RAVEN-6DoF CONTROLLER

Reference Manual 211112

Version 1.3

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

TABLE OF CONTENTS

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

Introduction

The Iris Dynamics motion platform is designed to move users in tight synchronization with a Virtual Reality (VR) simulation or game. This creates a more immersive experience and decreases the risk of motion sickness while increasing immersion and training or entertainment value.

IrisControls4 (IC4) is a flexible application that allows users to operate and monitor Iris Dynamics devices from a Windows PC using a USB connection. When IC4 is connected to the motion platform the program displays the Raven GUI, which can be used to interact with the platform.

The Raven controller controls the behaviour of the motors and pneumatic offset system according to a Mode of Operation, and incoming commands on either the RavenAPI or via the IrisControls GUI. The controller provides a Cueing and Washout algorithm to simulate accelerations without exceeding a configured motion envelope, or Direct Control over Degrees of Freedom. The controller reports degree of freedom positions, actuator positions, forces, and other information about the status of the platform.

Kinematic models are always running which translate degree of freedom positions to actuator positions and vice versa. In general, users of the Raven platform need only concern themselves with degrees of freedom.

Safety and Protection features are provided by the controller and can be adjusted through the IrisControls GUI. These features include DoF speed limits, DoF range of motion limits, Actuator force limits, Overtemperature protection, Loss of communication quality.

This document will detail the modes of operation, the motion control options, the safety features, and the IrisControls GUI.

Further Reading

UG221122 – RavenAPI
For information on the UDP programming API.

UG230413 – Raven Pneumatic Weight Offset
For information on setting up the pneumatic system.

UG230414 – Raven Power Supply
For information on selecting an appropriate battery and charging system.

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

PLATFORM MODES

The platform has four modes of operation: Off, Level Brake, Loading and Cueing.

Operation Modes Overview

Mode	Mode Description
Off	The position controller is disengaged. Actuators that are free of errors exert damping forces only. This is the default state when the GUI is disconnected and the actuators have errors. The platform is not supporting itself and will not respond to acceleration information.
Level Brake	The platform attempts to stay level while allowing itself to raise or lower depending on the net external load. This is the default state when the GUI is not connected and the actuators are initialized and error free. The platform will not respond to acceleration information. It is keeping itself level but cannot be moved.
Loading	Each degree-of-freedom can be commanded by the GUI or the RavenAPI by setting the washout targets. Accelerations from RavenAPI are ignored.
Cueing	Accelerations from RavenAPI are scaled according to the gain settings and reproduced by the platform.

Table 5: Platform Modes of Operation

Transitioning Between Operation Modes

Transitioning between modes can be done by clicking on the mode on the top left of the GUI. Only modes which can be transitioned to will be clickable. This is based on the platform's current mode.

Mode	Off	Level Brake	Loading	Cueing
Possible Transitions	Level Brake	Off	Level Brake	Level Brake
		Loading	Cueing	Loading

Table 6: Possible Transitions Between Platform Modes

Once the controller transitions into any of the other modes, transitions to Off are considered potentially dangerous as the platform will 'fall' to wherever the environment is compelling it. As such, the controller will not respond to requests to transition to the Off state unless the request is

made at least three times consecutively – ie 3 presses of the Off mode on the GUI or 3 Mode Change Request frames.

Pneumatic Modes

When using the Pneumatic Weight Offset system, different pneumatic modes are available. When the platform is in use the pneumatic modes are transitioned between automatically. They modes can also be selected manually. More information on the Pneumatic Weight Offset system is available in the Platform Pressure section below.

Mode	Mode Description
Vent	In this mode the fill valves are closed, the drain valves are open, and air is leaving the system. When the platform is in **Off** or **Level Brake** operational mode, the pneumatic system is put into Vent.
Lock	Closes all the valves, no air enters the system.
Min Power	In this mode the system opens and closes valves in order to minimize the power used by each actuator. When the platform is in **Loading** operational mode, the pneumatic system is in Min Power.
Seek	In this mode the system seeks to match the target pressures for each tank. When the platform is in **Cueing** operational mode, the pneumatic system is in Seek.
Manual	Selecting this mode allows you to manually fill or drain each tank. Valves can be opened or closed individually. The system will not seek a specific target in this mode.

Table 7: Platform Pneumatic Modes

Kinematic Models (degree of freedom control and measurement)

The kinematic models (forward and inverse) provide an abstraction layer between the degrees of freedom (surge, sway, heave, roll, pitch, yaw) and the actuator positions required to realize them.

The Raven platform firmware is compiled and deployed with a specific platform geometry specified. The kinematic models are not tunable, can not be disabled, and can not be overridden: the way that users interact with the platform is via degrees of freedom and not via actuator lengths.

