USER MANUAL

QBall 2 for QUARC

Set Up and Configuration

CAPTIVATE. MOTIVATE. GRADUATE.

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1 Introduction

1.1 Presentation

The QBall 2, shown in Figure 1.1, is an innovative rotary wing vehicle platform suitable for a wide variety of unmanned aerial vehicle (UAV) research applications. The QBall 2 is a quadrotor helicopter design propelled by four brushless motors fitted with 10-inch propellers. The entire quadrotor is enclosed within a protective carbon fiber cage (Patent Pending). The QBall 2's proprietary design ensures safe operation as well as opens the possibilities for a variety of novel applications. The protective cage is a crucial feature since this unmanned vehicle was designed for use in an indoor laboratory, where there are typically many close-range hazards (including other vehicles). The cage gives the QBall 2 a decisive advantage over other vehicles that would suffer significant damage if contact occurs between the vehicle and an obstacle.

Figure 1.1: QBall 2

To measure on-board sensors and drive the motors, the QBall 2 utilizes Quanser's on-board avionics data acquisition (DAQ) device and a wireless Gumstix DuoVero embedded computer. The DAQ is a high-resolution inertial measurement unit (IMU) and avionics input/output (I/O) card designed to accommodate a wide variety of research applications.

QUARC® , Quanser's real-time control software [1], allows researchers and developers to rapidly develop and test controllers on actual hardware through a Matlab® Simulink® interface. QUARC® 's open-architecture hardware and extensive Simulink® blockset provides users with powerful controls development tools. QUARC® can target the Gumstix embedded computer, automatically generating code and executing controllers on-board the vehicle. During flights, while the controller is executing on the Gumstix, users can tune parameters in real-time and observe sensor measurements from a host ground station computer (PC or laptop).

The interface to the QBall 2 is Matlab® Simulink® with QUARC® . The controllers are developed in Simulink® software with the QUARC® blockset on the host computer, and these models are compiled into executable files and downloaded to the target seamlessly. A diagram of this configuration is shown in Figure 1.2.

Section 1.2 outlines operator warnings found throughout this manual and 1.3 goes through the prerequisites. The general system description and component nomenclature are given in Section 2. The system model parameters and I/O specifications for the embedded computer module are given in Section 3. Section 4 goes into detail on how to setup the QBall 2, and Section 5 describes the battery charging procedure. Lastly, Section 6 contains a troubleshooting guide.

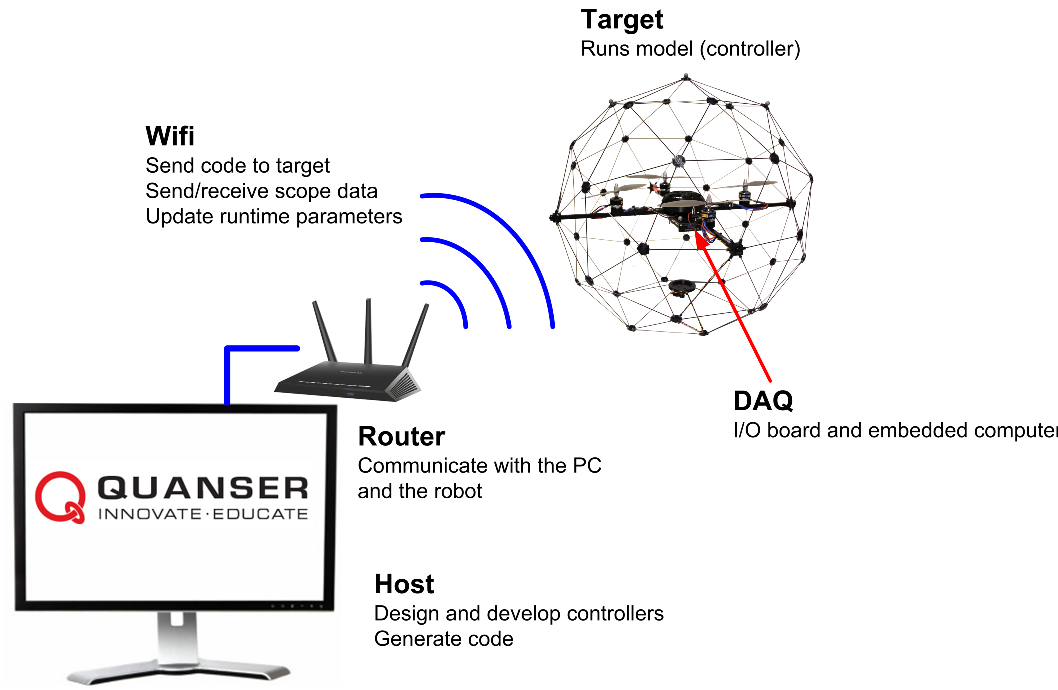


Figure 1.2: System diagram

Note: Please refer to the UVS Laboratory Guide [2] for the software prerequisites required. The UVS Laboratory Guide includes all the necessary information to run the QBall 2 flight controllers with the OptiTrack™ camera system.

1.2 Operator Warnings

⚠ **Caution:** This symbol marks specific safety warnings and operating procedures that are important for the safety of the QBall 2 and users. Read these warnings carefully. The QBall 2 is a powerful and potentially dangerous vehicle if used improperly. Always follow safe operating procedures when using the QBall 2. Quanser is not responsible for damages and injury resulting from improper or unsafe use of the QBall 2. Before connecting batteries or attempting to run the QBall 2, be sure to read this document and become familiar with the safety features and operating procedures of the QBall 2.

⚠ **Caution:** When handling the QBall 2, always make sure there are no models running and the power is turned off. It is recommended that users wear safety goggles to protect the eyes.

1.3 Prerequisites

The user should read and become familiar with the following:

- OptiTrack™ Quick Start Guide
- OptiTrack™ documentation provided by NaturalPoint
- QBall 2 Quick Start Guide
- Unmanned Vehicle Systems (UVS) Laboratory Guide [2]

2 System Hardware

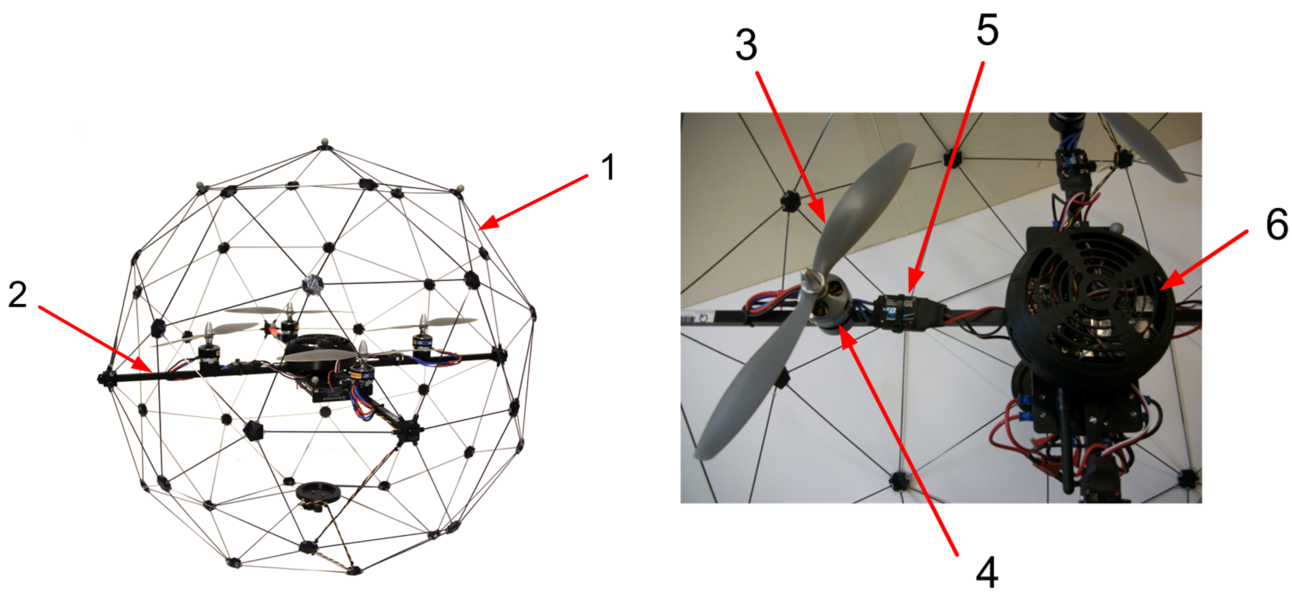
2.1 Main Components

The following hardware and software are required to run the QBall 2 system:

1. **UAV**: QBall 2 shown in Figure 1.1
2. **Batteries**: Two 3-cell, 2700 mAh Lithium-Polymer batteries
3. **Router**: A high-performance router pre-configured to enable wireless connectivity to QBall 2
4. PC or laptop
5. **Real-Time Control Software**: Matlab® /Simulink® and QUARC® configuration. See the *UVS Laboratory Guide* [2] for full details.
6. **Localization system**: OptiTrack™ camera system and software (see *UVS Laboratory Guide* [2] for more information)

2.2 QBall 2 Components

The components comprising the QBall 2 are labeled in Figure 2.1, Figure 2.2 and Figure 2.3 and described in Table 2.1. The QBall 2 joystick is illustrated in Figure 2.4.



