# Multimodal End-to-End Learning for Autonomous Steering in Adverse Road and Weather Conditions

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FGI autonomous driving research platform ARVO.

# Research goal and contribution

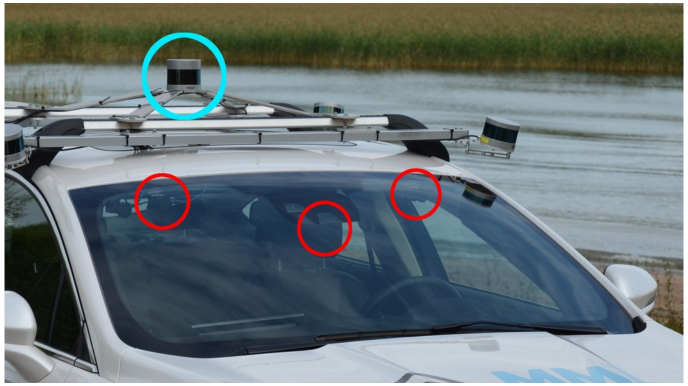
**Goal:** prediction of the car steering wheel angle from the car sensor data with a convolutional neural network in order to steer the car when staying on the current lane.

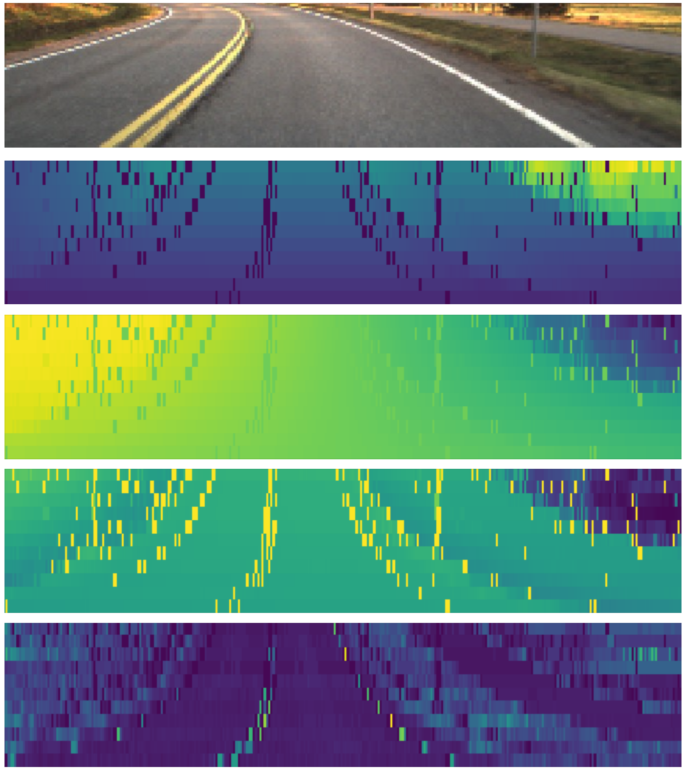
- *“End to End Learning for Self-Driving Cars”* Mariusz Bojarski et al., Nvidia, 2016

**Contribution:** extend the previous work

- to a **multimodal** setting using both camera + lidar
- performing quantitative real-world tests in **adverse road and weather conditions**
- **comparing** the model **performances** based on different data modalities

# Sensor setup and dataset





## Used sensors:

- 3 colour cameras (Point Grey Chameleon 3)
- Lidar (Velodyne VLP-32C)
- Steering wheel angle measurements from DataSpeed ADAS Kit drive-by-wire interface

## Input data:

- 63x306 front camera colour image
- 11x310 range image from lidar, 4 channels with x, y and z coordinate values and normalized reflectance

**Predicted output:** steering wheel angle

## Dataset:

- Training/validation set: 27 hours of prerecorded data from manual driving in Southern Finland and Western Lapland regions, validation set 10%
- Test set: four separate driving sequences, 30 min in total

