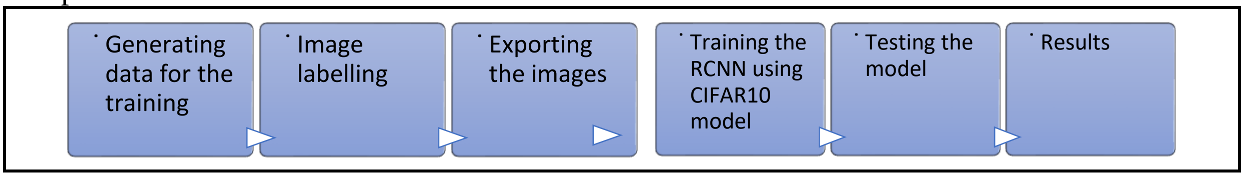


Figure 18 (Execution of RCNN-CIFAR10 in stop sign detection)

- Firstly, we captured the images of stop sign and school sign in different orientation for the accuracy using the given Logitech camera on a moving RC vehicle.
- Secondly, after capturing the image we exported the captured images into the MATLAB 2021a.

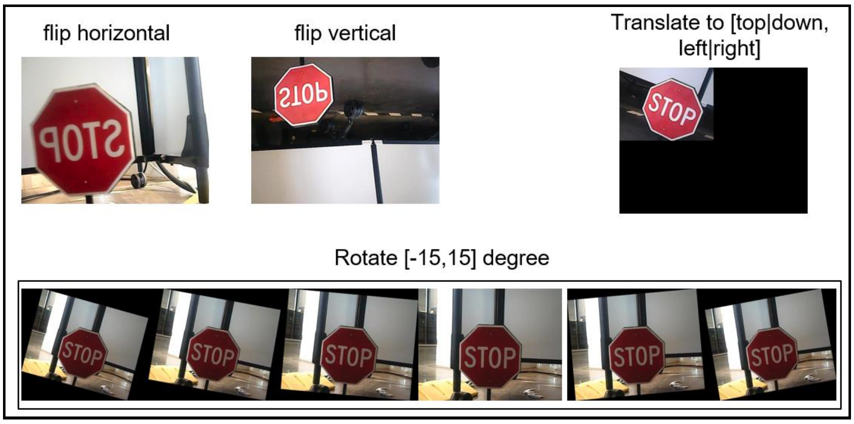


Figure 19(Training the model using stop signs)

- We trained the model using the CIFAR10 and after the training the model, we subjected that model into our program.
- In addition, we tested the integrated program to ensure whether its detecting or not.
- We again made a few changes in the subjected program for the accuracy in the detection and made a final subjected program.

➢ The above parameters used for training our model for detecting the stop signs and school signs:

Experimental Results:

CNN models	Layer #	performance	Time per second [s]	FPS
cifar10	15	Many false positive	0.15	6.7
alexnet	25	Many false positive	0.6	1.7
resnet18	71	accurate	0.68	1.47
googlenet	144	accurate	1.2	0.83

Figure 20 (Comparison of different CNN models)

Challenges:

- During training the dataset, it took more time to train than required.
- By using the deep learning approach using RCNN- CIFAR10 also it was detecting the yellow and red images as stop and school signs. Due to that it was sending message to the controller that it detected the stop sign. We later changed few parameters and reduced the error during detecting the stop and school signs.
- It requires a greater number of datasets to train the model compared to other approaches.
- Insufficient dataset
- Detection of sign with respect to color
- Sensitive to out of plane rotation
- Requires huge dataset.

Task -3 Communications:

- A connected vehicle is a vehicle that is equipped with a wireless local area network
- This allows the vehicle to share its information with other agents (e.g., vehicles, infrastructure, etc.) and acquire information from other agents as well.
- Typical examples: V2V (Vehicle to Vehicle), V2I (Vehicle to Infrastructure), V2P (Vehicle to pedestrian), etc.

TCP	UDP
Reliable—monitors message transmission, tracks data transfer to ensure receipt of all packets	Unreliable—no concept of acknowledgment, retransmission, or timeout –
Ordered—buffering provisions to ensure correct order of data packets	Not ordered—data arrives in order of receipt
Heavyweight—dedicated connection, provisions for speed and congestion control	Lightweight—no dedicated end-to-end connection, no congestion control
Streaming	Datagram oriented
Heavy overhead	Light overhead
Lower speed	Higher speed

Figure 21(Difference between TCP and UDP)

