

Specialty Plants

User Manual

Quanser Qball-X4

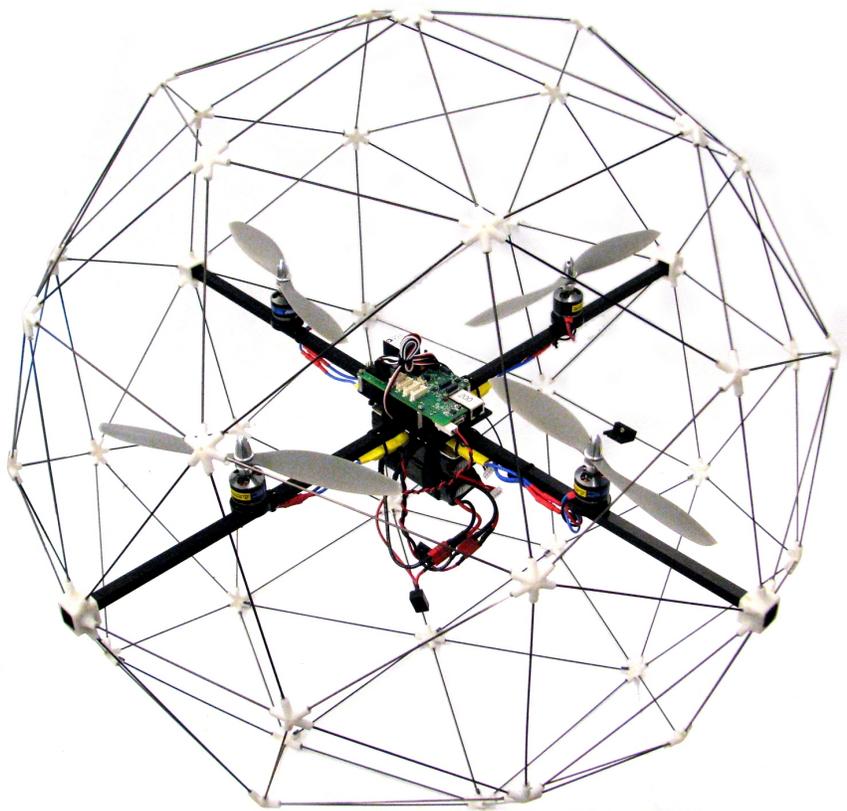


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1. Introduction

The Quanser Qball-X4 (Figure 1) is an innovative rotary wing vehicle platform suitable for a wide variety of UAV research applications. The Qball-X4 is a quadrotor helicopter design propelled by four motors fitted with 10-inch propellers. The entire quadrotor is enclosed within a protective carbon fiber cage (Patent Pending). The Qball-X4'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-X4 a decisive advantage over other vehicles that would suffer significant damage if contact occurs between the vehicle and an obstacle.

To measure on-board sensors and drive the motors, the Qball-X4 utilizes Quanser's on-board avionics data acquisition card (DAQ), the HiQ, and the embedded Gumstix computer. The HiQ 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, 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-X4 is MATLAB Simulink with QuaRC. The controllers are developed in Simulink with QuaRC on the host computer, and these models are downloaded and compiled into executables on the target (Gumstix [2]) seamlessly. A diagram of this configuration is shown in Figure 2.

Section 2 outlines operator warnings found throughout this manual, Section 3 goes through the prerequisites, and Section 4 lists various documents that are referenced in this manual. The general system description, component nomenclature, specifications, and model parameters are all given in Section 5. Section 6 goes into detail on how to setup the Qball-X4. Lastly, Section 7 contains a troubleshooting guide.

2. Operator Warnings

 This symbol marks specific safety warnings and operating procedures that are important for the safety of the Qball-X4 and users. Read these warnings carefully. The Qball-X4 is a powerful and potentially dangerous vehicle if used improperly. Always

follow safe operating procedures when using the Qball-X4. Quanser is not responsible for damages and injury resulting from improper or unsafe use of the Qball-X4. Before connecting batteries or attempting to run the Qball-X4, be sure to read this document and become familiar with the safety features and operating procedures of the Qball-X4.

 When handling the Qball-X4, 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.



Figure 1: Quanser Qball-X4

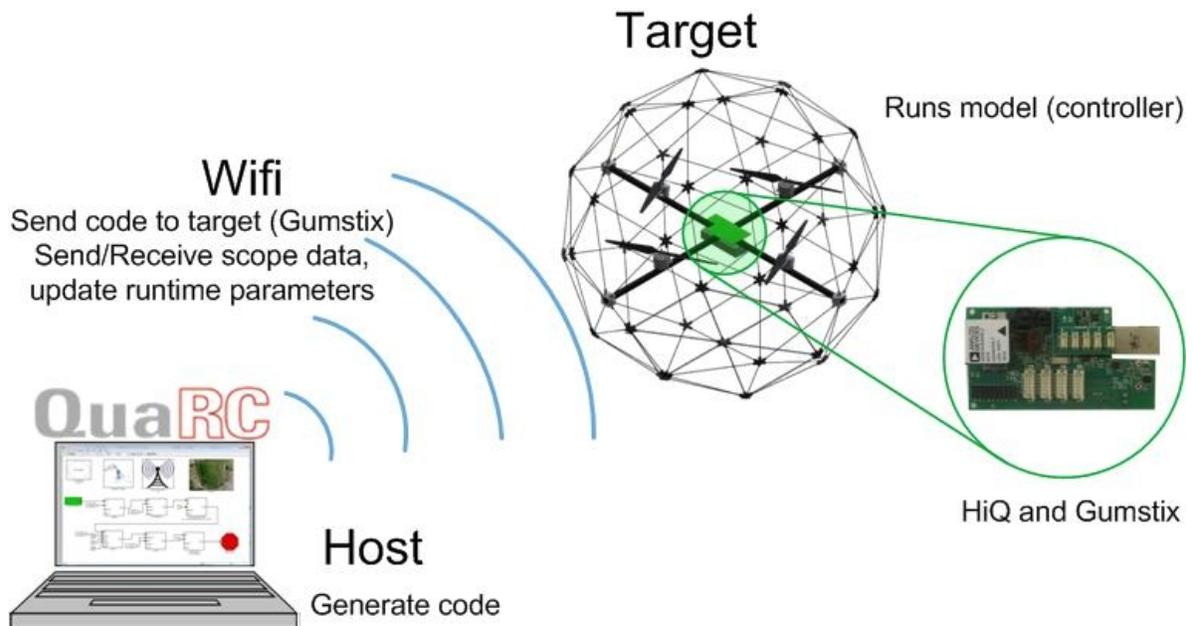


Figure 2: Communication Hierarchy

3. Prerequisites

To successfully operate the Qball-X4, the prerequisites are:

- i) To be familiar with the wiring and components of the Qball-X4.
- ii) To have QuaRC version 2.0 installed and properly licensed.
- iii) To be familiar with using QuaRC to control and monitor the vehicle in real-time, and in designing a controller through Simulink. See Reference [2] for more details.

