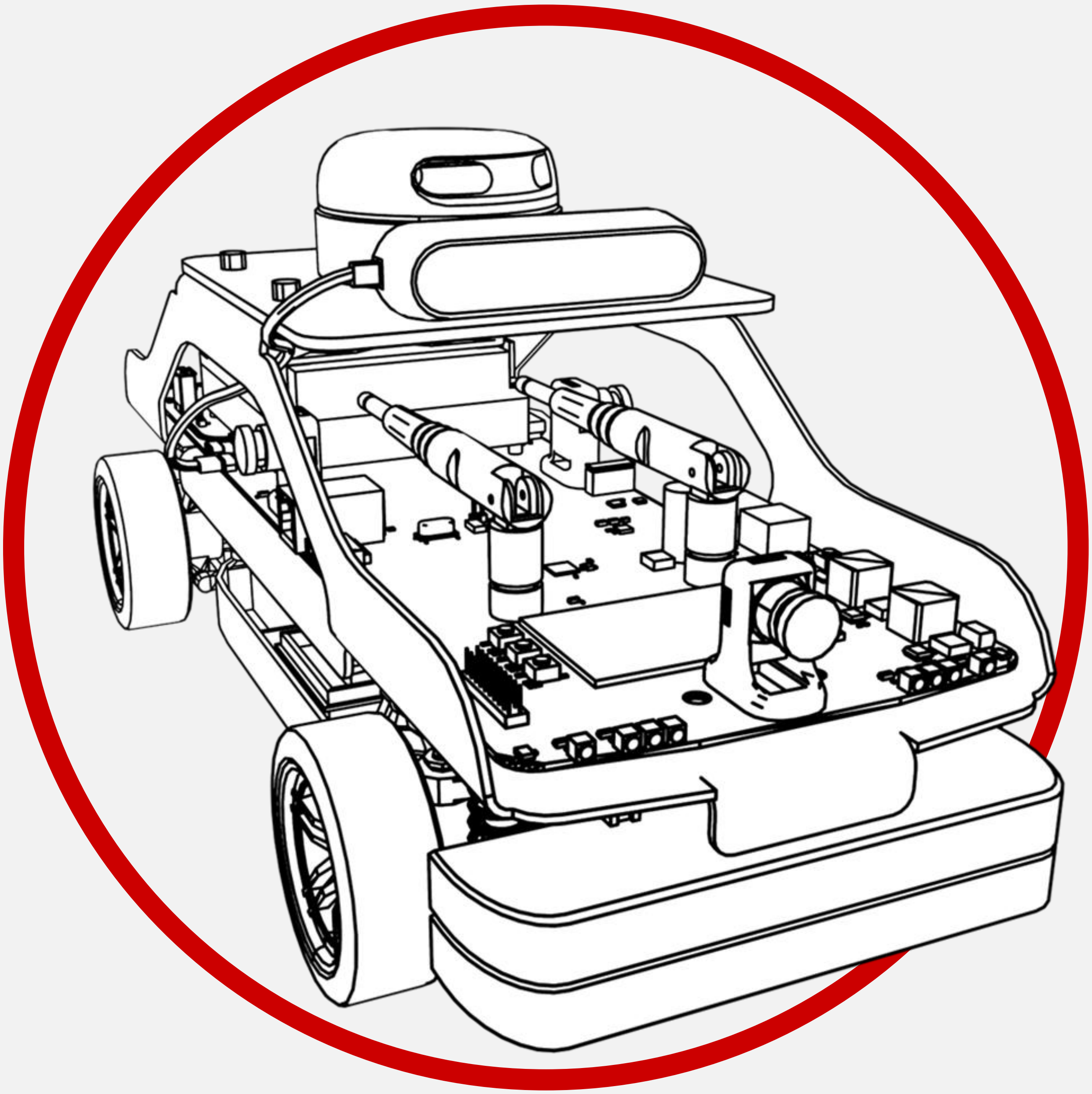

QCar 2

User Manual – System Hardware

v 1.0 – 1st Oct 2024

For more information on the solutions Quanser offers,
please visit the web site at: http://www.quanser.com

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Caution

This equipment is designed to be used for educational and research purposes and is not intended for use by the public. The user is responsible for ensuring that the equipment will be used by technically qualified personnel only. **NOTE:** While the GPIO, ethernet and USB ports provides connections for external user devices, users are responsible for certifying any modifications or additions they make to the default configuration.

Caution

The Intel RealSense D435 RGB-D camera is classified as a Class 1 Laser Product under the IEC 60825-1, Edition 3 (2014) internationally and EN 60825-1:2014+A11:2021 in Europe. The camera complies with FDA performance standards for laser products except for conformance with IEC 60825-1 Ed. 3 as described in Laser Notice No. 56, dated May 8, 2019. The RPLIDAR A2M12 reaches Class I laser safety standard and complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007.
Do not power on the product if any external damage is observed. Do not open or modify any portion of any laser product as it may cause the emissions to exceed Class 1. Invisible laser radiation when opened. Do not look directly at the transmitting laser through optical instruments such as a magnifying glass or microscope. Do not update laser product firmware unless instructed by Quanser.

Table of Contents

A. Hardware Components

The main QCar 2 components are listed in Table 1. These components are ID marked in Figure 1, which presents the front, top, left and right views of the QCar 2.