(a) Cage

(b) Propellers

Figure 2.1: QBall 2 components: cage and propellers

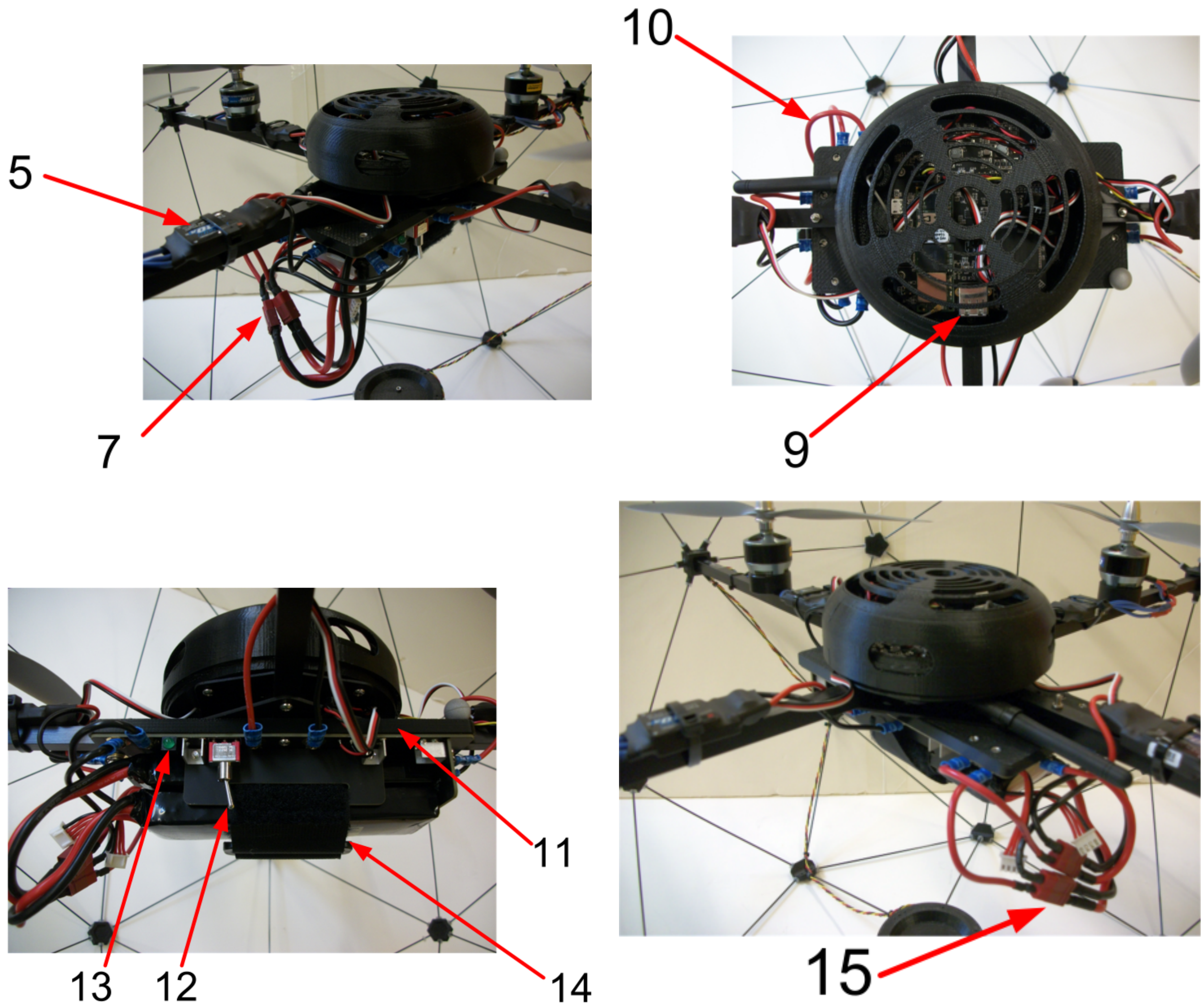


Figure 2.2: QBall 2 components: DAQ and power board

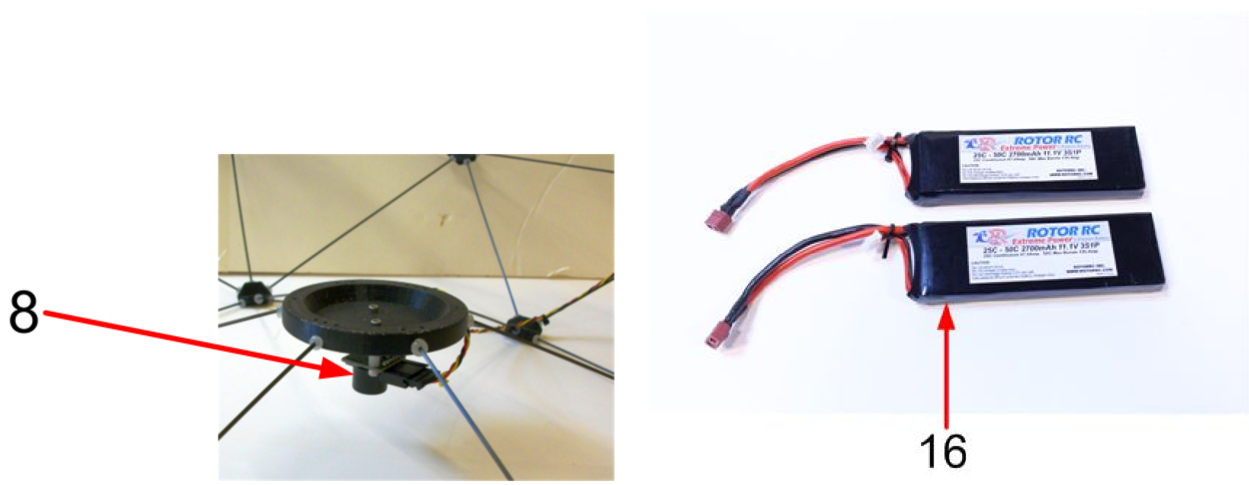


Figure 2.3: QBall 2 components: sonar and batteries

ID #	Description	ID #	Description
1	QBall 2 protective cage	9	USB input
2	QBall 2 frame	10	QBall 2 DAQ power cable
3	10x4.7 propeller	11	QBall 2 power distribution board
4	Brushless DC motor	12	QBall 2 power switch
5	Electronic Speed Controller (ESC)	13	QBall 2 power LED
6	QBall 2 DAQ	14	Battery velcro strap
7	Battery connector	15	Connected batteries
8	Sonar	16	3-cell 2700 mAh Lithium-Polymer batteries

Table 2.1: QBall 2 components

Figure 2.4: QBall 2 joystick

2.2.1 QBall 2 Frame

The QBall 2 frame (#2 in Figure 2.1) is the crossbeam structure to which the QBall 2 components are mounted including the DAQ, power distribution board, motors and speed controllers. The frame rests inside the QBall 2 protective cage (#1 in Figure 2.1). The QBall 2's protective cage is a carbon fiber structure designed to protect the frame, motors, propellers, and embedded control module (DAQ and Gumstix computer) during minor collisions.

⚠ **Caution:** The cage is **not intended** to withstand large impacts or drops from heights greater than 2 meters.

⚠ **Caution:** Do not pick up the QBall 2 from the cage as this may stress the cage and cause damage. Instead, when transporting the QBall 2 lift it from the ends of the frame using both hands to lift the frame from both sides.

2.2.2 QBall 2 Data Acquisition (DAQ) Device

Together with the Gumstix embedded computer, the QBall 2 data acquisition (DAQ) board controls the vehicle by reading on-board sensors and the positions from the OptiTrack™ camera system, and outputting motor commands. The DAQ is located inside a protective enclosure underneath the cross frame of the QBall 2. The enclosure lid is opened by gently rotating the lid counter-clockwise when viewed from the top.

Each motor speed controller (#5 in Figure 2.1) is connected to a PWM motor output on the DAQ (#6 in Figure 2.1).

There are four motor output channels available on the DAQ and they are labeled F, B, L, and R to represent motor commands to the front, back, left, and right motors, respectively. Each motor speed controller should be connected to its corresponding PWM output with the ground (black wire) towards the inside of the DAQ board (see Section 4.2 for wiring details). The QBall 2 comes with the motors already connected to the DAQ, so no manual assembly is necessary.

If it is ever required to remove the DAQ for testing or troubleshooting, the cables and wires must first be disconnected from the DAQ PCB and removed from the DAQ enclosure. Remove the DAQ cover by gently rotating it counter-clockwise (when viewed from the top of the QBall 2). Disconnect the power, sonar, motor, and any other I/O cables plugged into the DAQ and carefully extract them through the slots in the DAQ enclosure. Reattach the DAQ cover. Using an Allen wrench, remove the four screws shown in Figure 2.5, being careful to support the DAQ enclosure so it does not fall. When reassembling the DAQ, first attach the DAQ enclosure to the frame, making sure to align the arrow on the DAQ enclosure with the front of the vehicle (positive X axis direction). Then, remove the lid and carefully feed the power, sonar, and motor cables through the enclosure slots. Reattach the cables to their corresponding headers and screw on the enclosure lid.

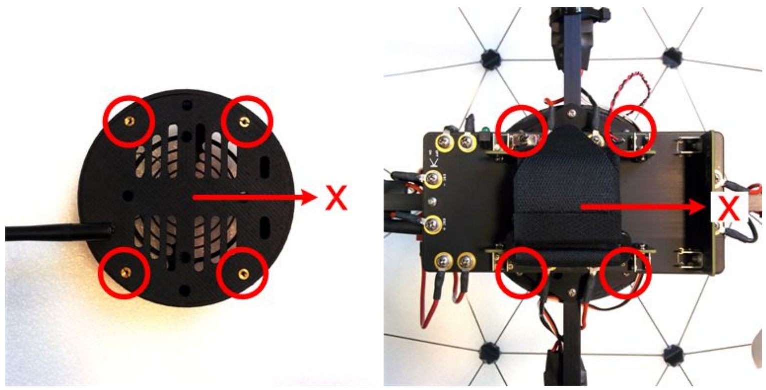


Figure 2.5: QBall 2 DAQ case mounting points

2.2.3 QBall 2 Power Distribution Board

The QBall 2 uses two 3-cell 2700 mAh LiPo batteries (#16 in Figure 2.1) to power the DAQ and motors. These batteries are housed underneath the QBall 2 power distribution board (#11 in Figure 2.1) below the QBall 2's cross frame and held in place using the provided Velcro strap (#14 in Figure 2.1). The power distribution board connects both LiPo battery packs in parallel and routes power to the four motors as well as the DAQ.

⚠ **Caution:** Make sure the batteries are connected and secured with the velcro strap before attempting to fly the QBall 2.

Secure the batteries to the power board before connecting the batteries to the QBall 2 battery connectors (#7 in Figure 2.1) and always turn off the power using the QBall 2 power switch (#12 in Figure 2.1) before changing batteries.