4. References

- [1] *Gumstix*: <http://gumstix.com/>
- [2] *QuaRC User Manual* (type `doc quarc` in Matlab to access)
- [3] *Park 400 Brushless motor - 740Kv*: <http://hobbyhobby.com/store/product/68199/Park-400-Brushless-Outrunner-Motor--740Kv/>
- [4] *Propellers description and technical information*: <http://www.rctoys.com/rc-products/APC-10-047-SF-CR.html>

5. System Hardware and Software Description

5.1. Main Components

To setup this experiment, the following hardware and software are required:

- **Qball-X4:** Qball-X4 as shown in Figure 1 above
- **HiQ:** QuaRC aerial vehicle data acquisition card (DAQ).
- **Gumstix:** The QuaRC target computer. An embedded, Linux-based system with QuaRC runtime software installed [1]
- **Batteries:** Two 3-cell, 2500 mAh Lithium-Polymer batteries
- **Real-Time Control Software:** The QuaRC-Simulink configuration, as detailed in Reference [2]

5.2. X4 Diagram

Figure 3 below is a basic diagram of the Qball-X4, 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.

 **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 pointing away from the operator.**

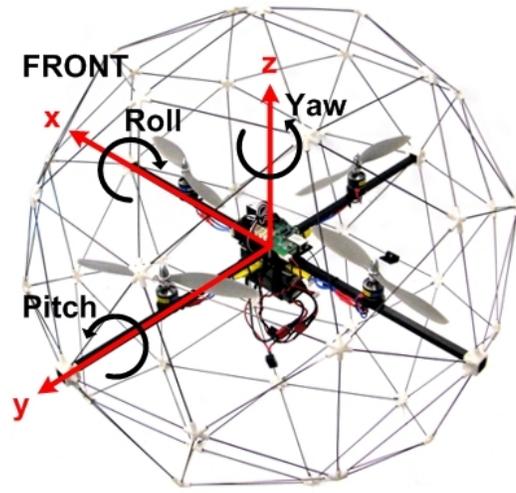


Figure 3: Qball-X4 axes and sign convention

5.3. Qball-X4 Components

The components comprising the Qball-X4 are labeled in Figures 4 to 11 and described in Table 1.

