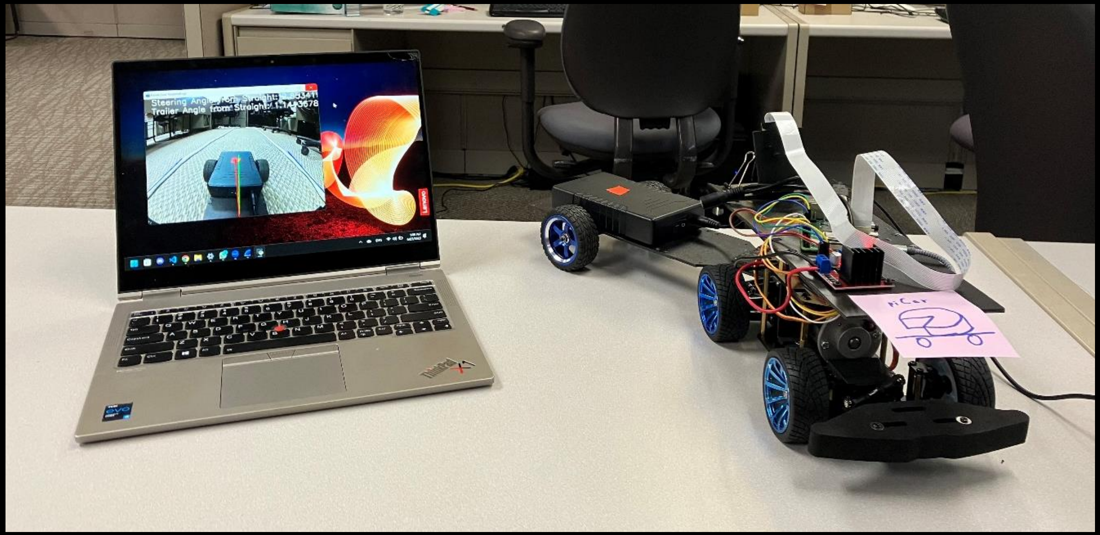
IOWA Driving Safety Research Institute

Back up the Truck



A SAFER SIM Education Project

October, 2023

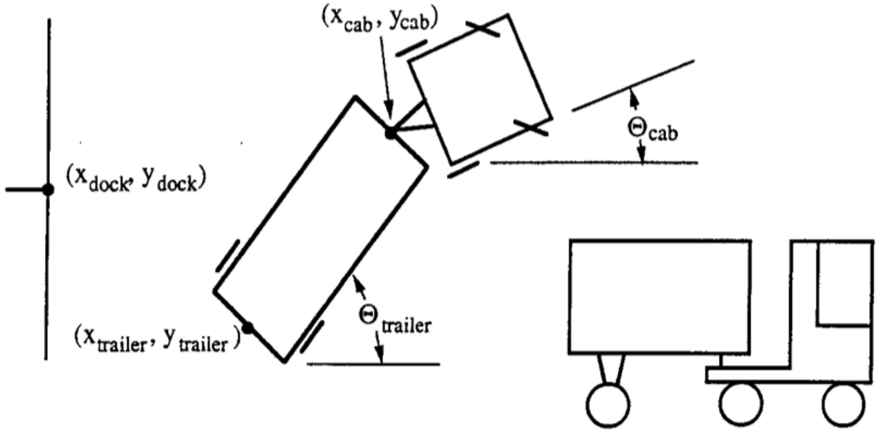
Celebrating 25 Years of the National Advanced Driving Simulator

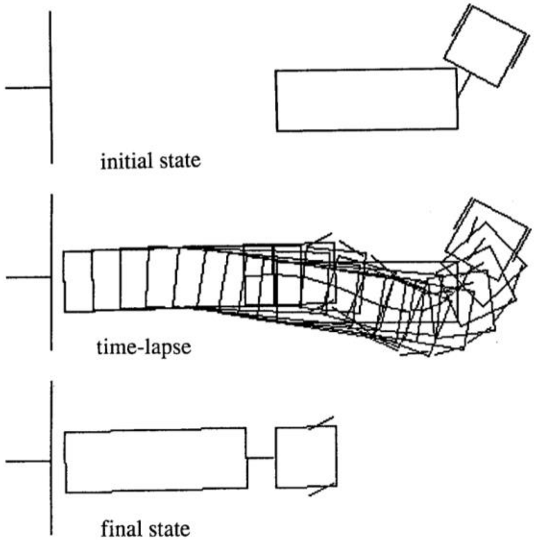
Project Aims

- Build a 1/10th scale model of a car and trailer
- Integrate sensors and control
  - Raspberry Pi 4b
  - Fisheye camera
  - 30W DC motor
  - L298N motor driver controller board
- Program the vehicle to drive autonomously in a lane
  - Start forward, then reverse
- Involve students throughout the process

