Rotary Motion Servo Plant: SRV02

2D Ball Balancer

User Manual

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1. Presentation

1.1. Description

The Quanser 2D Ball Balancer, i.e. 2DBB, pictured in Figure 1 consists of a plate on which a ball can be placed and is free to move. By mounting the plate on a two degree of freedom (2 DOF) gimbal, the plate is allowed swivel about any direction. The overhead camera is used with a vision system to measure the position of the ball. The two servo units underneath the plate are Quanser SRV02 devices. Each of them are connected to a side of the plate, also using 2 DOF gimbals. By controlling the position of the servo load gears, the tilt angle of the plate can be adjusted to balance the ball to a desired planar position.

Figure 1: Quanser 2D Ball Balancer system.

1.2. Prerequisites

The following is needed to run the 2-DOF Ball Balancer:

- PC meeting the recommended system configuration for the PGR Camera, as dictated in Reference [4], and the software being used to control the device.
- **PC with 1 or 2 6-pin FireWire ports**: If using the *Quanser Q3 ControlPAQ-FW* device, then a desktop PC with two FireWire ports is needed – one for the PGR camera and the other for the Q3. If the PC only has a single FireWire port, then the FireWire PCI Express board supplied can be installed as explained in Section 4.2. In that case, ensure there is a PCI Express slot available. If using a separate power amplifier (e.g. Quanser VoltPAQ), the only one FireWire port is required (for the PGR camera).

WARNING: Do not attempt to daisy chain the PGR Camera with the Q3 ControlPAQ-FW board. **The Q3 and PGR camera should each use there own 6-pin FireWire ports.** Otherwise, the bandwidth demand of the camera will interfere with the Q3 signals. It is also not advised to use a 4-pin FireWire port, via a 4-pin to 6-pin FireWire cable, with either the Q3 or PGR camera.

2. 2D Ball Balancer Components

The components of the 2D Ball Balancer are identified in Section 2.1. Some of the those components are then described in Section 2.2.

2.1. Component Nomenclature

The main components of the 2D Ball Balancer device are listed below in Table 1 and labeled in figures 2, 3, and 4.

ID #	Component	ID #	Component
1	Calibration Base	10	Camera stand
2	SRV02 for X-Axis	11	Camera height adjuster
3	SRV02 for Y-Axis	12	Camera
4	Coupling screw	13	Camera FireWire connector
5	Lever arm	14	Camera Holder
6	Lever arm gimbal	15	Camera Holder Extension
7	Plate	16	Camera Holder Screw
8	Support arm	17	Ball
9	Support arm gimbal		

Table 1: 2D Ball Balancer components.

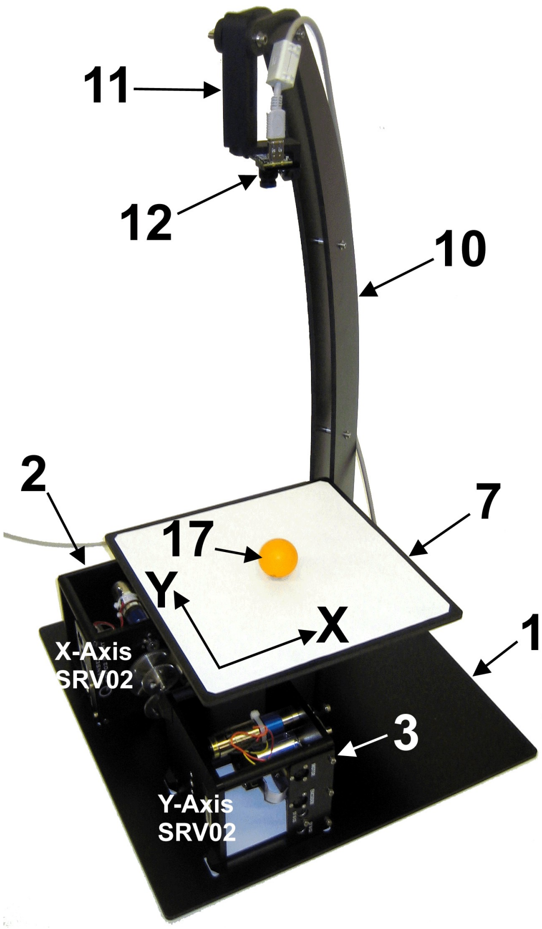


Figure 2: 2DBB components: full view.

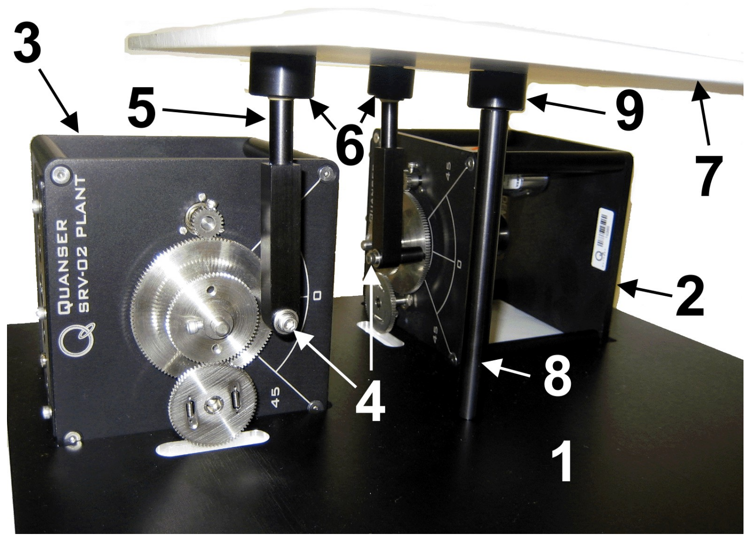


Figure 3: 2DBB components: servo from under the plate.