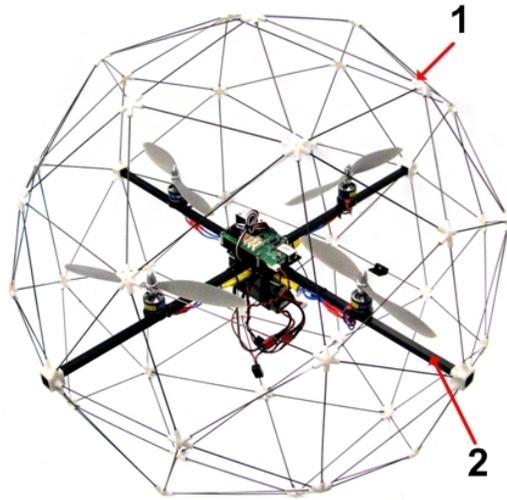


Figure 4: Qball-X4 cage and frame

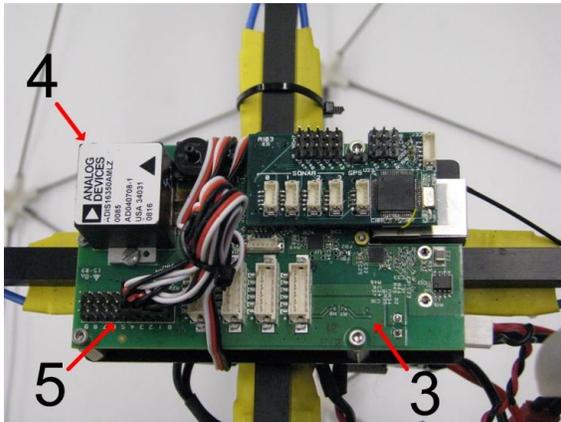


Figure 5: HiQ DAQ

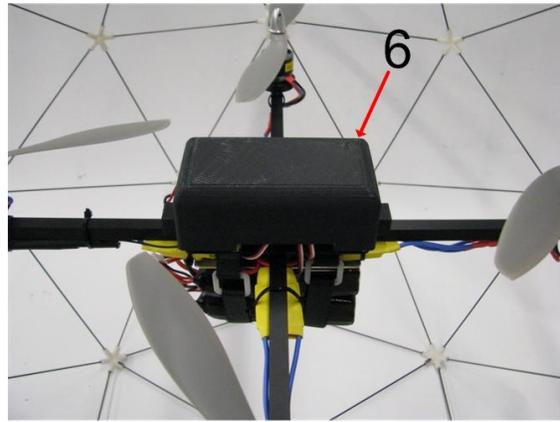


Figure 6: HiQ cover

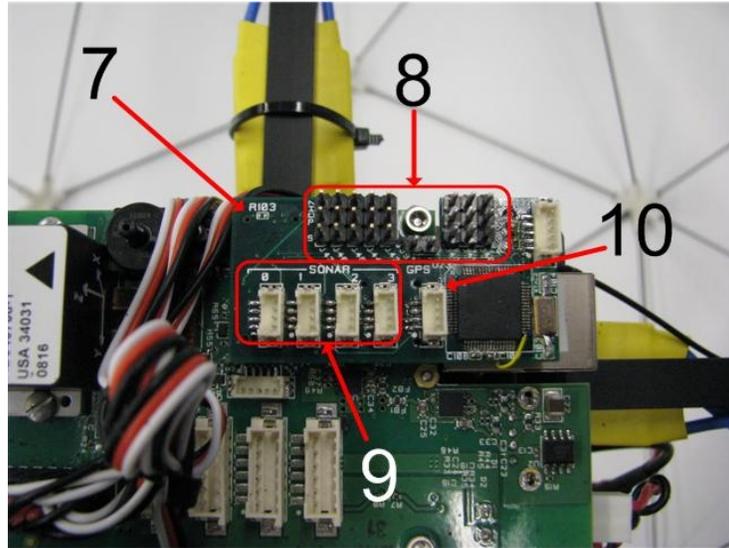


Figure 7: HiQ daughterboard with optional receiver inputs

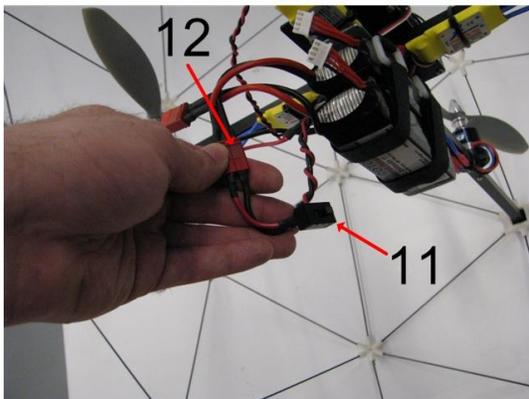


Figure 8: Battery switch and connector

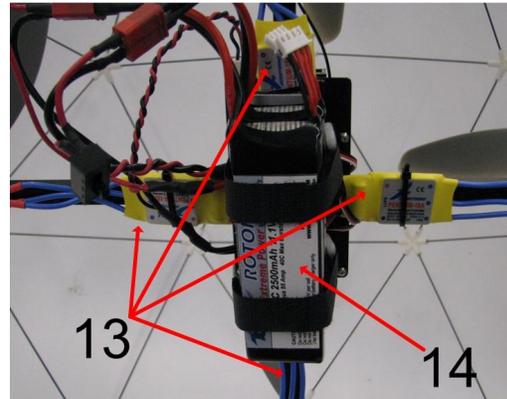


Figure 9: ESCs and batteries

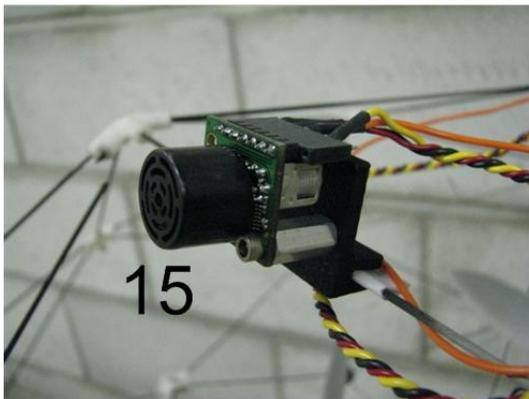


Figure 10: Optional sonar and sonar mount

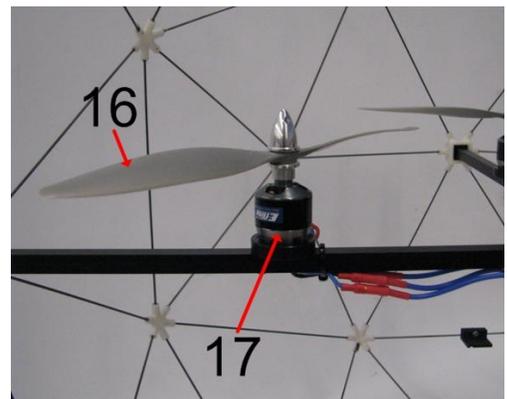


Figure 11: Motor and propeller

<i>ID #</i>	<i>Description</i>	<i>ID #</i>	<i>Description</i>
1	Qball-X4 protective cage	10	GPS serial input
2	Qball-X4 frame	11	Battery switch
3	HiQ DAQ with Gumstix	12	Battery connector
4	HiQ inertial measurement unit	13	Speed controllers (ESCs)
5	HiQ servo PWM outputs	14	LiPo batteries
6	HiQ cover	15	Optional sonar
7	HiQ daughterboard with optional receiver	16	Propeller (10x4.7)
8	Receiver inputs	17	Motor
9	Sonar inputs		

Table 1 Qball-X4 components

5.3.1. Qball-X4 frame

The Qball-X4 frame (#2 in Figure 4) is the crossbeam structure to which the Qball-X4 components are mounted including the HiQ DAQ, motors and speed controllers. The frame rests inside the Qball-X4 protective cage (#1 in Figure 4). The Qball-X4's protective cage is a carbon fiber structure designed to protect the frame, motors, propellers, and embedded control module (HiQ and Gumstix) during minor collisions. The cage is not intended to withstand large impacts or drops from heights greater than 2 meters.

 **Do not pick up the Qball-X4 from the cage as this may stress the cage and cause damage. Instead, when transporting the Qball-X4 lift it from the ends of the frame as in Figure 12, using both hands to lift the frame from both sides.**



Figure 12: Pick up the Qball-X4 from both ends of the frame

5.3.2. HiQ DAQ

The HiQ DAQ is the Qball-X4's data acquisition board. Together with the Gumstix embedded computer, the HiQ controls the vehicle by reading on-board sensors and outputting motor commands. Each motor speed controller (#13 in Figure 9) is connected to a PWM servo output on the HiQ (#5 in Figure 5). There are 10 PWM servo output channels available on the HiQ and they are labeled 0 to 9 with the ground pins (black wire on the servo cable) located closest to the outer edge of the HiQ board. Each motor speed controller should be connected in a specific order for the provided Qball-X4 controllers to function. Table 2 lists the motors and their standard corresponding servo channels.

<i>Motor</i>	<i>Servo output channel</i>
Back	0
Front	1
Left	2
Right	3

Table 2: Motor servo channels

The HiQ may have an optional daughterboard that contains additional I/O such as receiver inputs (#8 in Figure 7), sonar inputs (#9 in Figure 7), and a TTL serial input used for a GPS receiver (#10 in Figure 7). If the Qball-X4 is provided with a sonar (#15 in Figure 10) it should be connected to sonar input channel 0 as labeled on the daughterboard.

