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QHACK | HACKATHON

Self-driving car based on hybrid quantum-classical neural networks

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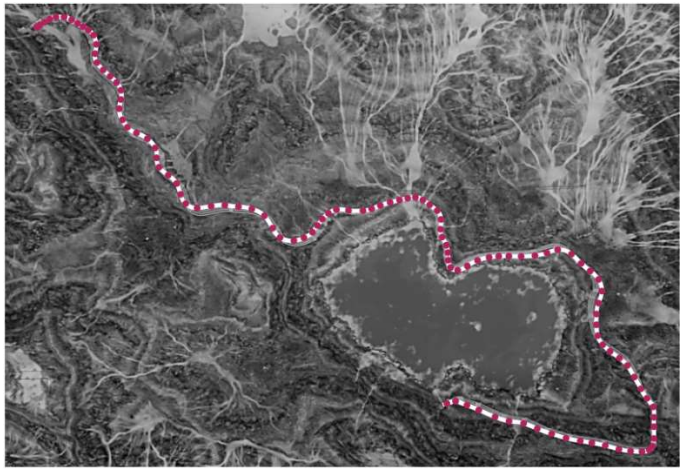
INTRODUCTION

INTRODUCTION | USE CASE

- Goal:
  - We want a self-driving car that can drive without human interaction
  - It should master the track without a car accident
- Track



INTRODUCTION | ENVIRONMENT

- The game is based on:
  - Unreal Engine
  - AirSim
  - Nvidia's end-to-end learning for
  - self-driving cars paper
  - Siemens / Austrian Institute of Technology
    - artificial intelligence workflow demo
    - including explainability
- Code:
  - Pennylane
  - TensorFlow / Keras

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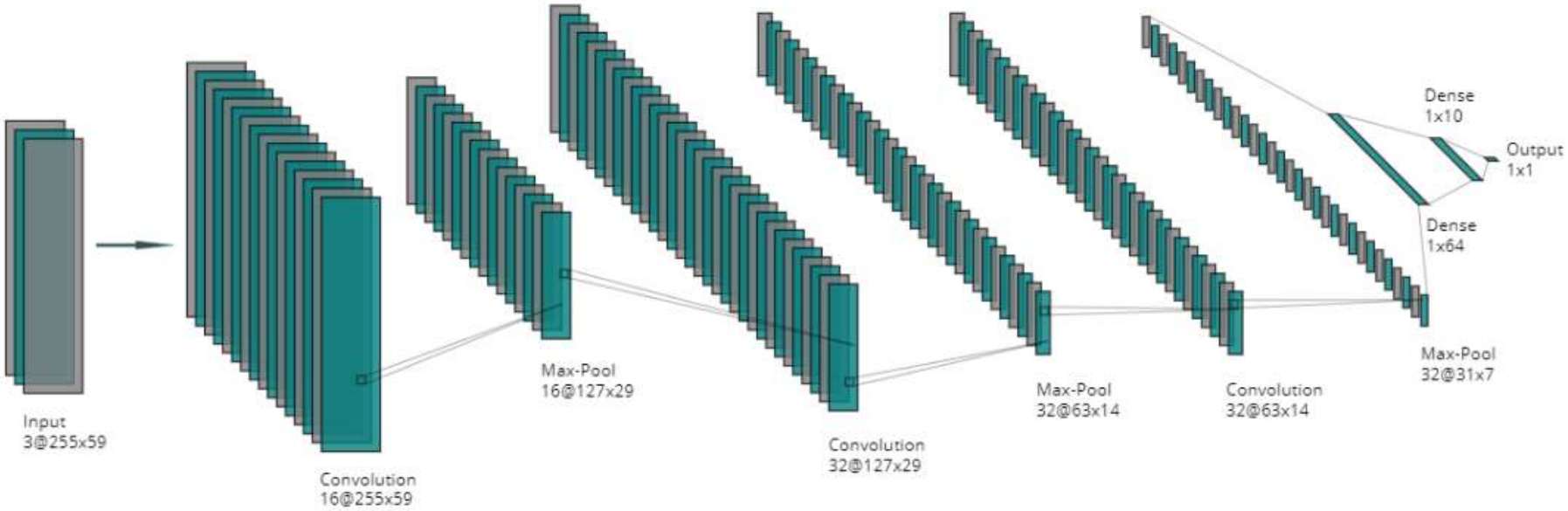
APPROACH