Inverse Kinematics (degree of freedom control)

This kinematic model translates degree of freedom translations and rotations into actuator lengths. This model is fed by the acceleration and washout algorithms to ultimately arrive at actuator length targets.

Users have control of output of the inverse kinematic model by commanding accelerations and/or commanding washout targets.

Forward Kinematics (degree of freedom measurement)

This model translates measured actuator lengths to degree of freedom translations and rotations. This model is fed by the actuator position sensors and provides information to the user about how the platform is currently positioned.

Users have access to the output of this model via the RavenAPI and can use it to delete platform motion from VR headsets and track platform positions.

Motion Control Options

The controller uses an FPGA to implement an acceleration cueing algorithm, and a washout algorithm. These two algorithms work together to provide control over the inverse kinematic model and ultimately control over the actuator lengths.

Onset Acceleration Cueing

Onset acceleration cueing attempts to replicate the accelerations of a simulated craft without exceeding the range of motion of the platform. It also attempts to minimize any accelerations on the rider contrary to the simulated accelerations.

Onset acceleration cueing can be achieved using the RavenAPI's acceleration command frames. Accelerations commanded for a given DoF are scaled the 'Primary' and individual DoF gains, and are subject to the maximum speed limit placed on that DoF, a high-pass filter, and the range of motion limit for that DoF. Furthermore, the washout algorithm will gradually restore that DoF back to its washout target according the settling time of the washout filter.

Tuneable Onset Acceleration Cueing Parameters

For information on adjusting these parameters, refer to the IrisControls GUI section.

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

- ***Primary Acceleration Gain***
  This gain (0 to 1) is applied equally to all incoming DoF accelerations and is used to globally scale down simulated accelerations.
- ***DoF Acceleration Gain***
  This gain (0 to 1) is applied only to a particular DoF and is used to scale this DoF down relative to other DoFs.
- ***DoF Max Speed***
  This setting is used to limit the speed (translational or rotational) that a DoF can reach. When this speed is reached, acceleration in the direction of that speed is no longer possible.
- ***DoF Range of Motion***
  This setting limits how close any actuator can be brought to its limit due to motion of a particular DoF. Increasing this setting for a particular DoF will progressively limit that DoF's range of motion.
- ***DoF Acceleration High Pass Filter***
  A first order high pass filter is applied to the incoming accelerations. Increasing the filter is effective when simulations include long sustained accelerations like corners.
- ***Washout Settling Time***
  The period over which the DoF returns to its settling time in the absence of ongoing acceleration commands. Decreasing this value will keep the DoF closer to its settling position. Increasing this value may reduce the un-commanded accelerations experienced by a rider, unless those accelerations result in the DoF's range of motion being exceeded.
- ***Washout Settling Position***
  In the absence of acceleration commands, a DoF will return to this position over the period of the settling time.

Direct DoF Control

When custom motion cueing and washout filters exist, the Raven offers a direct DoF control scheme. This mode allows control over the positions of the degrees of freedom. In affect, the acceleration cueing, and washout algorithm is bypassed allowing this behaviour must be implemented by the user application.

Direct DoF control is achieved by first setting the washout settling time for each to a low value, like 20 ms, and then by commanding a steady stream of washout settling targets. The platform DoFs will follow those targets. The 'washout' behavior in this case acts as a smoothing filter to interpolate between the incoming commands.

Command Smoothing

When selecting the washout settling times, care must be chosen to pick a value sufficiently low to minimize latency, but sufficiently high to smooth out the motion between received API frames. Generally, the settling time should be at least twice the inter-frame period. For example, if a simulator is only transmitting 60 frames per second, the settling times should be at least 35 ms. If that same simulator can instead transmit at 144 times per second, a settling time of 15 ms could be used instead.

Safety and Protection Features

For details on setting the following parameters, see Table 4: Raven Tuning Parameters in the GUI section.

Degree of Freedom Speed Limits

Each DoF has a speed limit which will limit how fast the acceleration cueing or washout algorithms may move a DoF target, which will limit the maximum mechanical energy.

Note that when the maximum speed is reached, acceleration and washout target commands are effectively 'clipped,' which can cause VR disassociation. If maximum speed limits are being reached during normal operation, cueing gains should probably be reduced to avoid clipping.

Degree of Freedom Range of Motion Limits

Two parameters work together to define a DoF's range of motion: the so-called 'safety distance' and 'safety width.' To understand this operation, it is necessary to understand to define the term: safety value.

Safety Value is the closest distance any one actuator is to reaching its extended or retracted deadstop. The platform has one single safety value which accounts for all the actuators. For example, if actuators have a travel range of 230 mm, and all are centered at 115 mm except for one which is extended to 200 mm, the safety value would be 30 mm. If that same actuator retracts to 10 mm, the safety value would be 10 mm.