⚠ **Caution:** LiPo batteries can be dangerous if charged improperly. Review the battery charging procedures (see Section 5) and monitor battery levels frequently during flight. The 3-cell LiPo batteries **can become damaged and unusable if discharged below 10 V**. It is recommended that the batteries be fully charged once they reach 10 V or less.

2.2.4 QBall 2 motors and propellers

The QBall 2 uses four E-Flite Park 480 (1020 Kv) motors (#4 in Figure 2.1) fitted with paired counter-rotating APC 10×4.7 propellers (#3 in Figure 2.1). The motors are mounted to the QBall 2 frame along the X and Y axes and connected to the four speed controllers, which are also mounted on the frame. The motors and propellers are configured so that the front and back motors spin clockwise and the left and right motors spin counter-clockwise (when viewed from the top). The Electronic Speed Controllers (ESCs) receive commands from the controller in the form of PWM outputs from 1 ms (minimum throttle) to 2 ms (maximum throttle). Minimum throttle and maximum throttle are mapped to values between 0 and 1, respectively, using the *HIL Write* block to outputs the motor commands (see Section 4.2 for details on the HIL blocks). The ESCs used in the QBall 2 are configured with the appropriate throttle range during assembly. It is important that when the controller executes it initializes the ESCs by setting the motor outputs to the minimum throttle 0, otherwise you can enter the program mode and alter the ESC settings. Review the ESC's manual for instructions on changing ESC settings.

2.2.5 QBall 2 Joystick

The QBall 2 joystick can be used to control the QBall 2. The joystick allows the operator to fly the QBall 2 using the controls for roll (rotating the QBall 2 about the x axis to fly left/right), pitch (rotating the QBall 2 about the y axis to fly forward/backward), and yaw (rotating the QBall 2 about the z axis to change its direction or heading).

2.3 Manufacturer Listing for Components

Below is a listing of the manufacturers for different components:

1. Gumstix: http://gumstix.com/
2. Park 480 Brushless motor - 1020Kv:
   http://hobbyhobby.com/store/product/68211%22Park-480-Brushless-Outrunner-Motor%2C-1020Kv%22/
3. Propellers description and technical information:
   http://www.rctoys.com/rc-products/APC-10-047-SF-CR.html
4. Hobbywing Flyfun-30A electronic speed controller manual:
   http://www.hobbywing.com/uploadfiles/sx/file/Manual/HW-01-V4.pdf
5. STMicroelectronics L3G4200D 3-axis gyroscope:
   http://www.st.com/web/catalog/sense_power/FM89/SC1288/PF250373
6. Freescale MMA8452Q 3-axis accelerometer:
   http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MMA8452Q

3 QBall 2 Model

This section describes the dynamic model of the QBall 2. The nonlinear models are described as well as linearized models for use in controller development. For the following discussion, the axes of the QBall 2 vehicle are denoted (x, y, z) and are defined with respect to the vehicle as shown in Figure 3.1. Roll, pitch, and yaw are defined as the angles of rotation about the x, y, and z axis, respectively. The global workspace axes are denoted (X, Y, Z) and are defined with the same orientation as the QBall 2 sitting upright on the ground.

3.1 Diagram

Figure 3.1 below is a basic diagram of the QBall 2, showing the axes and angles. Note that the axes follow a right-hand rule with the x axis aligned with the front of the vehicle.

Caution: The tail or back of the vehicle is marked with colored tape. When flying the vehicle it is common to orient the vehicle such that the tail is pointing towards the operator with the positive x axis (front) pointing away from the operator.

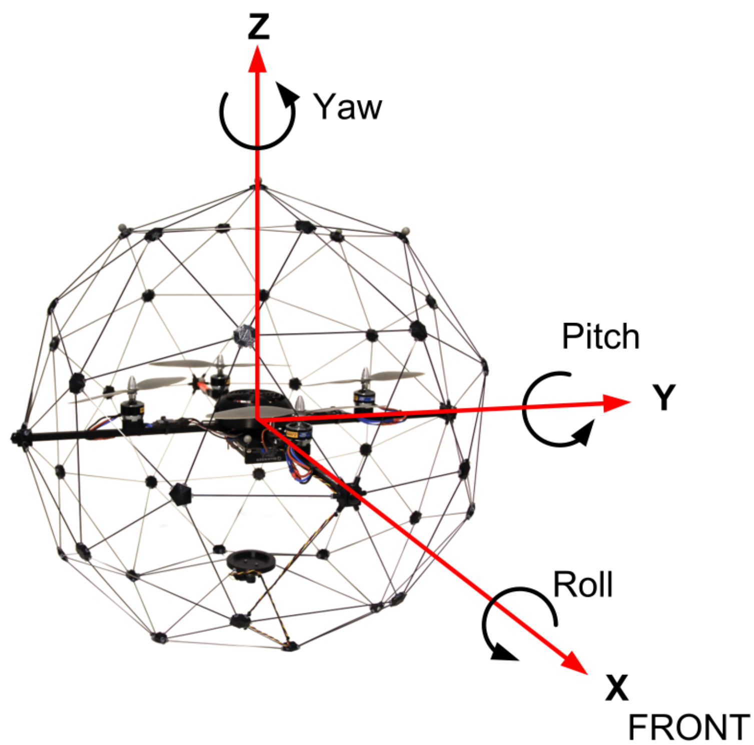


Figure 3.1: QBall 2 axes and sign convention

3.2 Actuator Dynamics

The thrust generated by each propeller is modeled using the following first-order system

$$F = K \frac{\omega}{s + \omega} u \tag{3.1}$$

where u is the PWM input to the actuator, ω is the actuator bandwidth and K is a positive gain. These parameters were calculated and verified through experimental studies and are stated in Table 3.1. A state variable, ν, will be used to represent the actuator dynamics, which is defined as follows,

$$\nu = \frac{\omega}{s+\omega} u. \tag{3.2}$$

3.3 Roll/Pitch Model

Assuming that rotations about the x and y axes are decoupled, the motion in roll/pitch axis can be modeled as shown in Figure 3.2. As illustrated in this figure, two propellers contribute to the motion in each axis. The rotation around the center of gravity is produced by the difference in the generated thrust forces. From Equation 3.2, let $u = \tilde{u}$, where $\tilde{u}$ is the control input for the pitch or roll dynamics that causes an increase or decrease in thrust force in the two pitch/roll motors shown in Figure 3.2 and such that the changes in force of each motor are opposite in direction so that the net result is a torque. For example, the control signal is applied to increase the force in motor 1 and decrease the force in motor 2. This change in motor forces is what causes the resulting torque and roll or pitch dynamics, so the net thrust force used to hover the QBall 2 can be ignored. The change in thrust generated by each motor can be calculated from Equation 3.1. The roll/pitch angle, θ, can be formulated using the following dynamics

$$J\ddot{\theta} = \Delta F L, \tag{3.3}$$

where

$$J = J_{roll} = J_{pitch} \tag{3.4}$$

are the rotational inertia of the device in roll and pitch axes and are given in Table 3.1. L is the distance between the propeller and the center of gravity, and

$$\Delta F = \Delta F_1 - \Delta F_2 \tag{3.5}$$

represents the net change in the forces generated by the motors. Note that the difference in the forces is generated by the difference in the inputs to the motors, i.e.

$$\Delta u = 2\tilde{u}. \tag{3.6}$$

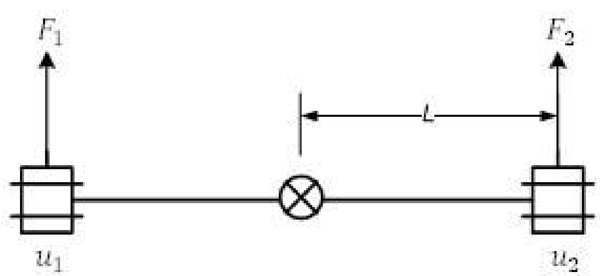


Figure 3.2: A model of the roll/pitch axis

By combining the dynamics of motion for the roll/pitch axis and the actuator dynamics for each propeller the following state space equations can be derived

$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \\ \dot{\nu} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & \frac{2KL}{J} \\ 0 & 0 & -\omega \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \\ \nu \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \end{bmatrix} \tilde{u}. \tag{3.7}$$

To facilitate the use of an integrator in the feedback structure a fourth state can be added to the state vector, which is defined as follows

$$\dot{s} = \theta. \tag{3.8}$$

After augmenting this state into the state vector, the system dynamics can be rewritten as

$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \\ \dot{\nu} \\ \dot{s} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{2KL}{J} & 0 \\ 0 & 0 & -\omega & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \\ \nu \\ s \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \\ 0 \end{bmatrix} \tilde{u}. \tag{3.9}$$

3.4 Height Model

The motion of the QBall 2 in the vertical direction (along the Z axis) is affected by all the four propellers. The dynamic model of the QBall 2 height can be written as

$$M\ddot{Z} = 4Fcos(r)cos(p) - Mg, \tag{3.10}$$

where F is the thrust generated by each propeller, M is the total mass of the device, Z is the height and r and p represent the roll and pitch angles, respectively. The total mass, M, is given in the Table 3.1. As expressed in this equation, if the roll and pitch angles are nonzero the overall thrust vector will not be perpendicular to the ground. Assuming that these angles are close to zero, the dynamics equations can be linearized to the following state space form

$$\begin{bmatrix} \dot{Z} \\ \ddot{Z} \\ \dot{\nu} \\ \dot{s} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{4K}{M} & 0 \\ 0 & 0 & -\omega & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Z \\ \dot{Z} \\ \nu \\ s \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \\ 0 \end{bmatrix} u. \tag{3.11}$$

3.5 X-Y Position Model

The motion of the QBall 2 along the X and Y axes is caused by the total thrust and by changing roll/pitch angles. Assuming that the yaw angle is zero the dynamics of motion in X and Y axes can be written as

$$\begin{aligned} M\ddot{X} &= 4Fsin(p), \\ M\ddot{Y} &= -4Fsin(r). \end{aligned}$$

Assuming the roll and pitch angles are close to zero, the following liner state space equations can be derived for X and Y positions.

$$\begin{bmatrix} \dot{X} \\ \ddot{X} \\ \dot{\nu} \\ \dot{s} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{4K}{M}p & 0 \\ 0 & 0 & -\omega & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} X \\ \dot{X} \\ \nu \\ s \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \\ 0 \end{bmatrix} u,$$

$$\begin{bmatrix} \dot{Y} \\ \ddot{Y} \\ \dot{\nu} \\ \dot{s} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{-4K}{M}r & 0 \\ 0 & 0 & -\omega & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Y \\ \dot{Y} \\ \nu \\ s \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \\ 0 \end{bmatrix} u.$$

3.6 Yaw Model

The torque generated by each motor, τ, is assumed to have the following relationship with respect to the PWM input, u:

$$\tau = K_y u,$$

where K_y is a positive gain and its value is given in Table 3.1. The motion in the yaw axis is caused by the difference between the reaction torques exerted by the two clockwise and the two counter-clockwise rotating propellers. The model of the yaw axis is shown in Figure 3.3, where the directions of the propeller motion are indicated. The associated reaction torque generated by the propellers (τ_i) will be in the opposite direction to the propeller motion indicated.