APPROACH | CLASSICAL NEURAL NETWORKS

- Output: steering angle

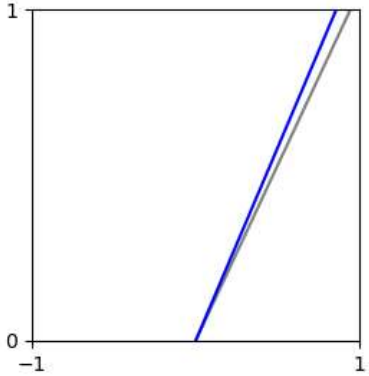


APPROACH | CLASSICAL NEURAL NETWORKS

- train model based on 5624 images
- Fix convolutional neural network (CNN) layer weights after training for transfer learning
- Used as a benchmark model for comparison
- Evaluation:

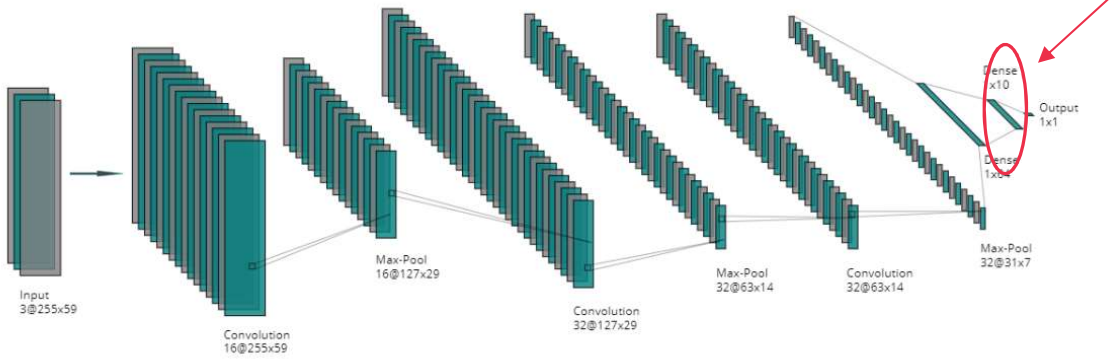
Test image

Steering angle

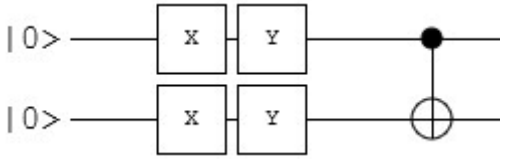


- grey: user steering angle
- blue: (AI) predicted steering angle

APPROACH | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS



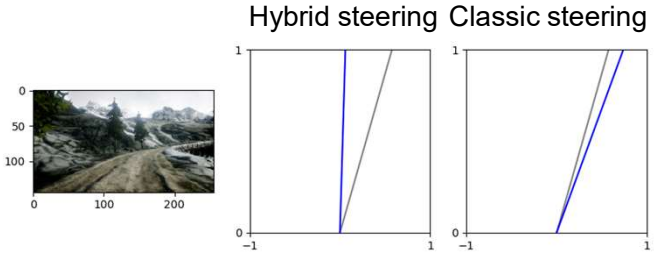
This layer is replaced with a variation quantum circuit



APPROACH | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

- 6 different variational quantum circuits
  - different amount of qubits
- Training
  - 100 training epochs
  - Keras Adam optimizer
  - Keras loss function: mean squared error
  - each model architecture was created four times and trained on two different hardware
  - tested against 27 test images and compared with the classical model

Test example:



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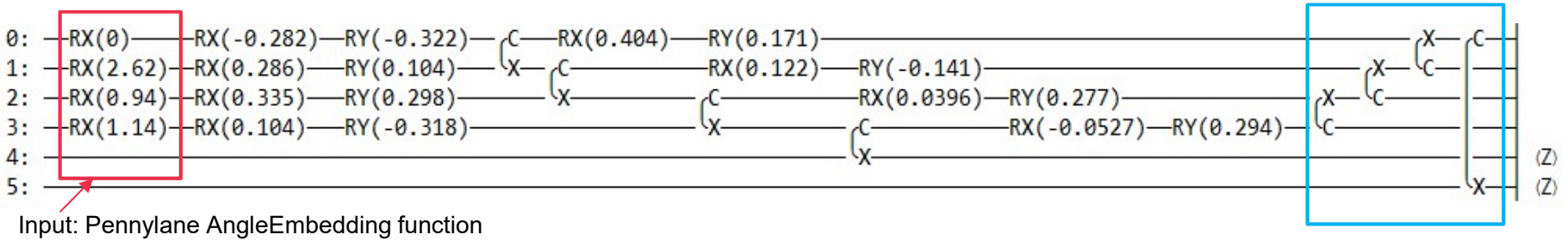
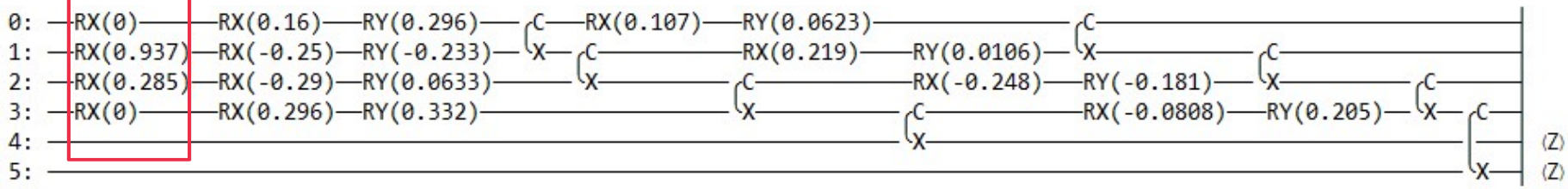
quantum circuit type 1



