



Researching
Robust
Vehicular
Lane Keeping
Algorithms

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Overview

Motivation

Background

Research goals

Experimental Setup

Methods

Results

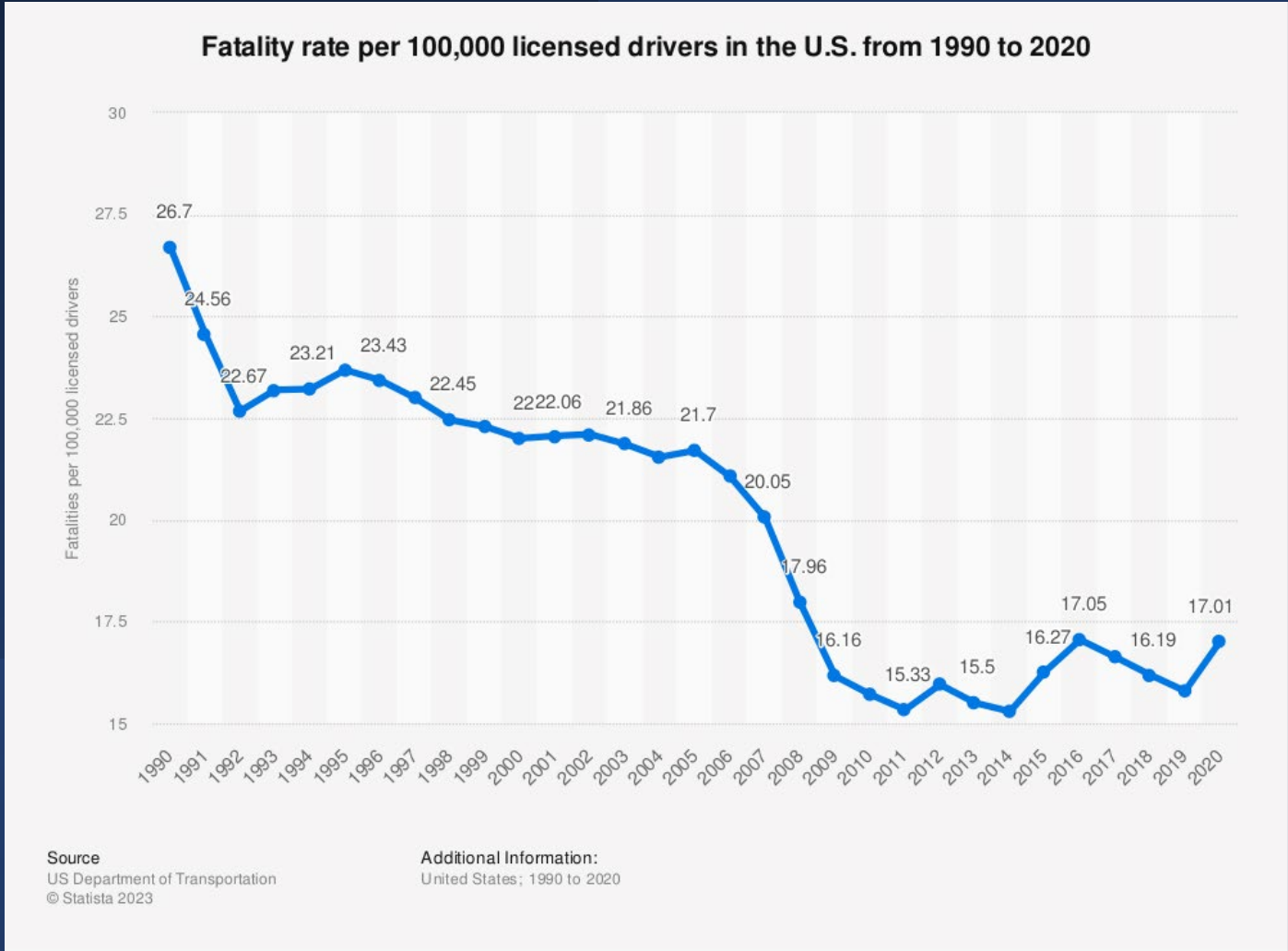
Future research





MOTIVATION

Vehicle Fatalities



Carlier, Mathilde. "Fatality Rate per 100,000 U.S. Licensed Drivers." *Statista*, 1 Aug. 2022, www.statista.com/statistics/191660/fatality-rate-per-100000-licensed-drivers-in-the-us-since-1988/.

SAE Levels of Driving Automation

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	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in “the driver’s seat”		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	

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	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
Example Features	<ul style="list-style-type: none"> • automatic emergency braking • blind spot warning • lane departure warning 	<ul style="list-style-type: none"> • lane centering OR adaptive cruise control 	<ul style="list-style-type: none"> • lane centering AND adaptive cruise control at the same time 	<ul style="list-style-type: none"> • traffic jam chauffeur 	<ul style="list-style-type: none"> • local driverless taxi • pedals/steering wheel may or may not be installed 	<ul style="list-style-type: none"> • same as level 4, but feature can drive everywhere in all conditions

Carlier, Mathilde. “Fatality Rate per 100,000 U.S. Licensed Drivers.” *Statista*, 1 Aug. 2022, www.statista.com/statistics/191660/fatality-rate-per-100000-licensed-drivers-in-the-us-since-1988/.

Dynamic Weather Conditions



Ong, Sandy. "At Singapore's Test Center, Self-Driving Cars Battle Fake Monsoons." *IEEE Spectrum*, 15 June 2023, spectrum.ieee.org/at-singapores-autonomous-vehicle-test-center-selfdriving-cars-battle-fake-monsoons.



"Seeing in the Rain – How Good Is Your AV's Sensor Performance?" *ADAS & Autonomous Vehicle International*, 30 May 2022, www.autonomousvehicleinternational.com/features/seeing-in-the-rain-how-good-is-your-avs-sensor-performance.html.