The motion in the yaw axis can be modeled using the following equation

$$J_y \ddot{\theta}_y = \Delta\tau.$$

In this equation, θ_y is the yaw angle and J_y is the rotational inertia about the z axis, which is given in Table 3.1. The resultant torque of the motors, $\Delta\tau$, can be calculated from

$$\Delta\tau = \tau_1 + \tau_2 - \tau_3 - \tau_4$$

$$\begin{bmatrix} \dot{\theta}_y \\ \ddot{\theta}_y \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \theta_y \\ \dot{\theta}_y \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{J_y} \end{bmatrix} \Delta\tau.$$

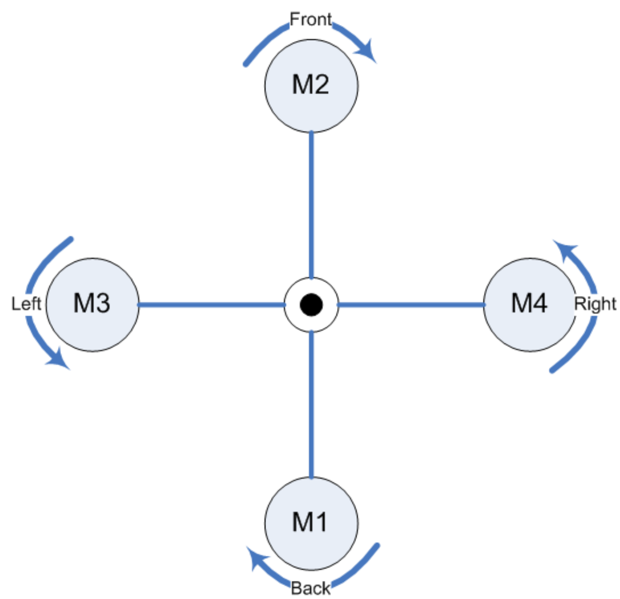


Figure 3.3: A model of the yaw axis with propeller direction of rotation shown.

Parameter	Value
K	12 N
ω	15 rad/s
J$_{roll}$	0.03 kg · m^2
J$_{pitch}$	0.03 kg · m^2
M	1.79 kg
K_y	0.4 N · m
J$_{yaw}$	0.04 kg · m^2
L	0.2 m

Table 3.1: System parameters

4 System Setup

Section 4.1 describes setting up the vehicle hardware. Section 4.2 describes the QBall 2 sensors and how they are accessed in QUARC® . Section 4.3 and 4.4 describe the procedures for configuring the wireless connection in order to communicate with the QBall 2.

4.1 QBall 2 Vehicle Setup

1. First, make sure that the router is setup and connected to your PC. See Section 4.3 for network and IP settings.

2. Check that all motors are securely fastened to the vehicle frame. Check that the propellers are firmly attached to the motors in the correct order: clockwise propellers (viewed from the top) on the front and back motors, counter-clockwise propellers on the left and right motors. Note that the back motor is indicated by a bright colored marking tape on the QBall 2 frame.

   ⚠ **Caution:** Check that the motors are firmly secured to the frame regularly (after every 2 hours of flight). Over time, vibrations in the frame may loosen the motor mounts. If a motor or mount feels loose, tighten it immediately.

   If a propeller is loose, use an Allen key to remove the cap holding the propeller to the motor and ensure the propeller mounting collar is pushed fully down onto the motor shaft. Replace the propeller on the mounting shaft and replace the motor cap and tighten it with an Allen key.

   ⚠ **Caution:** **Never change propellers or other components of the QBall 2 with the batteries connected!**

3. Install the batteries as illustrated in Figure 4.1. With the power switch in the off position, insert the batteries into the battery compartment on bottom of the power distribution board, making sure the batteries rest against the far wall of the compartment. Secure the batteries in place using the Velcro strap. Connect the batteries to the power board battery connectors.

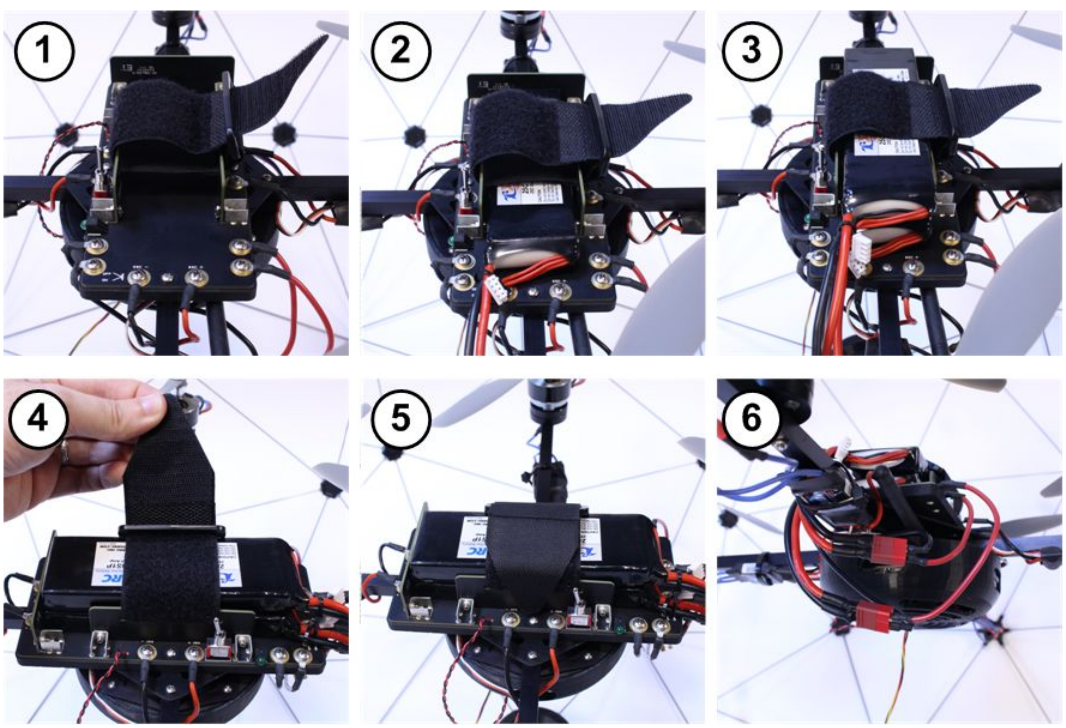


Figure 4.1: Battery connection procedure

4. Power on the QBall 2 using the power switch located on the power distribution board. After approximately 1

minute the Gumstix wireless module should be active and connected to the WiFi (see Section 4.3 for network setup).

4.2 QBall 2 Sensors

This section describes the blocks that are used to read the QBall 2 sensors in Simulink® and write outputs to the motors. The QUARC® Hardware-In-the-Loop (HIL) blockset is used to communicate with Quanser® data acquisition cards. For detailed information on the HIL blockset see the QUARC® HIL user guide in the Matlab® help under QUARC Targets/User's Guide/Accessing Hardware.

The QBall 2 DAQ provides several high-resolution avionics sensors, which are used to measure and control the stability of aerial vehicles. The I/O of the QBall 2 DAQ includes:

- 4 PWM motor outputs
- 2 configurable PWM outputs
- 3-axis gyroscope, $250/500/2000$ degrees-per-second selectable range
- 3-axis accelerometer, $\pm 2g/4g/8g$ selectable range
- Sonar height sensor, $0.2 - 7.65$ m range, 1 cm resolution
- Battery voltage measurement
- 2 analog inputs, 12-bit, $0 - 5$ V
- 1 SPI
- 8 digital I/O
- 1 UART
- 1 I^2C

Figure 4.4 shows the location of the I/O listed above on the QBall 2 DAQ. The DAQ I/O listed above is accessed using the QUARC HIL blockset. The UART, SPI, and I2C communication channels are accessed through the QUARC® Stream blockset. For more information on accessing communication stream data see the QUARC® help under QUARC Targets/User's Guide/Communications. Table 4.1 lists the HIL blocks used to communicate with the QBall 2's data acquisition hardware.

Note that there is another version of the QBall 2, referred to as the QBall 2+, launched in 2017. This version includes a flight controller (RotorGeek F3), that sits on top of the QBall 2 DAQ. If you have this version of the Qball 2, refer to the Flight Controller Manual found in the Documentation directory for more details on how to configure and use the flight controller.

Note: There are two ways to check whether or not you have the QBall 2 or QBall 2+. Firstly, there should be a sticker on the cross frame indicating that the unit is a QBall 2+ (Figure 4.2). Secondly, once you open the DAQ cover, the QBall 2+ DAQ is partially covered by the on-board flight controller and Quanser PCB (Figure 4.3), compared to the QBall 2 DAQ in Figure 4.4. Note that the flight controller is located between the Quanser PCB and the QBall 2 DAQ. The Quanser PCB provides users with the functionality to switch between using the flight controller and QBall 2 DAQ, offline. Note that this is not intended for an online midflight switch.