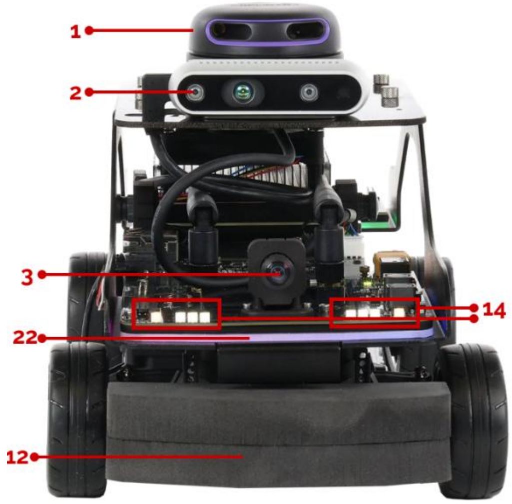
ID	Component	ID	Component
1	RPLiDAR A2 M12	12	Front bumper
2	Intel RealSense RGBD camera	13	Rear bumper
3	Front CSI camera	14	Front headlamps and indicators
4	Right CSI camera	15	Rear brake lights and indicators
5	Rear CSI camera	16	NVIDIA Jetson AGX Orin
6	Left CSI camera	17	Drive motor
7	WiFi 802.11 a/b/g/n/ac with dual antennas	18	720 count pre-gearing motor encoder
8	10/100/1000 Base-T Ethernet jack	19	Steering servo motor
9	HDMI connector	20	Speaker
10	XT-60 battery connector	21	LCD display
11	LiPo battery compartment	22	LED strip

Table 1. QCar 2 Components

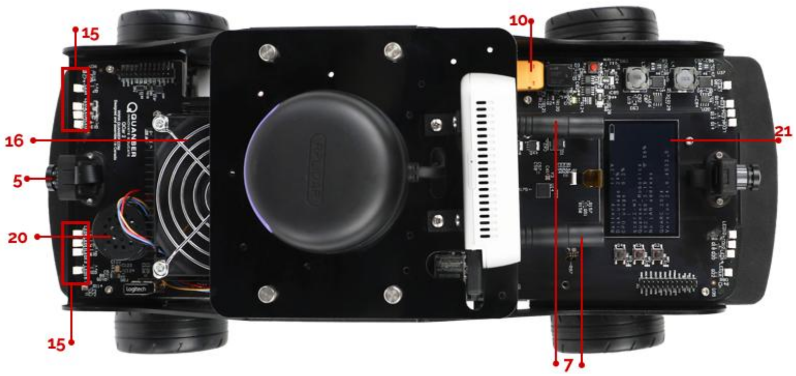
ESD Warning

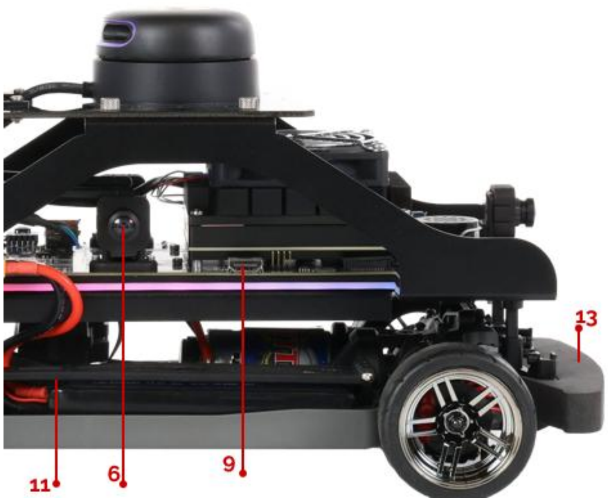
The QCar 2 internal components are sensitive to electrostatic discharge. Before handling the QCar 2, ensure that you have been properly grounded.

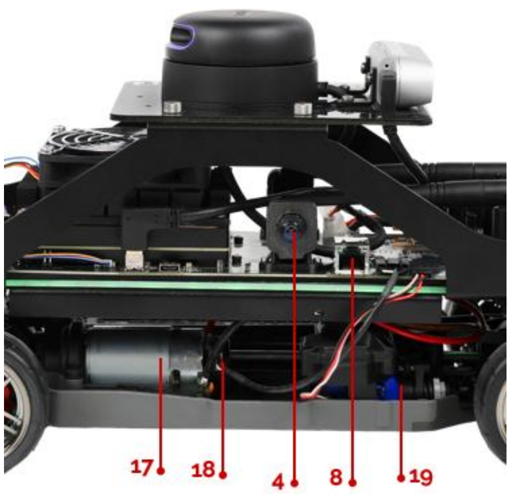
a. Front view



b. Top view







c. Partial left view

d. Partial right view

Figure 1. QCar 2 Components

i. NVIDIA Jetson AGX Orin

The QCar 2 is powered by an NVIDIA Jetson AGX Orin 32GB. The Jetson AGX contains an eight-core ARM Cortex A78AE v8.2, 2.2 GHz 64-bit CPU with 32 GB 256-bit LPDDR5 204.8 GB/s RAM.

The board has 200 TOPS of performance and contains a 1792-core NVIDIA Ampere GPU with 56 Tensor cores. The Jetson AGX Orin is suitable for computationally intensive applications, including artificial intelligence and image processing.

More information on this board can be found here.

The board includes 32 GB of storage via an eMMC. The Qcar 2 includes a 250 GB SSD for additional storage (not user accessible). A USB flash stick can be used for additional storage using the USB ports.