The platforms range of motion is confined by defining a Safety Value for each DoF at which point, that DoF can no longer affect further outward motion. This value is referred to as the **Safety Distance**. Since each DoF can have a different Safety Distance, it is possible to prioritize platform motion for a given DoF by setting its Safety Distance lower than others. In this way, as the platform reaches an extreme position, other DoFs will lose their effect while the given DoF can still affect motion.

The speed of a DoF will be gradually constrained from its maximum configured value down to zero, as the Safety Value of the platform approaches the configured Safety Distance. A second configuration called the **Safety Width** determines the range of safety values over which this progressive limiting occurs.

The following formula is used to calculate a DoF's maximum outward speed:

$$Max\ Outward\ Speed\ =\ Max\ Speed\ *\ \frac{(Safety\ Value - Safety\ Distance)}{Safety\ Width}$$

Note that when the Safety Value – Safety Distance is greater than the Safety Width, the maximum outward speed will be limited to the Max Speed setting for the DoF.

Actuator Force Limits

The Orca linear motors powering each leg of the motion contains its own memory and can be configured to limit its force output. When the configured force limit is met or exceeded on a motor it will signal a "force limit exceeded" error as well as limit any further output.

The Raven controller will respond to any error from any motor by demoting its Mode of Operation to Brake mode, which will result in motion to stop, and the platform to gradually lower to its resting positions.

Setting actuator force limits is a good practice during app development, to ensure that glitches in the incoming acceleration or DoF targets do not result in violent motions on the platform. Once there is confidence in the application controlling the platform, these limits can be disabled or brought closer to the rated force limits of the motors to enable the full acceleration capabilities of the platform.

Overtemperature Protection

The platform will demote to Brake mode and not allow transition to Loading and Cueing modes any time one or more motor reports a temperature over a configurable temperature threshold. The platform will remain in the overtemperature state until all motors have their temperature lowered below a second lower threshold.

Loss of Communication Quality

When a large gap between incoming API messages is detected, the platform will demote to Brake mode to protect against a bad network connection creating unintended motion. The gap required to trigger the Loss of Communication Quality error depends on the lowest-configured settling time: if an API frame is not received within twice the lowest-configured settling time, the error will be encountered.

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

IrisControls GUI

The GUI is a set of screens which can be used to monitor and interact with the platform. The GUI is generated when the motion platform is connected via USB to a computer running the IC4 software. An overview of each screen is below.

Home Screen

The home screen displays the most recent build date of the program.

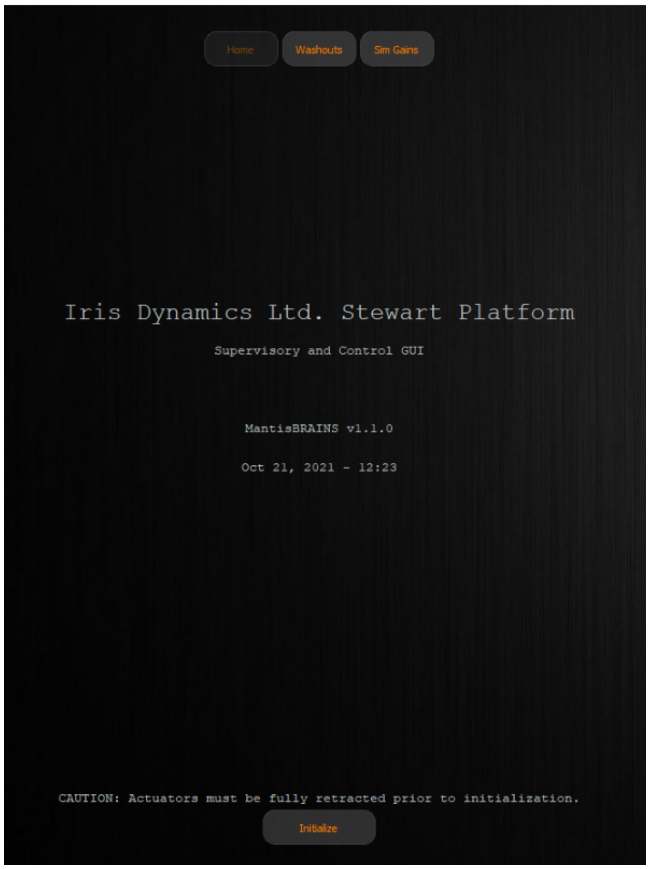

Image 1: The IC4 Home screen

It also contains the 'Initialize' button. This button sets the position of all actuators to zero.

Washout Screen

The washout values are the positions that the platform will return to when in Cueing mode. When in Loading mode, adjusting these values will move the platform immediately. The heave value can be used to lower the platform while loading a passenger.

