Mini-Project for 4A IA2R SIA
Data-Driven System Identification of Lateral Dynamics using the QCar Platform

Hugues Garnier

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1 Introduction

In this mini-project, you will apply data-driven system identification methods to obtain linear transfer function model of lateral dynamics of the Quanser QCar platform at different speeds from open-loop maneuvers.
This process mirrors the approach that studied the lateral dynamics of different vehicles used in the following two research papers:

- C.L. Pereira, D.H. B. de Sousa, and H.V.H. Ayala, *Three-axle vehicle lateral dynamics identification using double lane change maneuvers data*, 29th Mediterranean Conference on Control and Automation (MED'21), Bari, Italy, 2021.
- R.R. Da Silva, R.S. Rodrigues, A. Murilo, H.C. Ayala, E.L Silva Teixeira, *Lateral dynamic identification of a hatchback vehicle*, XLIV Ibero-Latin-American Congress on Computational Methods in Engineering (CILAMCE'2023), Porto, Portugal, November 2023.

2 Objectives

- Conduct open-loop maneuvers using the QCar platform to record steering angle input and yaw rate output for different speeds.
- Apply the data-driven system identification workflow using the CONTSID toolbox to obtain continuous-time linear transfer functions.
- Reflect on the usefulness of the identified models for control design and other applications.

3 Experiment Setup

3.1 Hardware Requirements

- Quanser QCar Platform.

The QCar platform from Quanser, shown in Figure 1 is an advanced, self-driving research vehicle designed for autonomous systems and AI applications. It features high-performance computing, multiple sensors (LiDAR, cameras, IMU, GPS), and real-time control capabilities. The platform provides an open and flexible environment for developing and testing autonomous vehicle algorithms. More information about the hardware components of the Qcar are available in the user manual available on the website for the course.

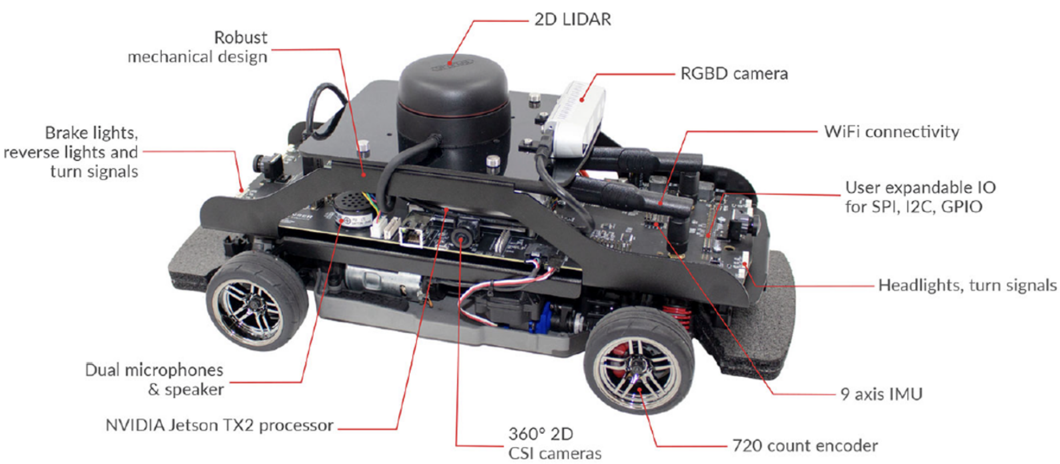

Figure 1: The Qcar and its main components.

There are 2 Qcars available. Make sure to use the Qcar that has been allocated to you for all of your data collection.

3.2 Software Requirements

- Matlab/Simulink 2024a or later
- QUARC Toolbox
- CONTSID Toolbox
- `Data_collection.slx` for QCar open-loop maneuver test and recording
- `save2file.m` for data logging

The two files are provided in the folder `C:/Temp/4A_SIA_Qcar/`

4 Experimental Setup

The main inputs/outputs of the Qcar are:

- Inputs:
  - Wheel motor speed command using the PWM input in %.
  - Steering angle command in rad.
- Outputs:
  - Yaw rate (or velocity) in rad/s.
  - Estimated longitudinal speed of the Qcar in m/s.

4.1 QCar Configuration

1. Power on the PC, the router and the QCar.
2. Open Matlab.

4.2 Prepare the Simulink Model

1. Go to the folder `C:/Temp/4A_SIA_Qcar/`

5 Open-Loop Maneuvers for Data Collection

To yield meaningful information about the vehicle lateral response, a number of open-loop maneuver tests must be performed. The test consists of applying constant longitudinal speed (via the wheel motor speed command) while employing time-varying steering angle commands. The process can be repeated for different longitudinal speeds and possibly for several steering angle maneuvers with different amplitudes.