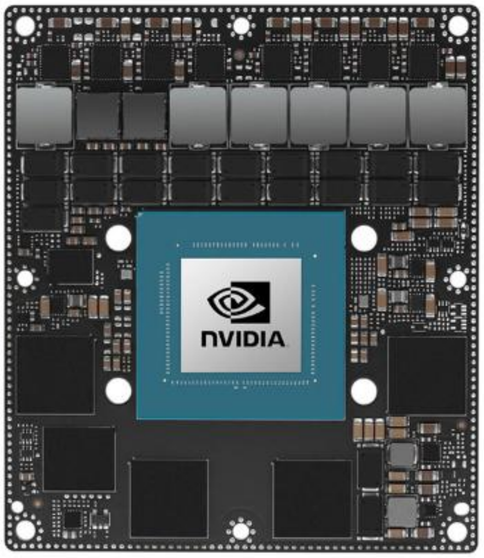


Figure 2. NIVIDIA Jetson AGX Orin 32GB

ii. LiDAR

The QCar 2 comes equipped with an RPLiDAR A2 (A2M12) as shown below. This 2D planar LiDAR supports up to 16000 samples per second, with scanning frequency of up to 15Hz (i.e., 15 revolution scan per second), and has a sensing range of up to 12m. The model rate and corresponding samples per second are summarized in Table 2 below. More information on this LiDAR can be found here. The LiDAR is Class I and eye-safe, with a wavelength of 785nm.

Figure 3. RP-LiDAR A2

Model Rate (Hz)	Samples per Second	Angular Resolution (degrees)
10 Hz	8000	0.225°
15 Hz	12000	0.225°
20 Hz	16000	0.225°

Table 2. Achievable frame rates and samples per revolution for the RPLiDAR A2

This LiDAR uses a 5-pin serial connector, connected to the J26 port on the QCar 2's DAQ card.

Note: TheJ26 LiDAR port can also be used for other LiDARs such as the RPLiDAR A1, A2 M8 or A3. For simultaneous use of LiDARs, consider using a USB based solution with the USB 3,1 port on the QCar 2.

iii. Intel RealSense D435 Camera

The QCar 2 comes equipped with an Intel RealSense D435 RGB-D camera. It includes an IR projector and two IR imagers, making this unit a stereo tracking solution. The camera can provide RGB, Infrared (left and right) and depth streams of data at frame rates and resolutions summarized in Table 3, as well as at fields of view in Table 4. More information can be found here.

Figure 4. Intel RealSense D435 RGBD camera

RGB		Infrared		Depth	
Resolution	Max. Frame Rate	Resolution	Max. Frame Rate	Resolution	Max. Frame Rate
1920 x 1080	30	1280 x 800	30	1280 x 720	30
1280 x 720	30	1280 x 720	30	848 x 480	90
960 x 540	60	848 x 480	90	848 x 100	100
848 x 480	60	848 x 100	100	640 x 480	90
640 x 480	60	640 x 480	90	640 x 360	90
640 x 360	60	640 x 360	90	480 x 270	90
424 x 240	60	480 x 270	90	424 x 240	90
320 x 240	60	424 x 240	90	256 x 144	90
320 x 180	60	256 x 144	90	n/a	n/a

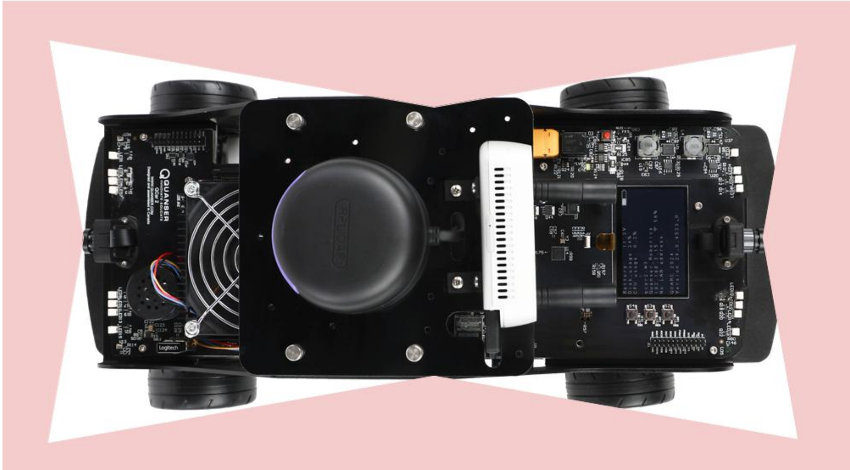
Table 3: Intel RealSense resolutions and frame rates

Camera	Horizontal	Vertical	Diagonal
RGB	69.4° ± 3°	42.5° ± 3°	77° ± 3°
Depth	87° ± 3°	58° ± 1°	95° ± 3°

Table 4. Intel RealSense D435 field of view

iv. 360° CSI Camera Suite

The QCar 2 provides 360° of vision through the placement of four 8MP 2D CSI cameras (Figure 5a) at the front, left, rear and right side of the vehicle. Each camera has a wide-angle lens providing up to 160° Horizontal-FOV (field of view) and 120° Vertical-FOV. The corresponding blind-spots have been shown in white in Figure 5b.



a. CSI camera

b. 360 camera coverage portraying the blind spots in white

Figure 5. CSI cameras with wide angle lenses and 360 vision via their placement.