Input: Pennylane AngleEmbedding function

Different to type 2

quantum circuit type 2



APPROACH | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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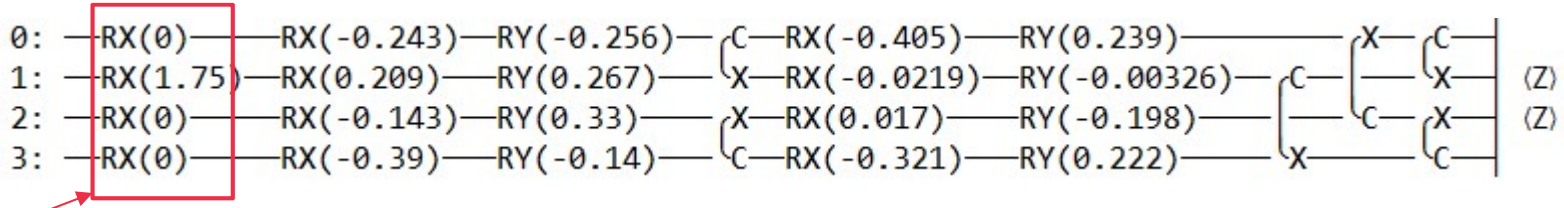
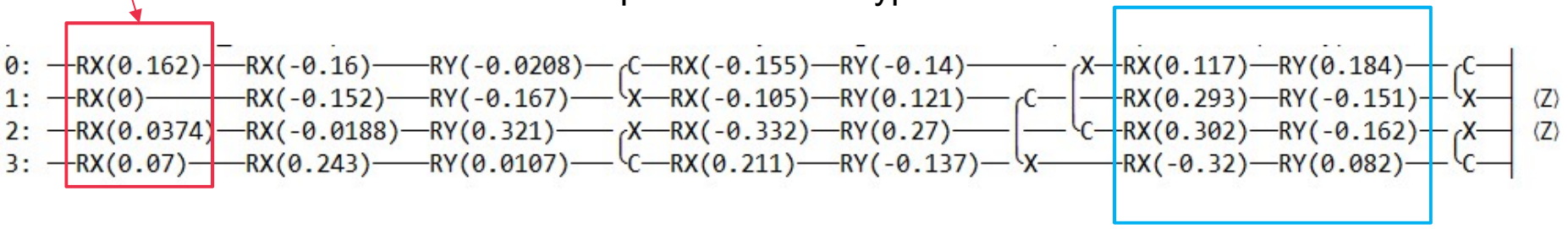
quantum circuit type 3