In the beginning…

- (1989) Nguyen and Widrow trained a neural network to back up a truck to a dock from an arbitrary starting position
  - Full state information





Nguyen and Widrow, "The truck backer-upper: an example of self-learning in neural networks," International 1989 Joint Conference on Neural Networks, Washington, DC, USA, 1989, pp. 357-363 vol.2

In comparison…

- This project is both easier and harder
- Easier: drive in a lane, rather than back up to a fixed dock
- Harder: no state information available—need to estimate it

Is speed a state?

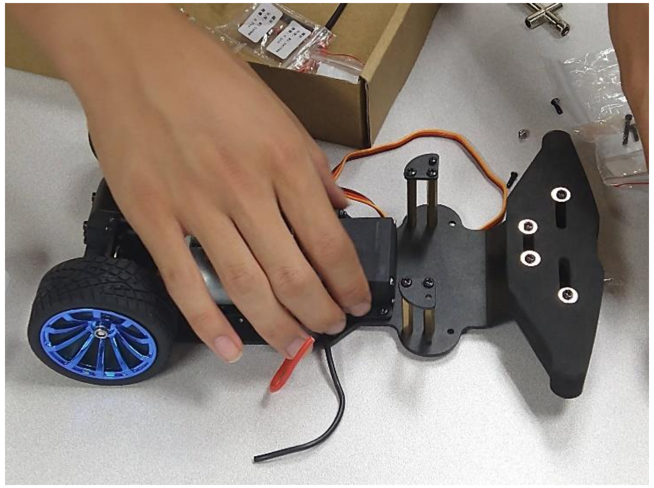
Nguyen and Widrow do not include speed. At low speeds, it can be neglected with little impact.

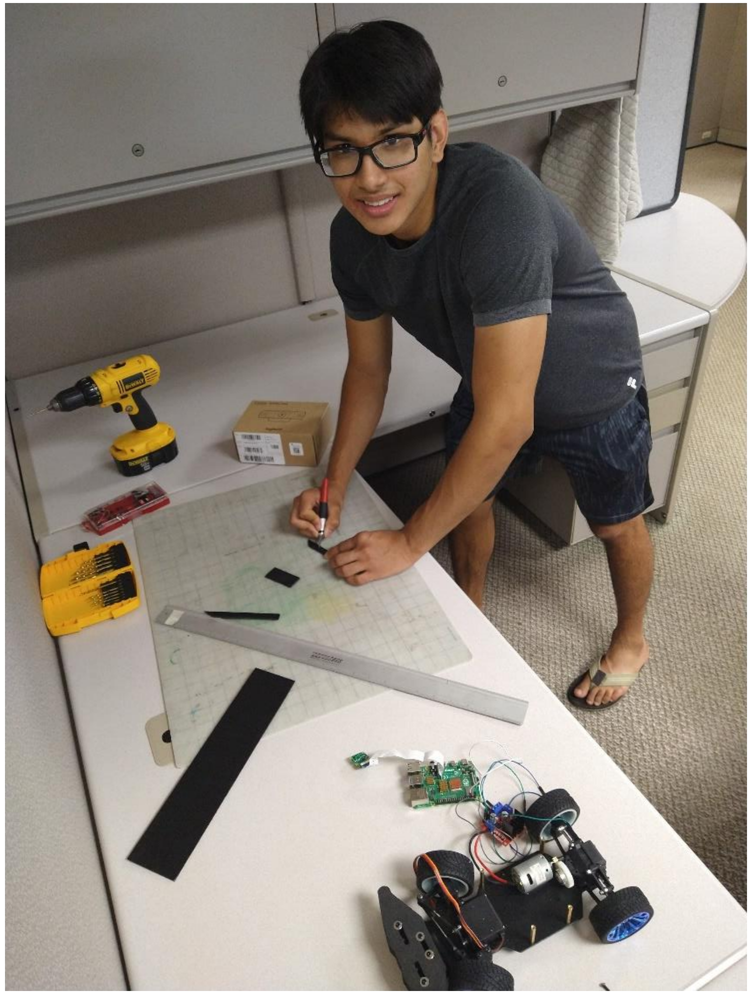
However, the state update does depend on speed:

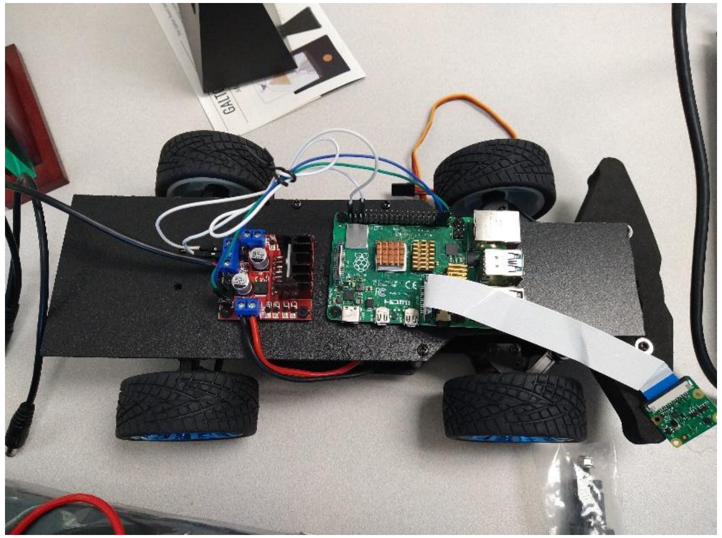
$$\dot{x} = v_1 f(x, \kappa),$$

We do include speed even though we are generally limited to low speeds. Our implementation has flexibility to generalize to higher speeds