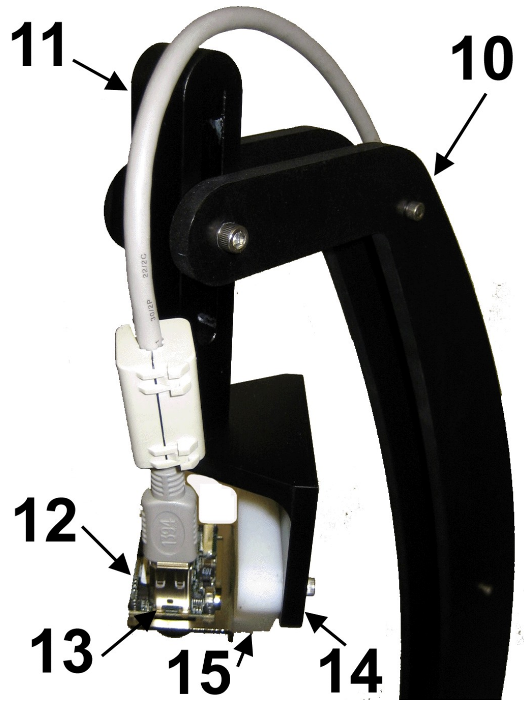


Figure 4: 2DBB components: camera.

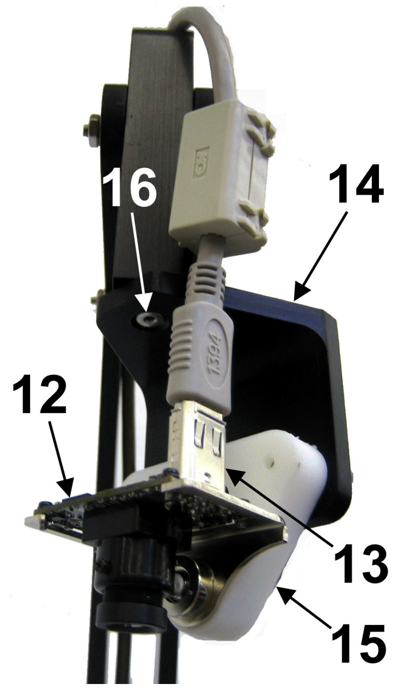


Figure 5: 2DBB Components: Camera (downward view).

2.2. Component Description

2.2.1. Camera (ID #12)

The Firefly MV pictured in Figure 4 is a high resolution IEEE-1394 digital camera. It is capable of transferring a 640 x 480 colour Y8 picture at 30 frames per second to a PC via its FireWire connection. Note that a 6 mm microlens is used instead of the standard 4 mm microlens so the entire plate could be viewed. See Reference [4] for more information.

⚠ **WARNING:** Make sure the calibration procedure in Section 4.4 is undergone to ensure the camera is properly focused before commencing any experiments.

2.2.2. SRV02 (Component #2 and #3)

Two Quanser SRV02 units are used in the 2DBB experiment, as shown by ID #2 and #3 in Figure 2 and Figure 3. It is a DC motor servo unit and is fully described in Reference [2].

2.2.3. Chassis

The chassis is composed of the calibration base, ID #2, the gimbals, ID #6 and ID #9, the camera support stand, ID #10, camera height adjuster, ID #11, and the plate, ID #7. All theses parts are made of durable ABS plastic and are precision crafted.

3. 2D Balance Table Specifications

Table 2, below, lists and characterizes the main parameters associated with the 2D Balance Table system. The *x*-direction of the 2D Balance Table is illustrated in Figure 6. It includes various dimensions and shows the variables α, θ_l, and x that are associated with the system (for the x-axis). Some of the parameters listed in Table 2 are used in the mathematical model.

Symbol	*Description*	*Matlab Variable*	*Value*	*Unit*	*Variation*
	Calibration base length		41.75	cm	
	Calibration base depth		41.75	cm	
	Camera support height		69.5	cm	
L_{tbl}	Table length	L_tbl	27.5	cm	
	Lever arm length		9.7	cm	
r_{arm}	Distance between SRV02 output gear shaft and coupled joint	r_arm	2.54	cm	
	Support arm length		14.6	cm	
r_b	Radius of ball.	r_b	1.96	cm	
m_b	Mass of ball.	m_b	0.003	kg	

Table 2: 2D Balance Plate system specifications.

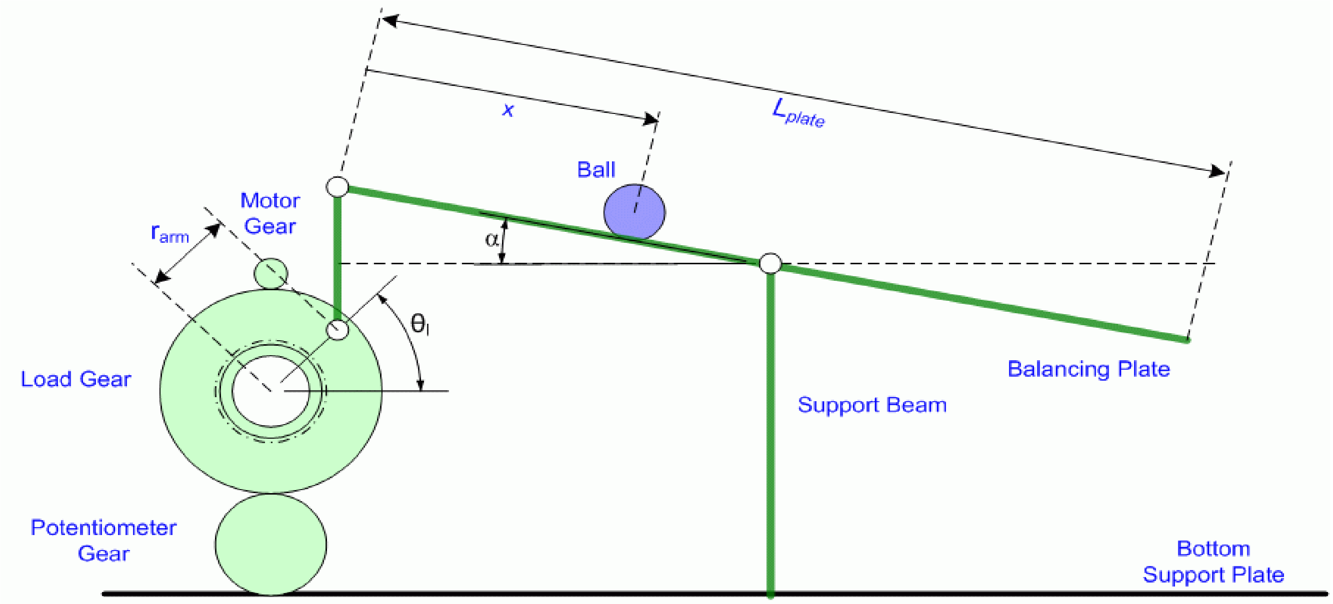


Figure 6: Schematic showing the x-direction of the 2D Ball Balancer system.

