Data-Driven Hardware-in-the-Loop Plant Modeling for Self-Driving Vehicles

Hannah Grady Nicholas Nauman Md Suruz Miah

Department of Electrical and Computer Engineering
Bradley University, Peoria, Illinois, 61625, USA

Sponsor: AutonomouStuff | https://autonomoustuff.com/
306 Erie Avenue, Morton, IL 61550
Telephone: 309-291-0966, email:info.as.ap@hexagon.com

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Outline

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Introduction

Applications of Autonomous Vehicles

- Autonomous vehicles are being developed by many companies for commercial and personal use
- Modeling different subsystems (such as, steering, brake, acceleration, ...) for autonomous vehicles is a challenging task
- Models for autonomous vehicle subsystems must be very accurate due to safety factors

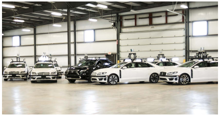

Figure 1: AutonomouStuff Vehicle Fleet[a]

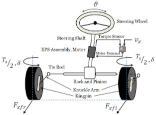

Figure 2: Autonomous Vehicle Steering System[b]

[a] https://hexagonpositioning.com/pi-brands/autonomoustuff

[b] https://www.autonews.com/article/20181105/OEM10/181109921/delphi-s-pace-award-winning-e-steer-an-autonomous-vehicle-building-block

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Problem Statement

Given input-output data of different subsystems, such as steering, acceleration, brake, shift, speed, and speed control, of an autonomous (self-driving) vehicle:

- Develop mathematical and/or block diagram models of these subsystems
- Develop machine learning-based models for the major subsystems of Lexus self-driving vehicle

Problem Statement

Given input-output data of different subsystems, such as steering, acceleration, brake, shift, speed, and speed control, of an autonomous (self-driving) vehicle:

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Proposed Solution

- Use state-space modeling techniques based on input and output data
- Use system identification modeling techniques
- Use machine learning (neural network) based modeling techniques

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Existing Solutions

- Use of System Identification Toolbox in MATLAB to create models from data [1]
  - Offers a variety of model choices
  - Needs a large amount of raw data to produce an accurate model
- Third order ARMAX model creates models using traditional methods of analysis [2]
  - Allows the use of traditional analysis methods to create a model
  - More room for error during calculations
- Steer-By-Wire method as a system model [3]
  - Can model systems with small non-linearities
  - Mechanical components replaced by electrical components
- Authors in [4] illustrate identification of multiple-input single-output model for maximum power point tracking of photovoltaic system.
  - Fourth order ARX model ended up giving the best fit

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System Identification Preliminaries

Preliminary Work

- Documentation on MATLAB's System Identification Toolbox and tutorials
- Literature Review
- Data Collection for steering, braking and acceleration subsystems

MATLAB Example: Dealing with Multi-Variable Systems: Identification and Analysis

- Learned how to create an iddata object from a given data set
- Created a state space model and compared it to the validation data
- Tried creating submodels for some of the channels in order to try and get a better fit
- Then created a MISO model and learned how to merge the two SISO models that were created earlier

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System Architecture

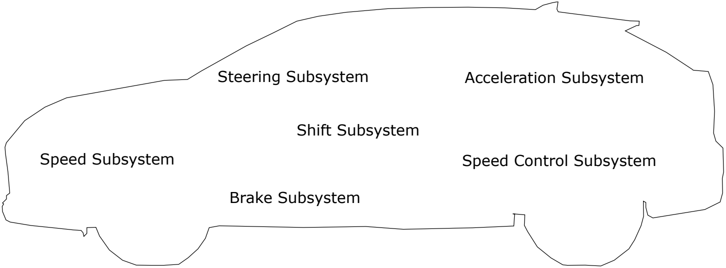

Figure 3: Lexus Vehicle with Subsystems

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System Architecture

The overall system architecture of this project consists of six subsystems:

- Steering
- Acceleration
- Brake
- Shift
- Speed
- Speed control

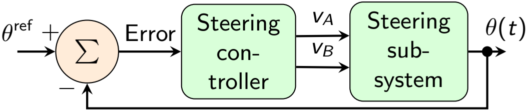

Figure 4: Steering subsystem block diagram.