5.3.3. Qball-X4 Power

The Qball-X4 uses two 3-cell 2500mAh LiPo batteries (#14 in Figure 9) to power the HiQ and motors. These batteries are held in place below the center of the frame using two velcro straps. The batteries should be stacked vertically and aligned with the aluminum plate on the bottom side of the frame and secured tightly with the velcro straps.

 **Make sure the batteries are firmly connected to the frame before attempting to fly the Qball-X4.**

Secure the batteries to the frame before connecting the batteries to the Qball-X4 battery connectors (#12 in Figure 8) and always turn off the power using the switches (#11 in Figure 8) before changing batteries.

 **LiPo batteries can be dangerous if charged improperly. Review the battery charging procedures 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 10.6 V or less.**

5.3.4. Qball-X4 Motors and Propellers

The Qball-X4 uses four E-Flite Park 400 (740 Kv) motors [3] (#17 in Figure 11) fitted with paired counter-rotating APC 10x4.7 propellers [4] (#16 in Figure 11). The motors are mounted to the Qball-X4 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.

5.4. Qball-X4 Model

This section describes the dynamic model of the Qball-X4. The nonlinear models are described as well as linearized models for use in controller development. For the following discussion, the axes of the Qball-X4 vehicle are denoted (x, y, z) and are defined with respect to the vehicle as shown in Figure 3. 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-X4 sitting upright on the ground.

5.4.1. Actuator Dynamics

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

$$F = K \frac{\omega}{s + \omega} u \quad (1)$$

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. A state variable, v , will be used to represent the actuator dynamics, which is defined as follows

$$v = \frac{\omega}{s + \omega} u \quad (2)$$

5.4.2. 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 13. As illustrated in this figure, two propellers contribute to the motion in each axis. The thrust generated by each motor can be calculated from Eq. (1) and using its corresponding input. The rotation around the center of gravity is produced by the difference in the generated thrusts. The roll/pitch angle, θ , can be formulated using the following dynamics

$$J \ddot{\theta} = \Delta F L \quad (3)$$

where

$$J = J_{roll} = J_{pitch} \quad (4)$$

are the rotational inertia of the device in roll and pitch axes and are given in Table 3. L is the distance between the propeller and the center of gravity, and

$$\Delta F = F_1 - F_2 \quad (5)$$

represents the difference between the forces generated by the motors.

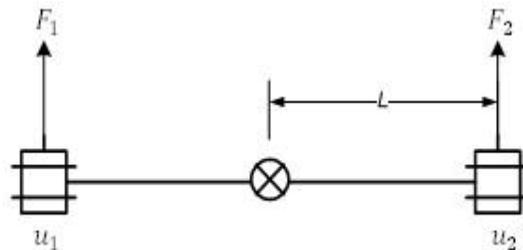


Figure 13: A model of the roll/pitch axis

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

$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \\ \dot{v} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & \frac{KL}{J} \\ 0 & 0 & -\omega \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \\ v \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \end{bmatrix} \Delta F$$

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

$$\dot{s} = \theta$$

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

$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \\ \dot{v} \\ \dot{s} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{KL}{J} & 0 \\ 0 & 0 & -\omega & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \\ v \\ s \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \\ 0 \end{bmatrix} \Delta F$$

5.4.3. Height Model

The motion of the Qball-X4 in the vertical direction (along the Z axis) is affected by all the four propellers. The dynamic model of the Qball-X4 height can be written as

$$M \ddot{Z} = 4 F \cos(r) \cos(p) - M g$$

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. 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

$$\begin{bmatrix} \dot{Z} \\ \ddot{Z} \\ \dot{v} \\ \dot{s} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{4K}{M} & 0 \\ 0 & 0 & -\omega & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Z \\ \dot{Z} \\ v \\ s \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega \\ 0 \end{bmatrix} u + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} - g$$

5.4.4. X-Y Position Model

The motion of the Qball-X4 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

$$M \ddot{X} = 4F \sin(p)$$

$$M \ddot{Y} = -4F \sin(r)$$

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

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

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

5.4.5. 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. The motion in the yaw axis is caused by the difference between the torques exerted by the two clockwise and the two counter-clockwise rotating propellers. The model of the yaw axis is shown in Figure 14.

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. The resultant torque of the motors, $\Delta \tau$, can be calculated from

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

The yaw axis dynamics can be rewritten in the state-space form as

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

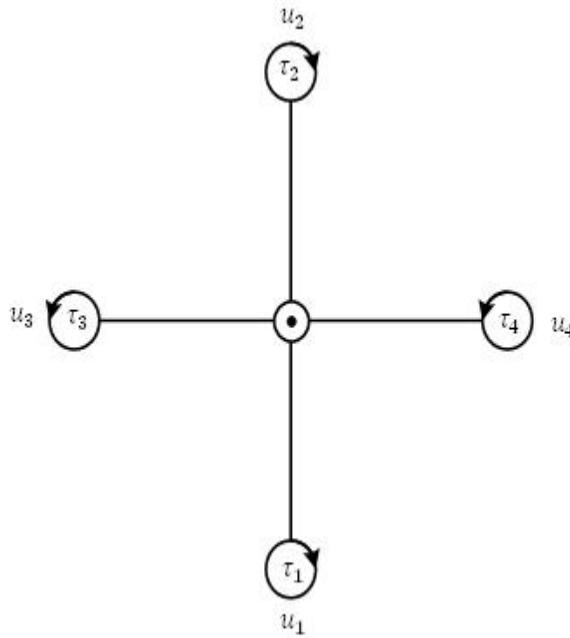


Figure 14: A model of the yaw axis with propeller direction of rotation shown.

<i>Parameter</i>	<i>Value</i>
K	120 N
ω	15 rad/sec
J_{roll}	0.03 kg. m^2
J_{pitch}	0.03 kg. m^2
M	1.4 kg
K_y	4 N.m
J_{yaw}	0.03 kg. m^2
L	0.2 m

Table 3: System parameters

6. System Setup

Section 6.1 walks through setting up a wireless connection with Windows. Section 6.2 describes setting up the vehicle hardware. Section 6.3 explains how to properly setup the QuaRC-Simulink interface and create a new Simulink model that will run on the vehicle. Finally, Section 6.4 describes the blockset and tools used to read the vehicle sensors and write motor outputs.

