TECHNISCHE UNIVERSITÄT WIEN

Autonomous Racing Cars
191.119 (VU 4,0) Semester: 2022S

Race Car & Simulator

2022-03-03

Student data

Matrikelnummer	Firstname	Lastname
01613004	Severin	Jäger

1 Race Car Hardware

a.) The UST-10LX lidar sensor [1] has the following specifications:

- Maximum range: Surface-dependant: 10 m for white paper, 4 m for a diffuse surface with 10 % reflectance
- Minimum range: 6 cm
- Number of rays: One rotating ray
- Scanning angle: 270° FOV, 0.25° resolution
- Update rate: 40 Hz
- Input voltage: 10 V to 30 V DC

b.) The NVIDIA Jetson Xavier NX [2] has the following specifications:

- Connectivity: 4× USB 3.1, Micro USB, Gigabit Ethernet, HDMI, Display Port, MicroSD, 2× MIPI CSI-2 camera interface, GPIO pins, busses (I2C, I2S, SPI, UART)
- Heterogeneous system consisting of a CPU complex with three dual-core CPUs (Carmel core: ARM-based, superscalar), a GPU with 384 CUDA and 48 Tensor cores, two NVDLA deep learning accelerators and a programmable vision accelerator
- Memory: 8 GB LPDDR4x and 16 GB eMMC flash
- The module requires a 9 V to 20 V DC power supply

c.) The VESC 6 plus electronic speed controller [3] and its successor VESC 6 MKV [4] have the following specifications:

- Interfaces: CAN, USB, COMM (UART/SPI/I2C/ADC), SWD (JTAG), PPM (for reference input) motor sensor input (e.g, for Hall sensor), BLDC
- Measurement of speed, current and voltage (per phase), motor revolution, ampere and watt hours

d.) The Velineon 3500 motor [5] has the following specifications:

- Brushless DC motor (BLDC)
- The maximum rpm is 50000. However, the motor features a k_v of 3500, this means 3500 rpm per volt applied to the motor without mechanical load. As the battery voltage is nominally 11.1 V (see below), this leads to 38850 rpm in our setup. Note that the battery might be charged up to higher voltages.

- As the car contains some gears, the wheel rotation speed calculates to $\omega_w = \frac{1}{\rho}\omega_m$ with the drive ratio ρ and the motor rotation speed $\omega_m = \frac{2\pi}{60}\text{rpm}_m$. The car speed then depends on the wheel diameter D as $v_{car} = \frac{D}{2}\omega_w = \frac{D}{2}\frac{1}{\rho}\frac{2\pi}{60}\text{rpm}_m$. The Fiesta [6] has a ρ of 19.69 and a D of 0.102 m, thus $v_{car} = 2.7124 \times 10^{-4}\text{rpm}_m$. For the Slash [7] car, $D = 0.1095$, $\rho = 11.82$, and $v_{car} = 4.851 \times 10^{-4}\text{rpm}_m$ hold. The Slash seems to be more aggressive and thus ships with a motor with significantly higher k_v. The main physical parameters (i.e. the size) is roughly identical.

e.) The SparkFun OpenLog Artemis IMU module [8] has the following specifications:

- Connectivity: USB C, I2C, UART, SWD (JTAG), MicroSD, four ADC channels
- The module is based on the Apollo3 Blue MCU [9] which provides a temperature sensor, a 14-bit ADC with 1.2MS/s, and a comparator
- The measurement capabilities are in the ICM-20948 MotionTracking IC [10] which hosts a 3-axis gyroscope, a 3-axis accelerometer, and a 3-axis magnetic field sensor on a single chip.

f.) The power distribution board hosts a PDQ30-Q24-S12-D DC/DC converter IC [11] with the following specifications:

- The provided output voltage is 12 V with an accuracy of ±1.5 %. The current is limited to 3.9 A.
- The input voltage is supposed to be between 9 V and 36 V. Below 8.5 V, the under-voltage shutdown becomes active.

g.) The battery is a 3-cell LiPo type with a 25C rating and 5000 mAh [12]. It has the following specifications:

- A nominal voltage of 11.1 V.
- The battery itself does not provide any cut-off, however LiPo batteries should not be discharged below 3.2 V per cell [13]. For a three-cell battery, this makes 9.6 V.

2 Car Simulaton Model

a.) The f1tenth simulator [14] implements both the kinematic single track and the single track model from [15]. The single track model is far more advanced as it not only considers kinematic but also dynamic aspects. In the simulator ROS node, only the single track model is used in the `update_pose` function. Nonetheless, the single-track update function internally uses the kinematic single track model if the velocities are below 0.5 m/s as the single track model becomes singular für small velocities.

b.) The single-track model implementation in the f1tenth simulator has the following parameters with their corresponding default values:

- Wheelbase: 0.3302 m
- Friction coefficient 0.523
- Height of centre of gravity 0.074 m
- Distance from centre of gravity to front axle 0.158 75 m
- Distance from centre of gravity to rear axle 0.171 45 m
- Cornering stiffness coefficient of front wheels 4.718 rad^{-1}
- Cornering stiffness coefficient of rear wheels 5.4562 rad^{-1}
- Vehicle mass 3.47 kg
- Moment of inertia around z axis from centre of gravity 0.047 12 $\text{kg} \cdot \text{m}^2$