The Build

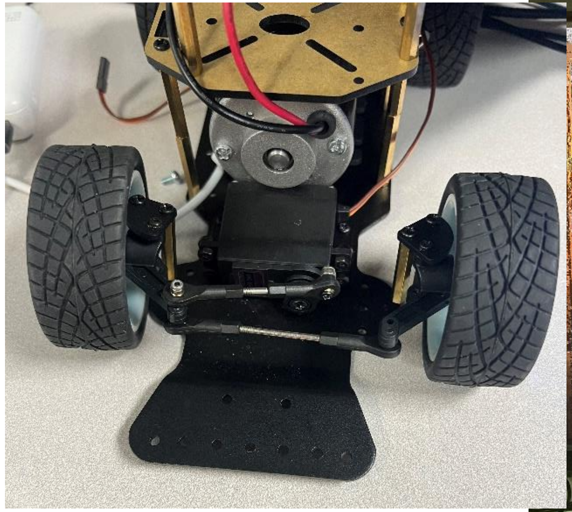


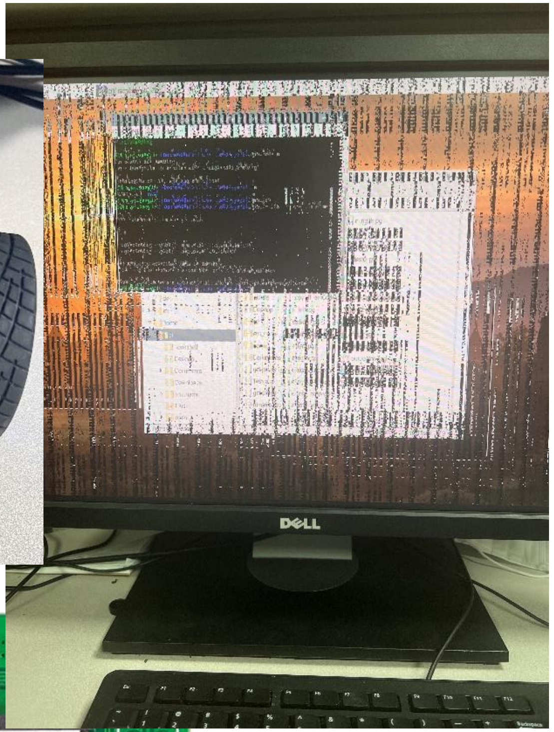


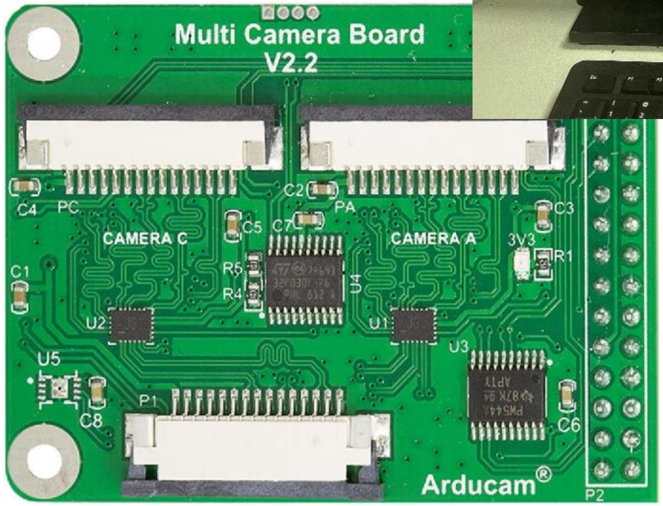


Technical Issues

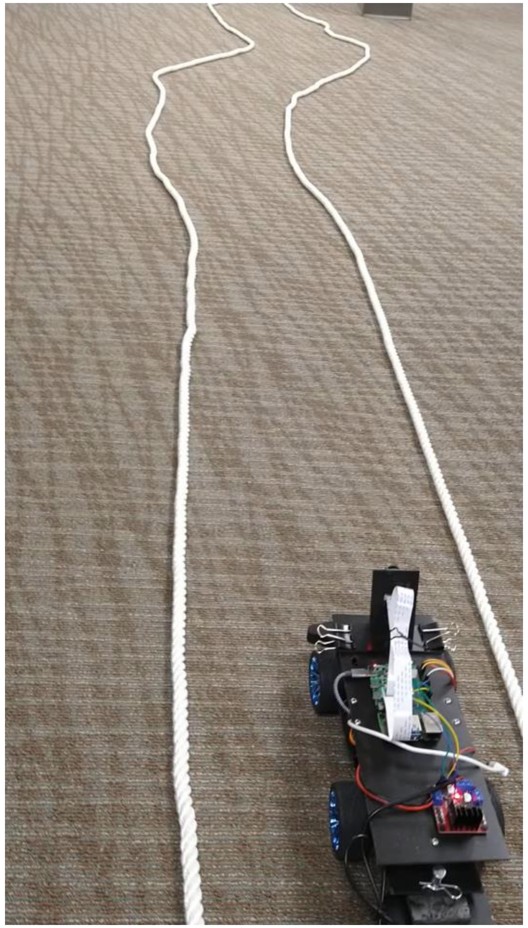
- Casualties
  - 1 fried Raspberry Pi
  - 1 undersized DC motor
- Wrong turns
  - A multi-camera board designed to support multiple cameras, but which took up too many pins on the Pi
- Sabotage
  - The L298N spec sheet swapped labels on two pins, causing weeks of head-scratching