6.1. Establishing Wireless Connection

The Qball-X4 uses an ad-hoc peer-to-peer wireless TCP/IP connection for communicating with the host computer and/or other Quanser unmanned vehicles. The Qball-X4 package comes with a USB wireless adapter to setup the host computer with a wireless connection for use with the Qball-X4 and other Quanser unmanned vehicles. These steps outlined below for setting up the host computer wireless connection only need to be performed once.

1. After installing the USB wireless adapter that is provided, Windows should detect a network called GSAH, an “Unsecured Computer-to-Computer Network”. This is the peer-to-peer network used by the vehicle.
2. Open the **Status** of the wireless network, then click on Properties.
3. Under “This connection uses the following items:”, scroll down to Internet Protocol (TCP/IP), then double click on it.
4. Instead of obtaining an IP address of the computer automatically, enter the following:
IP address: 182.168.1.xxx (any unused number)

Subnet mask: 255.255.255.0

Default gateway: 182.168.1.xxx (same as IP)

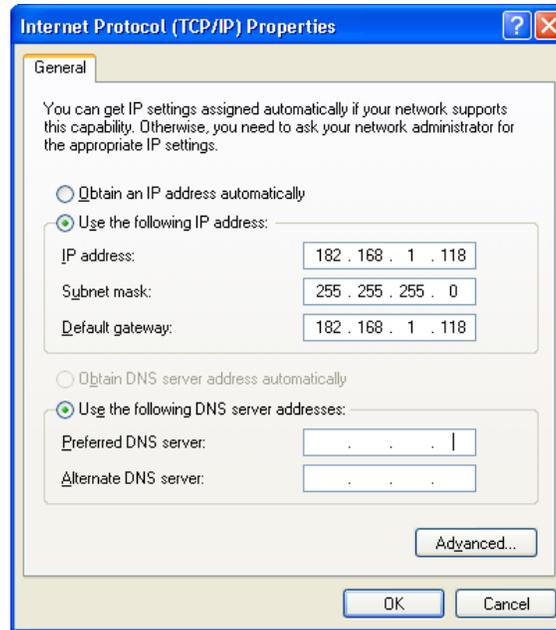


Figure 15: Wireless USB adapter settings

5. Connect to the GSAH network through the Windows network connections list.
6. If the Qball-X4 is powered on, the Qball-X4 can be pinged by typing “ping {IP of Qball-X4}” in the Run box in Windows (go to the Start menu and click Run).

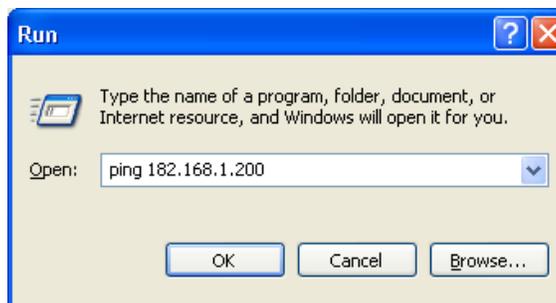


Figure 16: Pinging the Qball-X4

6.2. Qball-X4 Vehicle Setup

1. First, 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 on the Qball-X4 frame.



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 shaft 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. **Never change propellers or other components of the Qball-X4 with batteries connected.**

2. Install the batteries. Placing the Qball-X4 upsidedown so that it rests on the top of the cage. Align the two Qball-X4 batteries with the plate located on the bottom of the frame and secure the batteries tightly using the two velcro straps as shown in Figure 17. Connect the batteries to the battery connectors and place the Qball-X4 upright again so it rests on the bottom of the cage.

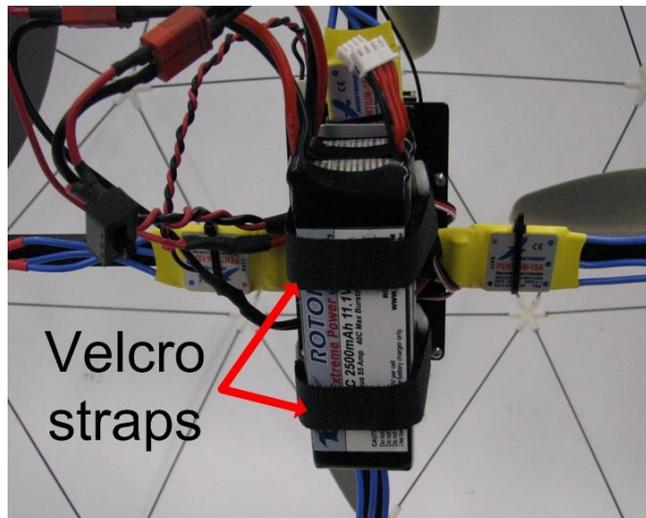


Figure 17: Batteries secured with velcro straps.

3. Power on the Qball-X4 using the two power switches connected to the battery cables

(#11 in Figure 8). After 1 minute the Gumstix wireless module should be active. Connect to the GSAH ad-hoc network on the host PC (see section 6.1. Establishing Wireless Connection).

6.3. QuaRC: Quanser Real-Time Control

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-X4:

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 Real-Time Workshop should be `quarc_linux_arm.tlc`. Browse through the system target list to locate the proper file if necessary (Figure 18).