Hand-Crafted vs. Deep Learning [1]

comparable for both, although HistWind has a considerably lower execution time. In [13], the ACTor (Autonomous Campus TranspORt) vehicle was used for testing a deep learning-based approach for lane centering using a pretrained inception network and transfer learning. However, since this approach is computationally intensive and requires specialized hardware, we did not attempt deep learning-based solutions in our work. Additionally, due to the test course being predefined, any deep learning-based solution would have resulted in an overfitted model. The



Background

Self-Drive Cars Architecture [2]

Perception

```
graph TD; Perception[Perception] --> Localizer[Localizer  
GPS-, LIDAR-, or camera-based]; Localizer --> Decision-Making[Decision-Making];
```

Localizer

GPS-, LIDAR-, or camera-based

Decision-Making

Preprocessing [3]



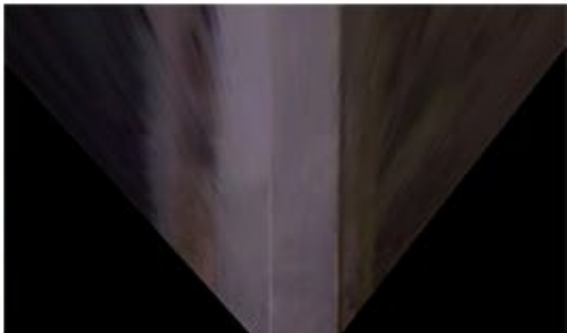
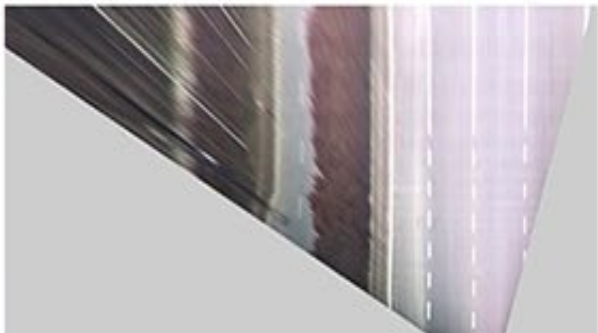
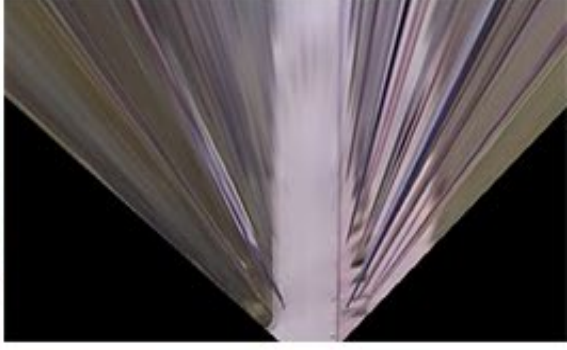
Median Blurring



Gaussian Blurring



Inverse Perspective
Mapping

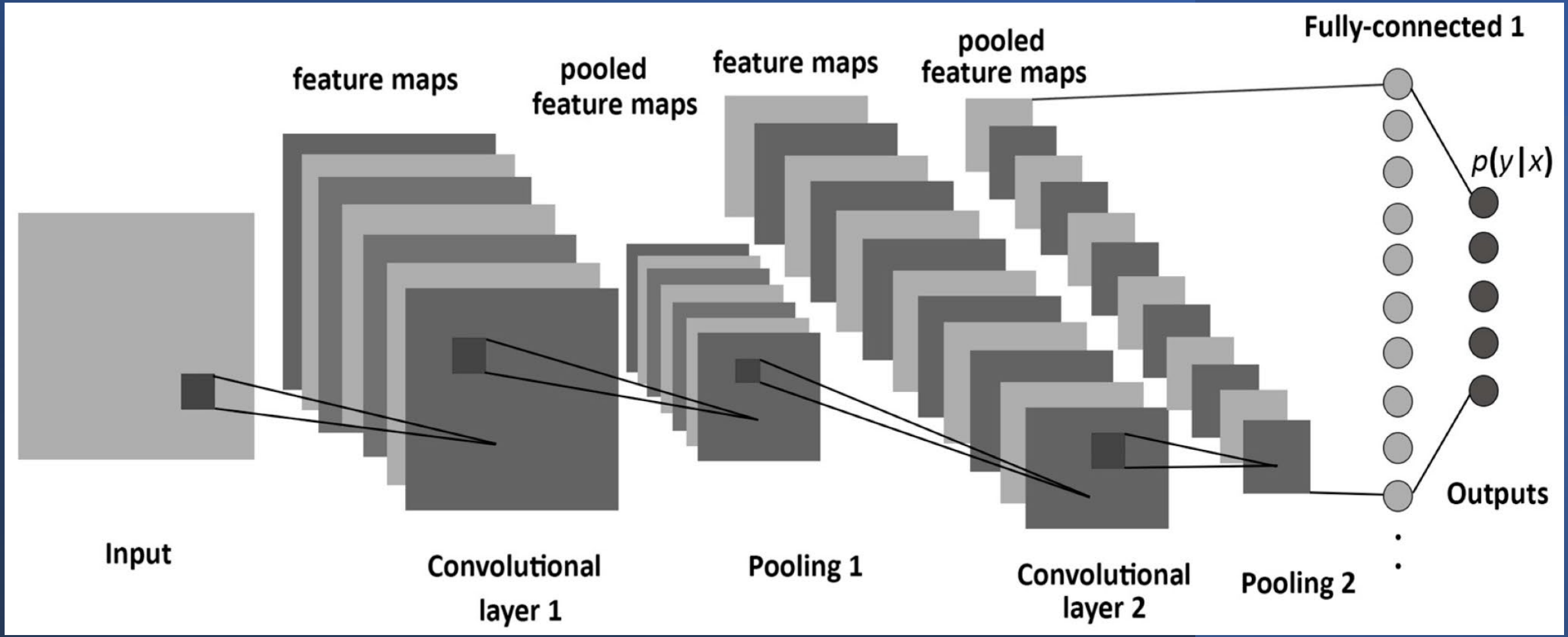


Preprocessing (Continued) [4]