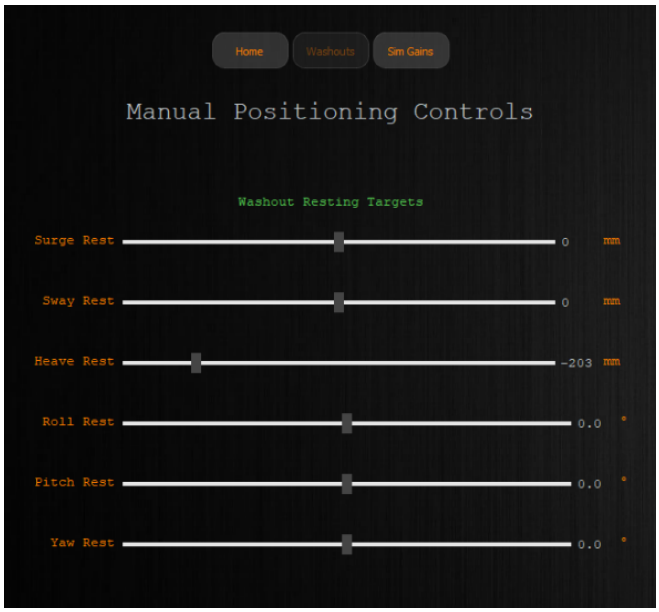

Image 2: The IC4 Washout Screen

The sliders are only interactive when the platform is in Loading or Cueing mode. Slider values can safely be moved beyond the limits of the platform's travel.
Sliders can be adjusted in three ways:

- By dragging the slider handle up or down
- By clicking on the handle and then using the arrow keys to adjust the slider value
- By clicking on the current value, typing in a new one, and pressing return/enter or tab.

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

Gains Screen

Incoming acceleration data is multiplied by the gains values indicated in this screen. Incoming data is multiplied by both the relevant DoF gain, and the primary gain value, separately. For example, surge acceleration values are multiplied by surge gain and then the primary gain.

Image 3: The IC4 Sim Gains screen

The roll and pitch washout gains are how closely the platform should mimic the roll and pitch angles being sent to the platform. These values are only used when the RavenAPI messages with message ID 21 or 85 are used. See the Using RavenAPI to Send Commands section for more information.

Sliders in this screen can also be adjusted in three ways:

- By dragging the slider handle up or down
- By clicking on the handle and then using the arrow keys to adjust the slider value
- By clicking on the current value, typing in a new one, and pressing return/enter.

These values can be updated all at once by loading a config file. See the Configuration Files section below for more information.

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

Pneumatic Screen

When using the Pneumatic Weight Offset system, the pneumatic screen provides current information on the three air tanks connected to the platform. See the Platform Pressure section for more information on the Pneumatic Weight Offset system, and the Platform Modes section for more information on the pneumatic modes.

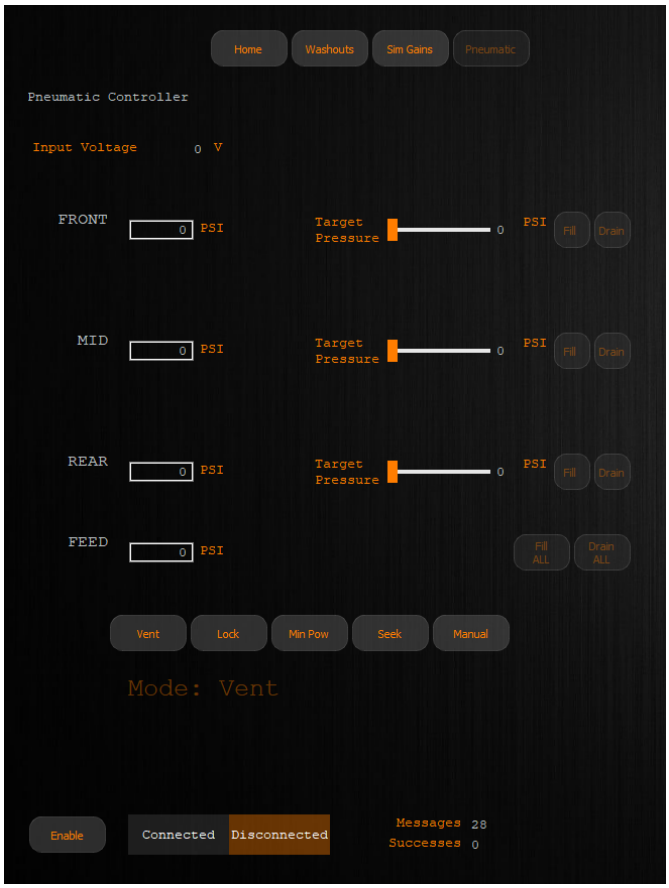

Image 4: The IC4 Pneumatic screen

This screen displays the target pressure of each tank and the current pneumatic mode. The mode can be changed on this screen using the buttons.

Vent mode: All drain vales are open, fill valves are closed.

Lock mode: All valves are closed.