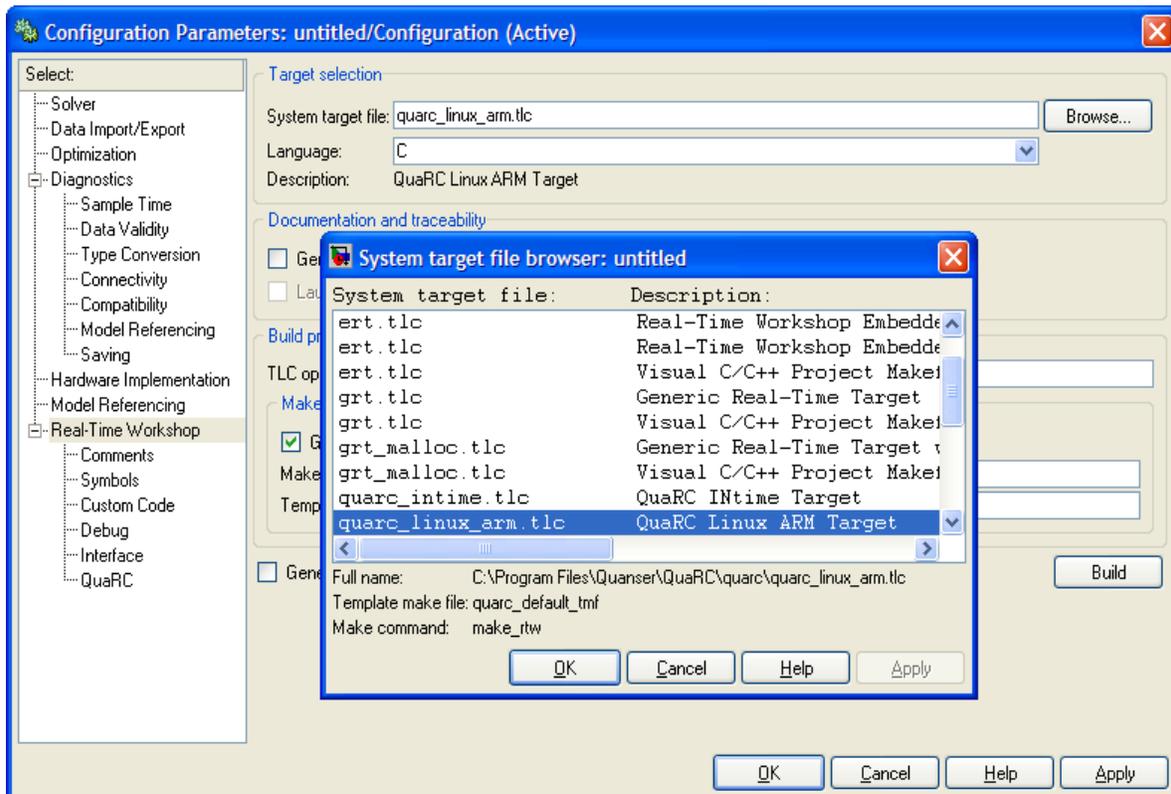


Figure 18 QuaRC Option Menu.

4. In order to run the QuaRC model on the target vehicle, the target's IP address must be specified. To setup the default target address for **all linux-ARM targets**, go to the

QuaRC menu and select Preferences. The Target type parameter should be set to `linux_arm`. Replace the Default Model URI with the IP address of the desired target vehicle, e.g., `"tcpip://182.168.1.200:17001"` without quotes.

Alternatively, to set the target address for the **current model only** open the model options under the QuaRC/Options menu and choose Interface on the left hand pane. Under the MEX-file arguments, type `'-w -d /tmp -uri %u', 'tcpip://{IP of Gumstix}:17001'`. Include the single quotation marks (Figure 19). Replace {IP of Gumstix} with the IP of your Gumstix, e.g. `'tcpip://182.168.1.200:17001'`.

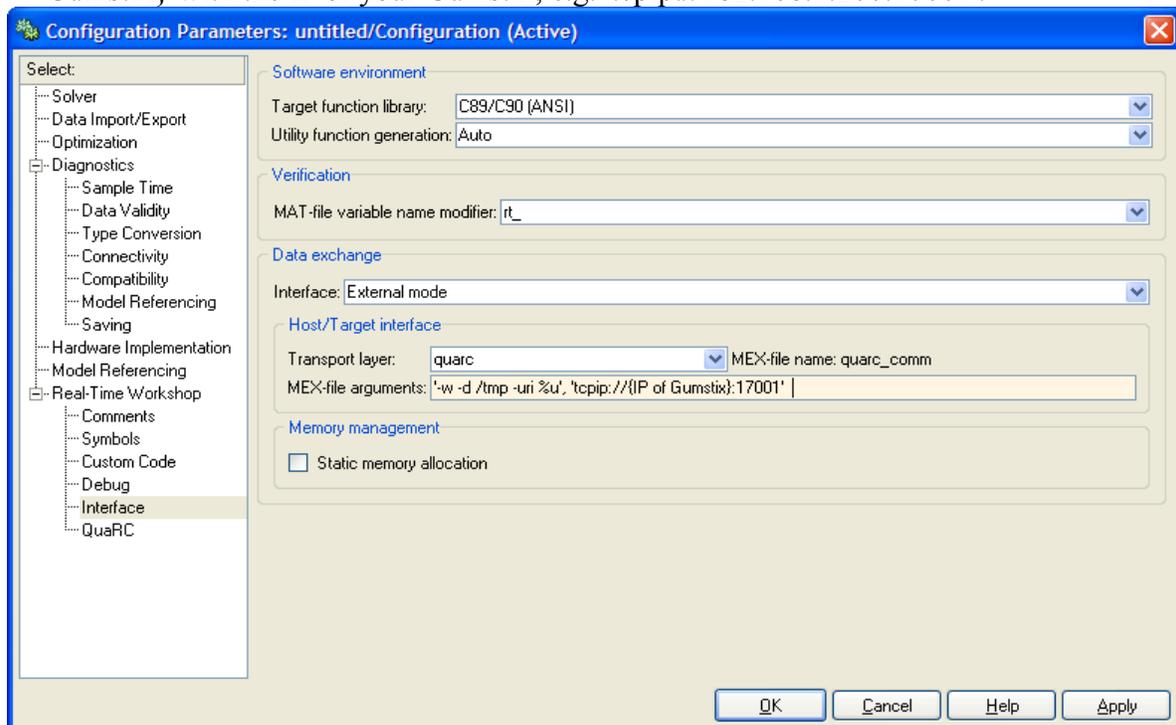


Figure 19: Configuring MEX-file arguments

5. 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.
6. The model is now ready to be compiled on the target vehicle. 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.

6.4. Qball-X4 Sensors

This section describes the blocks that are used to read the Qball-X4 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, including the HiQ. 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. Table 4 lists the HIL blocks used to communicate with the Qball-X4's data acquisition hardware.