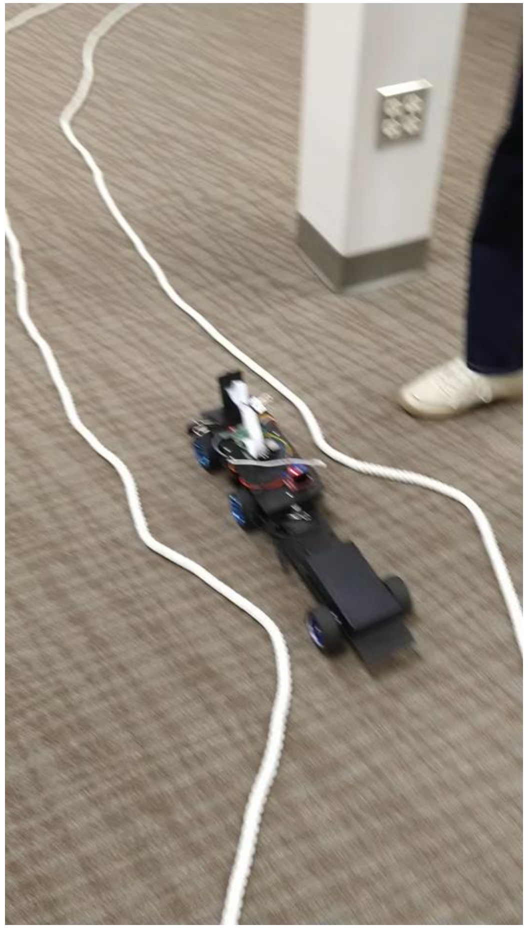


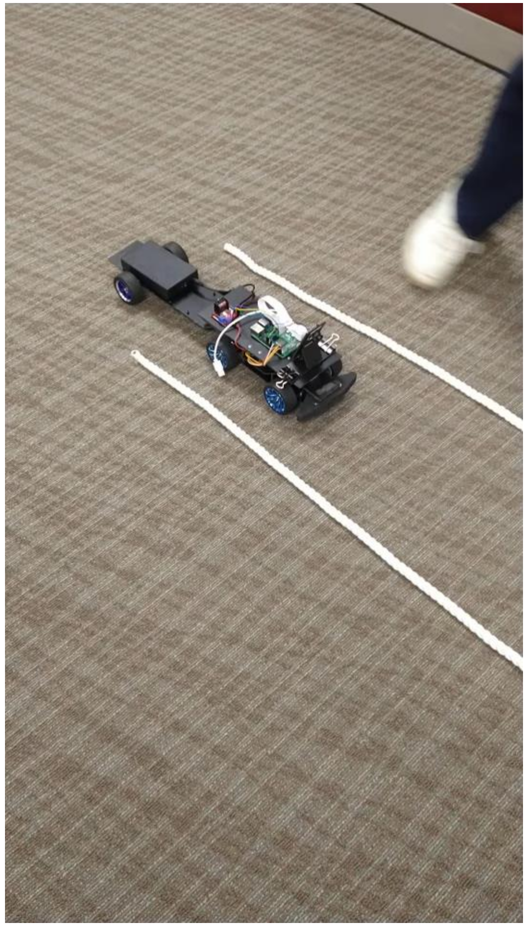




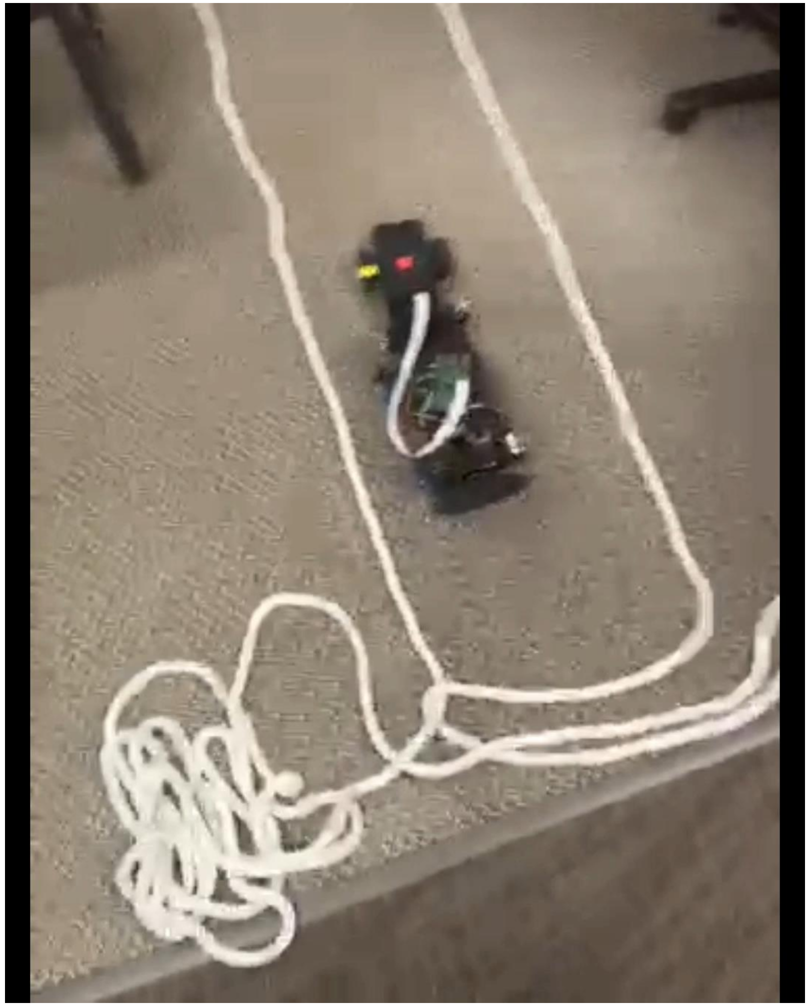
Driving Forward

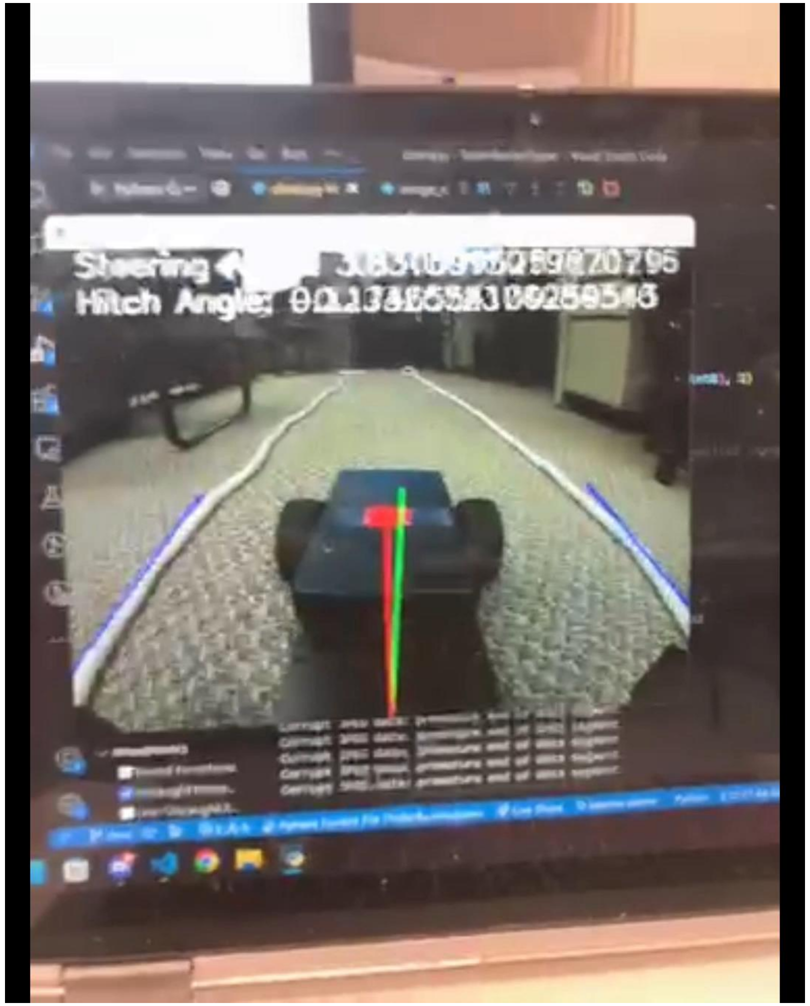






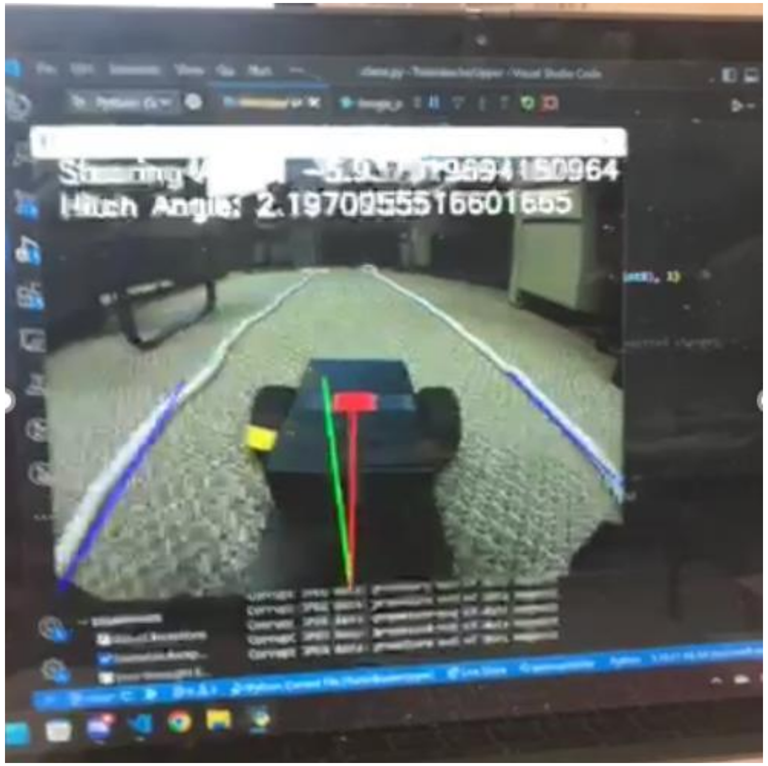
Driving Backward





Going Deeper

- Very little state information about the vehicle is directly measured
  - Steering is commanded. Mapped normalized input to engineering units
  - Speed unknown
  - Hitch angle unknown
- Our solution was to mount the camera on the car and estimate state from the image
  - Lane lines (white)
  - Hitch angle (red)
  - Wheel speed (yellow)
- We also integrated a cool video streaming capability that gives it an augmented reality visualization



Open Source Software

- Check it out on github: https://github.com/cschwarz68/TrailerBackerUpper
- Runs in three modes
  - Manual. Controlled by Logitech G F310 game controller
  - Auto Forward. Assumes camera faces forward
  - Auto Reverse. Assumes camera faces backward
- Relies on external camera streaming code
  - https://github.com/ancabilloni/udp_camera_streaming
- Image processing uses OpenCV, the open computer vision library

Speed Estimation

- Problem: motor voltage provides torque control, not speed control. It’s hard to accurately maintain constant speed under varying loads (e.g. when the vehicle steers around curves)
- Solution: mark a tire with yellow tape and count rotations