Similarly, the *y*-direction of the 2D Ball Balancer system is as shown in Figure 6 except with the ball position variable *y* and its own associated table and servo angles, α and θ_l.

4. System Setup

See Section 4.1 for instructions on how to put the 2D Ball Balancer plant together. Unless you PC already has two separate FireWire ports, then you may need to install the supplied FireWire card as summarized in Section 4.2. Then, go through the software installation in Section 4.3 and the calibration procedure in Section 4.4 before performing the experiments.

4.1. Assembly

Follow this procedure to setup the 2D Ball Balancer module for experimental use:

1. Before beginning, ensure both SRV02 devices are setup in the high-gear configuration, as detailed in Reference [2].
2. Lay the calibration base, component #1 in Figure 2, flat on a table surface.
3. **Setting up camera stand**: As shown in Figure 7, place the camera stand, component #10, into the corner of the calibration base and align the two screw holes on the bottom of the stand with the holes in the corner of the base plate.

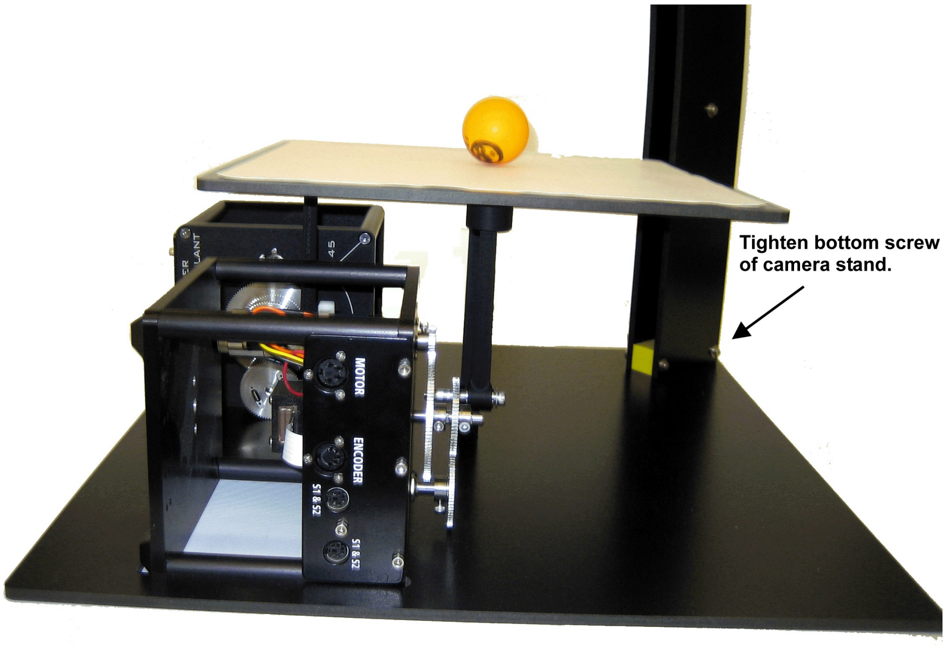


Figure 7: Setting up camera stand in 2DBB system.

4. As shown in Figure 8, insert two screws from the beneath the calibration base and screw them into the base of the camera stand. To do this, carefully move the base plate off the edge of a table so that it's easy to access its bottom panel. Be careful and support the stand before the screws are tightened.

Figure 8: Tighten screws underneath base plate.

5. **Installing the camera**: Before being able to mount the camera on the stand, screw the side of the camera onto the *camera holder extension* piece, as shown by ID #15 in Figure 5.
6. Using the two screws, fasten the extension piece on the actual *camera holder* component, ID #14, as shown in both Figure 4 and Figure 5.

7. Mount the *camera holder* on the *camera height adjuster* piece, ID #11 in Figure 4, and tighten the *camera holder screw*, shown by ID #16 in Figure 5.
8. Slide the *camera height adjuster* to the top of the camera stand, as depicted in Figure 4, and tighten the screw on the side into a washer and nut. Adjust the height so that it is about midway.
9. As pictured in Figure 7 and Figure 9, place each SRV02 unit on their side into the cut-out sections of the calibration base with the potentiometer gear being in the down position (and the small 24-tooth pinion gear in the top position).