Note that Althoff and Würsching also mention the vehicle width, which is however not used in their equations. As this model only considers a single track, it does not play any role.

c.) Already answered above.

d.) The parameters can be determined as follows

- Wheelbase: Given in the chassis datasheet, otherwise the distance between the tire centres can be measured
- Friction coefficient: Tables of friction between certain material combinations are available
- Height of centre of gravity: Hard to measure, but can probably be estimated
- Distance from centre of gravity to front axle: Find the longitudinal centre of gravity by balancing the car on some thin object. Then, measure the distance.
- Distance from centre of gravity to rear axle: As above.
- Cornering stiffness coefficient of front wheels: Some tire models and estimation techniques from the literature might help, but this is hard to model. Maybe it can be learnt.
- Cornering stiffness coefficient of rear wheels: As above
- Vehicle mass: Use a kitchen balance.
- Moment of inertia around z axis from centre of gravity. Create a simple 2D mass distribution model (e.g. assume uniformly distributed mass for each component with know mass) and apply the parallel axis theorem to compute the inertial moment relative to the centre of gravity.

In general, all mentioned parameters can be identified/learnt from the system. However, this only makes sense if most parameters are already well-known and if reasonable start values are present as the identification has to take place on the physical car.

e.) The f1tenth model has the following constraints:

- $v_{max} = 7\,\mathrm{m}\cdot\mathrm{s}^{-1}$
- $a_{max} = 7.51\,\mathrm{m}\cdot\mathrm{s}^{-2}$
- $a_{brake} = 8.26\,\mathrm{m}\cdot\mathrm{s}^{-2}$
- $\delta_{max} = 0.4189\,\mathrm{rad}$
- $v_{\delta_{max}} = 3.2\,\mathrm{rads}^{-1}$

f.) The constraints might be obtained as follows:

- v_{max}: Find a suitable straight track and go as fast as you can while recording the speed (e.g. with by integrating the acceleration measured by the IMU).
- a_{max}: Accelerate from rest with maximal power and record the acceleration with the IMU. Make sure you do not slip.
- a_{brake}: Break from a very high velocity to rest and record the acceleration with the IMU. Make sure you do not slip.
- δ_{max}: Steer (at rest) to the very left or right and use a triangle ruler.
- $v_{\delta_{max}}$: Drive circles with the maximum steering angle and with different velocities (without slipping). Record the angular acceleration measured by the IMU, integrate, and take the maximum.

3 Simulator: f1tenth_simulator

Please consider the video uploaded to TUWEL.

References

[1] Hokuyo Automatic Co., Ltd, *Scanning laser range finder smart-URG mini UST-10LN specification*, 2020. [Online]. Available: https://hokuyo-usa.com/application/files/2216/0857/9125/UST-10LN_Specifications_REV.pdf.

[2] NVIDIA corporation, *NVIDIA jetson xavier NX series system-on-module datasheet*, 2021. [Online]. Available: https://developer.nvidia.com/embedded/downloads.

[3] B. Vedder, *VESC 6.5*, 2018. [Online]. Available: https://vesc-project.com/sites/default/files/Benjamin%20Posts/VESC_6_plus.pdf.

[4] Trampa Boards Ltd, *VESC MkV*. [Online]. Available: https://trampaboards.com/1-x-vesc-6-mkv--p-27529.html.

[5] Traxxas, *Velineon 3500 Brushless Motor Instructions*. [Online]. Available: https://traxxas.com/sites/default/files/KC2015-R00_3351R%20Velineon%203500%20Brushless%20Motor%20Installation%20Instructions_140520-EN.pdf.

[6] ——, *1/10 Scale Ford Fiesta® ST Rally*. [Online]. Available: https://traxxas.com/products/models/electric/ford-fiesta-st-rally.

[7] ——, *Slash 4x4 Ultimate*. [Online]. Available: https://traxxas.com/products/models/electric/slash-4x4-ultimate.

[8] SparkFun Electronics, *SparkFun OpenLog Artemis*. [Online]. Available: https://www.sparkfun.com/products/16832.

[9] Ambiq Micro, Inc., *Apollo3 Blue MCU datasheet*, 2022. [Online]. Available: https://ambiq.com/wp-content/uploads/2020/10/Apollo3-Blue-MCU-Datasheet.pdf.

[10] TDC Corp., *ICM-20948 datasheet*, 2017. [Online]. Available: https://invensense.tdk.com/wp-content/uploads/2016/06/DS-000189-ICM-20948-v1.3.pdf.

[11] CUI Inc., *PDQ30-D datasheet*, 2021. [Online]. Available: https://www.cui.com/product/resource/pdq30-d.pdf.

[12] Traxxas, *Traxxas Power Cell LiPo Battery*. [Online]. Available: https://traxxas.com/products/parts/batteries/idpowercellbatteries/lipo/2832X-5000mah-111v-3S-25C.

[13] ——, *Traxxas Guide to Batteries and Chargers*. [Online]. Available: https://traxxas.com/battery-basics.

[14] *F1TENTH racecar simulator*, Accessed 11.03.2022. [Online]. Available: https://github.com/f1tenth/f1tenth_simulator.

[15] M. Althoff and G. Würsching, *CommonRoad: Vehicle models*, 2020. [Online]. Available: https://gitlab.lrz.de/tum-cps/commonroad-vehicle-models/blob/master/vehicleModels_commonRoad.pdf.