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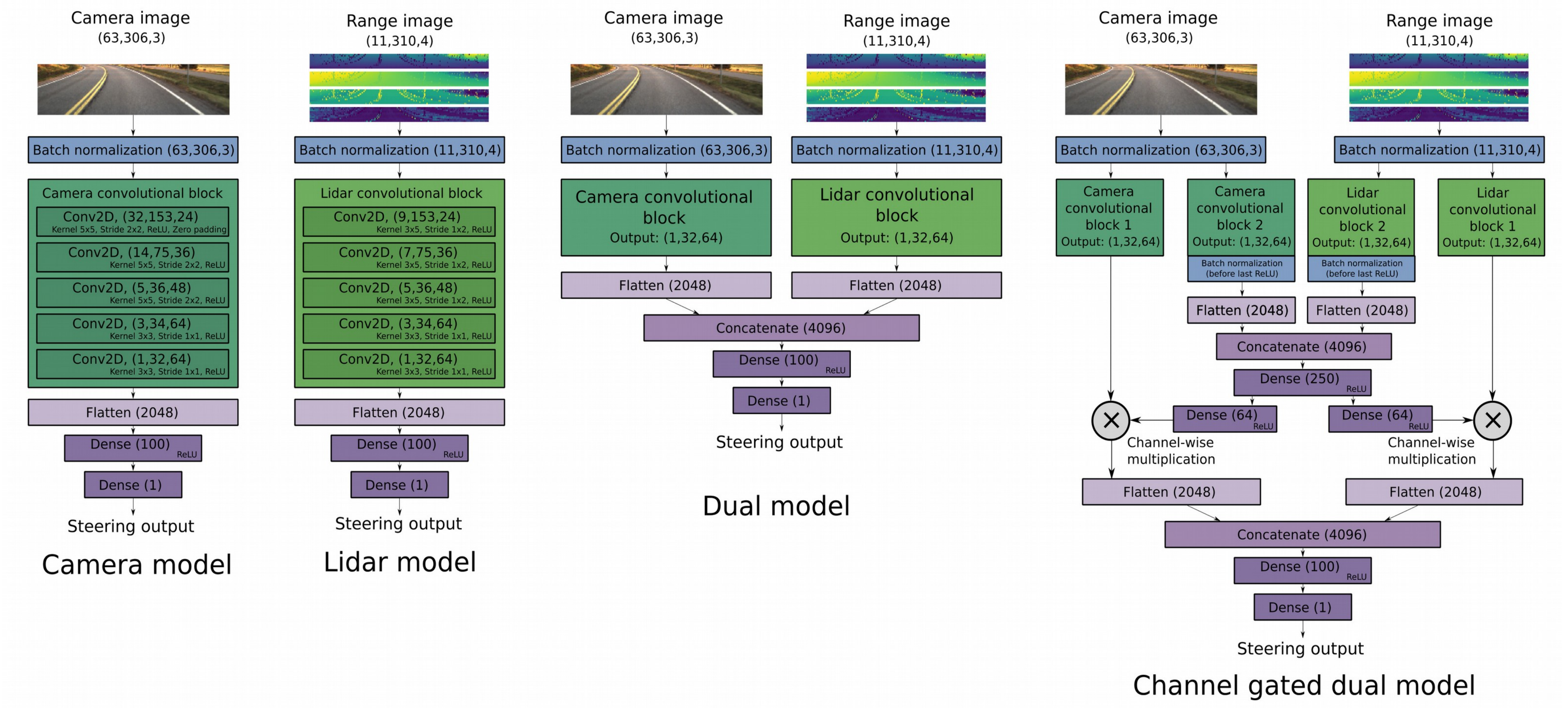
# Models




**Camera model** and **Lidar model** use only one data modality, **Dual model** uses both. **Channel gated dual model** uses both modalities with a gating subnetwork to gate the channels used in steering based on their (supposed) reliability.

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# Validation and test set errors

Samples from the 4 sequences of the test set (30 min total)

| | Validation set RMSE | Test set RMSE |
|---|---|---|
| Camera model | 9.41° | 7.18° |
| Lidar model | 9.24° | 7.33° |
| Dual model | 8.44° | 6.75° |
| Channel gated dual model | 8.23° | 6.00° |

- Camera model and Lidar model have relatively similar performance.
- Dual models are better – using both modalities improves performance.
- The gating architecture also improves performance.

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# On-road test 1: unclear lane markings

| | Level of autonomy $\left(=\dfrac{\textit{autonomously driven time}}{\textit{test time}}\right)$ | Driver interventions |
|---|---|---|
| Camera model | 92.7% | 21 |
| Lidar model | 95.1% | 14 |
| Dual model | 94.4% | 15 |
| Channel gated dual model | 93.3% | 20 |

Length: 9.5 km
Speed: 30 km/h – 40km/h
Several steep curves and hills

Low sun level caused overexposure that disturbed the performance of the models using camera modality. Also different circumstances between tests (different sun position and traffic) caused contradictive results. The test road was chosen to be challenging by purpose.

# On-road test 2: gravel road

| | Level of autonomy $\left(=\frac{\textit{autonomously driven time}}{\textit{test time}}\right)$ | Driver interventions |
|---|---|---|
| Camera model | 98.9% | 3 |
| Lidar model | 100.0% | 0 |
| Dual model | 100.0% | 0 |
| Channel gated dual model | 100.0% | 0 |

Length: 4.1 km
Speed: 25 km/h
Several curves and hills

The model performances were good, only the camera model suffered from image overexposure issues.

See a video of several on-road tests:

https://www.youtube.com/watch?v=wKrj7cSBKfE

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# Conclusion

- The proposed architecture using both camera and lidar data demonstrates good performance in challenging road and weather conditions.
- Lidar modality supports the camera modality when the camera suffers from bad data quality.
- Some challenging situations still persist, they can probably be solved with more training data and better data augmentation.