Deep Learning

Convolutional
Neural Net

Long-Short Term
Memory



Vehicle Steering Methods

Spring method center approximation [5]

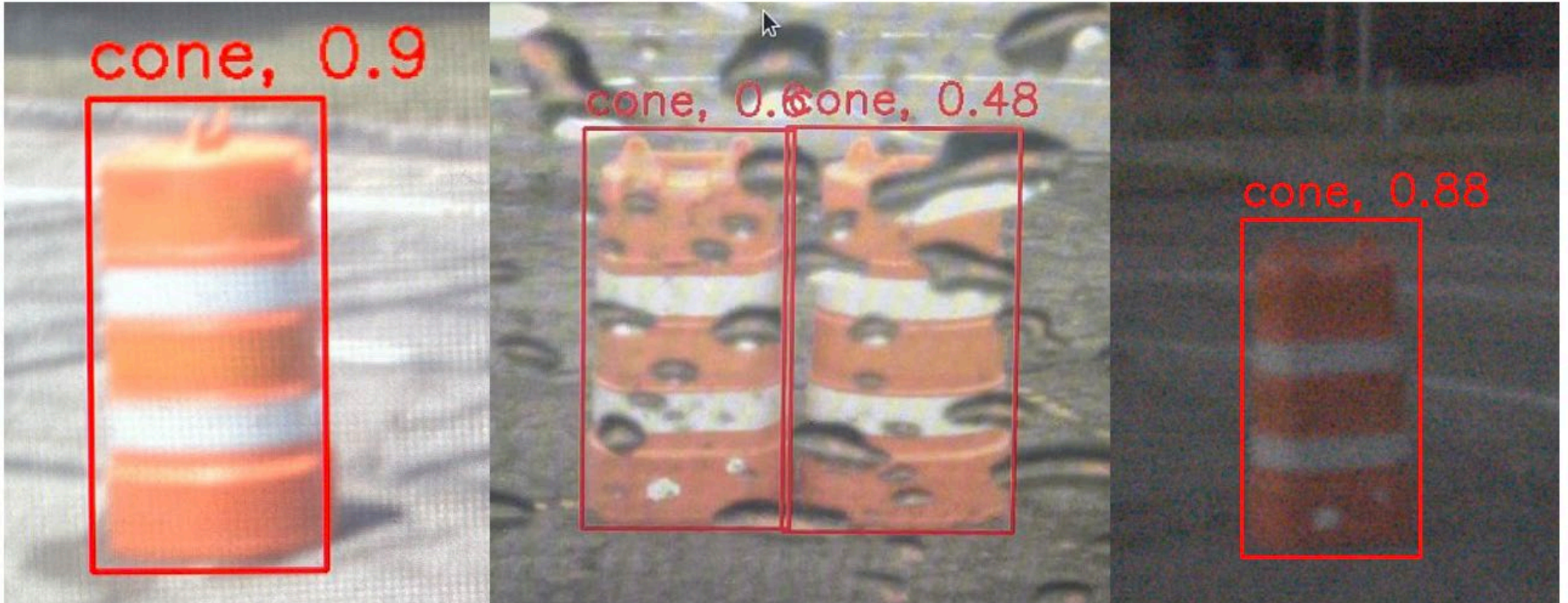
- Canny edge detection
- Hough line detection

Shifted line following

Blob detection

End-to-end deep learning [6]

Object Detection





Research Goals

- Develop a robust lane following algorithm
 - Narrow lane lines
 - Poor road conditions
 - Variable lighting conditions
 - Shadows
 - Rain
- Compare classical and deep learning methods



Experimental Setup



Our Track

- Variable turn radius
- Narrow lines
- Cracks and potholes
- Shadows depending on time
- Starting marker



ACTor 2

- Polaris Gem e2 electric vehicle(ACTor 2)
 - Drive-by-wire system
 - Forward-facing Mako G-319 Camera
 - 2064 × 1544 resolution
 - 37 htz
 - ROS support
 - On-board Ubuntu Linux computers