Input: Pennylane AngleEmbedding function

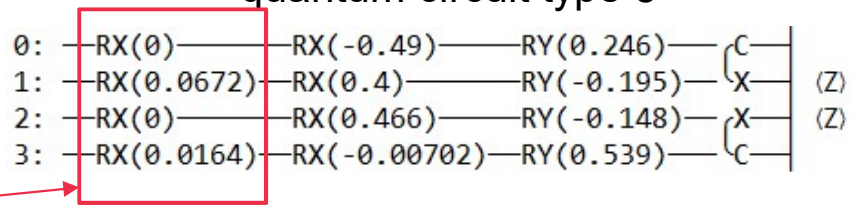
quantum circuit type 4



Different to type 3

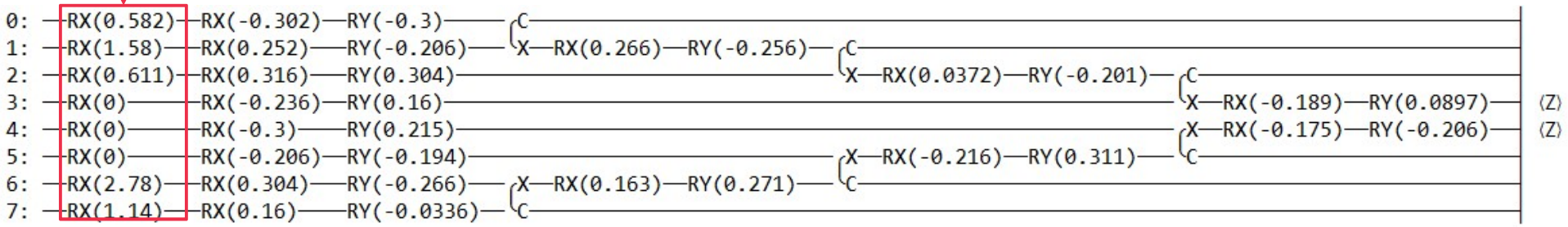
APPROACH | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

quantum circuit type 5



Input: Pennylane AngleEmbedding function

quantum circuit type 6



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TEST RESULTS

RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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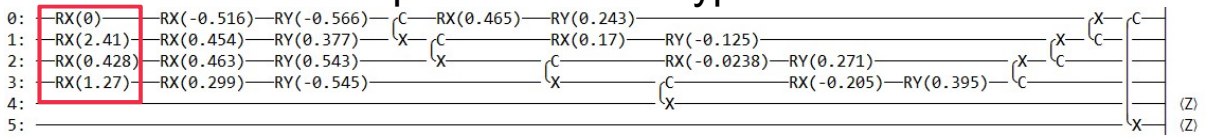
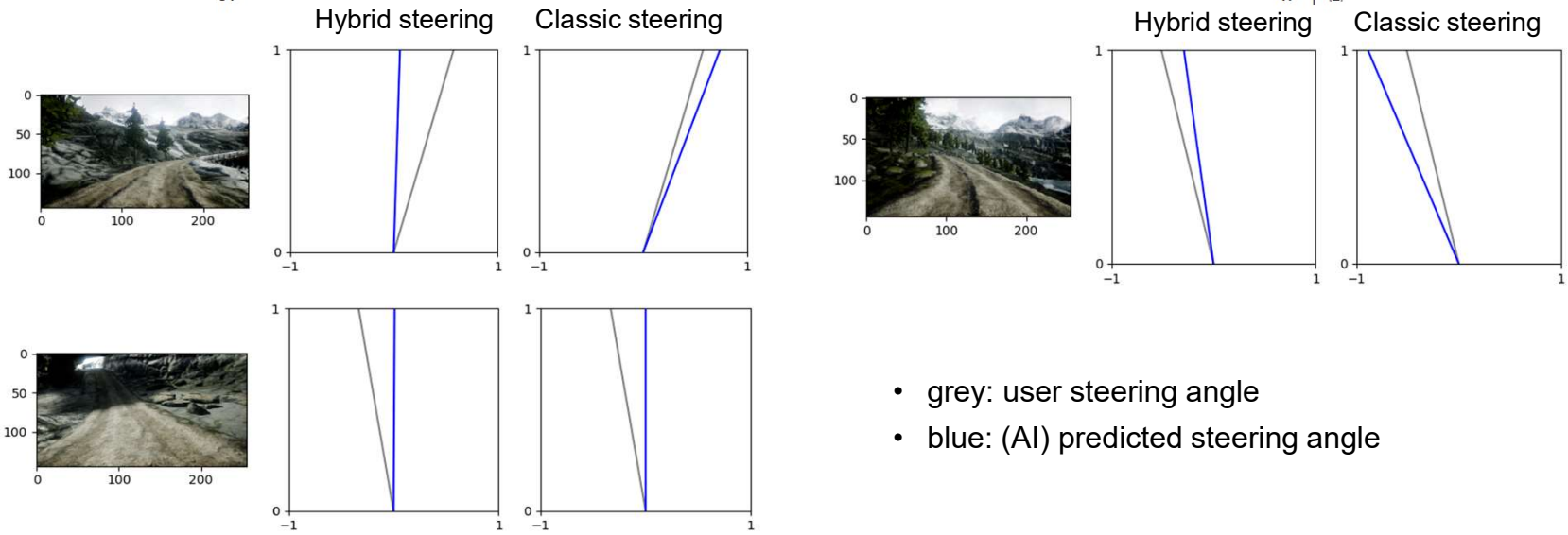
quantum circuit type 1