<i>Block</i>	<i>Description</i>
 <p data-bbox="266 772 477 821">HIL Initialize Qball-X4 HiQ (hiq_aero-0)</p>	<p data-bbox="527 621 1382 705">The HIL Initialize block selects the DAQ board and configures the board parameters. The HIL Initialize block is named via the <i>Board name</i> parameter, and all other HIL blocks reference the corresponding HIL Initialize through its name.</p> <p data-bbox="527 726 1382 898">For the HiQ, there is a board-specific option for selecting the gyroscope model installed on the HiQ. The gyro model is specified by typing “gyro_model=16405” in the HIL Initialize <i>Board-specific options</i> parameter or by selecting the model from the board-specific options dialog. The valid values for the gyro_model option are: 16350, 16360, 16400, and 16405. The gyroscope number is found on the label of the gyroscope (#4 in Figure 5).</p>
 <p data-bbox="293 1052 440 1100">HIL Read Write Qball-X4 HiQ</p>	<p data-bbox="527 919 1382 1035">The HIL Read Write block is used to read sensor measurements from the HiQ and write motor commands to the four Qball-X4 motors. The inputs and outputs are specified with numeric channel numbers given in Table 5 and Table 6, respectively.</p>

Table 4: HIL blocks used by the Qball-X4.

To initialize the HiQ 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 'hiq_aero' to configure the HiQ DAQ and, if desired, enter a name in the Board name field as shown in Figure 20.

Next, to read and write from the HiQ, add a HIL Read Write block to the model (note that the HiQ 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 HiQ are listed in Table 5 and Table 6 below. Enter the channel numbers to be read/written or use the browse buttons to open a channel selection dialog as shown in Figure 21.

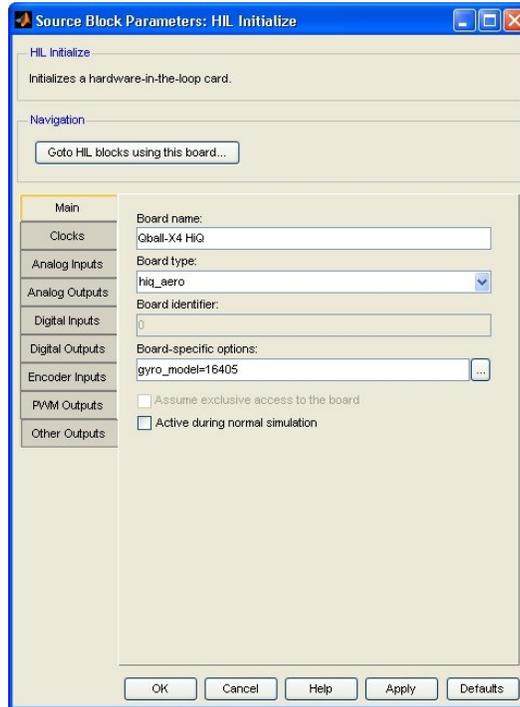


Figure 20: HIL Initialize block with the HiQ board selected.

<i>Channel type</i>	<i>Read channel numbers</i>	<i>Description</i>
Analog	none	-
Encoder	none	-
Digital	none	-
Other	3-6	Sonar inputs 0 to 3
	3000-3002	Gyroscope inputs: X, Y, Z axis
	4000-4002	Accelerometer inputs: X, Y, Z axis
	8000-8002	Magnetometer inputs: X, Y, Z axis
	11000	Operating capacity (battery)

Table 5: HiQ input channels

<i>Channel type</i>	<i>Write channel numbers</i>	<i>Description</i>
Analog	none	-
PWM	0-9	Servo outputs 0 to 9
Digital	none	-
Other	none	-

Table 6: HiQ output channels

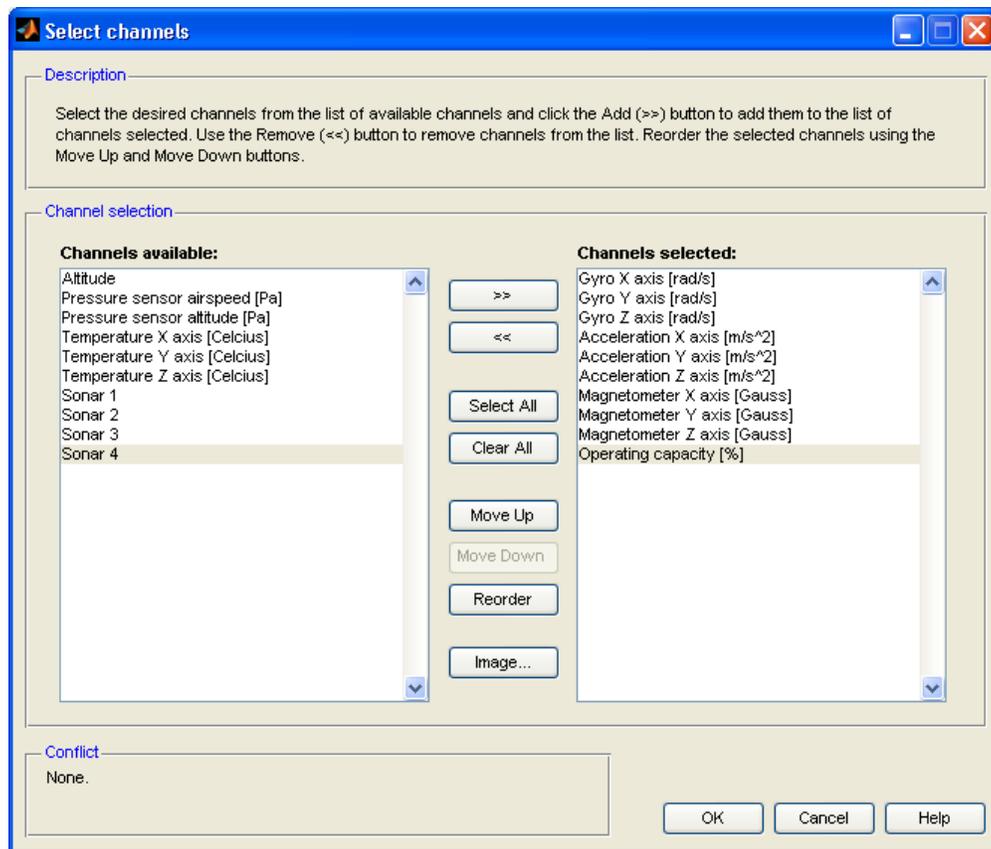


Figure 21: Channel selection dialog for the HiQ.