Methods

Two Approaches

Hybrid
Model

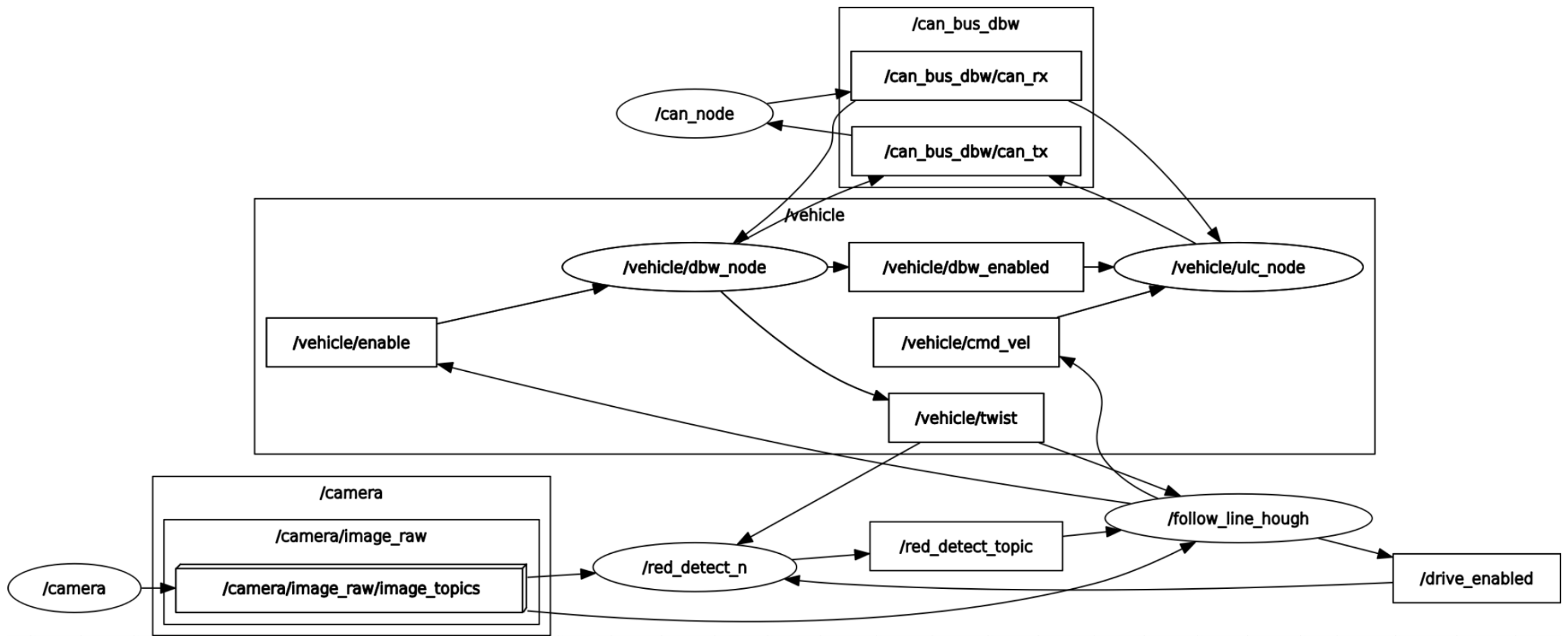
Deep
Learning

Hybrid Model

- Process image with combination of deep learning model and classical techniques
- Pure classical algorithm to drive vehicle



Hybrid Code Architecture



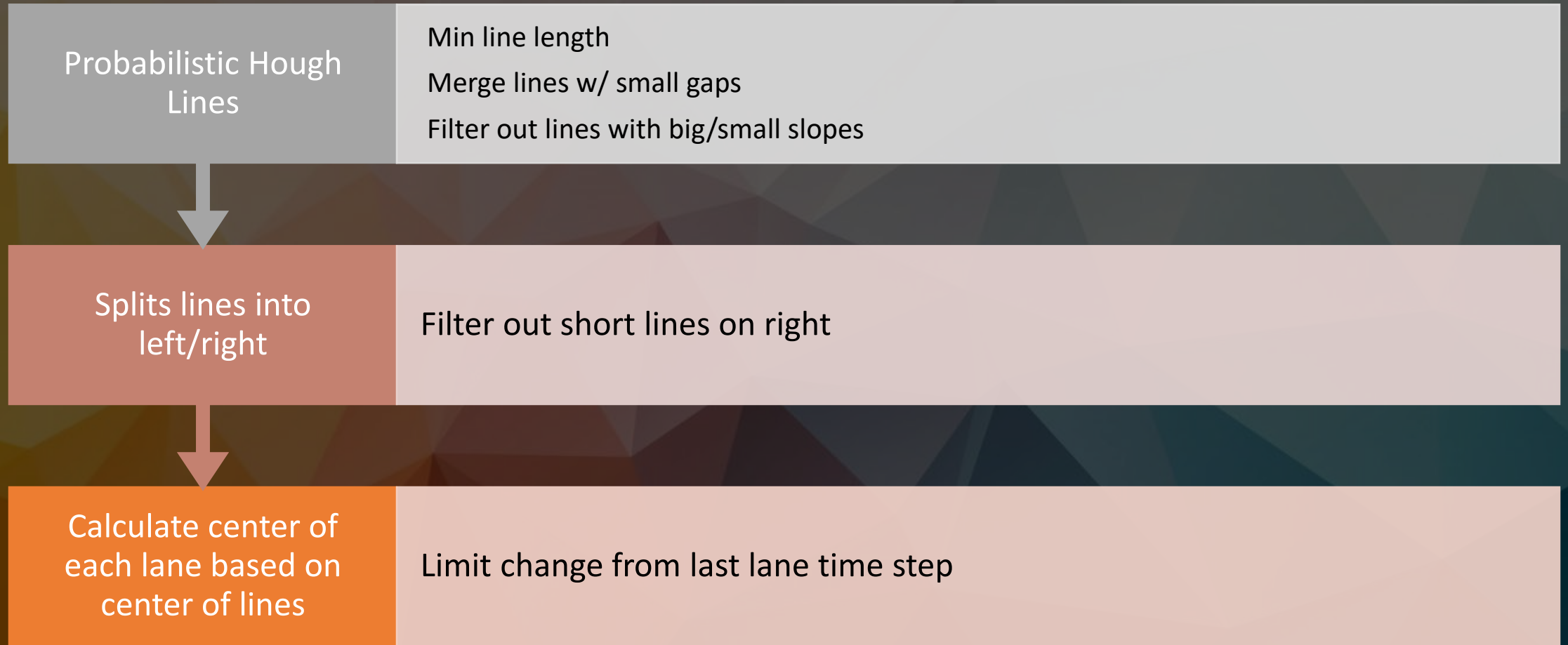
A blue carpeted floor with white lines, likely a robot competition field. A small white robot with a yellow sensor strip is visible on the floor. The image is partially obscured by a white, torn-paper-like border on the right side.