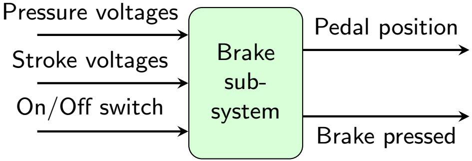

Figure 5: Brake subsystem block diagram

System Architecture

Subsystems

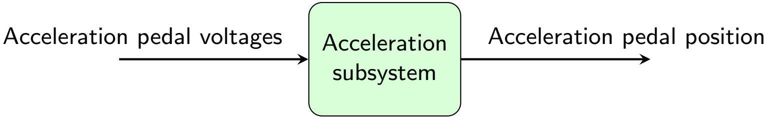

Figure 6: Acceleration subsystem block diagram

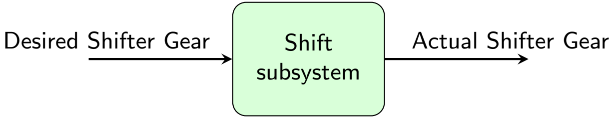

Figure 7: Shift subsystem block diagram

System Architecture

Subsystems

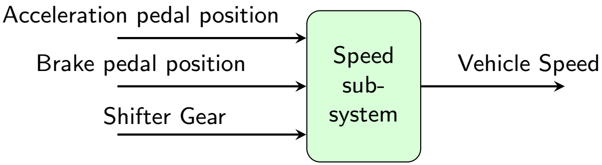

Figure 8: Speed subsystem block diagram

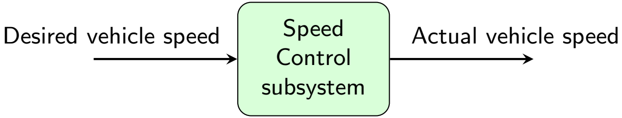

Figure 9: Speed Control subsystem block diagram

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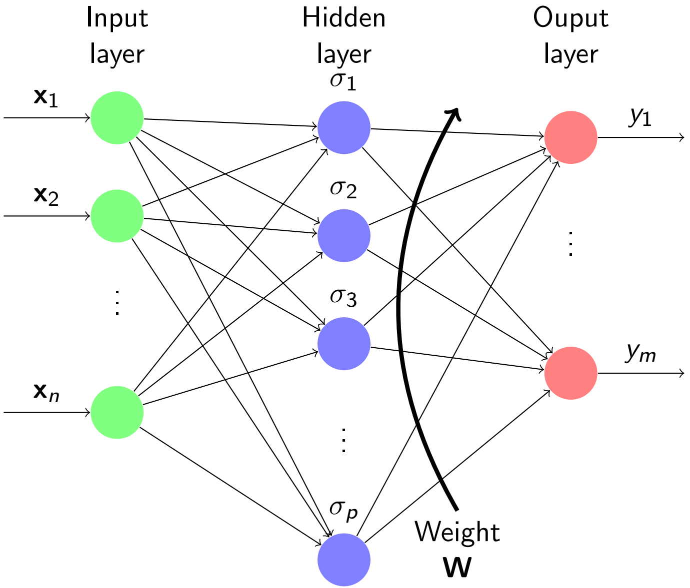
Modeling using Neural Networks



Modeling using Neural Networks

- Used MATLAB's Neural Network Time Series App
- All models generated using the Bayesian Regularization Algorithm
- Models trained using collected log data

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Modeling Vehicle Subsystems

System Requirements

Specifications

Proposed vehicle subsystem models are expected to fulfill requirements listed below' :

- Resulting plant model will consist of reasonably accurate subsystem models
- Subsystem models must reach an accuracy level of at least 95%
- Steering model can handle very small changes in steering angles
  - smooth out any non-linear discontinuities that would normally be measured by the steering motor, especially for small changes in the steering angle, depicted in 11.

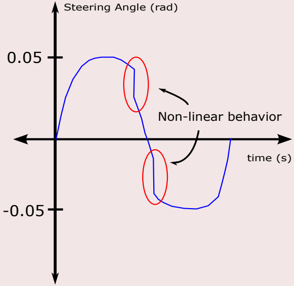
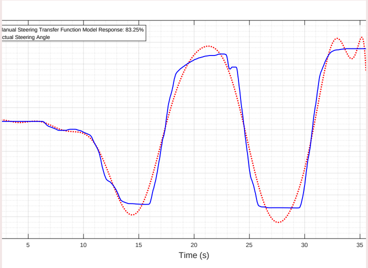


Figure 11: Steering Non-linear Behavior

Outline

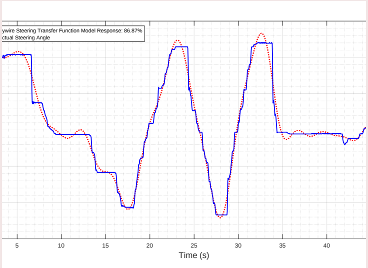
Manual Mode

- y-axis represents the steering angle in radians; range of -10 to 10
- Model was able to achieve a best fit percentage of 83.25%