For the Qball-X4, PWM outputs 0-3 are used to command the four motors. The range of PWM output values is 0.05 to 0.10 (5% to 10% of a 20ms duty cycle), which corresponds to a 1ms to 2ms pulse, respectively. A command of 0.05 corresponds to zero throttle, which will cause the motors to stop. A command of 0.10 corresponds to full throttle.

The 3-axis gyroscope and accelerometer measurements are used to measure the Qball-X4 dynamics and orientation (roll, pitch and yaw). The magnetometer can be used as a digital compass to measure the Qball-X4 heading (yaw angle). These IMU inputs are crucial for controlling the flight of the Qball-X4.

The operating capacity input measures the battery capacity as a percentage (0-1) of the Qball-X4's input voltage operating range from 10V minimum to 20V maximum. Since the LiPo batteries used to power the Qball-X4 should be charged at 10.6V, the operating capacity should be monitored (note that 10.6V corresponds to an operating capacity of 0.06 or 6%). Figure 22 shows an example of how the operating capacity can be monitored so that a low battery warning will be displayed on the host PC if the operating capacity reaches 8% or less (corresponding to 10.8V or less) using the Show Message on Host block (found in the Simulink library under QuaRC Targets\Sinks\Error Handling). Note that the HiQ input voltage measurement can be calculated according to the formula $V = 10x + 10$, where x is the operating capacity.

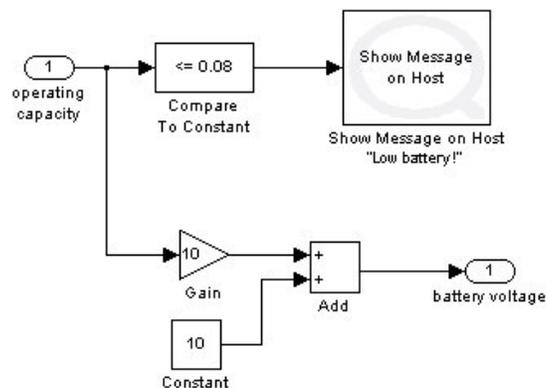


Figure 22: Monitoring the HiQ battery level.

⚠ Note that the HiQ operating capacity measures only the battery used to power the HiQ. It is recommended that the Qball-X4 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.

7. Troubleshooting Guide

For any issue, the first and easiest troubleshooting solution on any electronic device is to reboot the device. Turn off the Qball-X4, then turn it back on again. For troubleshooting any

problem with the Qball-X4, 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-X4 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://182.168.1.xxx:17000`, where xxx corresponds to the IP address of the Qball-X4.

7.1. The model fails to build/connect or the QuaRC console does not successfully open.

1. Remove the Qball-X4 cover so that the HiQ is visible. Plug in the battery to the battery connector (Figure 8). Turn on the power switch and look at the bottom of the Gumstix (attached to the bottom of the HiQ) for the orange power LED. After approximately 30 seconds, a blue LED will flash to indicate the wifi module is powering on, and is attempting to connect to another computer on the ad-hoc wifi network. If the blue LED flashes and remains on, then the wifi module is functioning and is able to find another node on the ad-hoc wireless network. If the blue LED flashes and then turn off, the Gumstix is not able to detect other nodes (e.g., the host PC) on the ad-hoc wireless network. Check that the USB wifi adapter is inserted properly in the host PC and is configured according to the network configuration procedure outlined in this manual (Section 6.1. Establishing Wireless Connection). Verify that the host PC is connected to the wireless ad-hoc (GSAH) network and try to successfully ping the Gumstix by going to the Windows Start → Run and typing “ping 182.168.1.xxx” (without quotation marks), where xxx corresponds to the IP address of your vehicle. If the blue LED never flashes, the wireless antenna or wireless module may be disconnected. Turn off the power and verify that the Gumstix wireless module and antenna are properly connected. The wireless module shown in Figure 23 is located on the bottom side of the green Gumstix computer. Make sure the wireless module and antenna are secured and retry the above steps to establish a wireless connection.



Figure 23: Wifi Module

7.2. The Qball-X4 sensors are not being read correctly or they are stuck at some constant value.

1. 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.

7.3. 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”.

1. The maximum sample rate recommended for the Gumstix is 500 Hz (0.002 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.
2. The HIL Read Write block should only be used once in a diagram. These blocks perform large data transfers between the HiQ and the controllers, 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.
3. 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.

7.4. Trying to start the Qball-X4 model results in the error “Unable to locate the dynamic link library or shared object.”

1. This error indicates that the Qball-X4 driver is not found on the target. Make sure that the model target type is set to Linux ARM by navigating to the QuaRC menu QuaRC\Options\Real-Time Workshop pane and changing the System target file to `quarc_linux_arm.tlc`. Open a console through the QuaRC menu QuaRC\Console for all, and verify that the console window displays the target IP of your vehicle in the window title.

7.5. Building a model fails with the error “Not enough system resources are available to perform the operation.” The hard disk is full on the Gumstix computer.

1. 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. Clearing all models from the Gumstix hard disk must be done manually using PuTTY, or any ssh client. Using PuTTY, log into the Gumstix by connecting to it using the IP listed on the vehicle, and use the user name “root”, and password “quanser” (without quotation marks). Navigate to the `/var/spool/quarc` directory, which is where all generated code and compiled models reside. Use the “ls” command to list all contents of this directory to see all models that have been downloaded to the Gumstix. **Note: be careful executing any remove/delete command on your Gumstix, as incorrect usage could permanently damage the file system, rendering the Gumstix unusable.** Individual models/code can be manually removed from the `/var/spool/quarc` directory. To remove all generated code and controllers, run the command “`rm -rf /var/spool/quarc/*`” (without quotation marks). To confirm there are no longer any models on the Gumstix, execute the command “`ls /var/spool/quarc`” and there should be nothing listed.