- Alternate solution: a more elegant solution that would require more hardware modifications would be to add an encoder to a wheel

Model Predictive Control

- Problem: backing up a trailer is not achievable with traditional PID controllers because of the need to steer opposite and make steering reversals
- Solution: implement a nonlinear control method like MPC
- Model Predictive Control (MPC)
  - Measure (or estimate) vehicle state at time t
  - Simulate vehicle from time t to time $t + t_{\Delta}$
  - Compute final error at t_{Δ} and iterate simulations using optimization
  - Send best steering input to actual vehicle and run until t_{Δ}

Deep Learning

- NVIDIA trained a convolutional neural network (CNN) to drive a car on the road
  - Bojarski, M., Del Testa, D., Dworakowski, D., Firner, B., Flepp, B., Goyal, P., ... & Zieba, K. (2016). End to end learning for self-driving cars. *arXiv preprint arXiv:1604.07316*.
- David Tian used the NVIDIA model to train a 1/10th scale car to drive in a marked lane
  - https://github.com/dctian/DeepPiCar
- We used the same NVIDIA model to train our vehicle to drive forward in a marked lane
  - We recorded a set of images and the steering values predicted by an independent controller
  - This set was used to train the CNN and use it to navigate
  - Developed code to generate a training set of images and steering values

Education and Outreach

- Used the robot as a demo and prop for a marketing exercise
- Demonstrated its function to a group of jr. high and high school students as part of a tour