Hybrid Method Preprocessing

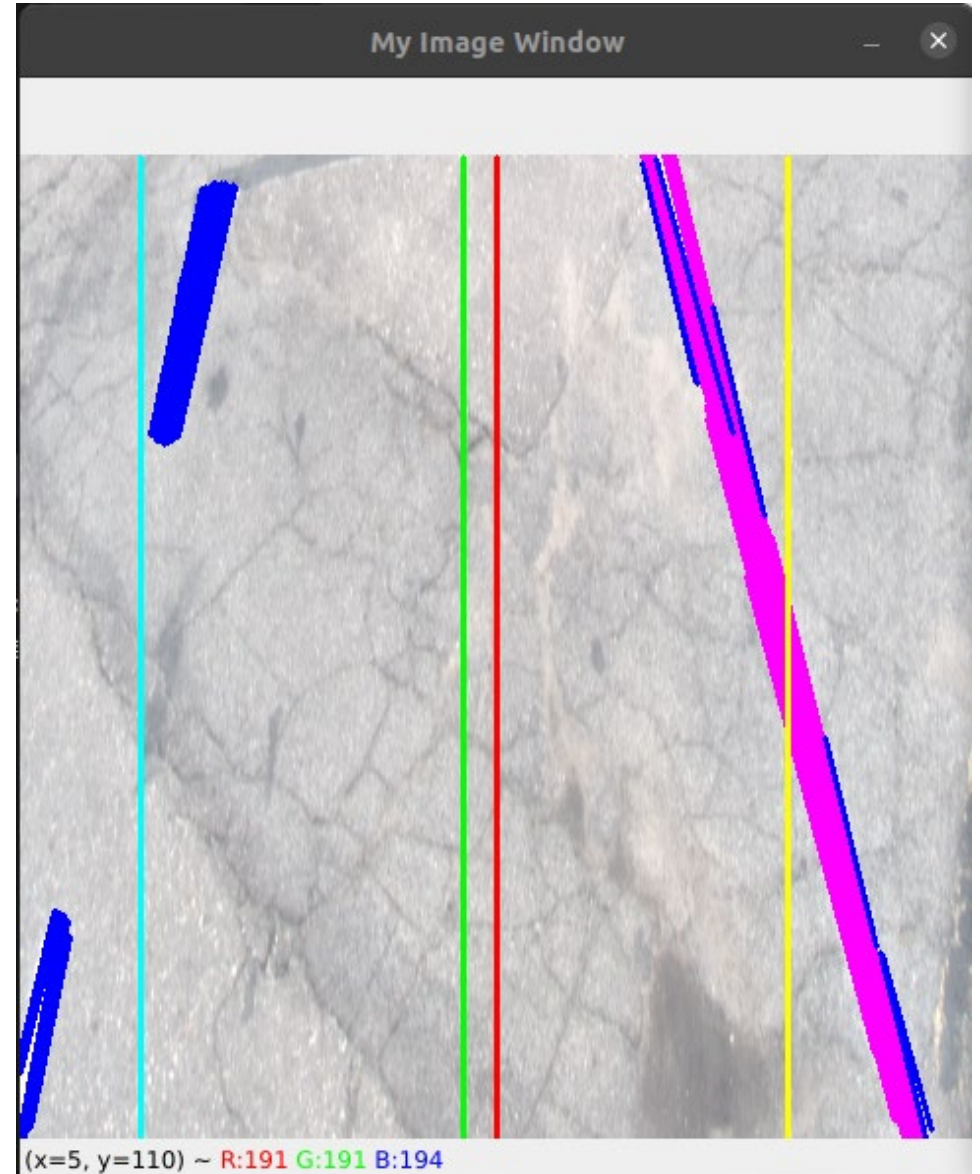
- Crop image to bottom third
- Gaussian blur
- Resize to 200x200
- Pass into pre trained deep learning model
- Resize to 500x500



Hybrid Method Algorithm



- Red: Camera center
- Cyan: Left lane projection
- Yellow: Right lane projection
- Green: Projected center of lane
- Magenta: Long lines, used for right side



Hybrid Method Steering

- Calculate steering yaw based on lane center
- Push onto buffer
- Calculate mean of buffer and steer the vehicle
 - Smoother, less extreme steering