These cameras are indexed in Simulink, Python and C/C++ using the camera IDs as presented in Table 5. The frame resolutions, frame rates and corresponding FOV are documented in Table 6.

Camera	ID	Camera	ID
Right	0	Front	2
Rear	1	Left	3

Table 5. Camera indexing IDs

Resolution	Max Frame Rate (FPS)	Horizontal FOV	Vertical FOV
3280 x 2464	21 Hz	160°	120°
1640 x 1232	80 Hz	160°	120°
820 x 616	80 Hz	160°	120°
1640 x 820	120 Hz	160°	80°
820 x 410	120 Hz	160	80°

Table 6. Achievable frame rates for CSI cameras

The extrinsic matrices of multiple sensors, such as cameras, IMU and LiDAR, have been provided below. The intrinsic matrices have not been provided, as they vary with resolution. Each extrinsic matrix transforms a 3D world coordinate expressed in the body frame $\{B\}$, into a 3D world coordinate expressed in the sensor frame of reference $\{C\}$.

The body frame is located between the front and rear axles on the ground plane.

Facing any camera, the z axis of the camera points straight outwards, the x axis points towards the left, and the y axis points downwards, as shown in Figure 6a. The body frame's x axis points longitudinally forwards, the z axis points upwards, and the y axis points towards the left side of the vehicle, as shown in Figure 6b. As a result, the rotation matrix part of each extrinsic matrix has a determinant of -1. For virtual QCar 2, all distances are 10x.

front_axle_to_body

$$^{B}T_{FA} = \begin{bmatrix} 1 & 0 & 0 & 0.130 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.031 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

rear_axle_to_body

$$^{B}T_{RA} = \begin{bmatrix} 1 & 0 & 0 & -0.130 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.031 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

csi_front_to_body

$$^{B}T_{C} = \begin{bmatrix} 0 & 0 & 1 & 0.183 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0.110 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

csi_left_to_body (battery side)

$$^{B}T_{C} = \begin{bmatrix} 1 & 0 & 0 & 0.012 \\ 0 & 0 & 1 & 0.033 \\ 0 & -1 & 0 & 0.110 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

csi_rear_to_body

$$^{B}T_{C} = \begin{bmatrix} 0 & 0 & -1 & -0.152 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0.110 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

csi_right_to_body (pass)

$$^{B}T_{C} = \begin{bmatrix} -1 & 0 & 0 & 0.012 \\ 0 & 0 & -1 & -0.053 \\ 0 & -1 & 0 & 0.110 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

imu_to_body

$$^{B}T_{IMU} = \begin{bmatrix} 1 & 0 & 0 & 0.011 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.089 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

realsense_to_body

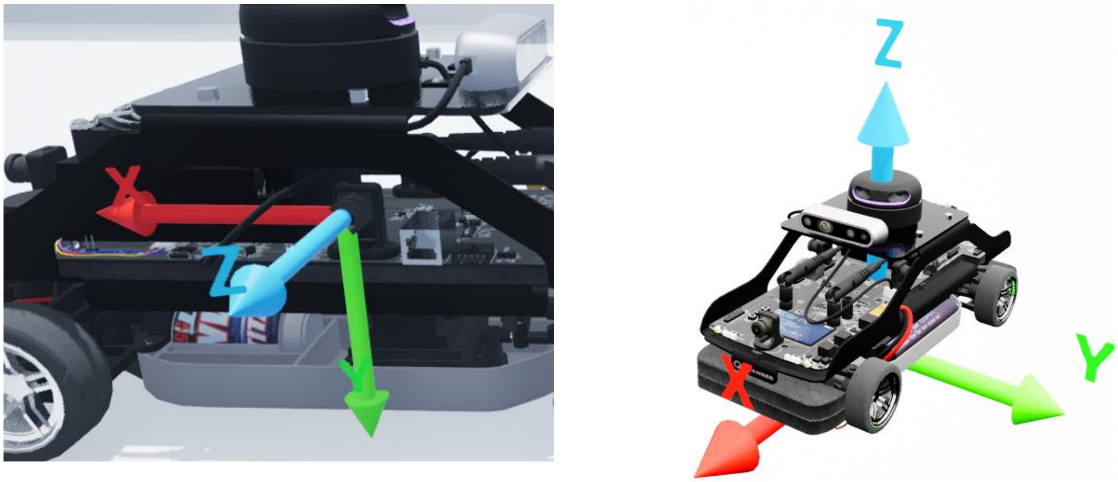
$$^{B}T_{C} = \begin{bmatrix} 0 & 0 & 1 & 0.095 \\ -1 & 0 & 0 & 0.032 \\ 0 & -1 & 0 & 0.172 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

rplidar_to_body

$$^{B}T_{L} = \begin{bmatrix} -1 & 0 & 0 & -0.012 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0.193 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

cg_to_body

$$^{B}T_{CG} = \begin{bmatrix} 1 & 0 & 0 & -0.011 \\ 0 & 1 & 0 & 0.0029 \\ 0 & 0 & 1 & 0.0814 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



a. Camera frame $\{C\}$ b. Body frame $\{B\}$

Figure 6. Camera and body reference frames used in the extrinsic matrices

As an example, a point A located on the floor 1m ahead of the QCar 2 is expressed in front CSI camera frame as

$$^{C}p_{CA} = [0 \quad 0 \quad 1]^T$$

This point can be expressed in the body frame coordinates as,

$$B_x = {}^{B}T_C \begin{bmatrix} ^{C}p_{CA} \\ 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0.183 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0.110 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 1.183 \\ 0 \\ 0.110 \\ 1 \end{bmatrix}$$