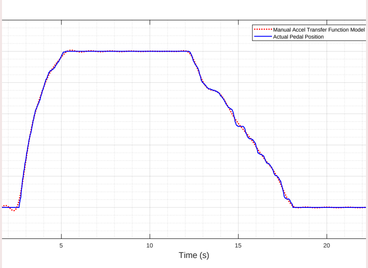
By-Wire Mode

- y-axis represents the steering angle in radians; range of -10 to 10
- Model was able to achieve a best fit percentage of 86.87%



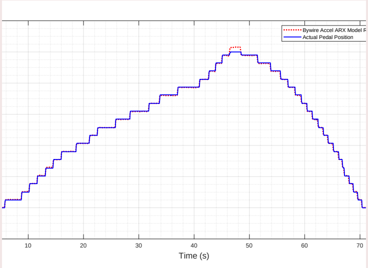
Manual Mode

- y-axis represents the acceleration pedal position as a percentage; range of -0.2 to 1.2
- Model was able to achieve a best fit percentage of 98.3%



By-Wire Mode

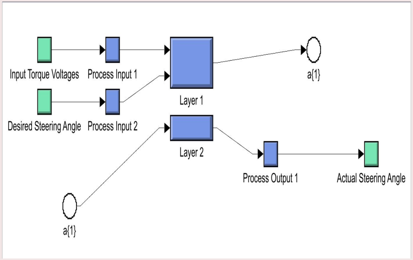
- y-axis represents the acceleration pedal position as a percentage; range of -0.2 to 1.2
- Model was able to achieve a best fit percentage of 97.69%



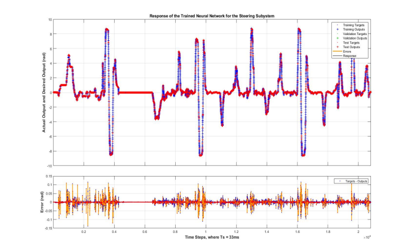
Transfer Function Modeling

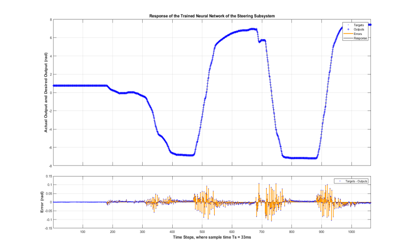
Brake System Simulation

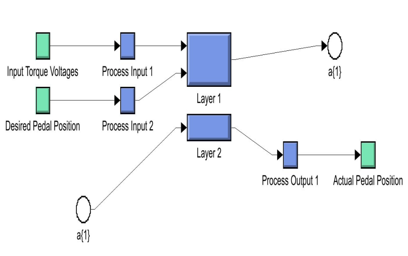
- Only manual models were considered
- There were no transfer function models that could satisfy both the best fit and error requirements



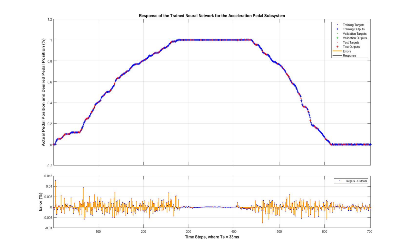
- Only a few samples are just outside of the accuracy requirements
- y-axis of top graph represents the actual and desired steering angle in radians

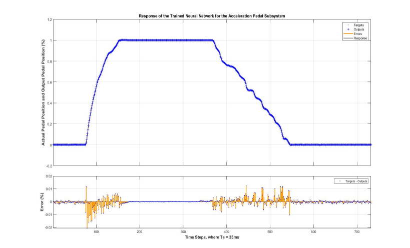






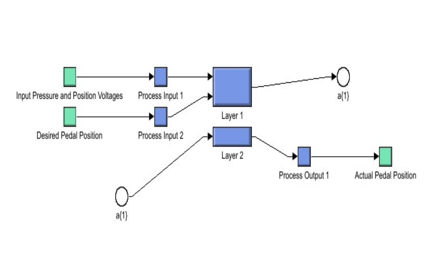
- All samples within 2% of the actual output
- y-axis of top graph represents the actual and desired acceleration pedal position as a percentage
- Fewer concerns about connections in Simulink



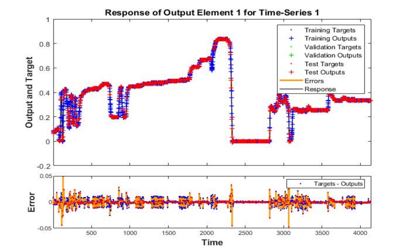


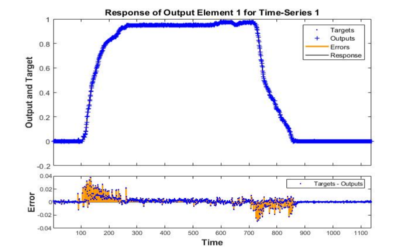
Neural Network Modeling

Brake System Simulation



- With this model, the error is kept below 5%
- y-axis of top graph represents the actual and desired brake pedal position as a percentage
- Provides better results than the transfer function model