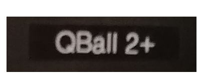


Figure 4.2: QBall 2+ main frame sticker

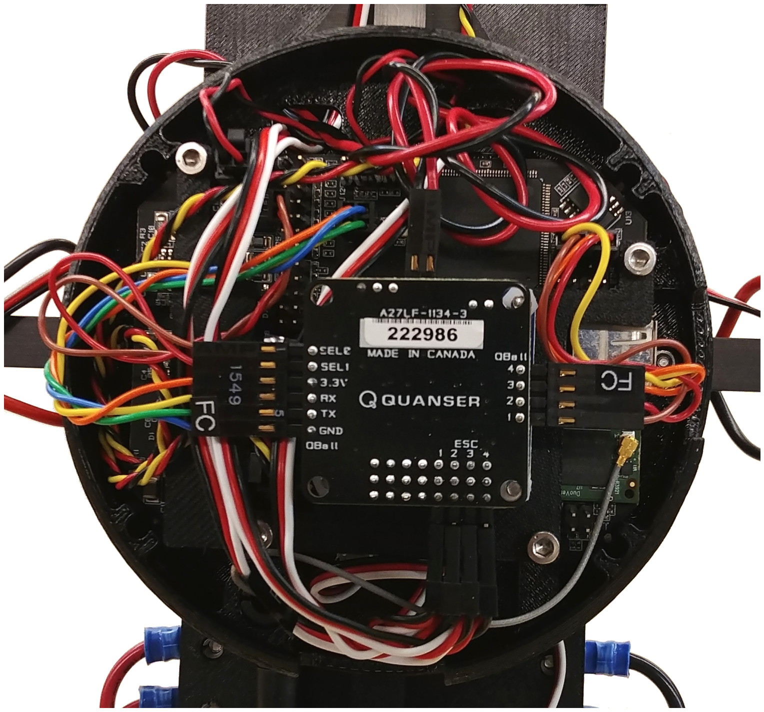


Figure 4.3: QBall 2+ DAQ with Quanser PCB and flight controller

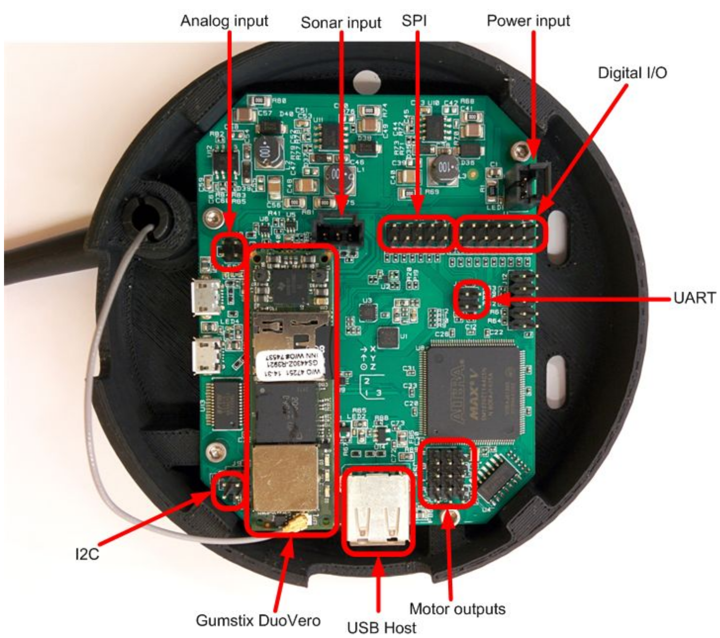


Figure 4.4: QBall 2 DAQ board.

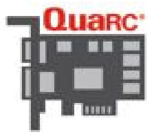
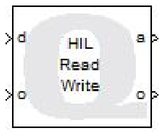
Block	Description
 HIL Initialize QBall 2 (qball2-0)	The *HIL Initialize block* selects the DAQ board and configures the board parameters. The HIL Initialize block is named via the Board name parameter, and all other HIL blocks reference the corresponding *HIL Initialize* through its name. The HIL blocks will interface to the DAQ specified in the *HIL Initialize Board* type parameter (qball2).
 HIL Read Write1 (QBall 2)	The *HIL Read Write* block is used to read sensor measurements from the DAQ and write motor commands to the four QBall 2 motors. The inputs and outputs are specified with numeric channel numbers given in Table 4.2 and Table 4.3, respectively.
 HIL Watchdog (QBall 2)	The *HIL Watchdog* block is used to set the timeout limit for the watchdog timer. For the QBall 2 DAQ board, if there is no motor output command received for a consecutive period of time exceeding the watchdog timeout value then the watchdog will trigger, forcing the motor outputs to 0. The default timeout value for the watchdog is 50ms unless specified otherwise with this block. This block can be used to change the timeout value if 50ms is not suitable.

Table 4.1: HIL blocks

To initialize the QBall 2 DAQ board, a HIL Initialize block must be placed in the model. The HIL Initialize block is used to initialize a data acquisition card and setup the I/O parameters. In the HIL Initialize block, select the board type 'qball2' to configure the QBall 2 DAQ and, if desired, enter a name in the Board name field as shown in Figure 4.5.

Next, to read and write from the QBall 2 DAQ, add a HIL Read Write block to the model (note that the QBall 2 DAQ is optimized for best performance when a single HIL Read Write block is used in a model, adding more HIL I/O blocks may reduce the performance, particularly the maximum sample rate). In the HIL Read Write block, select the board name corresponding to the board name given in the HIL Initialize block. The channels available for reading and writing for the DAQ are listed in Table 4.2 and Table 4.3 below. Enter the channel numbers to be read/written or use the browse buttons to open a channel selection dialog as shown in Figure 4.6.

Channel type	Read channel numbers	Description	Units
Analog	$0-1$	Analog inputs	V
	2	Supply voltage (battery)	V
Encoder	*none*	-	
Digital	$0-7$	Reconfigurable digital I/O	
Other	0	Sonar height sensor	m
	$3000-3002$	3-axis gyroscope (x, y, z)	$\mathrm{rad/s}$
	$4000-4002$	3-axis accelerometer (x, y, z)	$\mathrm{m/s^2}$
	10000	Temperature sensor	$^\circ\mathrm{C}$

Table 4.2: QBall 2 input channels

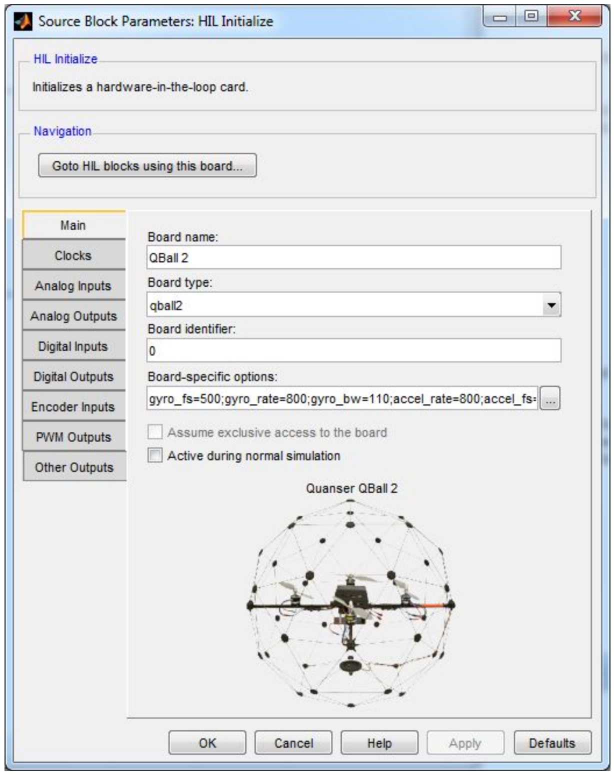


Figure 4.5: HIL Initialize block with the QBall 2 board selected.

Channel type	Write channel numbers	Description	Units
Analog	*none*	-	
PWM	$0-1$	PWM outputs	% duty cycle from 0-1
Digital	$0-7$ 8	Reconfigurable digital I/O LED	
	9	ESC enable	
Other	11000 11001 11002 11003	Left motor Right motor Front motor Back motor	Throttle from 0-1 Throttle from 0-1 Throttle from 0-1 Throttle from 0-1

Table 4.3: QBall 2 output channels

Note: For QBall 2+ users, DIO#0 and DIO#1 are not available, as these are used to switch between the flight controller and QBall 2 DAQ. Refer to the Flight Controller Manual found in the Documentation directory for more details.

For the QBall 2, the Other output channels $11000 - 11003$ are used to command the left, right, front, and back motors, respectively. The range of the motor output values is 0 to 1 (minimum throttle to maximum throttle), which corresponds to a 1ms to 2 ms PWM pulse, respectively. A command of 0 corresponds to zero throttle, which will cause the motors to stop.

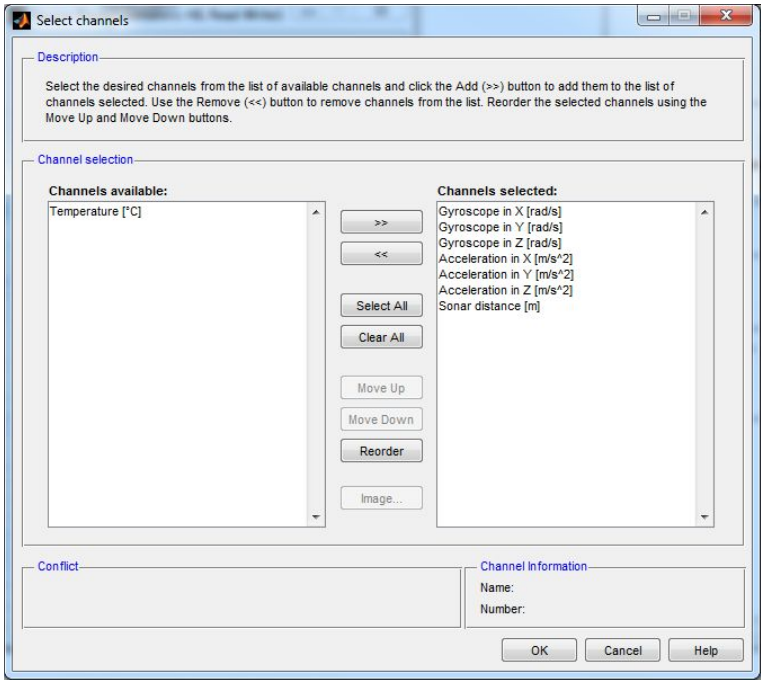


Figure 4.6: Channel selection dialog for the HIL Read Write block

The 3-axis gyroscope and accelerometer measurements are used to measure the QBall 2 dynamics and orientation (roll, pitch and yaw). These IMU inputs are crucial for controlling the flight of the QBall 2. The QBall 2 DAQ utilizes a STMicroelectronics 3-axis gyroscope [6] and a Freescale 3-axis accelerometer [7]. The QBall 2 sonar sensor is the Maxbotix XL-Maxsonar EZ3, which measures distances between 20cm and 765cm with 1cm resolution. Objects between 0-20cm are ranged as 20cm. The sonar sensor is positioned at the bottom of the QBall 2 and is used to measure the QBall 2 height for closed-loop height control.