The point in body frame is then $B_x = [1.183 \quad 0 \quad 0.110]^T$.

v. Drive Motor and Steering Servo

The QCar 2 comes equipped with a motor that has an integrated cooling fan. The motor parameters are listed in Table 7. Onboard overcurrent protection from the microcontroller will ensure that the motor enters an **Overcurrent** state if the following conditions are met,

1. current draw of 5 Amps continuously for 2 seconds
2. current draw of 10 Amps continuously for 0.5 seconds
3. current draw of 15 Amps continuously for 0.125 seconds

Once in the **Overcurrent** state, the LCD will show an 'Overcurrent' message, and the motor will enter **Neutral** mode. To revert to normal operation, the HIL device must be closed and opened again, which is most easily achieved by restarting the application (script/executable).

⚠ Caution: Holding the motor in a stalled position for a prolonged period at applied voltages of over 5V can result in permanent damage.

Symbol	Description	Value
R_m	Terminal resistance	0.4 Ω
k_t	Torque constant	0.0047 N-m/A
k_m	Motor back-emf constant	0.0047 V/(rad/s)
τ	Steering time-constant	0.16 s

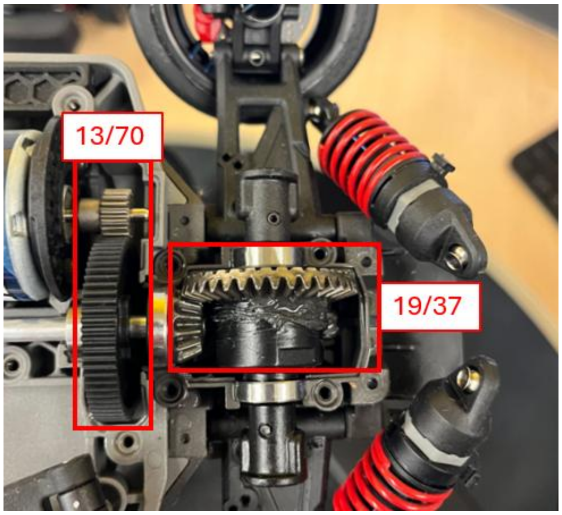
Table 7: QCar 2 drive motor parameters

The steering servo accepts commands in the range of -0.5 to 0.5 radians. Its time constant is presented in Table 7.

vi. Encoder

The QCar 2 includes a pre-gearing encoder used to measure the angular position of the drive motor. This US Digital E8T-720-125 single-ended optical shaft encoder provides 720 counts per revolution or 2880 counts per revolution in quadrature mode. The encoder's datasheet can be found included in the supplementary_material folder located with the user manuals.

The drive motor pinion is connected to the differential drive via gears with a reduction of 13/70 and the differential drive is connected to the wheels via gears with a reduction of 19/37.



Gear reduction from drive motor to wheels

With this gear ratio, a wheel radius of 0.033 and 720 counts per revolution set to quadrature mode, the conversion from encoder counts to meters, or counts/s to m/s, is the following:

$$distance(m) = encoderCounts * (\frac{1}{CountsPerRev * 4}) * pinToSpurRatio * 2\pi * radius$$

$$distance(m) = encoderCounts * (\frac{1}{720 * 4}) * (13 * 19) \ / \ (70 * 37) * 2\pi * 0.033$$

$$distance(m) = encoderCounts * (\frac{1}{2880}) * 0.01977$$

An encoder speed measurement is also available. This is based on the time between encoder edges, and is considered a 'hardware velocity', available in counts/s through the **Other** channels in the HIL API.

vii. Battery

The QCar 2 uses a 3S (3-cell 11.1 Volts) 3300 mAh capacity lithium polymer (LiPo) battery (Figure 7a) with a female XT-60 connector. More information on the provided battery is summarized in Table 8. The battery can be charged using the provided EV-Peak E4 charger (Figure 7b). Under-voltage protection ensures that the QCar 2 automatically shuts down when the battery voltage drops below 10.0V. If the battery voltage drops below 10.5V, a 'LOW BAT' warning message is displayed on the LCD. For more information, see the User Manual - Power document.

a. LiPo 3s 3300mAh with balancer cable (4 wire connector) and XT60 female connector

b. EV-Peak E4 charger

Figure 7. LiPo battery and charger provided with the QCar 2

#	Item	Value
1	Cells	3S (3 cells in series)
2	Battery capacity	3300 mAh
3	Minimum continuous discharge rating	31 C
4	Connector on battery side	XT60 (Female)
5	Maximum voltage per cell	4.2 V
6	Nominal voltage per cell	3.7 V
7	Minimum voltage per cell	3.5 V
8	Battery weight	267 (±20) grams
9	Battery dimensions (LxWxH)	136.5 mm x 42.6 mm x 21.6 mm

Table 8. LiPo battery characteristics

LiPo Battery Safety

Caution: Before using any batteries, chargers/balancers, or power supplies, users must first read the manuals packaged with their equipment. Quanser supplies these guidelines for charging batteries, but it is the users' responsibility to ensure they are operating their equipment safely and correctly. Quanser is not responsible for any damages resulting from use of batteries, power supplies, chargers, or balancers.