4.1 Methodology:

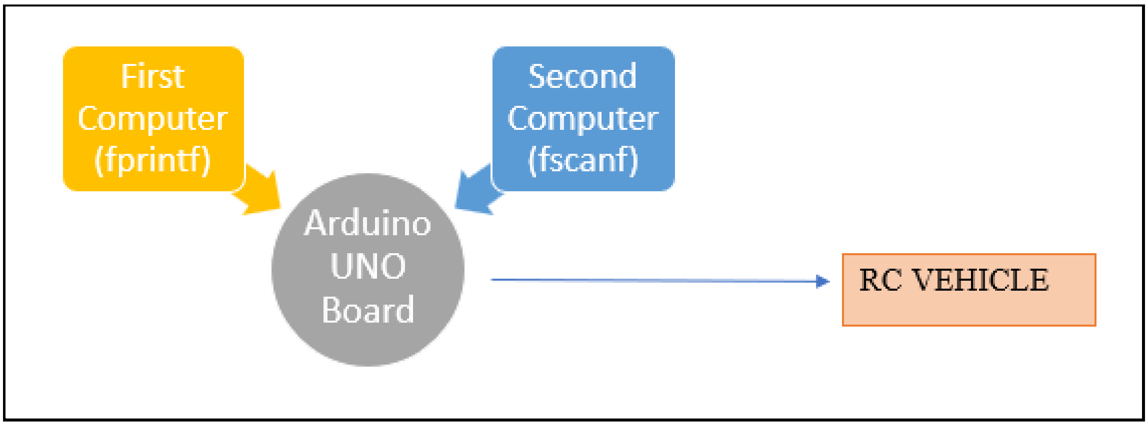


Figure 22(Implementation of UDP Communications)

Steps:

- By comparing both the communications, we decided to use the UDP approach for communication to read the commands.
- We decided the controller part to run on udpB (Second computer) and stop sign recognition (First computer) on udpA where both laptops communicate and sends the commands to Arduino then controls the vehicle in the test track.

Challenges:

- At the first time we faced challenge in running the udp program in the MATLAB 2022a version. It was throwing a error that no udp package on your matlab version but if we check in MATLAB's manager it was installed in default. Later we uninstalled the MATLAB from the laptop then re-installed the MATLAB 2021a version finally it was working.
- During running of the RC vehicle on the track, there was delay in sending the sign recognition message to the second computer due to which the RC vehicle was suddenly accelerating and it was uncontrollable.

Experimental Results:

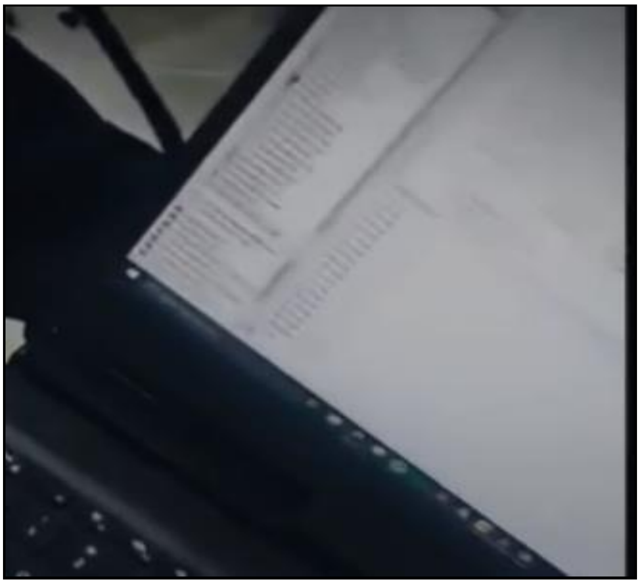


Figure 23(Communication from first to second laptop)

5. Task -4 Vehicle Controls:

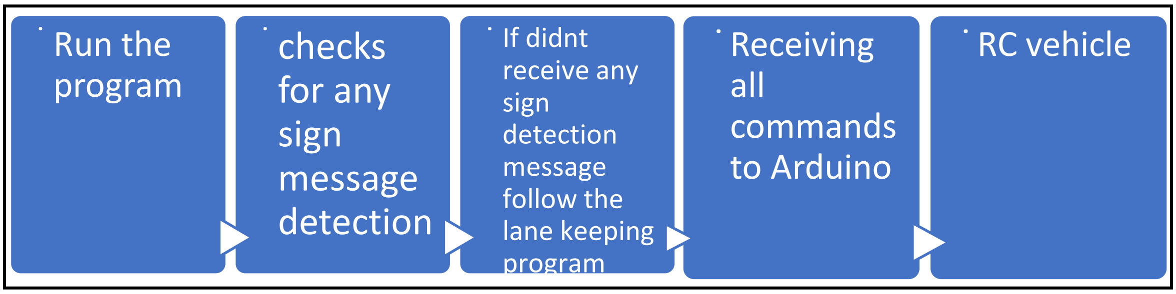


Figure 24 (Overview of Vehicle Control)

6. Accomplishments:

a. We kept lots of efforts on edge detection using different approaches and we finally decided to consider the Sobel operator as it was giving us the best results.
b. Our lane keeping was acceptable accuracy as most of the time it was steering and navigating frontward in the track direction and also has perfect designed Stanley controller.
c. We even made the vehicle successfully for few seconds near Stop sign and made the vehicle slowdown near school sign. For reference, the video has been attached next to presentation video.
d. The communication from both the laptops was perfect.

7. References:

[1] https://www.researchgate.net/figure/CIFAR-10-CNN-_structure-block-diagram_fig8_322957424

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[5] Atherton, T., Kerbyson, D.: 'Size invariant circle detection', Image VisionComput., 1999