5.1 Open-Loop Maneuver Setup

- The QCar should be placed close to the wall.
- A **step-like input** will firstly be applied to the steering angle command to induce yaw rate changes.
- The maneuver should be performed at different motor speeds using the PWM (Pulse-Width-Modulation) input which is expressed in % of the duty cycle (see the Appendix for further details):
  - 10 %
  - 12.5 %
  - 15 %
  - 17.5 %
  - 20 %

5.2 Experimental procedure

1. Open the file `Data_collection.slx` in Simulink.

2. Set the IP address of your Qcar by following the steps:
   Go to Hardware tab, then Code Generation, then Interface as shown in Figure 2.

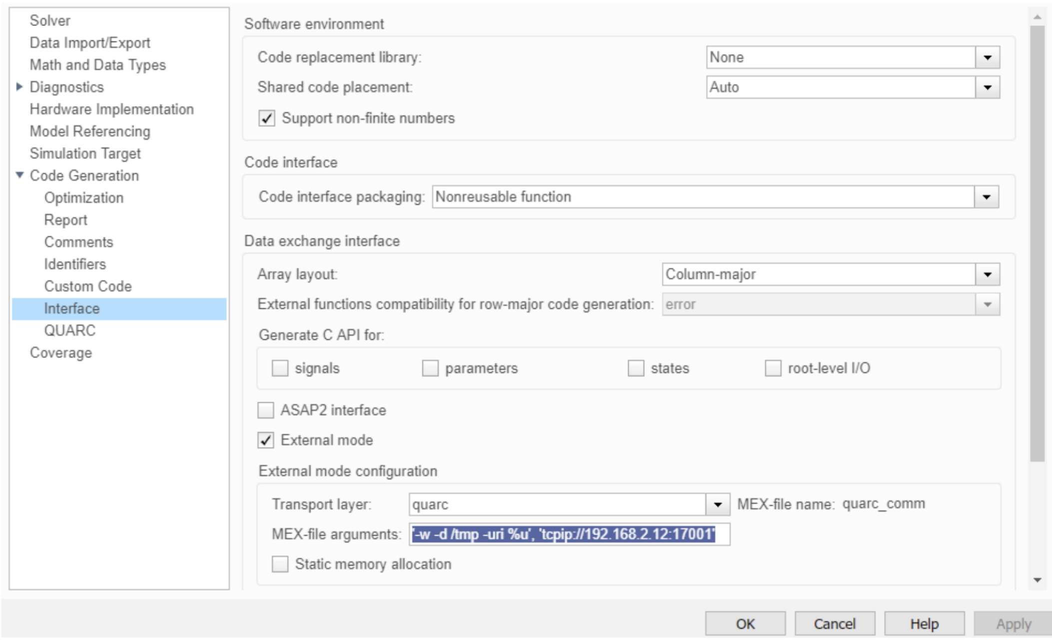

Figure 2: Qcar IP address setting for code generation.

   The MEX-file argument field should be filled with this:
   `'-w -d /tmp -uri %u', 'tcpip://192.168.2.XX:17001'`
   The XX should be set to 11, 12 or 13.
   To get the number for your Qcar, look on the LCD display when it is turned ON.

3. Set the amplitude of the **motor speed** using PWM input to 10% via the constant block in orange.

4. Configure the different switches so that the **steering angle command** takes the form of a **step-like function**.

5. Select the amplitude of the step (via the gain block in yellow) and the duration (in s) of the experiment via the Stop time in the Hardware tab.

6. Click on Monitor & Tune to run the Simulink model.

7. Click on stop if the Qcar comes to close to an obstacle (a wall for example).

8. Record the relevant input/output data by executing in the Matlab command window: `save2file(data)`.
   An estimate of the Qcar longitudinal speed (computed from the wheel encoder) will also be recorded. The execution of the .m file will display a figure with the relevant input/output data and save them in a .mat file with the day and time of recording, written at the end of the file name.

9. Repeat the procedure for different motor speed commands.

5.3 Perform Other Open-Loop Steering Maneuvers

Repeat the experimental procedure described above for different open-loop maneuvers. Options are available in the .slx file such as:

- Double Lane Change Maneuvers (as in the military vehicle study);
- Simple Single Sinus Maneuvers;
- Sinus Chirp Maneuvers. It is a persistently exciting signal used to disturb the system over a specified range of frequencies (the default case has starting and ending frequencies of 0.2 and 6 Hz, respectively.

1. Set the switches to select a new maneuver.
2. Set the amplitude of the **motor speed** using PWM input to a given value via the constant block in orange.
3. Set the amplitude of the steering angle command. It is recommended to vary the amplitude from 0.1 to 0.5 rad (5,7 to 28.6 degrees).
4. Set the duration of the test of the experiment via the Stop time in the Hardware tab.
5. Record the relevant input/output data by executing in the Matlab command window: `save2file(data)`.
6. Repeat the procedure for different wheel motor speed commands.