Caution: Note that the sonar works best over a hard surface which will reflect the ultrasonic signals. The sonar may not work over carpet or other surfaces that will disperse the ultrasonic signals. Always test the sonar first by disabling the QBall 2 motor outputs and lifting the QBall 2 to see if the sonar is functioning as expected.

The battery voltage input measures the supply voltage connected to the QBall 2 DAQ. Since the LiPo batteries used to power the QBall 2 should be charged when they reach a voltage of no less than 10 V, the battery capacity should be monitored.

Caution: It is recommended that the QBall 2 batteries are always changed in pairs. Follow the directions of the charging system that is supplied to ensure the batteries are charged properly and safely (see Section 5).

The QBall 2 DAQ provides several I/O channels for interfacing additional sensors. Figure 4.4 shows the QBall 2 DAQ and its interfaces. Figure 4.7 shows the layout of the QBall 2 DAQ header pins and Table 4.4, Table 4.5 and Table 4.6 list the various I/O pins found on the QBall 2 DAQ.

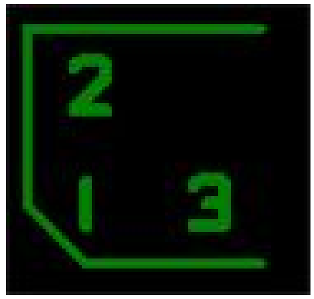


Figure 4.7: Pin mapping for the DAQ headers

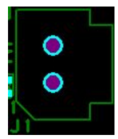
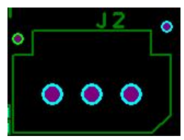
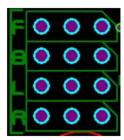
I/O	Header	Pin	Signal
Power input	J1 	1	V_{in}
		2	GND
Sonar input	J2 	1	5V
		2	sonar height measurement
		3	GND
Motor outputs	ESC F/B/L/R 	1	PWM motor output
		2	Not connected
		3	GND

Table 4.4: QBall 2 DAQ pin list: J1, J2, ESC F/B/L/R

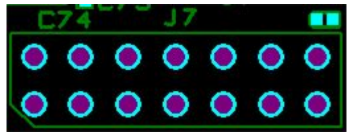
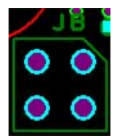
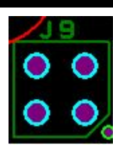
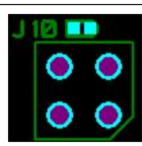
I/O	Header	Pin	Signal
Digital I/O	J7 	1	DIO channel 7
		2	DIO channel 3
		3	DIO channel 6
		4	DIO channel 2
		5	DIO channel 5
		6	DIO channel 1
		7	DIO channel 4
		8	DIO channel 0
		9	PWM output channel 5
		10	PWM output channel 4
		11	GND
		12	3.3V
		13	GND
		14	3.3V
Analog inputs	J8 	1	Analog input channel 6
		2	GND
		3	Analog input channel 2
		4	5V

Table 4.5: QBall 2 DAQ pin list: J7, J8

I/O	Header	Pin	Signal
I2C	J9 	1	GND
		2	SDA
		3	3.3V
		4	SCL
UART	J10 	1	GND
		2	RX
		3	3.3V
		4	TX

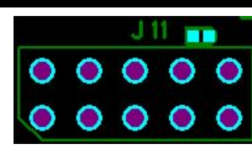
I/O	Header	Pin	Signal
SPI	J11 	1	SOMI
		2	CS3
		3	SIMO
		4	CS2
		5	CLK
		6	CS1
		7	GND
		8	CS0
		9	GND
		10	3.3V

Table 4.6: QBall 2 DAQ pin list: J9, J10, J11

4.3 Establishing Network Connection

The QBall 2 package comes with a pre-configured wireless router that broadcast the password protected *Quanser_UVS* WiFi network SSID. The QBall 2 is configured to automatically connect to *Quanser_UVS*. It uses a TCP/IP connection for communicating with the host computer and/or other Quanser® unmanned vehicles.

The Host PC and each of the vehicles must have unique IP addresses and the range of these addresses are defined in Table 4.7.

Host PC(s)	`192.168.2.10` to `192.168.2.19`
Quanser vehicles (Gumstix)	`192.168.2.20` to `192.168.2.254`

Table 4.7: Host PC and Quanser Vehicle IP Ranges

⚠ **Caution:** It is possible to connect the control station PC to the *Quanser_UVS* network using WiFi connection with the password *UVS_wifi*. However, to minimize delay in the data communication, it is recommended to connect the control station PC to the *Quanser_UVS* network via a wired connection.

These following procedure shows how to set up the host computer to connect to the *Quanser_UVS* wireless network via wired connection and only need to be performed once:

1. Connect your PC network card to any of the ports of the router (e.g. port number 1 to 4) using the network cable provided.
2. Power up the wireless router.
3. Turn ON the QBall 2 power and wait for it to boot up. Wait for about 60 seconds for the QBall 2 Gumstix to establish a connection to the *Quanser_UVS* wireless network.
4. Go to the *Network and Sharing Center* in Windows.

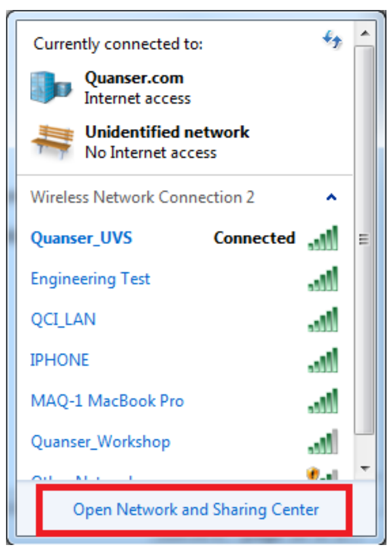


Figure 4.8: Open network settings

5. Click on *Change adapter settings*.
6. Right-click on the *Local Area Connection x, Unidentified network connection* and click *Properties*.
7. In the *Properties* window, select the *Internet Protocol Version 4 (TCP/IPv4)* item and click on *Properties*.

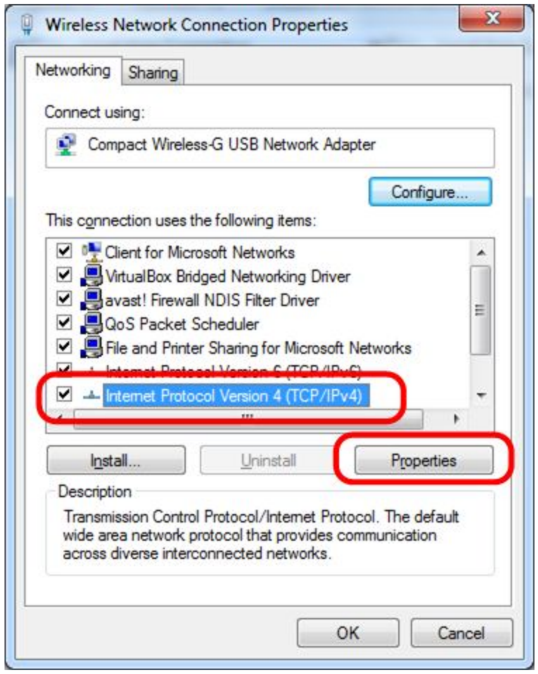


Figure 4.9: Network properties

8. **Setting Host PC IP address**: Instead of obtaining an IP address of the computer automatically, select *Use the following IP address* and enter the following:
   - IP address: `192.168.2.10`
   - Subnet mask: `255.255.255.0`

   Note: For multiple host PCs, use different IP addresses within the valid range.

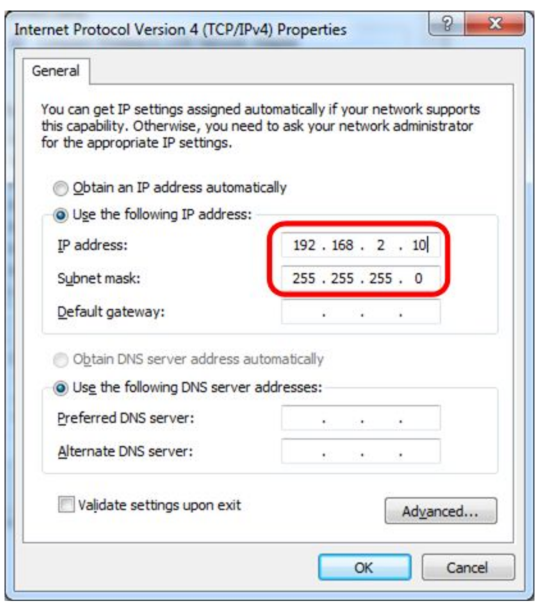


Figure 4.10: IP settings

9. Make sure you can connect to the router by using the ping command. As shown in Figure 4.11, click on the *Run* item under the Windows *Start* menu and type: `ping > 192.168.2.1`.