Min Power: Valves are opened or closed to minimize motor power draw.

Seek: Valves are opened or closed to reach the target pressure for each tank.

Manual: Valves can be opened or closed individually.

Sliders can be adjusted in three ways, as described in Gains Screen and Washout Screen section.

Information available on this screen includes:

- Target pressures of all air tanks.
- The current pneumatic mode.
- Whether the pneumatic system is connected.
- The number of messages that have been sent between Raven and the Pneumatic Hat, as well as how many of those have been successful.

Actuators Screen

The actuators screen provides current information about each actuator. The graph tracks position and power over time.

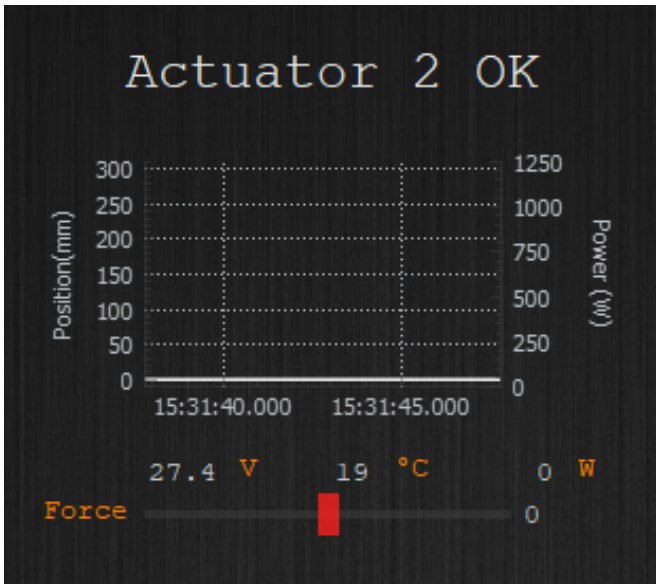

Image 5: Read out of a single actuator from the Actuator screen

Information available on this screen includes:

- Actuator position
- Power in watts
- Current voltage of the actuator
- Current temperature of the actuator
- Force currently being applied to the actuator

Temperature and power draw information is also available along the bottom of the GUI.

Interacting with Graphs

Double clicking on a graph will freeze graph movement. The graph can then be explored by clicking and dragging with the mouse. Scroll wheel movement zooms in and out. Double click on the graph again to resume movement.

Cueing Screen

The Cueing screen displays the acceleration values which are being sent to Raven and the target positions of all the actuators. This information will only update in Loading and Cueing mode. See the Platform Modes section below for more information about the different modes.

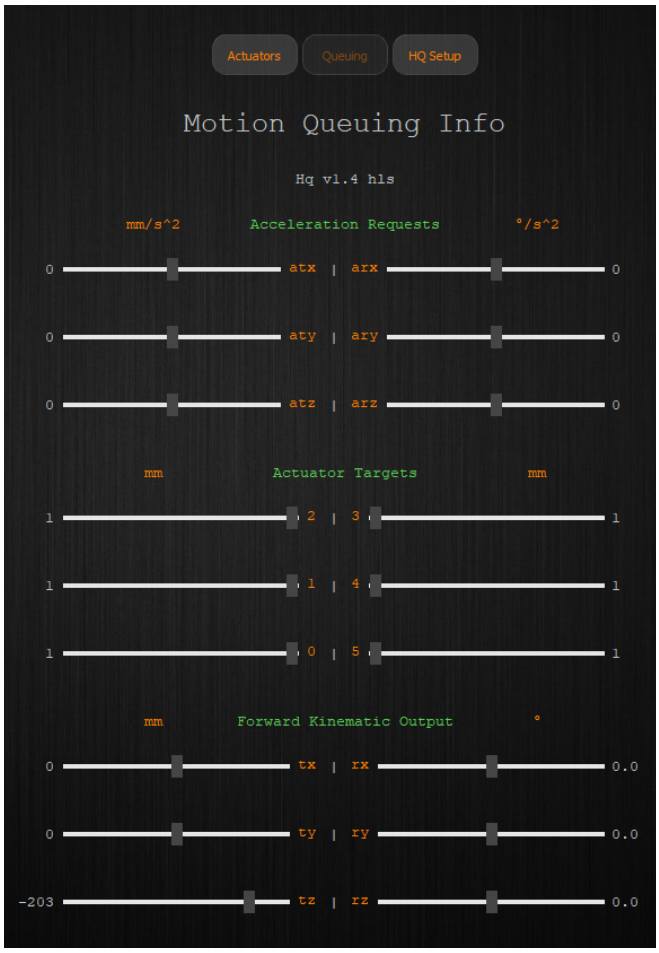

Image 6: The IC4 Cueing Screen

Acceleration Requests

These sliders display the acceleration values which are being sent to Raven.