Caution: Charge and store LiPo batteries in a location where a battery fire or explosion (including smoke hazard) will not endanger life or property. Do not charge LiPo batteries near flammable materials, liquids or objects.

Caution: Prior to using the QCar 2, visually check the battery for bloating or damage. If the battery exhibits bloating DO NOT USE it. Visual bloating of the battery is dangerous - discard it in accordance with your country's relevant recycling and disposal laws.

Caution: A battery voltage below 10V increases the risk of uneven charge between the three cells. If you experience issues charging a battery that is consistently below 10V, discard it in accordance with your country's relevant recycling and disposal laws

Note: Use and store batteries in a dry environment.

Caution: Do not charge the battery under direct sunlight.

Caution: Do not charge the battery when the battery feels hot. If it does, you should place it in a metal container and observe signs of swelling or heating for at least 30 minutes.

Ensure that the metal container doesn't short the leads of the battery, which may cause a fire!

Caution: If your LiPo battery is subjected to a shock (such as a crash) you should place it in a metal container and observe signs of swelling or heating for at least 30 minutes.

Ensure that the metal container doesn't short the leads of the battery, which may cause a fire!

Caution: Always be present when charging batteries and **do not leave batteries connected to the chargers or the QCar 2 overnight**.

⚠ Caution: Keep LiPo batteries away from children and animals.

⚠ Caution: Never charge a LiPo battery that has ballooned or swollen due to overcharging, undercharging or from a crash.

⚠ Caution: Never charge a LiPo battery that has been punctured or damaged in a crash. After a crash, inspect the battery pack for signs of damage. After a crash, inspect the battery pack for signs of damage.

⚠ Caution: Protect your LiPo batteries from accidental damage during storage and transportation. Do not put battery packs in pockets or bags where they can short circuit or can come into contact with sharp or metallic objects.

Note: If you require additional batteries, please contact Quanser. If you are using batteries not supplied by Quanser, ensure that the connection and polarity match.

⚠ Caution: Never charge the LiPo battery in a moving vehicle.

⚠ Caution: Never overcharge the LiPo battery.

⚠ Caution: Never leave the LiPo battery unattended during recharging.

⚠ Caution: Do not charge LiPo batteries near flammable materials, liquids or objects.

⚠ Caution: Ensure that charging leads are connected correctly. Reversing polarity charging can lead to battery damage, fire or explosion.

⚠ Caution: A LiPo battery fire is a chemical fire. Have a suitable fire extinguisher (class D/for electrical fires) or a large bucket of dry sand near the charging area. Do not try to extinguish electrical battery fires with water.

⚠ Caution: Reduce risks from fire/explosion by storing and charging LiPo batteries inside a suitable container: a LiPo storage sack/bag or metal/ceramic container is advised.

Caution: Do NOT attempt to disassemble, modify, or repair the LiPo battery.

Caution: Never use a battery that is warm from charging or charge a battery that is warm from usage.

Note: Consider how you would deal with a LiPo battery fire/explosion as part of your normal fire safety and evacuation planning.

Note: When discarding a LiPo battery, discard it in accordance with your country's relevant recycling and disposal laws.

Note: Monitor charging LiPo batteries for signs of overheating.

Battery Performance

The battery's performance has been summarized in Table 9 below.

Condition	Battery Life	Distance Driven
Only Motor Driving at 20% (1.14 m/s)	125 min	8.3 km
Motor at 25% (1.3 m/s) with all cameras + lidar	85 min	6.6 km
Motor at 25% (1.3 m/s) with all cameras + lidar + all headlights and LED strip	65 min	5.3 km
No motor. All cameras + lidar (no lights)	116 min	n/a
No motor. All cameras + lidar + all headlights and LED strip	75 min	n/a

Table 9. Battery performance depending on driving conditions/modes

viii. IMU

The QCar 2 includes a 6-axis IMU. The specifications are summarized in Table 10 below and all data is provided in the body frame shown in Figure 6b.

Sensor	Description
Accelerometer	16-bit with configuration range ±2g to ±16g
Gyroscope	Configurable range from ±15.525 °/s to ±2000 °/s

Table 10. IMU specifications on the QCar 2

ix. Dimensions

The QCar 2 is based on a 1/10th scale car (i.e., Traxxas 4-Tec 2.0). Its dimensions have been summarized in table 11. The wheelbase and track are shown in Figure 8.

Item	Value
Length	0.425 m
Width	0.192 m
Height	0.2 m
Wheelbase (Fig. 8 #1)	0.256 m
Front and rear Track (Fig. 8 #2, #3)	0.170 m
Maximum steering angle	±30° (0.52 radians)
Tire diameter	0.066 m

Table 11. QCar 2 dimensions

Figure 8. QCar 2 wheelbase and track

x. PCB and integrated Data Acquisition (DAQ)

The QCar 2 PCB is equipped with a wide array of components to support expanded I/O capabilities. These components are summarized in Table 12 and displayed in Figure 9. These I/O include:

1. 2 user PWM output channels.
    i. Standard PWM, RC, OneShot and Multishot are all supported. *
2. Motor throttle and steering control
3. 2 unipolar user analog input channels, 12-bit, +3.3V *
4. Battery level, electronics current and motor current analog inputs
5. 3 encoder channels (motor position plus up to two additional encoders).
6. 11 reconfigurable digital I/O*
7. 3 user buttons*
8. 16 LEDs with intensity control for car headlights and signals
9. 33 individually programmable RGB LEDs for bottom lighting
10. 3-axis 16-bit accelerometer, range configurable for ±2g to ±16g.
11. 3-axis gyroscope, range configurable for ±15.625 deg/s to ±2000 deg/s.
12. temperature sensor
13. 2 general purpose 3.3V high-speed serial ports*
14. 1 high-speed 3.3V SPI port (up to 25 MHz) *
15. 1 1.8V I2C port (up to 1 MHz) *
16. 1 3.3V I2C port (up to 1 MHz) *
17. 2 CAN bus interfaces (supporting CAN FD)
18. 1 USB port
19. 1 USB-C host port
20. 1 USB-C On-the-Go port (host or device)
21. LCD display (black & white, 400x240 pixels)
22. 4 microphones
23. 1 speaker

* See figure 10 for pin diagram

ID	Description
1	Headlamps
2	Front left/right indicators
3	Brake Lamps
4	Reverse indicators
5	Rear left/right indicators
6	J10 (I2C) [24 pin] *
7	J11 (GPIO, ENCs, PWMs, ADCs) [24 pin] *
8	J19 (CAN) [8 pin] *
9	J25 (steering servo motor) [3 pin] *
10	J24 (motor encoder) [5 pin] *
11	J26 (LIDAR) [5 pin] *
12	2x Front microphones
13	2x Rear microphones
14	Speaker
15	HDMI connector
16	10/100/1000 Base-T Ethernet Jack
17	2x USB-C Ports (1x for RealSense Camera, 1x On-the-Go port as host or device)
18	USB 3.1 port
19	LCD display (black & white, 400x240 pixels)
20	NVIDIA Jetson AGX Orin
21	Pi camera connector
22	Male XT-60 battery connector
23	Main power push-button
24	User push buttons

Table 12. QCar 2 PCB components
(* See Figure 10 for pin diagram)

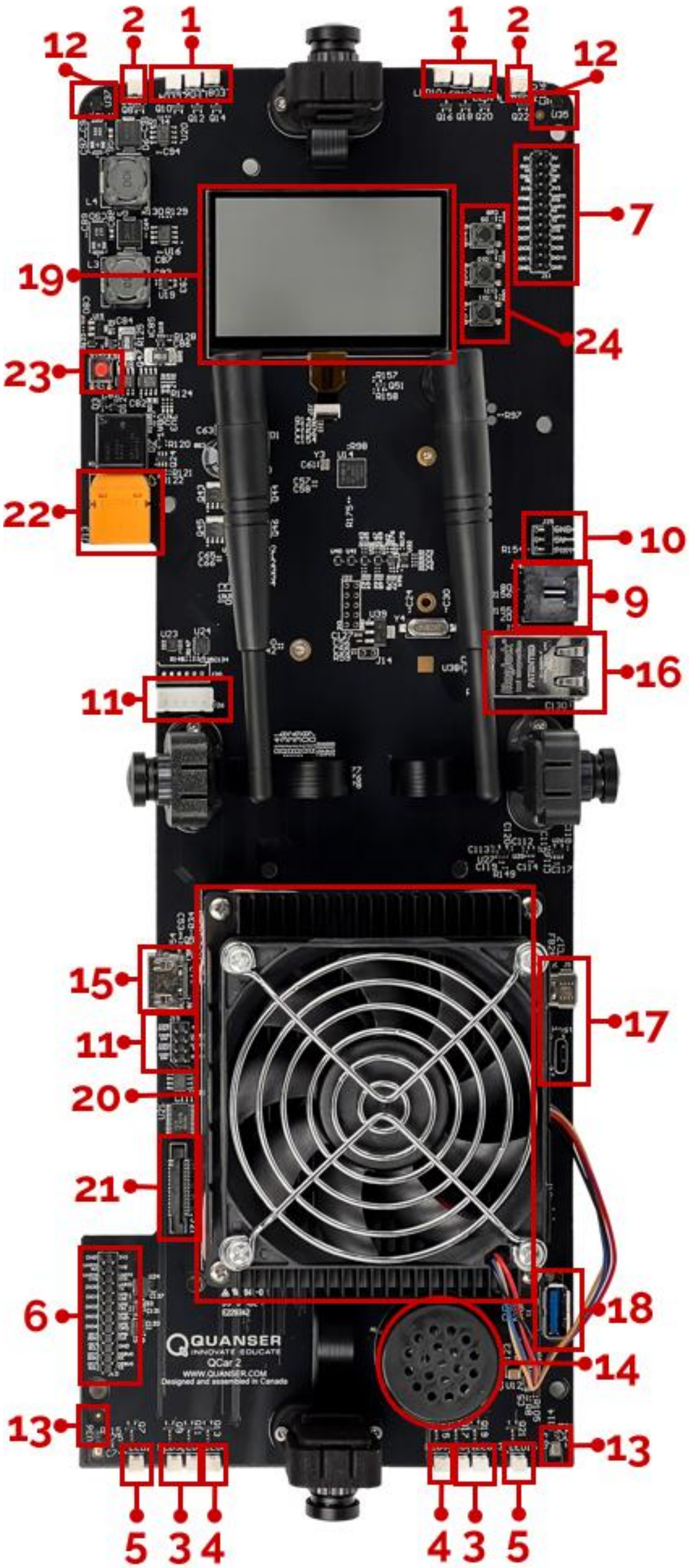


Figure 9. QCar 2 PCB components

> ⚠ Note: Note that all pins are 3.3V and are *not* 5V tolerant unless marked otherwise. Be aware that some of the I/O are 1.8V and are *not* 3.3V tolerant. The analog inputs only support 0 to +3.3V. *Exceeding these voltages may damage the board!*