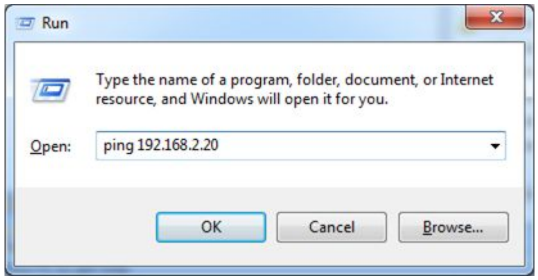


Figure 4.11: Pinging the QBall 2

If the connection to the router is successful you will see the ping replies in the command window. **If you cannot ping the router, check network connectivity and your IP address before going to the next step.**

10. **QBall 2 Connection:** Make sure the QBall 2 is powered ON and that the QBall 2 can be pinged by typing the following in the Windows Run menu: `ping {IP of the QBall 2}`.

    If the connection is successful you will see the ping replies in the command window. **If you cannot ping the QBall 2, then check the network connectivity and your IP address before proceeding.**

    - Make sure sure you waited long enough for the QBall 2 to connect to the *Quanser_UVS* network (at least 60 seconds).
    - Verify IP address is correct.
    - Turn OFF the power of the QBall 2 and turn it back ON again.
    - You may need to disable Windows Firewall to establish a connection.

4.4 Configuring Models for the QBall 2

This section applies only to files that are to be run on the Gumstix target on the QBall 2. Please refer to the UVS Laboratory Guide for the Simulink® files that are provided with the system. Simulink® should have a new menu item called QUARC® once QUARC® has been installed. The following steps are required to setup a new QUARC® model for the QBall 2:

1. Create a new Simulink® model, or open an existing model to be run on the Gumstix.
2. Click on the `QUARC` menu, then select `Options`.
3. The `System target file` under `Code Generation` should be `quarc_linux_duovero_2016.tlc`. Browse through the system target list to locate the proper file if necessary (Figure 4.12).

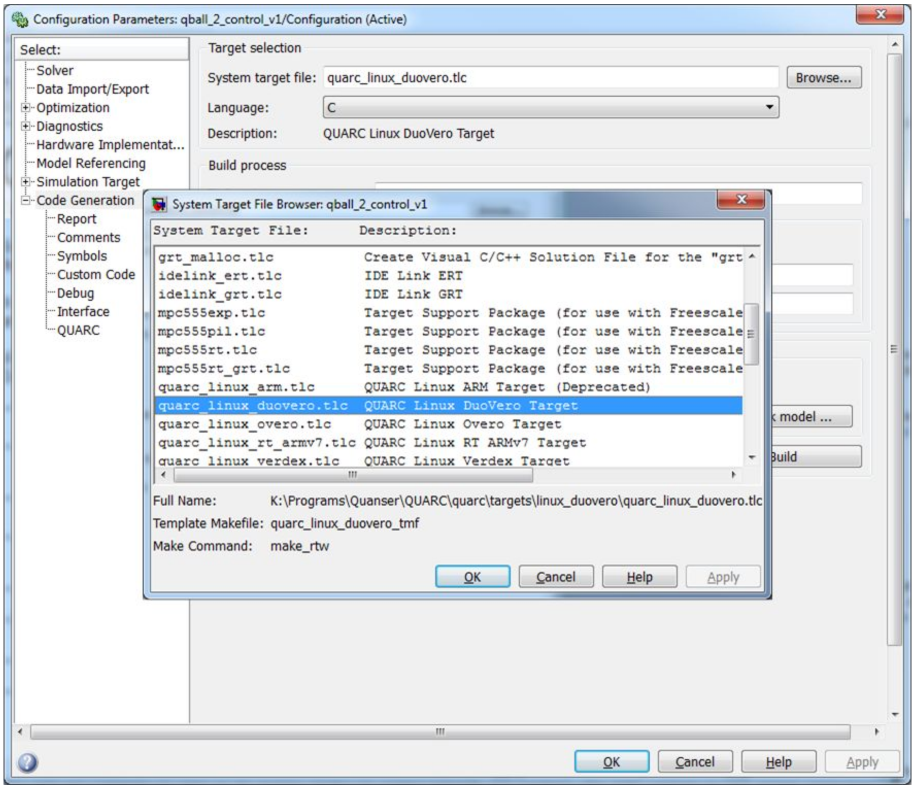


Figure 4.12: QUARC® Option Menu

4. In order to run the QUARC® model on the target vehicle, the target's IP address must be specified. You can set up the model so they automatically download to a default address or set the IP address manually in the Simulink diagram.

   Configuring Default Target: To setup the default target address for **all linux-duovero targets**:

   (a) Go to the `QUARC | Preferences`.

   (b) Under the *Model* tab, replace the *Default Model URI* with the IP address of the desired target vehicle. For example, replace the URI string `tcpip://linuxdev:17001?nagle=no,keep_alive=1` shown in Figure 4.13 to `tcpip://192.168.2.200:17001?nagle=no,keep_alive=1`.

5. **Configuring Manual Target:** Alternatively, to set the target address for the **current model only**:

   (a) Open the model options by going to the `QUARC | Options` menu.

   (b) In the left hand pane, go to `Code Generation | Interface` menu.

   (c) As shown in Figure 4.14, under the MEX-file arguments type:
   `'-w -d /tmp -uri %u','tcpip://{IP of Gumstix}:17001?keep_alive=1'`
   Replace `{IP of Gumstix}` with the IP address of your QBall 2 and include the single quotation marks at the start and end of the command. For example, for a QBall 2 with an IP address of `192.168.2.98`, set the mex-argument command to:
   `'-w -d /tmp -uri %u','tcpip://192.168.2.98:17001?keep_alive=1'`

6. Select `External` for simulation mode, instead of `Normal`, which indicates that the model is to be run on the target machine (Gumstix) rather than simulating the model on the host machine.

7. The model is now ready to be compiled and downloaded to the target. If the wireless connection to the vehicle has been established, a QUARC® console can be opened to show additional messages and progress during model compilation by going to the menu item `QUARC | Console` for all. Building the model (`QUARC | Build`) will begin the code generation and compiling steps. Output from the compilation is shown in the QUARC® console. This step may take a few minutes to complete.

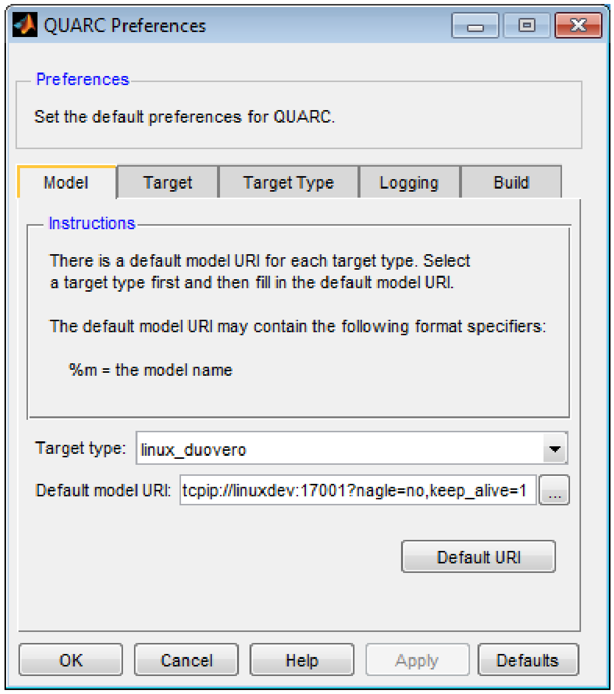


Figure 4.13: Configuring a default target

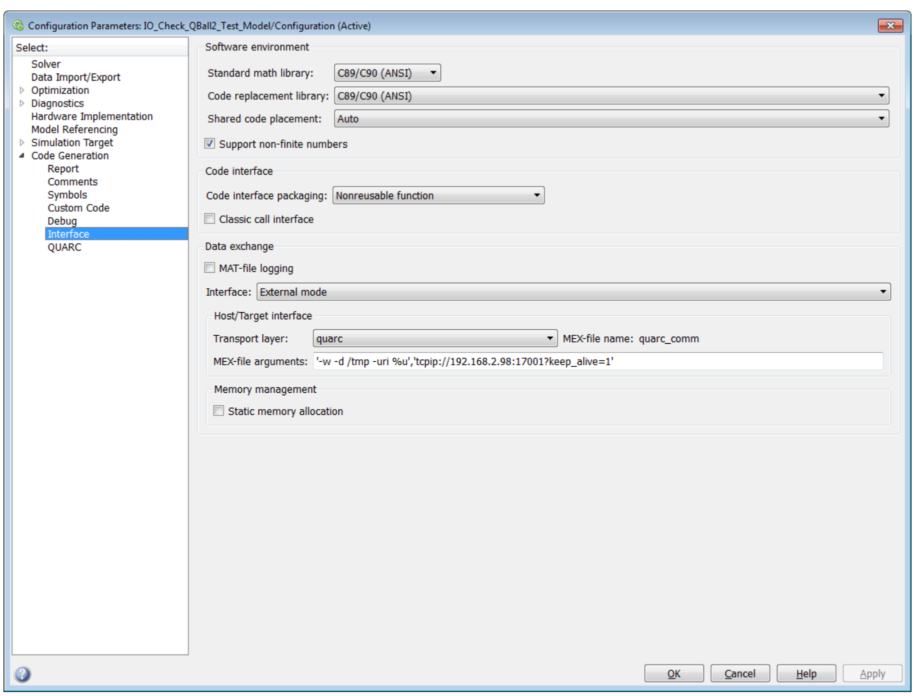


Figure 4.14: Model target IP settings

5 Charging Batteries

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.