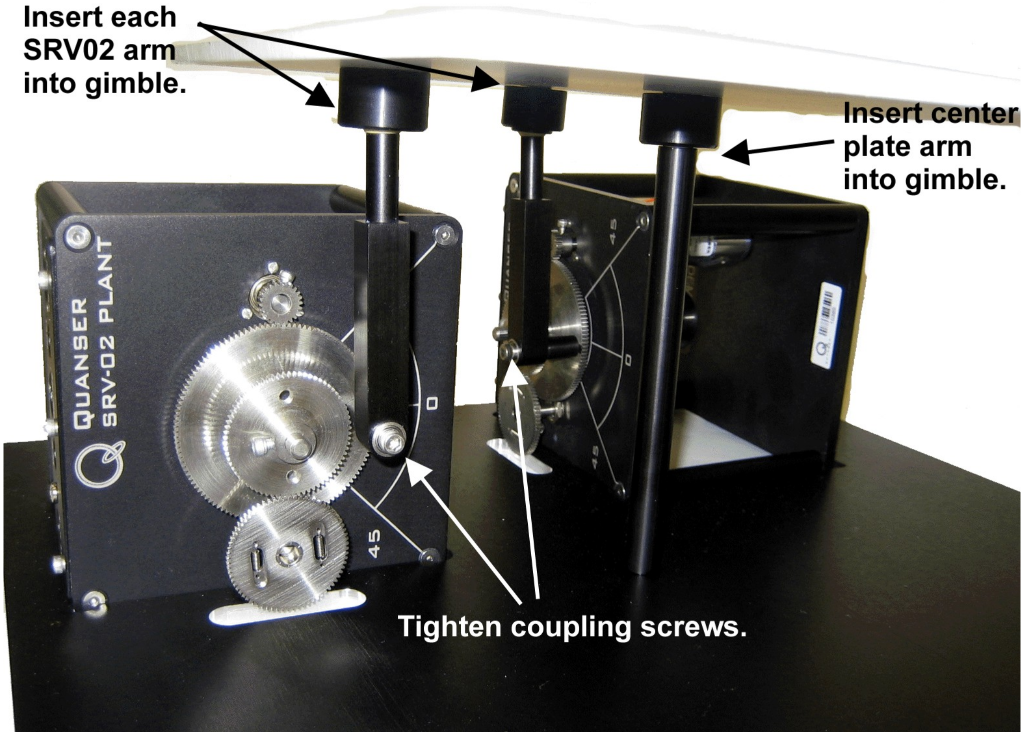


Figure 9: Setting up SRV02 devices for the 2DBB system.

10. As pictured in Figure 9, place the *support arm*, component #8, in the middle of the calibration base and insert its other end into the gimbal located in the center of the underside of the plate.
11. For each SRV02, tighten the coupling screw (component #4) of the lever arm (ID #5) into the screw hole of the large 120-tooth load gear, as illustrated in Figure 9.

4.2. Installing the PCI-Express FireWire Card

If your PC only has a single FireWire connector, then it is highly recommended that the *PCI-Express Controller Card* supplied is installed. See the manufacturer website for details on installing this board. The basic procedure is this:

1. Ensure PC is powered OFF.
2. Install *PCI-Express Controller Card* in the PCI-Express port on the PC.
3. Power ON the PC.

4. Once booted, the *Found New Hardware* wizard should load. Select *No, not this time* option to ignore the Windows Update and click on the *Next* button.
5. The wizard should now be ready to install a driver component for the device. Click on the *Next* button.
6. Click on the *Continue* button if a window is prompted.
7. Once the wizard has completed installing the driver, click on *Finish* button.
8. You will have to go through steps 4-7 multiple times for each component (can be up to 10 different components).
9. Once the driver is installed and the device is ready, the FireWire connectors on the board can used with the Q3-ControlPAQ or the PGR Camera.

4.3. Software Installation

In order to calibrate the camera and use it with the vision algorithm that detects the position of the ball, go through the following steps:

1. Go to the Point Grey Research website: http://www.ptgrey.com/support/downloads/index.asp.
2. Create an account and download the PGR FlyCapture v1.8 software.

WARNING: Do NOT download the latest version of FlyCapture2 v2.2. This is not compatible with QUARC.

3. Add the *bin* folder of the flycap software to the *Path* environmental variable. For instance, to add the default C:\Program Files\Point Grey Research\PGR FlyCapture\bin path, do the following:
    1. Go to Control Panel | System.
    2. In the *Advanced* tab, click on the *Environmental Variables* button.
    3. Under the *System variables* list, select the *Path* variable and slick on the *Edit* button.
    4. Go to the end of the string, add a semicolon, and enter the path *C:\Program Files\Point Grey Research\PGR FlyCapture\bin*.

WARNING: Make sure the *Path* environmental variable is updated with the FlyCap path. Otherwise, some issues can be encountered when attempting to use the camera in software other than FlyCap.

4.4. Calibration

Once the hardware and software is setup, follow this procedure to calibrate the 2D Ball Balancer:

1. As illustrated in Figure 9, above, manually rotate the load gear of each servo around the 0 degree position. That is, the coupling screw should be aligned with the marked 0 degree position.
2. Place the ball approximately in the middle of the plate, as pictured in Figure 9, and adjust the angles of the SRV02 load gears until the ball ceases to move. The ball does not have to be exactly in the center of the plate.
3. The camera has to be calibrated. Thus before going through the following steps, make sure the camera software has been installed, is connected to the PC, and has been tested using the software supplied by the camera manufacturer, e.g. FlyCap.

4. Ensure the camera is parallel with ground and **the cover is not on the lens**.
5. Run the FlyCapexe program and you should see the ball and plate, for example as shown in Figure 10.