- grey: user steering angle
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RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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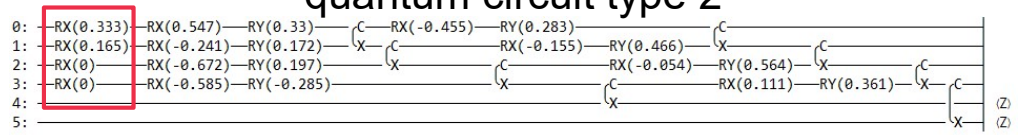
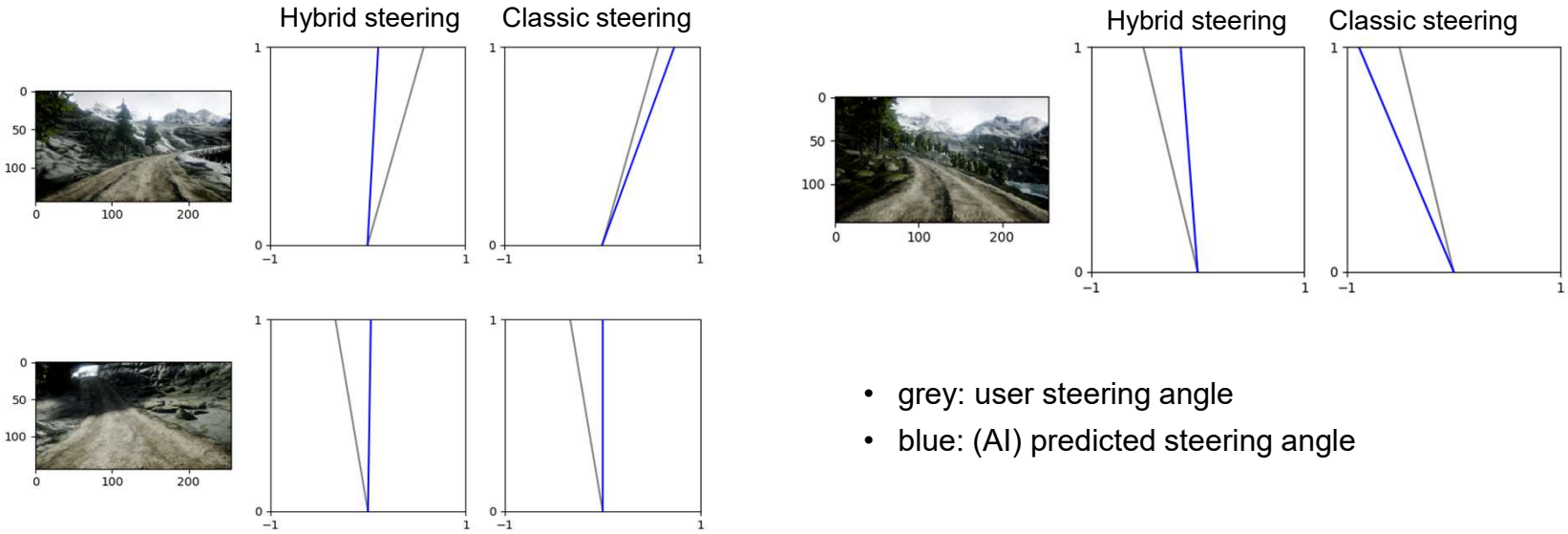
quantum circuit type 2





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RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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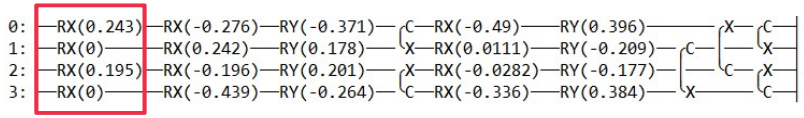
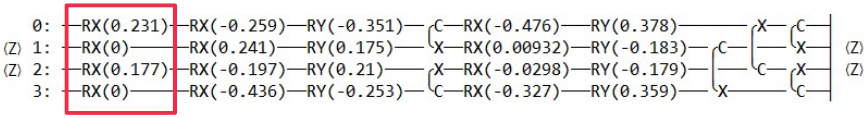
quantum circuit type 3

