Explorations and Lessons Learned in Building an Autonomous Formula SAE* Car from Simulations

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FORMULA TECHNION

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Formula Student Competition

The formula student association consists of approximately 600 universities from all over the world. The goal in the SAE formula competitions is the construction of a fully functioning race car from scratch within only one academic year, every year.
Last year, a new competition had opened, in which the students are required to take one of their formula cars from previous competitions, and make it driverless.

This project focuses on developing an autonomous driving algorithm completely in simulation and then deploying on a real car. This consist of training a deep neural network that uses only a single camera as input for inferring car steering angles in real-time.

Training Environment

Seeing that we couldn't acquire a sufficient amount of recorded data using a real formula car, we designed a simulated race track environment that mimics the competition's conditions.
Our premise is that the model would perform better in the real world as the simulated environment becomes more realistic. The physics and dynamics of the car were fine-tuned to resemble the actual car.
Our simulation is based on an open source project called AirSim[1], created by Microsoft on Unreal Engine 4.

Actual car

Simulated car model in UE4

Training Data

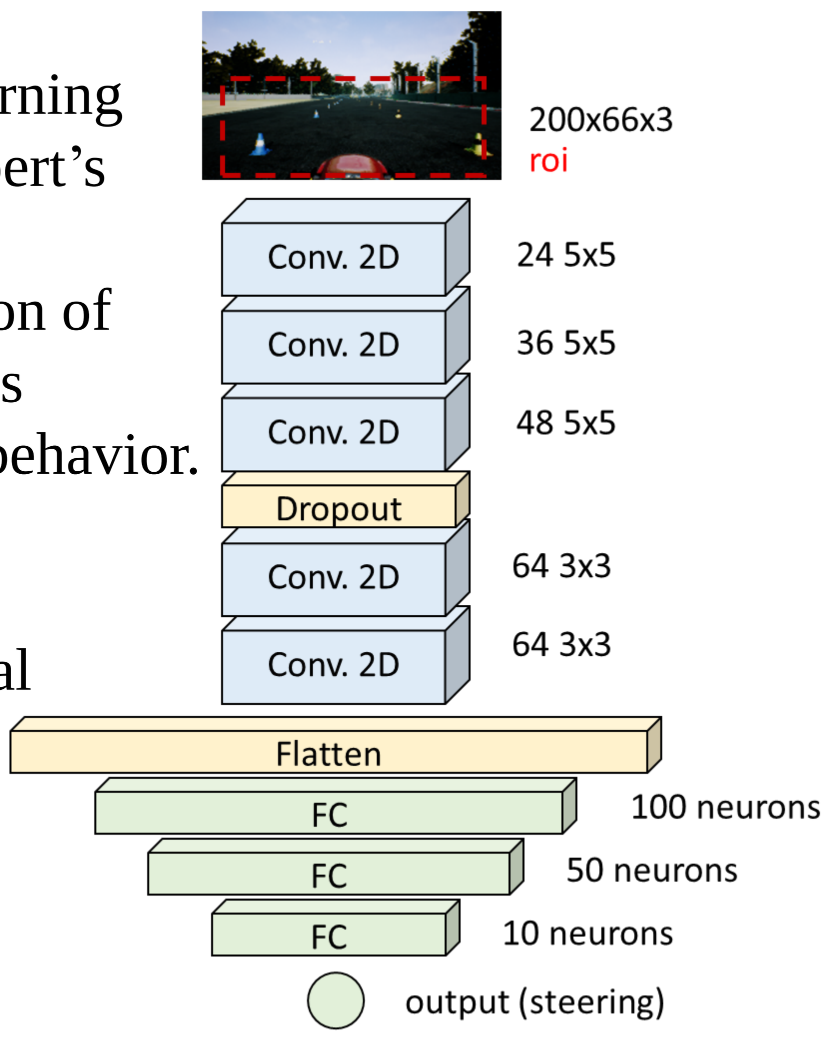
For the purpose of encouraging a satisfying generalization of the model, we used a wide variety of data types, recorded by several human drivers:

- Environment conditions such as temperature and cloudiness.
- "CycleLight" - Simulating a short day cycle, thus preventing overfitting to certain lighting conditions, and helps in overcoming a shortage of data.
- Driving Styles:
  - Safe and normative - Relatively straight tracks.
  - Swerved - Prebuilt tracks with sharp turns.
  - Drunk - Constantly turning sharply from one edge of the road to the other.
  - Shifted[2] - Driving normatively with an altered camera position. The recorded steering angle is later changed in accordance to the position of the camera.

Algorithm and Model Network

Imitation learning method:
The motivation behind imitation learning is to teach a model to mimic the expert's actions based on the observations .
Using a carefully selected distribution of recorded labeled data, the model was trained to imitate a human driver's behavior.

Model architecture:
The chosen architecture of our neural network model is a modified version of PilotNet[3]. We have used it throughout our training procedure.



Testing

Empirically, it has been shown throughout our testing processes that running the model on an unseen track and monitoring it's behavior and time spent on track, produces a better estimation of the model's performance than classic test sets.

Model	Changes	Val Loss	Time On Track
Basic CNN	-	0.0570000	2 minutes
PilotNet	-	0.0000345	10 seconds
PilotNet	Leaky ReLu	0.0000279	3 minutes
PilotNet	Drunk style data added	0.0039492	5 minutes
PilotNet	Removing car state from input	0.0130848	6 minutes
PilotNet	CycleLight, added shifted driving	0.0028828	3 hours

The major change observed in the transition to the last model, was mainly caused by the introduction of a carefully selected data distribution.

From Simulation To Reality

Our main contribution is the implementation of our trained model in real environment, using only simulated data for the training phase, without fine-tuning on real world data.
To make the transfer from simulation to real world as smooth as possible, we made several adaptations and optimizations:

- Installation of a Nvidia Jetson TX2 for efficient inference.
- Executing our model using TensorFlow instead of Keras, to achieve high frame rates.
- Assembling a professional lens to illustrate simulated camera performance.
- Managing reliable communication between the steering mechanism and the network output.

Our experiments took place in an obstacle-free road segment, dedicated for autonomous vehicles.
The final model performs exceptionally well on all tested tracks in simulation and in real-world.

Driving on an experimental road segment in Israel

* A student formula design competition organized by SAE international (previously known as the Society of Automotive Engineers)

[1] AirSim: High-Fidelity Visual and Physical Simulation for Autonomous Vehicles: *https://github.com/Microsoft/AirSim*
[2] Learning a CNN-based End-to-End Controller for a Formula Racecar: *https://arxiv.org/pdf/1708.02215.pdf*
[3] Explaining How a Deep Neural Network Trained with End-to-End Learning Steers a Car: *https://arxiv.org/pdf/1704.07911.pdf*