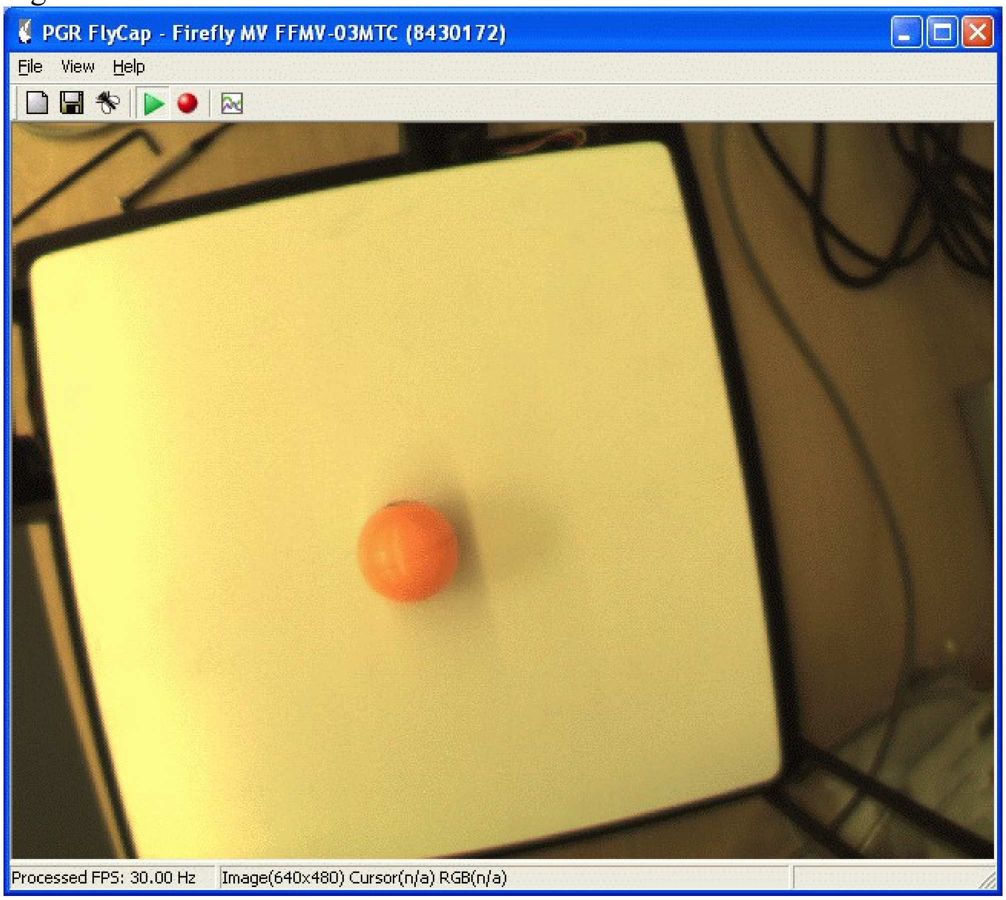


Figure 10: Initial view in FlyCap software.

6. Adjust the height of the camera by moving the camera height adjuster, ID# 11 in Figure 4. Typically the middle position works well.
7. To rotate the camera, slightly loosen the *camera holder screw*, which is component #16 in Figure 5. Rotate the *camera holder* such that the plate edges are parallel with the camera view, as shown in Figure 11. The FireWire connector of the camera should be facing away from the stand towards you as shown in Figure 2.

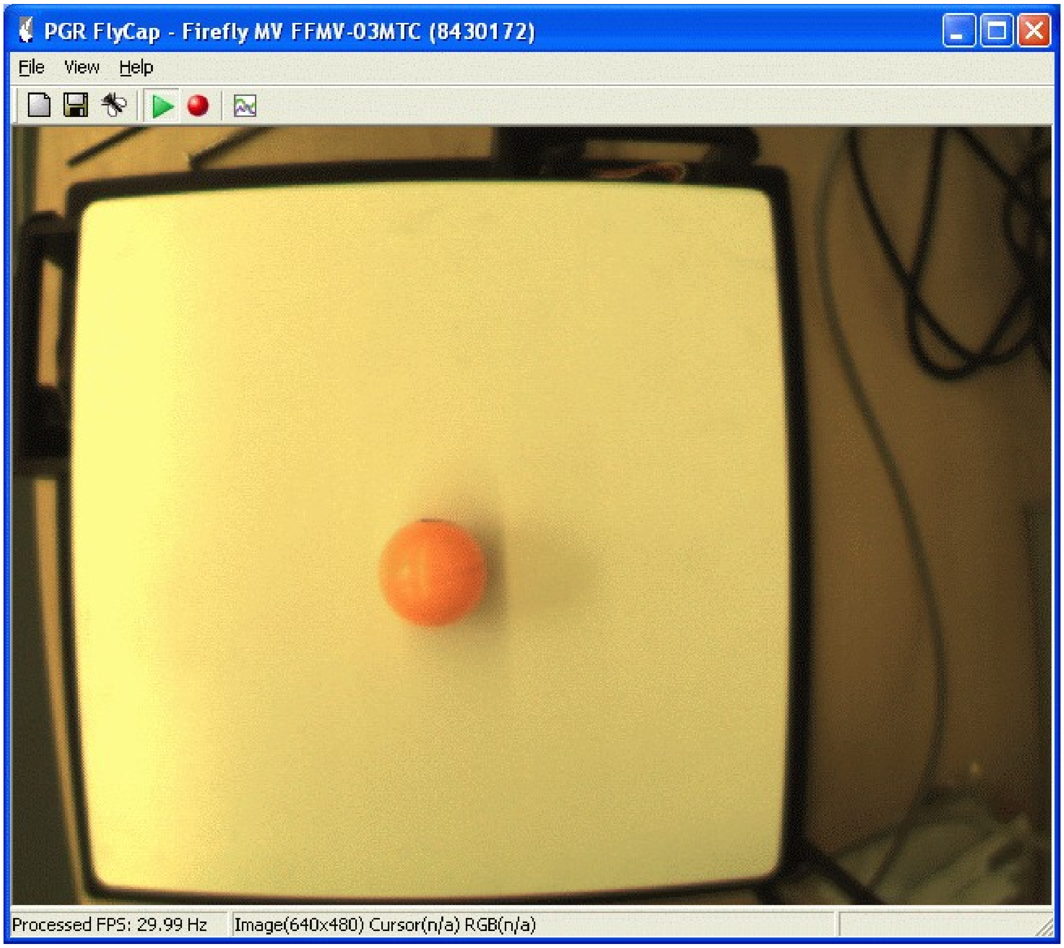


Figure 11: View after rotating camera. Plate edges aligned with camera view border.

8. Click on the *fly* icon and go to *Advanced* | *Custom Image* menu item.
9. The goal is to adjust the *Left*, *Top*, *Width*, and *Height* camera parameters so mostly only the plate is shown in the FlyCap view. These parameters can be changed only by increments of 20 pixels and there is a maximum amount for each.
10. Set the *Height* and *Top* parameters such that the plate fits in the view vertically. For instance, by changing the *Height* from 480 down to 440 and increasing *Top* from 0 to 40 the view goes from what is shown in Figure 11 to Figure 12.