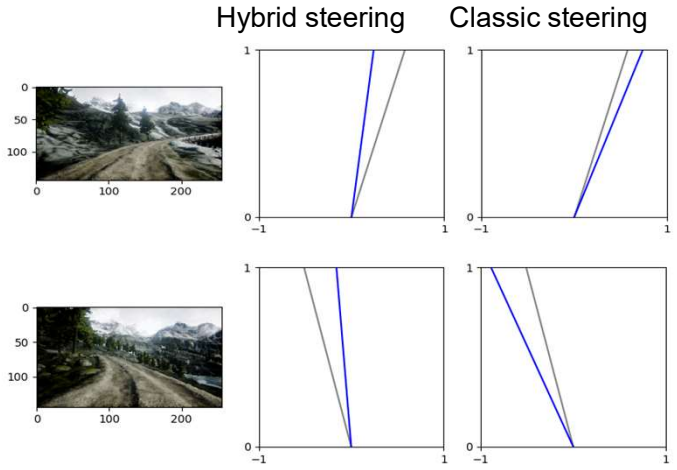
Epoch 100

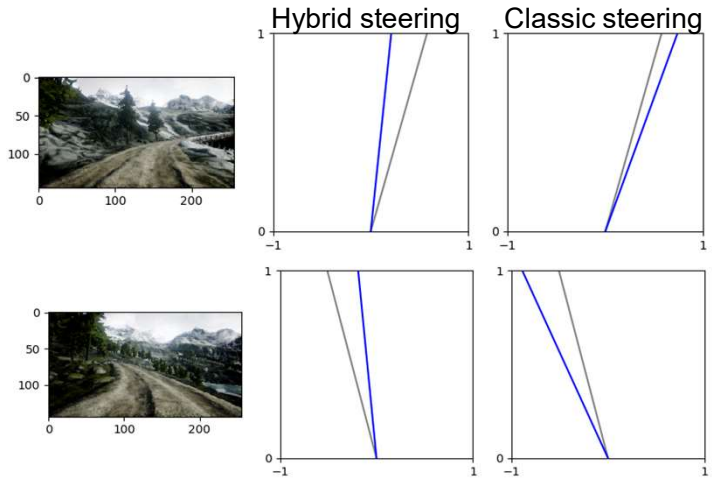


Epoch 75



Model comparison based on epochs, as the simulation results are very different compared to the test results.





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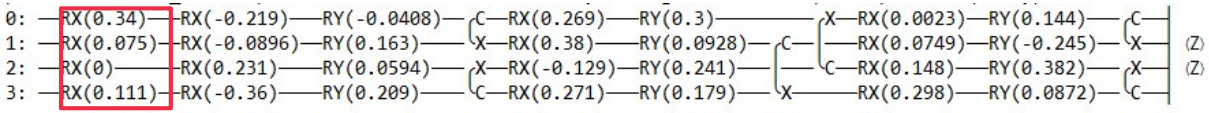
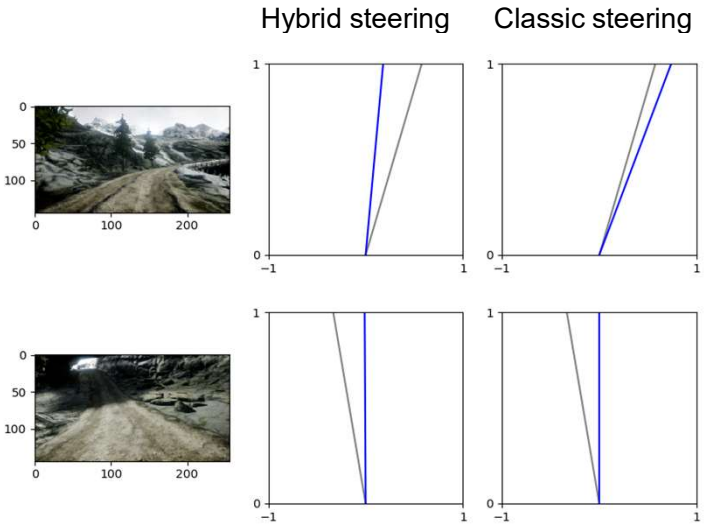
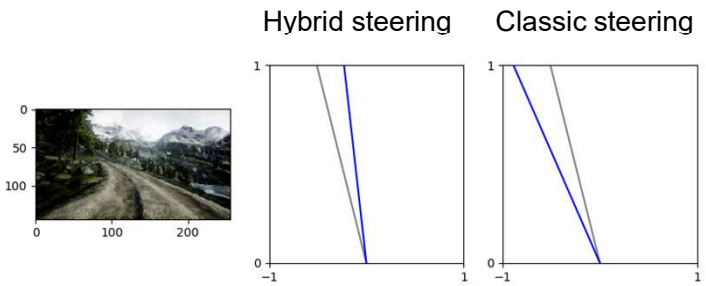
RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

quantum circuit type 4







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RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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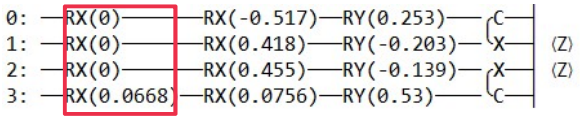
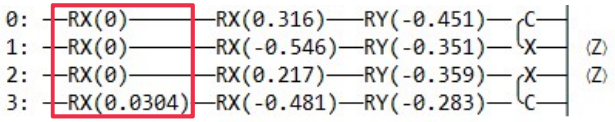
quantum circuit type 5