Before charging or using any batteries observe these safety guidelines:

- Read all instruction manuals for batteries, chargers, balancers, and power supplies.
- Use and store system in a dry environment.
- Do not charge under direct sunlight.
- Do not charge battery when battery feels hot.
- Charge battery away from flammable objects.
- Always be present when charging batteries and do not leave batteries connected to the chargers or the QBall 2 overnight.
- Charge and store LiPo batteries in a location where a battery fire or explosion (including smoke hazard) will not endanger life or property.
- Keep LiPo batteries away from children and animals.
- Consider how you would deal with a LiPo battery fire/explosion as part of your normal fire safety and evacuation planning.
- Never charge a LiPo battery that has ballooned or swelled due to overcharging, undercharging or from a crash.
- Never charge a LiPo battery that has been punctured or damaged in a crash. After a crash, inspect the battery pack for the signs of damage.
- When discarding a LiPo battery, discard it in accordance with your country's recycling laws.
- Never charge the LiPo battery in a moving vehicle.
- Never overcharge the LiPo battery.
- Never leave the LiPo battery unattended during recharging.
- Do not charge LiPo batteries near flammable materials or liquids.
- Ensure that charging leads are connected correctly. Reverse polarity charging can lead to battery damage, fire, or explosion.
- Have a suitable fire extinguisher (for electrical fires) or a large bucket of dry sand near the charging area. Do not try to extinguish electrical battery fires with water.
- Reduce risks from fire/explosion by storing and charging LiPo batteries inside a suitable container: a LiPo sack or metal/ceramic container is advised.
- Monitor recharging LiPo batteries for signs of overheating.
- Protect your LiPo battery 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.
- If your LiPo battery is subjected to a shock (such as a crash) you should place it in a metal container and observe for signs of swelling or heating for at least 30 minutes.
- Do not attempt to disassemble or modify or repair the LiPo battery.

5.1 Battery Charging Components

Figure 5.1 illustrates the hardware components supplied with the battery chargers.

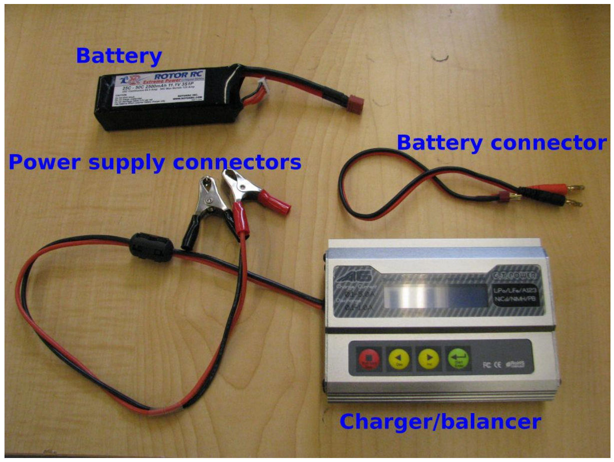


Figure 5.1: Battery charging components

The battery charger/balancer is supplied with either an individual power supply that connects to one charger or a shared power supply that can be connected to multiple chargers. The battery charger supplied with the system can typically charge various types of batteries. Ensure that the charger is set to LiPo type batteries since these are the batteries supplied with the QBall 2. The charger contains a balancer that ensures even charging across cells within the battery. Figure 5.2 shows the output terminals of the charger connected to the battery cable and the balancer ports.

Figure 5.2: Battery charger output ports

5.2 Battery charging procedure

Setup procedure:

1. Ensure all prerequisites are met.
2. Connect the power supply to the charger.
3. Connect the battery connectors to the battery charger output terminals.

Charging procedure:

1. The correct number of cells and charge must be set. Set the charger to 3-cell LiPo battery, $11.1(3S)$, and a charge rate of $2.7\ \mathrm{A}$ (since the supplied batteries have a rating of $2700\ \mathrm{mAh}$). Use the navigation keys to change the settings as described in the battery charger's user manual.
2. Connect the battery with the appropriate wires. Also, connect the balancer cable to the balancer. The connections are labeled according to the number of cells in the battery. Refer to your user manual for the battery details.
3. Start the charger according to the procedure described in the charger user manual. Typically this is done by holding the Start/Enter button until a beep is heard and if prompted to confirm press START again to begin charging.
4. Upon completing a full charge the charger should beep and display that the charge is complete.

6 Troubleshooting

For any issue, the first and easiest troubleshooting solution on any electronic device is to reboot the device. Turn off the QBall 2, then turn it back on again. For troubleshooting any problem with the QBall 2, it is always a good idea to open the QUARC® console in case additional information is printed to the console by going to the QUARC® menu and clicking on `Console for all...`. The console must be opened after the QBall 2 has booted and established a WiFi connection. If the console is opened successfully it establishes a connection to the target and the console window has the title `QUARC Console for * at tcpip://192.168.2.xxx:17000`, where `xxx` corresponds to the IP address of the QBall 2.

If you are still unable to resolve the issue after reading through this section, contact `tech@quanser.com` for further assistance.

1. **The QBall 2 has crashed! What should I do?**
   First, make sure that the model is stopped and the power is turned off. Do not approach the QBall 2 if the model is still running or the propellers are turning. Upon stopping the QBall 2 model, a saved data MAT-file is created on the host PC in the current directory. Make a backup of this saved file for review. If support is needed from Quanser® , they will ask for this file so that the issue may be better diagnosed. See the UVS Laborartory Guide [2] for more information on plotting saved data.

2. **You cannot ping the QBall 2**

   Make sure the router is on and the WiFi light on the router is on. Check that the network adapter of the host PC is connected to the router (or the wireless network `Quanser_UVS`) and is configured according to the network configuration procedure outlined in this manual (Section 4.3). Verify that you can successfully ping the QBall 2 by going to the Windows `Start | Run` and typing `>ping192.168.2.xxx`, where `xxx` corresponds to the IP address of your QBall 2. Turn off the QBall 2 power and verify that the Gumstix and antenna are properly connected. Make sure the Gumstix and antenna are securely connected and retry the above steps to establish a wireless connection. Recycle the power or turn on the robot and wait for approximately 60 seconds.

3. **The model fails to build/connect or the QUARC® console does not successfully open**.

   Remove the QBall 2 embedded controller cover so that the Gumstix board is visible. Plug in the battery to the battery connector. Turn on the power switch and look at the Gumstix for the green power LED. After approximately 30 seconds, a red LED will flash to indicate the WiFi module is powering on, and is attempting to connect to the wifi network. If the red LED flashes and remains on, then the WiFi module is functioning and is able to find the wireless network. If the red LED flashes and then turn off, the Gumstix is not able to detect the wireless network. Check that the host PC and is configured according to the network configuration procedure outlined in this manual (Section 4.3). Verify that the host PC is connected to the router (or the wireless network `Quanser_UVS`) and try to successfully ping the Gumstix by going to the Windows `Start | Run` and typing `ping>192.168.2.xxx`, where `xxx` corresponds to the IP address of your vehicle. If the red LED never flashes, the wireless antenna may be disconnected. Turn off the power and verify that the Gumstix wireless antenna is properly connected. Make sure the wireless antenna is secured and retry the above steps to establish a wireless connection. Recycle the power or turn on the robot and wait for approximately 60 seconds.

4. **The QBall 2 sensors are not being read correctly or they are stuck at some constant value**

   Using the *HIL Read* block, output all possible channels. Check these outputs using scopes and displays, and determine if the problem lies with a particular sensor, or set of sensors, or if the issue is global across all sensors.

5. **The Simulink® model appears to run slowly (i.e., the simulation time runs slower than actual time), or the console displays the message** `Sampling rate is too fast for base rate.`

   (a) The maximum sample rate recommended for the Gumstix is 1000 Hz (0.001 s). However, if there are complex calculations (such as image processing) performed within the model, then this could potentially limit the sample rate of the model. Try reducing the model sample rate in the menu `QUARC | Options | Solver` by increasing the `Fixed-step size (fundamental sample time)` parameter or change sample rates of blocks that take longer to run.

If you are using image processing blocks, ensure that signal duration is set to 1 by going to `Tools | External Mode Control Panel | Signal & Triggering | Duration` menu on the model (The default value is 10000).

(b) The *HIL Read Write* block should only be used once in a diagram. These blocks perform large data transfers between the data acquisition board and the Gumstix, so placing more than one of these blocks will cause multiple reads to be performed in the same sample instant, which is unnecessary. To achieve the optimal performance, use only one *HIL Read Write* block for the entire model.

(c) To determine the execution time of blocks or subsystems within the model, use the Computation Time block found in the library under `QUARC Targets | Sources | Time`. This block outputs the computation time of a function call subsystem, measured using an independent high-resolution time source. Blocks can be placed inside a function call subsystem and connected to the Computation Time block to determine their execution time during each sample instant. This helps identify the bottlenecks in the model (blocks/subsystems with the highest execution time) and can identify blocks/subsystems whose computation time is greater than the sample time of the model. Try increasing the sample time of those blocks whose computation time is greater than the sample time of the model so that the blocks run in a slower rate thread.

6. **Trying to start the QBall 2 model results in the error:** `Unable to locate the dynamic link library or shared object.`

   This error indicates that the QBall 2 driver is not found on the target. Make sure that the model target type is set to `quarc_linux_duovero_2016.tlc` by navigating to the menu `QUARC | Options | Code Generation` pane and changing the System target file to `quarc_linux_duovero_2016.tlc`. Open a console through the menu `QUARC | Console` for all, and verify that the console window displays the target IP of your vehicle in the window title.

7. **Building a model fails with the error:** `Not enough system resources are available to perform the operation.`

   When several models are compiled, the disk space on the Gumstix may become full, and you will no longer have space to build models. Using the clean option in the QUARC® menu under `QUARC | Clean` all will remove all generated code and compiled code for the current model, but this will only free up the space used by the current model. To view all models currently downloaded on the target select Manage target under the `QUARC` menu. The current model's target must be powered on and ready to accept a connection. The target information is displayed including all models that have been downloaded to the target. To clear all downloaded models select all the models in the list and click `Remove`.

   Note: This will only remove generated code from the target and will not delete the source models on the host PC.

BIBLIOGRAPHY

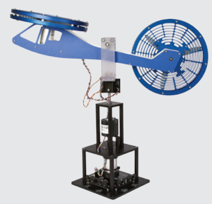
[1] Quanser Inc. *QUARC User Manual*.

[2] Quanser Inc. *Unmanned Vehicle Systems (UVS) Laboratory Guide*, 2016.

Quanser aerospace and unmanned systems for teaching and research

3 DOF Helicopter

2 DOF Helicopter



3 DOF Hover

QBall 2

Unmanned Vehicle Systems Lab

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