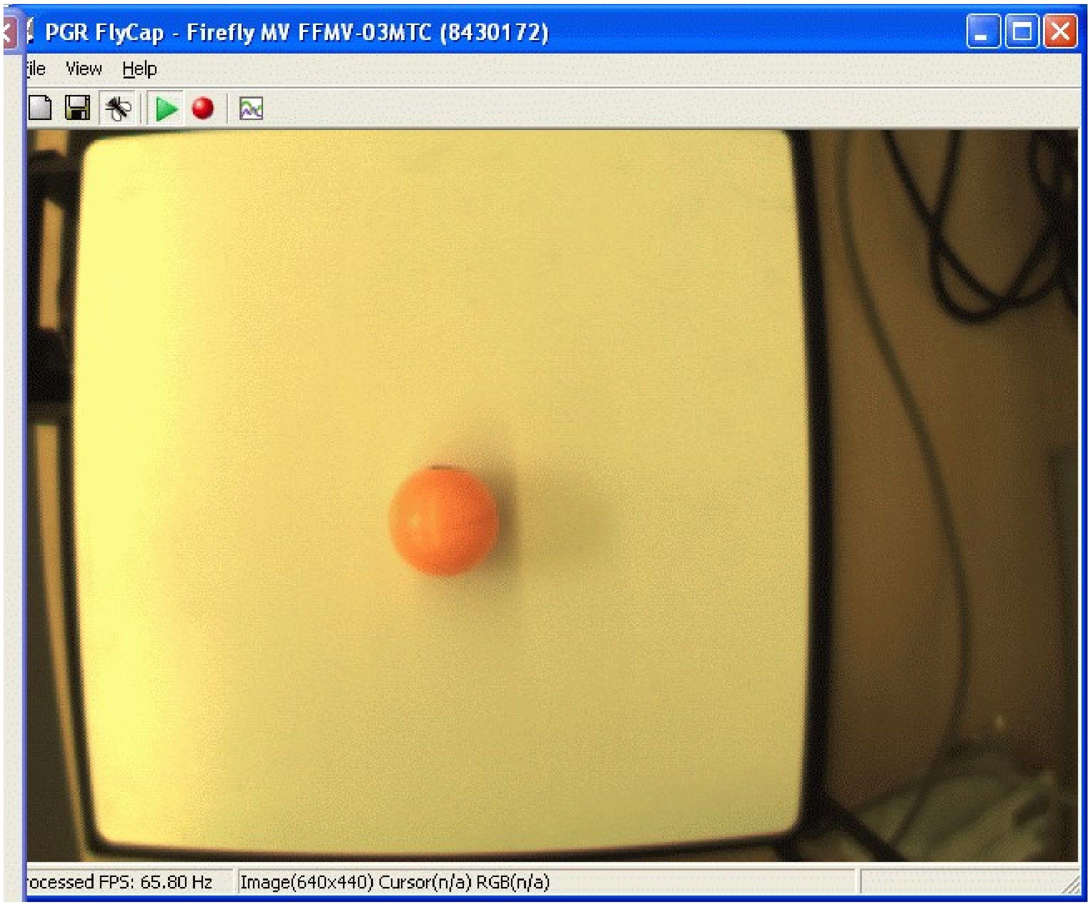


Figure 12: View after adjust the Height and Top parameters.

11. Set the *Width* to the same value as the *Height*, so the border of the camera image surrounds the plate. For example, setting the *Width* to 440 changes the view to Figure 13.

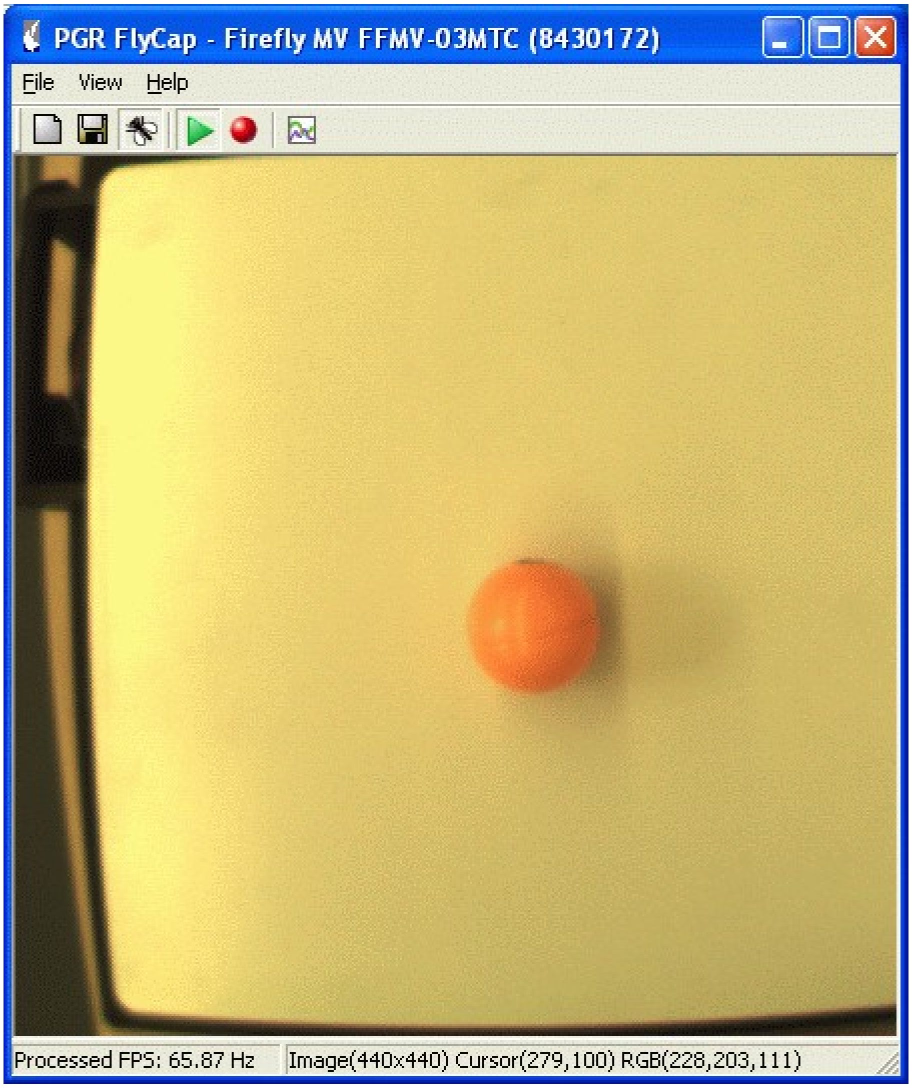


Figure 13: View when setting Width to same value as Height.