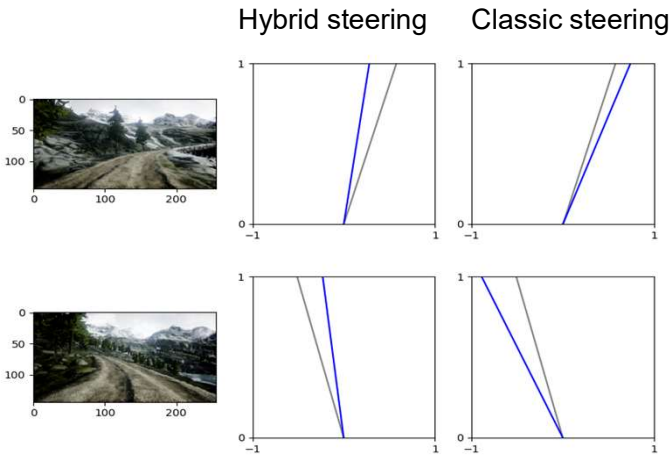
Hardware 1

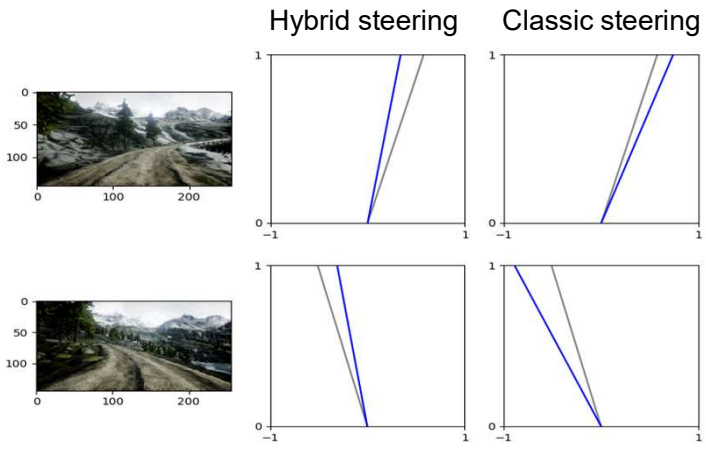


Hardware 2



Model comparison based on different hardware, as the training data were randomly mixed and the simulation results are the same.





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RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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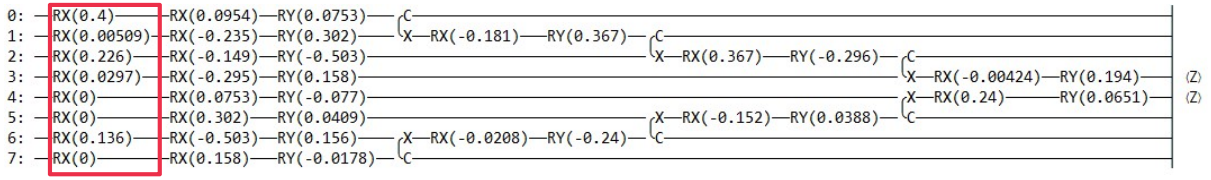
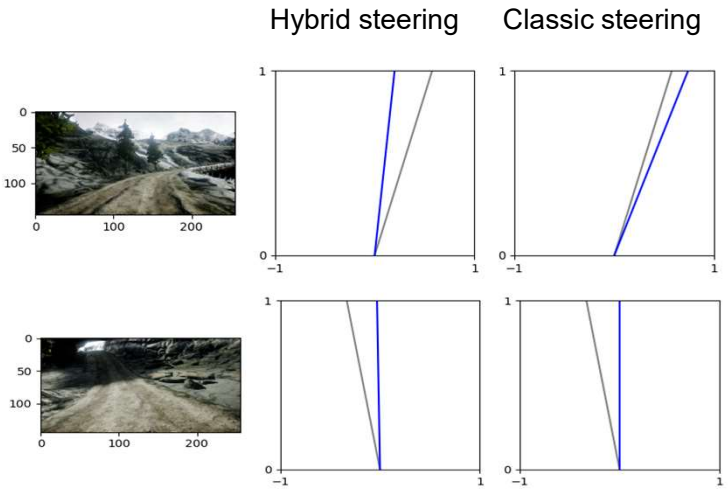
quantum circuit type 6





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RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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- Test results
  - All 6 quantum circuit types show similar results
- Open questions:
  - How much influence does a quantum circuit and it’s configuration have in a hybrid approach?
  - How big is the influence of the previously trained weights?
  - Would the models differ more if they had to be completely retrained without transfer learning?