Hybrid Method Segmentation

Weather conditions are dynamic, and need dynamic processing

Image classification vs segmentation

Classification: There is a cat
in this picture

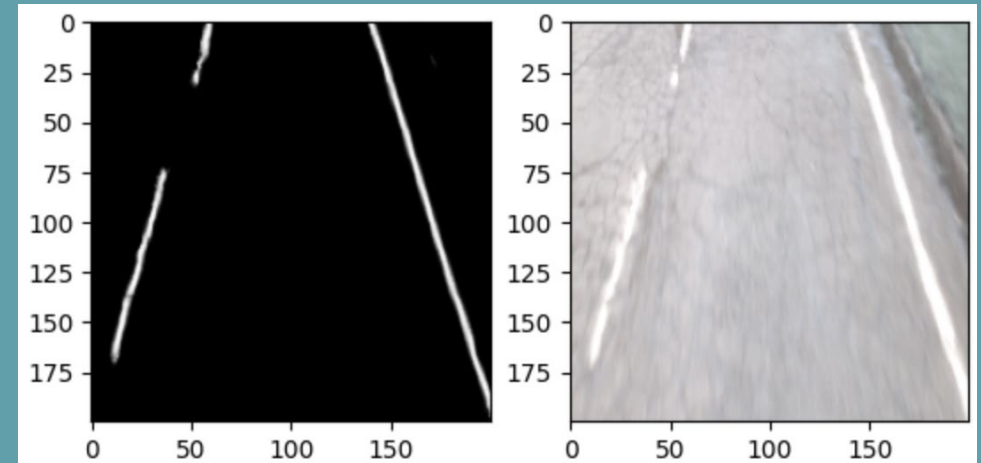
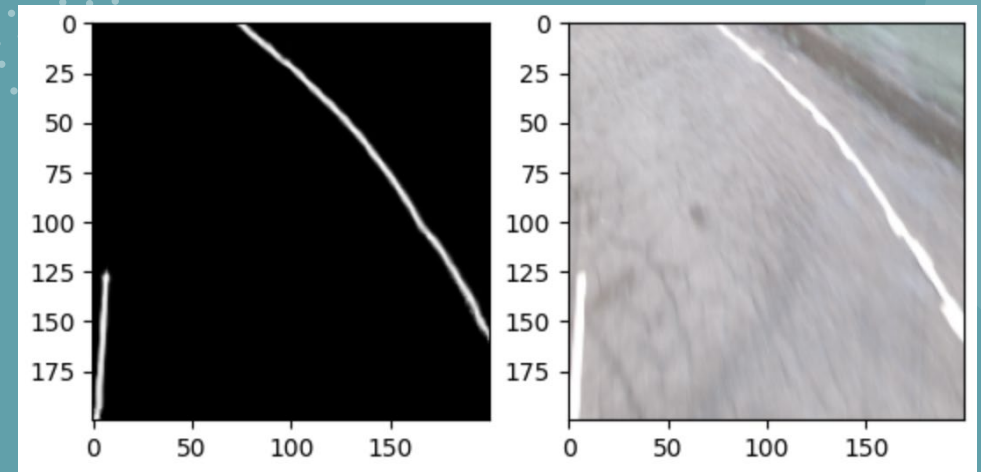
Segmentation: These pixels
are a cat



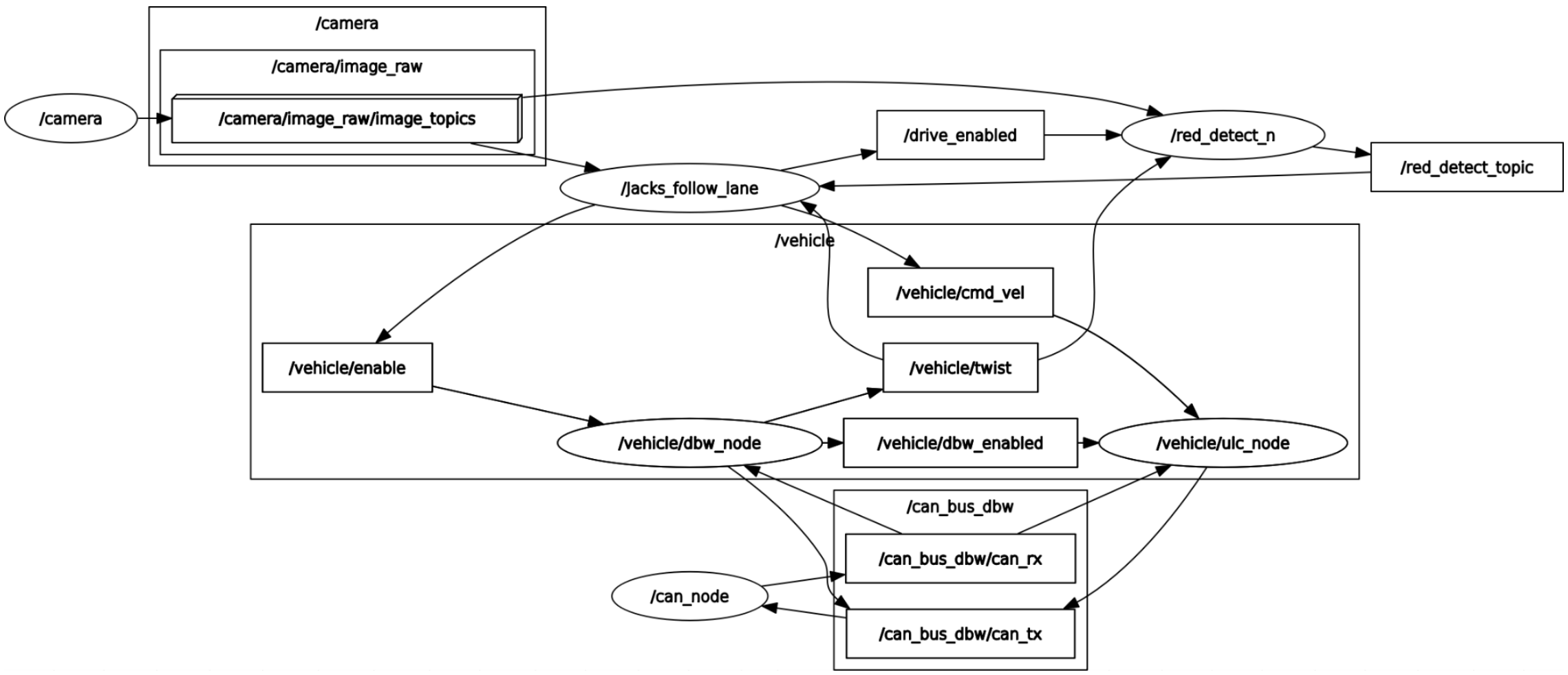
“Image Segmentation : Tensorflow Core.” *TensorFlow*, www.tensorflow.org/tutorials/images/segmentation.
Accessed 18 July 2023.