You can, if you want, implement a Moose Test (similar to the hatchback vehicle study). There is however no block available in Simulink to generate a Moose test. You will have to generate it.

You should have at least 10 dataset corresponding to open-loop maneuvers obtained for varying steering angle commands and for different constant longitudinal speeds (via the motor speed command).

6 System Identification Using the CONTSID Toolbox

Use the CONTSID toolbox to perform continuous-time system identification and obtain motor speed command-to-yaw rate transfer functions for different speeds.

Below is a list of the steps that should be considered (see the slides presenting the practical aspects of data-driven modelling available on the course website):

- Description of the experimental dataset.
- Data pre-processing (informative data selection, etc).
- Model structure selection (method used and results).
- Parameter estimation (methods used and results).
- Model validation (method used and results.

7 Results Presentation

7.1 Tabulate Model Parameters

The final **identified models** should be presented in a table similar to the following format:

Motor speed (%)	Car speed (m/s)	Gain (K)	Other model parameters	...	Fit (%)	R^2
10						
12.5						
15						
17.5						
20						

Table 1: Identified model parameters at different speeds for a given open-loop maneuver.

7.2 Reflection Questions

- How does **speed** affect the **transfer function** behavior?
- How do the **model parameters** change with speed?
- Are the identified models **suitable for control design**?

8 Submission Requirements

This mini-project will be evaluated via

- an oral presentation of 15 mn that will take place on **Wednesday, March 5 at 8:00 am** ;
- a written report. The length of your report is limited to 10 pages. It must be submitted by e-mail in a .pdf file with your names appearing on the front page. The deadline for the submission of your lab report to the instructor is **Friday, March 7 at 6:00 pm** (see below for further instructions).

Your report should be a scientific document. As such, it should be self-contained: that is, someone who has never seen the mini-project instructions should be able to understand the problem that you are solving and how you are solving it.
All of your choices should be thoroughly explained and motivated. Your final linear models must capture the essential behavior of the dynamic system. However, the most important thing is not that you succeeded in producing the absolute best models, but that you can explain the shortcomings and merits of your models. These shortcomings and merits can come from different aspects and can be of a different nature, such as total fit, fit from input to output, physical interpretation. Therefore, be as clear as possible in your explanations. Also include relevant plots of the phenomena that characterize your choices (and explain what you can see in them). Which final model structure you recommend and why?
Below is a list of the steps that should be included in your report:

1. Short description of the process (input(s), measured output(s), etc).
2. Description of the experiment design (type of inputs, possible constraints, etc).
3. Description of the experimental datasets.
4. Data pre-processing (informative data selection, etc).
5. Model structure selection (method used and results).
6. Parameter estimation (methods used and results).
7. Model validation.
8. Conclusion. Discuss the strengths/weaknesses of the identified model(s) and specify which model(s) do you recommend and why.
9. You can in an appendix, but this is not mandatory, suggest a control strategy (give at least the closed-loop block diagram) to move the Qcar from a given to a desired position.

Appendix

Pulse Width Modulation (PWM) for motor speed command

As its name suggests, pulse width modulation speed command works by driving the motor with a series of 'ON-OFF' pulses and varying the duty cycle, the fraction of time that the output voltage is 'ON' compared to when it is 'OFF', of the pulses while keeping the frequency constant.

The power applied to the motor can be controlled by varying the width of these applied pulses and thereby varying the average DC voltage applied to the motors terminals. By changing or modulating the timing of these pulses the speed of the motor can be controlled, ie, the longer the pulse is 'ON', the faster the motor of the Qcar wheels will rotate and likewise, the shorter the pulse is 'ON' the slower the motor will rotate. In other words, the wider the pulse width, the more average voltage applied to the motor terminals as shown in Figure 3, the stronger the magnetic flux inside the armature windings and the faster the motor will rotate.

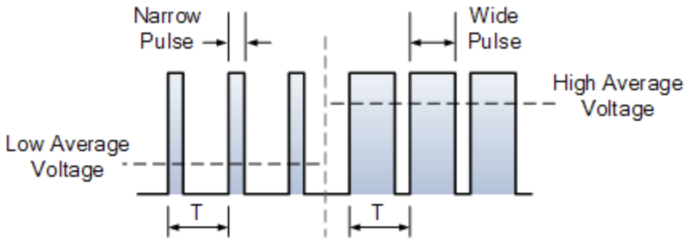

Figure 3: Illustration of Pulse Width Modulation (PWM) signals for motor speed command

The use of PWM to control a small motor has the advantage in that the power loss in the switching transistor is small because the transistor is either fully 'ON' or fully 'OFF'. As a result the switching transistor has a much reduced power dissipation giving it a linear type of control which results in better speed stability.
Also the amplitude of the motor voltage remains constant so the motor is always at full strength. The result is that the motor can be rotated much more slowly without it stalling.

See for more details:
`www.electronics-tutorials.ws/blog/pulse-width-modulation.html`