Slider Title	Full Description	Associated DoF
atx	Acceleration Translation X Axis	Surge
aty	Acceleration Translation Y Axis	Sway
atz	Acceleration Translation Z Axis	Heave
arx	Acceleration Rotation X Axis	Roll
ary	Acceleration Rotation Y Axis	Pitch
arz	Acceleration Rotation Z Axis	Yaw

Table 1: Acceleration Request Sliders

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

Actuator Targets

The actuator target sliders show the goal extension of each actuator in millimetres (mm). This is the commanded position of each actuator – not necessarily the realized position of them.

Forward Kinematic Output

These sliders display the current positions of each DoF of the platform. These are the realized positions of the platform.

Slider Title	Full Description	Associated DoF
tx	Translation X Axis	Surge
ty	Translation Y Axis	Sway
tz	Translation Z Axis	Heave
rx	Rotation X Axis	Roll
ry	Rotation Y Axis	Pitch
rz	Rotation Z Axis	Yaw

Table 2: Forward Kinematic Output Sliders

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com

HQ Setup Screen

The HQ Setup Screen displays and configures all the tuning parameters.

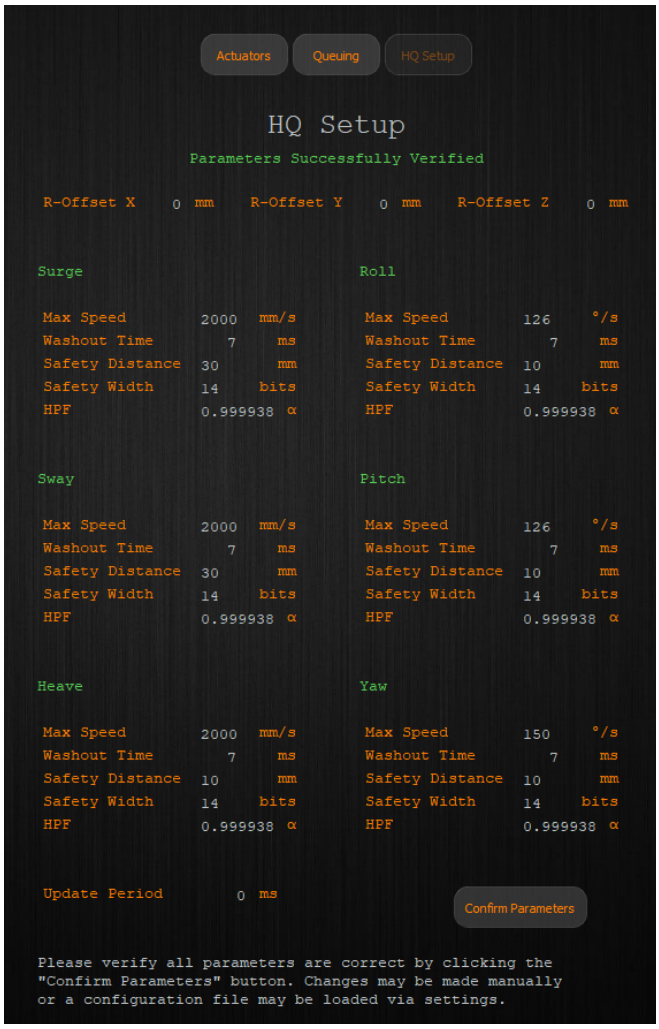

Image 7: The IC4 HQ Setup Screen

Parameters can be configured directly by typing in the values and then hitting the 'Confirm Parameters' button, or a configuration file can be loaded. For more information about config files, see the Configuration Files section.

Parameter	Description
Max Speed	The maximum speed the platform will move with respect to that DoF.
Washout Time	The settling time of the specified DoF.
Safety Distance	The platform's minimum remaining travel of the actuator which is closest to being full extended/retracted.
Safety Width	The minimum data width required to prevent quantization errors.
HPF	The alpha values used for the high pass filter.

Table 3: HQ Setup Parameters

IC4 Console Screen

The Console Screen can be used to send serial commands to the Raven firmware for tuning. Commands are entered in the text box below the console, and replies are displayed in the console. Pressing the up and down keys cycles through previously sent commands.