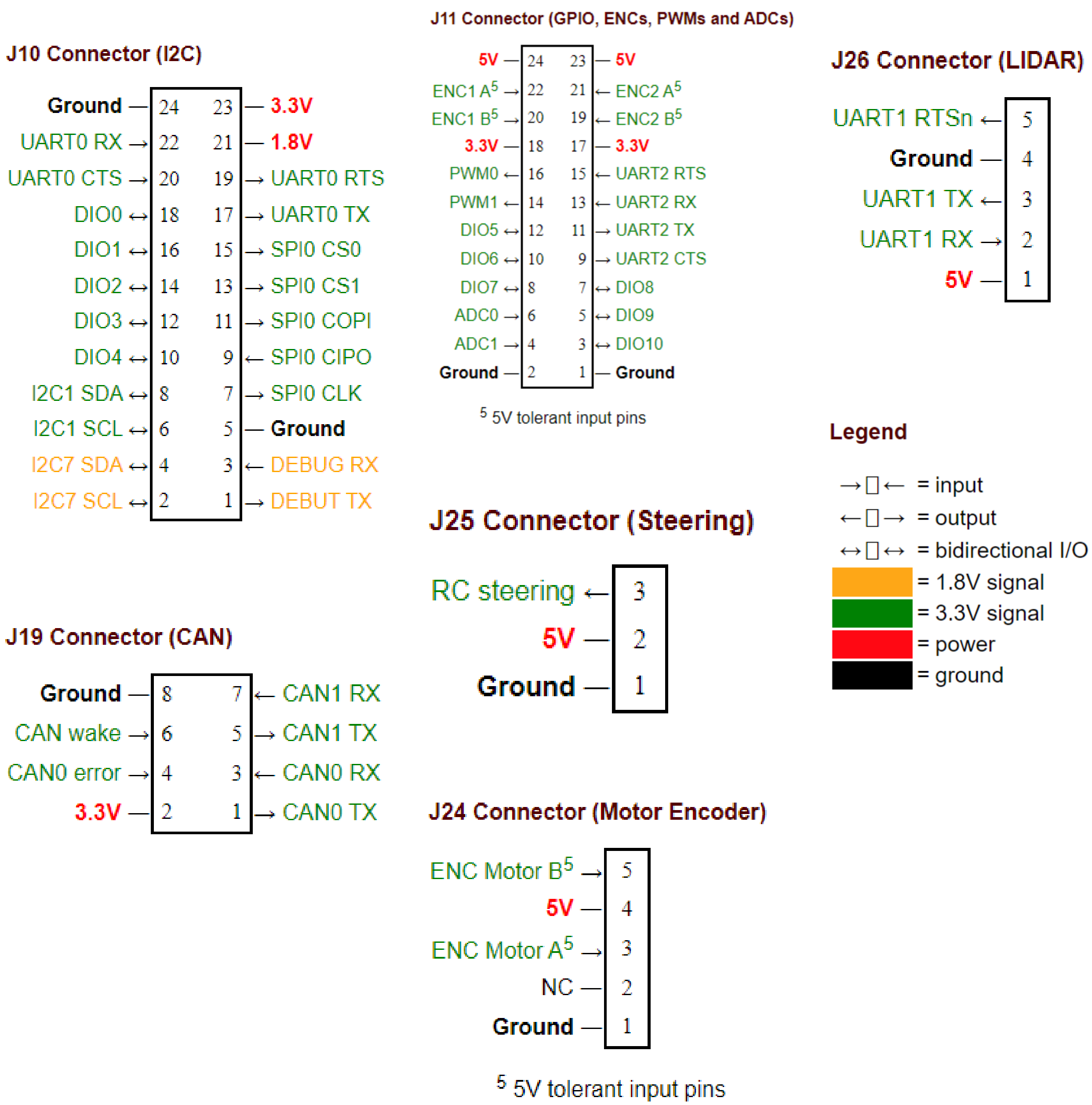


Figure 10. Pin I/O diagram (max current - 5A for 5V pins, 5A for 3.3 V pins, 0.2A for 1.8V pins)

B. Environmental

The QCar 2 is designed to function under the following environmental conditions:

- Standard rating
- Indoor use only
- Temperature 5°C to 40°C
- Altitude up to 2000 m
- Maximum relative humidity of 80% up to 31°C decreasing linearly to 50% relative humidity at 40°C
- Pollution Degree 2
- Mains supply voltage fluctuations up to 10% of nominal voltage
- Maximum transient overvoltage 2500 V

C. Electrical Considerations

ESD warning	The QCar 2 internal components are sensitive to electrostatic discharge. Before handling the QCar 2, ensure that you have been properly grounded.
Caution	Maximum recommended total current draw from the power pins on user headers is - 5 Amps for 5V - 5 Amps for 3.3V - 0.2 Amps for 1.8V
Caution	Do not have conductive material touch either the top or bottom surface of the PCB as it can short the LiPo battery, cause sparks and damage the electronics.
Caution	Do not remove the Jetson Orin AGX fan connector or obstruct the fan as it may cause overheating and damage the Jetson Orin AGX.
Caution	The QCar 2 is not waterproof.

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