Hybrid Method Segmentation

- Over 300 training images were hand drawn
- Model was trained on over 3,000 images with the help of data augmentation
- This model works well in shadows, and bright conditions

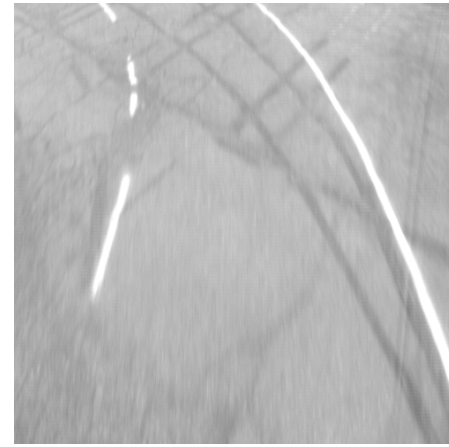


Deep Learning Code Architecture

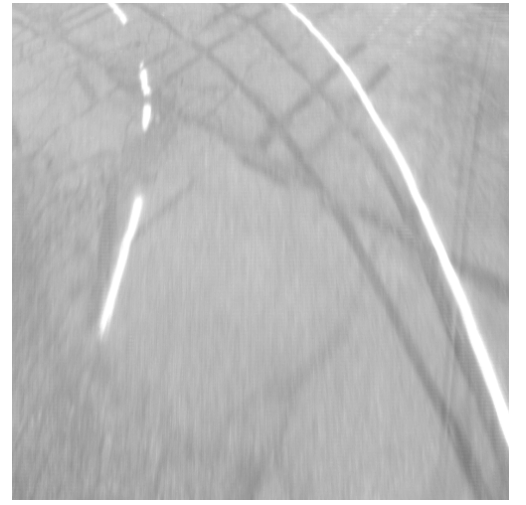


End-to-End Deep Learning

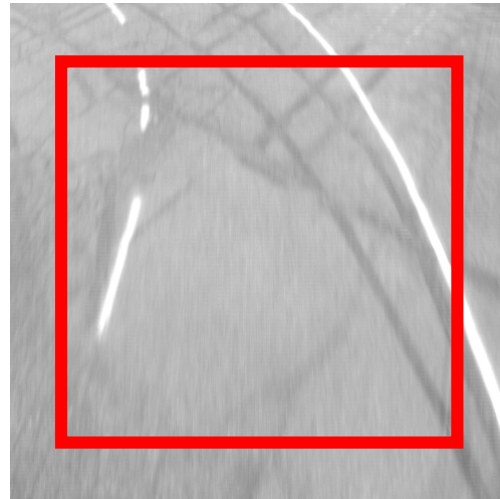
- Over 800,000 training images
- Data augmentation
- Mean absolute error of 0.0201 after training