- Currently on load to a group of computer science students who are using it for a course project

IGNITE: Engineering Success Conference 2023

Conclusions

- 1/10th scale cars make good platforms for development, proof-of-concept, education, demonstration, and entertainment
  - There are several groups and professors who use them in their work
- We went beyond the typical autonomous driving car to a harder problem of backing up a trailer in a lane
- A lot of the educational value in the project was in the students who got to work on it and learn new skills
- With its foundation of code for image processing, motor control, game controller, and navigation, the robot is well positioned as a platform for students to do new work on machine vision, machine learning, control techniques, etc.

Acknowledgements

- Funding provided by SAFER SIM
- Workplace Learning Connection interns
  - Bill Chen, Kyle Chi, Natalie Hawk, Raven Levitt, Marcus Miller, Tommy Rogers, Bivan Shrestha, Alex Yao
- University of Iowa undergraduate students
  - Amol Bhagavathi, Adithya Mukundan, Christopher Nair, Alan Ramirez
- David Tian for posting a series of articles on the development of DeepPiCar
  - https://github.com/dctian/DeepPiCar
- An Nguyen for live video feed streaming code
  - https://github.com/ancabilloni/udp_camera_streaming

Driving Safety Research Institute

2401 Oakdale Blvd.
Iowa City, IA 52242

319-335-4673

dsri.uiowa.edu

Find us on:

IOWA