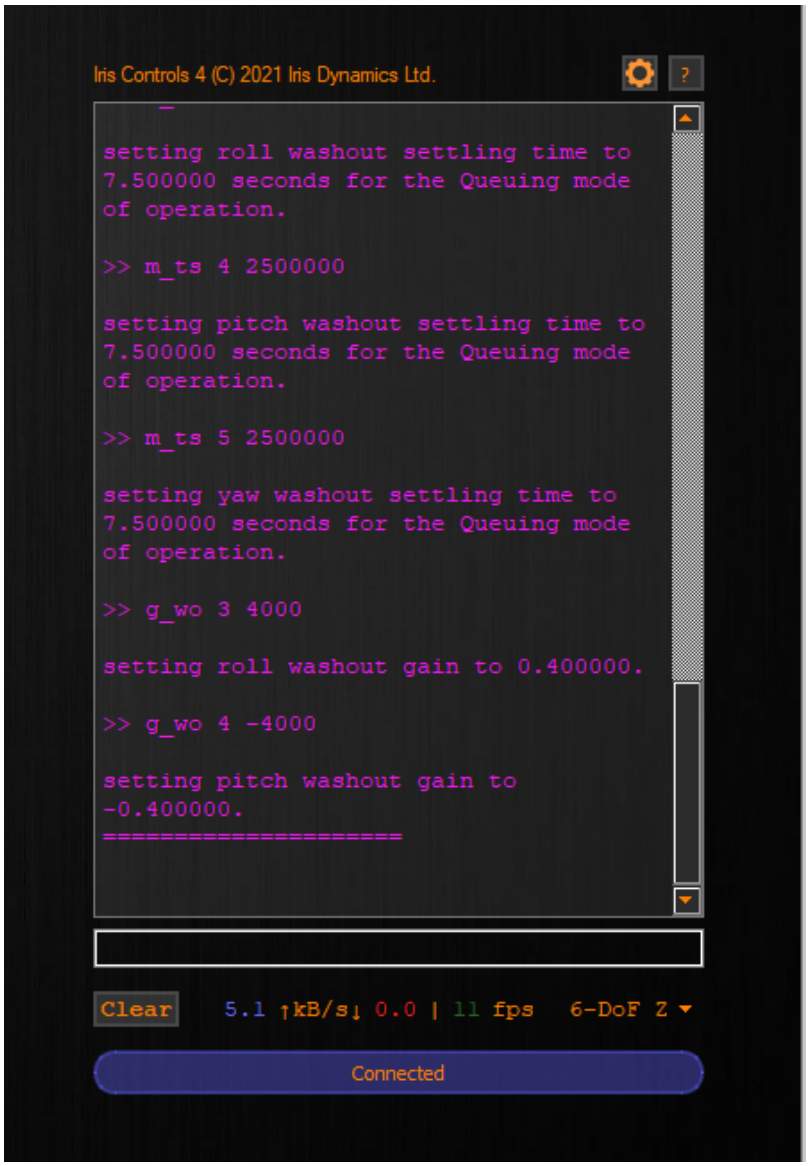

Image 8: The IC4 Console Screen

Tuning parameters are listed in Table 1. The square brackets in the syntax are optional.

Note: there are separate settings for each of the Level Brake, Loading, and Cueing modes of operation. The above commands set the Cueing mode only. To adjust a setting for the current mode of operation, add "_c" to the command.

Tuning Parameter	Syntax	Description
Primary Gain setting for accelerations	g_prime [gain_setting]	Applies this gain to all accelerations. This setting is divided by 10000.
DoF Gain settings for accelerations	g_dof [dof_id] [gain_setting]	Applies this gain to a specific DoF. This setting is divided by 10000.
DoF Maximum Speed	m_vmax [dof_id] [maximum_speed]	The maximum speed of the DoF is set to a value in mm-per-second or mdeg-per-sec
DoF Safety Distance	m_sd [dof_id] [safety_distance_in_mm]	The safety distance of the DoF is set to a value in mm.
DoF Safety Width	m_sw [dof_id] [safety_width_in_bits]	The safety width of the DoF is set to a value in bits.
DoF Washout Settling time	m_ts [dof_id] [value_in_milliseconds]	The settling time of the DoF is set to a value in milliseconds.
DoF High Pass Filter Alpha	m_hpf [dof_id] [alpha]	The high pass filter alpha of the DoF is set to a value. This setting is divided by 1,000,000.
Overheat Protection Thresholds	m_oht [high_threshold] [low_threshold]	The overheat protection thresholds are set in degrees Celsius. The high threshold is the temperature at which overheat protection begins. The low threshold is the temperature at which the overheat protection ends.

Table 4: Raven Tuning Parameters

Actuator Banner

Along the bottom of the GUI is a banner with information about each actuator. This information includes temperature, power draw, and fps. This banner is independent of the screens and is always visible.

CONFIGURATION FILES

Creating a Configuration File

The gains and washouts must be set for each individual simulation. You can set all these values at once by loading a config file.

Image 9: A Config File

Config files are created in a text editor, such as Notepad. The file can contain any introduction text before the heading “START”. After the start heading, the file must contain each parameter listed in the example above, and the value that it should be set to.

Save the file as a .txt and follow the instructions below to load into IC4.