12. Tune the *Left* offset such that the plate fits inside the view of the camera. In this case, by increasing the *Left* parameter from 56 to 100 pixels we obtain the image shown in Figure 14.

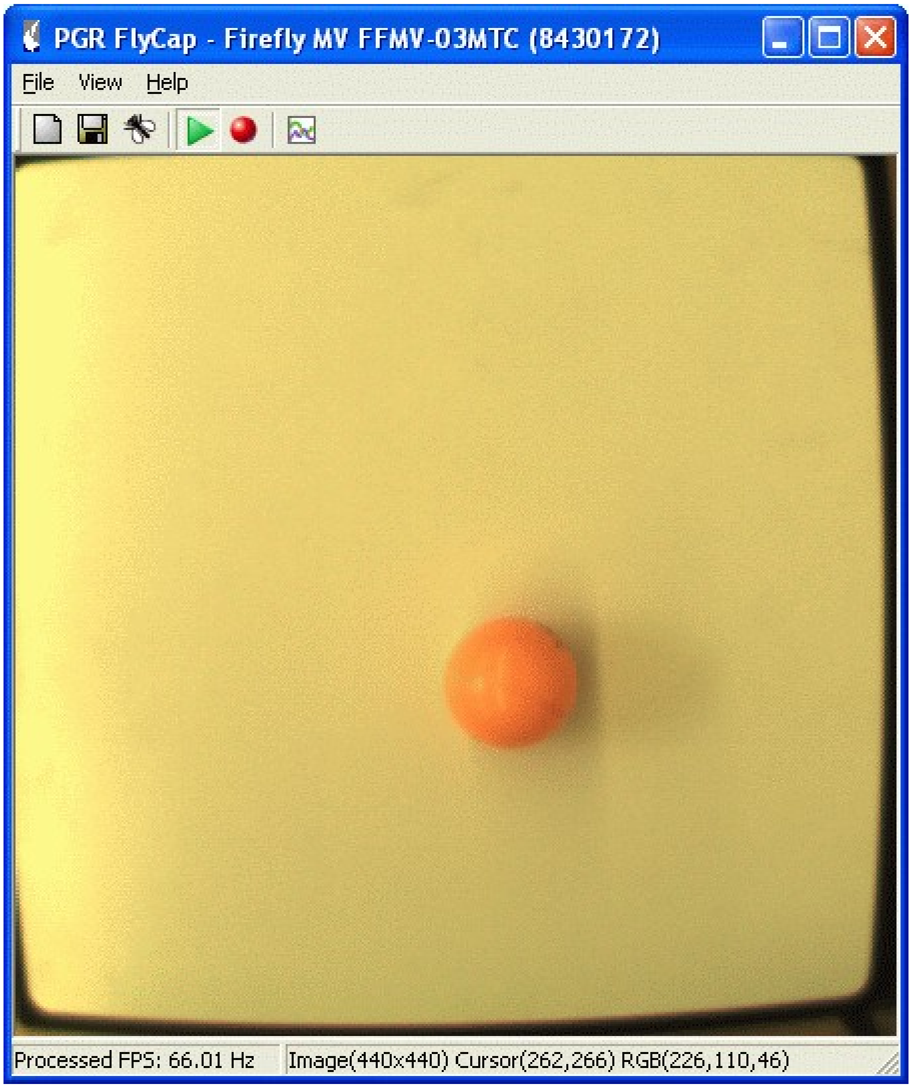


Figure 14: View after adjusting the Left offset. Only the plate is now viewed in the FlyCap software.

13. Adjust the focus on the camera by rotating the lens such that the ball on the video feed is crisp.
14. In conclusion, for this particular Ball Balancer, we need a 440 x 440 image with a *Height* offset of 40 and *Width* parameter of 100 so the plate is square in the FlyCap view. The resulting *Custom Image* tab is shown in Figure 15. Note also, that these parameters will vary across different Ball Balancer setups, e.g. depending on where the height adjuster is placed. Make any final adjustments needed and ensure that only the balance table is shown in the video feed. **Record the final *Left*, *Top*, *Width*, and *Height* camera parameters.** They will be needed for the camera control software.