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SIMULATION RESULTS

RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

- The best hybrid models were used to compete against each other on a track
- If the car has an accident, the simulation will stop

This view is used for the prediction

RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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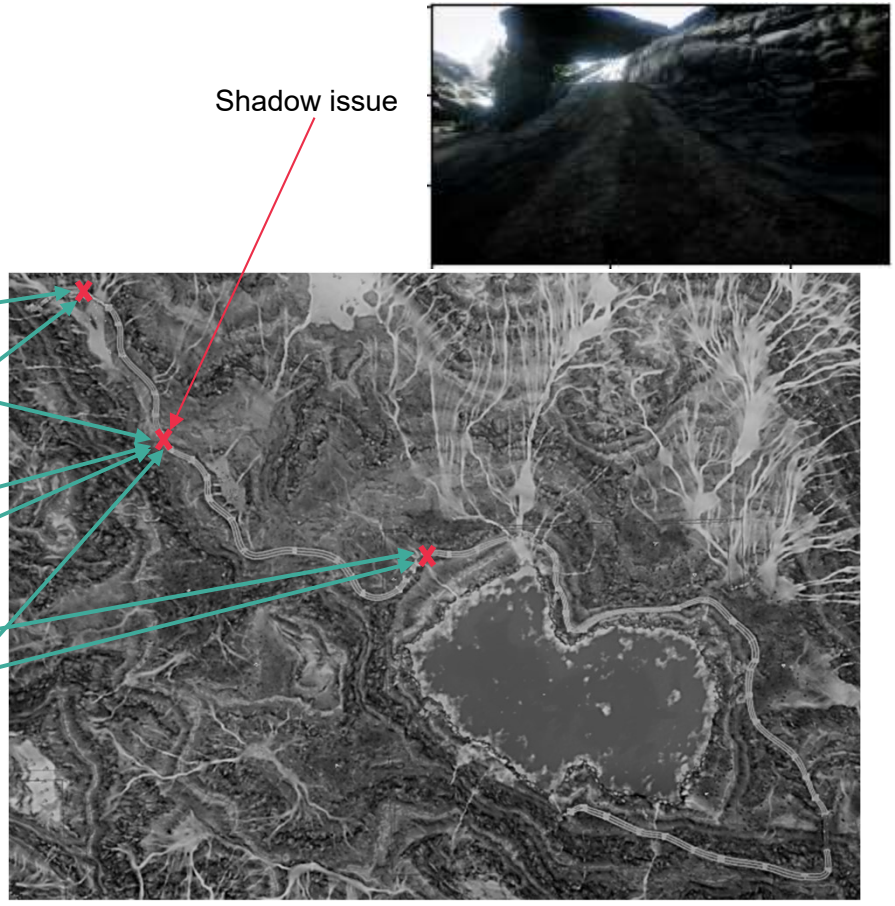
- Hybrid models
  - Type 1: epoch 86 – validation loss 0.0009381
  - Type 2: epoch 79 – validation loss 0.0010381
  - Type 3:
    - Epoch 75 – validation loss 0.0015353
    - Epoch 100 – validation loss 0.0011060
  - Type 4: epoch 94 – validation loss 0.0012984
  - Type 5:
    - Epoch 85 – validation loss 0.0006215
    - Epoch 94 – validation loss 0.0004812
  - Type 6: epoch 97 - validation loss 0.0006447



RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

- The best hybrid model:
  - Type 5 (epoch 94) model: https://github.com/DenisKatic/SelfDrivingQuantumHybrid/blob/main/documents/Quantum_hybrid_type_5_simulation.mp4

RESULT | HYBRID QUANTUM-CLASSICAL NEURAL NETWORKS

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- Results & Questions
  - Although the models had similar test results, the simulation results are different
  - A performance difference between type 1 and 2, although they have a similar circuit
  - Would further training epochs for complex quantum circuit models improve the results to such an extent that they would be comparable to type 5 models?
  - Do the complex models already have problems with the barren plateaus and can this be determined?

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THANK YOU