Loading a Configuration File

1. Select the settings cog just above the console on the right of the screen.

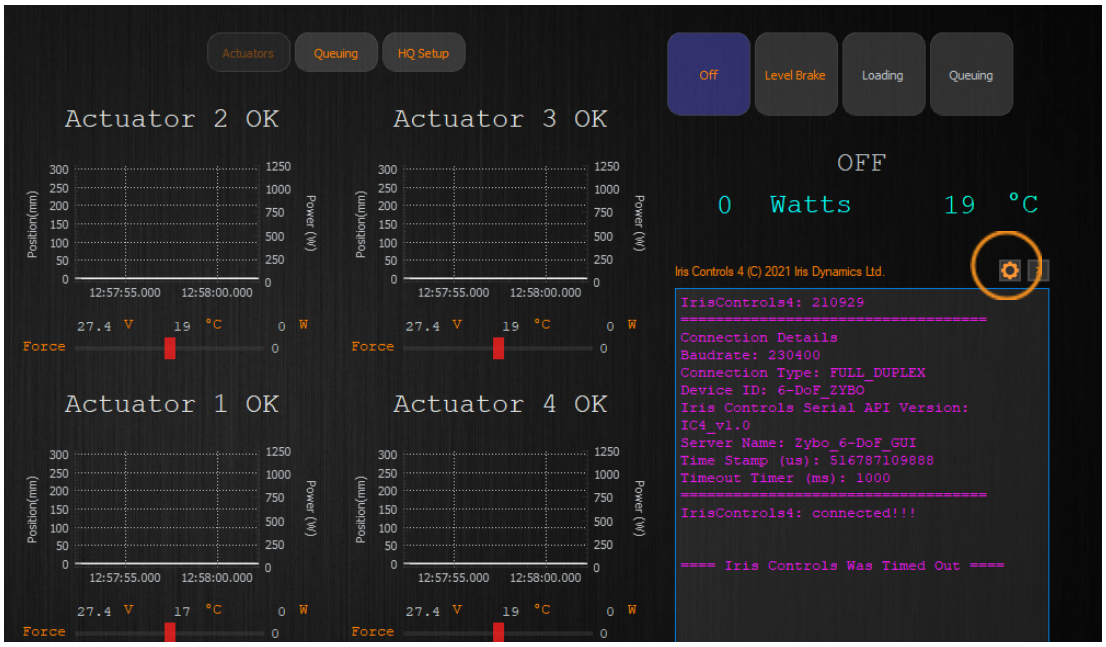

Image 10: IC4 console screen.

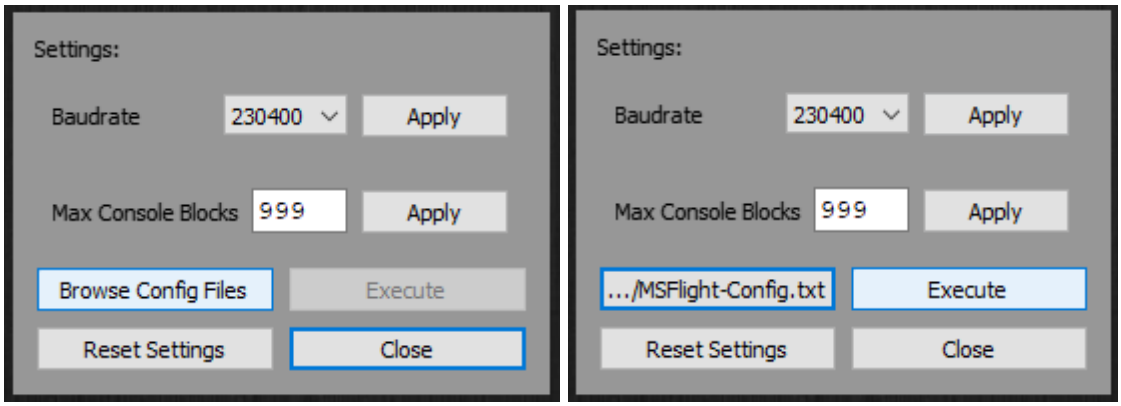

Image 11: Config file loading wizard

2. Select the 'Browse Config Files' button and navigate to the config_files folder. Select the file for the simulation you are loading and press 'Execute'.
3. Ensure that the gains values have updated – there should be a message in the console confirming this.

PLATFORM PRESSURE

Air pressure is used to suspend the platform. This decreases the load on the actuators.

Please see the Raven Pneumatic System User Guide (UG230413) [PDF] for details on this system.

REVISION HISTORY

Version	Date	Author	Reason
1.0	November, 2021	kc	Initial Release
1.1	July, 2022	kc	Added information on the PWO system
1.2	April, 2023	Kh	Added information about control modes and safety features
1.3	November, 2023	kh	Removed legacy pneumatic system information and added link to the new documentation.

Iris Dynamics Ltd. Victoria, British Columbia T +1 (888) 995-7050 F +1 (250) 984-0706 www.irisdynamics.com