Outline

Software and Hardware

- Software
  - MATLAB's System Identification Toolbox
  - MATLAB's Neural Network Time Series Toolbox
  - DSpace/Control Desk
  - Vector CANAlyzer
- Hardware
  - Laptop
  - PACMod ECU
  - CANCase
  - CAN bus

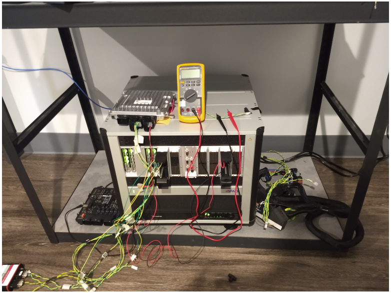
Validation and Testing

Experimental Setup

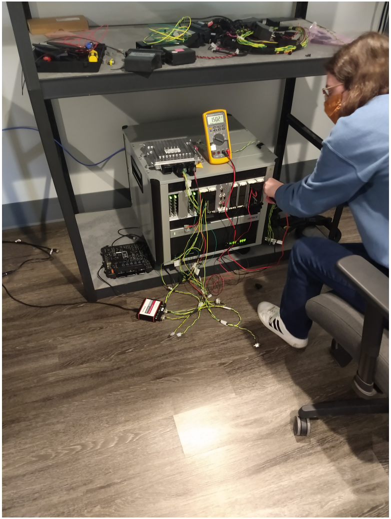
Control Method

- Manual Mode
  - Vehicle is not autonomous
  - Torque voltages are sent by the vehicle ECU
- By-Wire Mode
  - Vehicle is autonomous
  - Torque voltages are sent by the PACMod ECU
  - Torque voltages sent from the vehicle ECU are discarded by open-circuiting the motors

Figure 16: Autonomous Vehicle Data Collection Setup



- HIL Bench
- Measuring output voltages to confirm results



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- Testing data points using Control Desk software

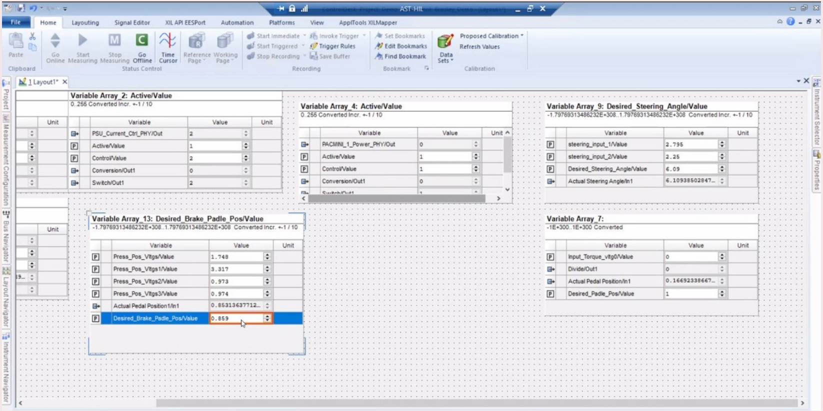

Figure 17: Model Validation Setup

Outline

Conclusions and Future Work

Conclusions and Challenges

- Conclusions
  - Switch from transfer function to neural network models
  - Neural network modeling worked best
- Challenges
  - Time constraints
  - Hardware constraints

Future Work

- Model shift, speed, and speed control subsystems
- Test models using Hardware-in-the-Loop
- Create new vehicle controllers

Outline

References I

[1] R. Adnan, M. H. F. Rahiman, and A. M. Samad, “Model identification and controller design for real-time control of hydraulic cylinder,” in *2010 6th International Colloquium on Signal Processing its Applications*, 2010, pp. 1–4.

[2] B. Li, R. Wang, Y. Zhang, and Z. Wang, “Modeling of steering system of high speed intelligent vehicle by system identification,” in *Proceedings of the IEEE International Vehicle Electronics Conference (IVEC'99) (Cat. No.99EX257)*, 1999, pp. 243–246 vol.1.

[3] S. A. Saruchi, H. Zamzuri, S. A. Mazlan, M. H. M. Ariff, and M. A. M. Nordin, “Active front steering for steer-by-wire vehicle via composite nonlinear feedback control,” in *2015 10th Asian Control Conference (ASCC)*, 2015, pp. 1–6.

References II

[4] M. Hussain, A. Omar, and A. Samat, “Identification of multiple input-single output (miso) model for mppt of photovoltaic system,” in *2011 IEEE International Conference on Control System, Computing and Engineering*, 2011, pp. 49–53.