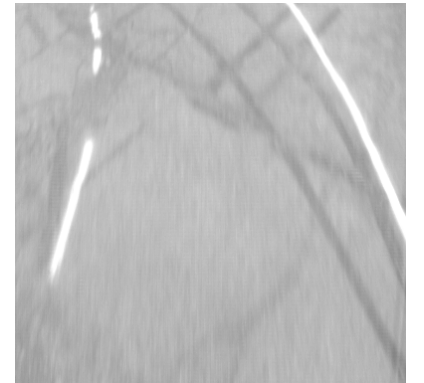
Normal Image



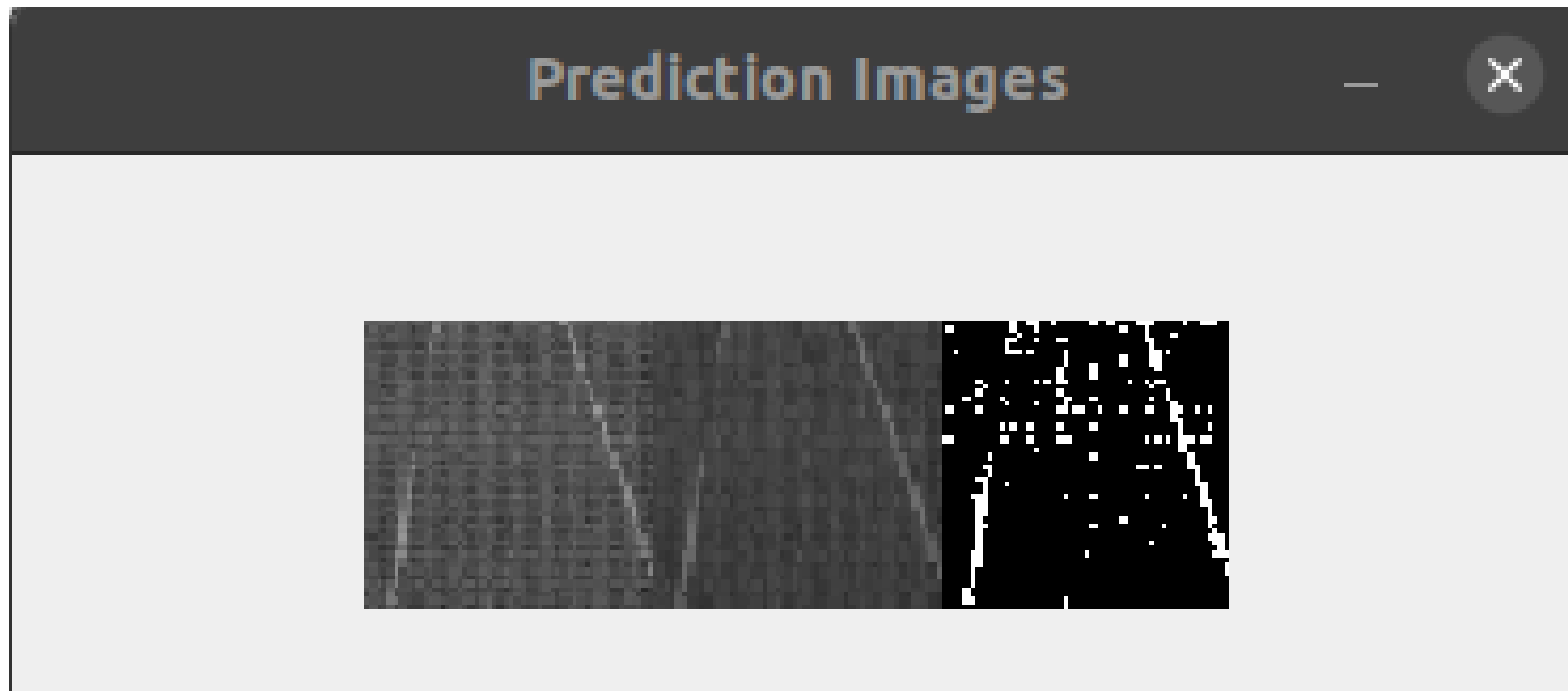
Enlarged Image



Randomly Cropped Image



New Image



End-to-End Deep Learning

- Create three unique images, and predictions
- Remove outlier predictions
- Take the average of the predictions as well as the current yaw



Results

Results

Results (max 5 laps)	July 17, Morning		July 17, Afternoon	
	Inner	Outer	Inner	Outer
Deep Learning	0.5	5	2	5
Hybrid	5	5	5	5

Hybrid Algorithm Data

```

** Lap#1, t taken: 85.84 seconds
  Avg speed: 1.01 m/s, 3.62 km/h,  2.25 miles/h
  Avg steer centering err = 142.0198135198135
  Comfortability: 0.023241677541585314

** Lap#2, t taken: 84.81 seconds
  Avg speed: 1.02 m/s, 3.66 km/h,  2.28 miles/h
  Avg steer centering err = 145.34551886792454
  Comfortability: 0.023190110860394703

** Lap#3, t taken: 84.41 seconds
  Avg speed: 1.02 m/s, 3.68 km/h,  2.29 miles/h
  Avg steer centering err = 131.09834123222748
  Comfortability: 0.023400407860713547

** Lap#4, t taken: 84.01 seconds
  Avg speed: 1.03 m/s, 3.70 km/h,  2.30 miles/h
  Avg steer centering err = 122.80595238095238
  Comfortability: 0.022248059684231842

** Lap#5, t taken: 82.20 seconds
  Avg speed: 1.05 m/s, 3.78 km/h,  2.35 miles/h
  Avg steer centering err = 135.36009732360097
  Comfortability: 0.02329315541563858

```

Outside lane

```

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** Lap#1, t taken: 80.81 seconds
  Avg speed: 0.88 m/s, 3.18 km/h,  1.98 miles/h
  Avg steer centering err = 28.88490099009901
  Comfortability: 0.06345778984365416

** Lap#2, t taken: 79.90 seconds
  Avg speed: 0.89 m/s, 3.22 km/h,  2.00 miles/h
  Avg steer centering err = 57.54067584480601
  Comfortability: 0.061710444161101836

** Lap#3, t taken: 83.31 seconds
  Avg speed: 0.86 m/s, 3.09 km/h,  1.92 miles/h
  Avg steer centering err = 52.22569027611044
  Comfortability: 0.056144771270666874

** Lap#4, t taken: 84.21 seconds
  Avg speed: 0.85 m/s, 3.05 km/h,  1.90 miles/h
  Avg steer centering err = 31.290973871733968
  Comfortability: 0.05607789853746472

** Lap#5, t taken: 97.10 seconds
  Avg speed: 0.74 m/s, 2.65 km/h,  1.65 miles/h
  Avg steer centering err = 31.647785787847578
  Comfortability: 0.05637109896735136

```

Inside lane

Reasons for Failure

1. Sudden change in lighting conditions

2. Lack of error correction

3. Sharp turns cause algorithms to “lock on” to opposite lane

4. Lack of proper Hough line filtering

5. Not enough time to thoroughly train segmentation model



Future Research



Future Research

- Integrate classical and DL models together
- Increase reliability
 - Field testing
 - More training data
 - Error correction
 - Sunrise/sunset





Future Research (Continued)

- Night compatibility
- Recursive Convolutional Neural Networks (RCNNs)
- Unsupervised training for the segmentation model

References

1. Rao S, Quezada A, Rodriguez S, Chinolla C, Chung C-J, Siegel J. Developing, Analyzing, and Evaluating Vehicular Lane Keeping Algorithms Using Electric Vehicles. *Vehicles*. 2022; 4(4):1012-1041. <https://doi.org/10.3390/vehicles4040055>
2. Badue, Claudine, et al. "Self-Driving Cars: A Survey." *Expert Systems with Applications*, vol. 165, 2021, p. 113816, <https://doi.org/10.1016/j.eswa.2020.113816>.
3. *Preprocessing Methods of Lane Detection and Tracking for ... - Arxiv.Org*, arxiv.org/pdf/2104.04755.pdf. Accessed 18 July 2023.
4. Tang, Jigang, et al. "A Review of Lane Detection Methods Based on Deep Learning." *Pattern Recognition*, vol. 111, 2021, p. 107623, <https://doi.org/10.1016/j.patcog.2020.107623>.
5. Kaddis, Ryan, et al. "Developing, Analyzing, and Evaluating Self-Drive Algorithms Using Electric Vehicles on a Test Course." *2022 IEEE 19th International Conference on Mobile Ad Hoc and Smart Systems (MASS)*, 2022, <https://doi.org/10.1109/mass56207.2022.00101>.
6. Eraqi, Hesham M., et al. "End-to-End Deep Learning for Steering Autonomous Vehicles Considering Temporal Dependencies." *arXiv.Org*, 22 Nov. 2017, arxiv.org/abs/1710.03804.

A background image showing horizontal light trails in various colors (yellow, blue, red, white) against a dark background, suggesting a long-exposure photograph of a city street at night.

Thank you. Questions?