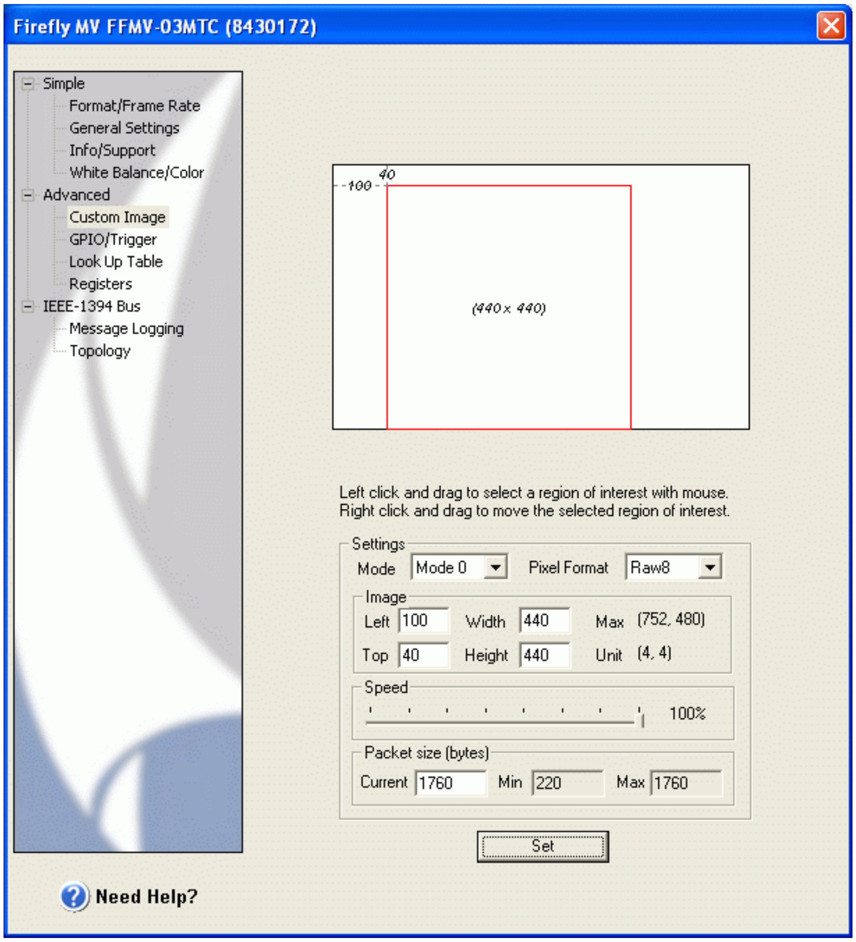


Figure 15: Final parameters set in the "Custom Image".

15. **RGB Values**: In the FlyCap software, bring the mouse cursor over the ball and record the RGB values measured in the bottom right corner of the status toolbar, as shown in Figure 14, above. The RGB values are needed for the image detection algorithm when running the controller.
16. Make sure the FlyCap software is closed before running any of the camera-related controllers in the laboratory.

5. Wiring Procedure

The following is a listing of the hardware components used in this experiment:

- **Power Amplifier**: Quanser VoltPAQ, Q3 ControlPAQ-FW, or equivalent.
- **Data Acquisition Board**: Quanser Q2-USB, Q8-USB, Q3 ControlPAQ-FW, QPID, or equivalent.
- **Rotary Servo Plant**: Quanser SRV02- ET or SRV02- EHR.
- **2D Ball Balancer**: Quanser 2D Ball Balancer Module

See the references listed in Section 8 for more information on these components. The cables supplied with the device are described in Section 5.1 and the procedure to connect the above components is given in Section 5.2.

5.1. Cable Nomenclature

Table 3, below, provides a description of the standard cables used in the wiring of the 2DBB system.

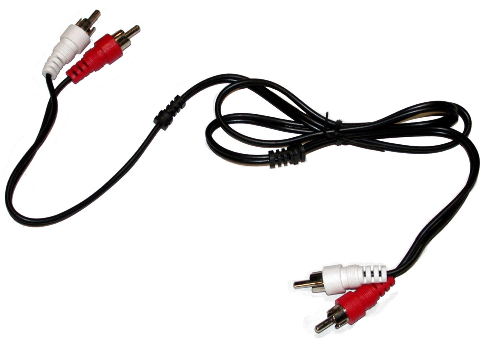
Cable	Designation	Description
 *Figure 16: "2xRCA to 2xRCA" cable*	2xRCA to 2xRCA	This cable connects an analog output of the data acquisition terminal board to the power module for proper power amplification.
 *Figure 17 "To Load" Cable*	4-pin-DIN to 6-pin-DIN	This cable connects the output of the power module, after amplification, to the desired DC motor on the servo.
 *Figure 18 "Encoder" Cable*	5-pin-stereo-DIN to 5-pin-stereo-DIN	This cable carries the encoder signals between an encoder connector and the data acquisition board (to the encoder counter). Namely, these signals are: +5VDC power supply, ground, channel A, and channel B.

Table 3 Cable Nomenclature

5.2. Typical Connections

This section describes the typical connections used to connect the 2DBB plant to a data-acquisition board and a power amplifier, e.g. Quanser VoltPAQ-X2. The wiring is described in detail in the procedure below and summarized in Table 4.

Follow these steps to connect the 2DBB system:

1. It is assumed that the data-acquisition board is already installed as discussed in the Reference [1].
2. Make sure everything is powered off before making any of these connections. This includes turning off your PC and the amplifiers.
3. Connect the 2xRCA to 2xRCA cable from the *Analog Output Channel #0* on the terminal board to the *Amplifier Command* connector on the power amplifier that will be connected to the *x*-axis SRV02. See cable #1 shown in Figure 21. This carries the attenuated SRV02 *x*-axis motor voltage control signal, $V_{m,x}/K_{a,x}$, where $K_{a,x}$ is the X amplifier gain.
4. Connect the 2xRCA to 2xRCA cable from the *Analog Output Channel #1* on the terminal board to the *Amplifier Command* Connector on the power amplifier that will be connected to the *y*-axis SRV02. See cable #2 shown in Figure 21. This carries the attenuated SRV02 *y*-axis motor voltage control signal, $V_{m,y}/K_{a,y}$, where $K_{a,y}$ is the Y amplifier gain.
5. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN from *To Load 0* on the amplifier to the *Motor* connector on the SRV02. See connection #3 shown in Figure 20 and Figure 21. The cable transmits the amplified voltage that is applied to the *x*-axis SRV02 motor and is denoted $V_{m,x}$.
6. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN from *To Load 1* on the amplifier to the *Motor* connector on the SRV02. See connection #4 shown in Figure 20 and Figure 21. The cable transmits the amplified voltage that is applied to the *y*-axis SRV02 motor and is denoted $V_{m,y}$.
7. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder* connector on the *x*-axis SRV02 panel to *Encoder Input # 0* on the terminal board, as depicted by connection #5 in Figure 20 and Figure 21. This carries the *x*-axis load shaft angle measurement and is denoted by the variable $\theta_{l,x}$.

CAUTION: Any encoder should be directly connected to the Quanser terminal board (or equivalent) using a standard 5-pin DIN cable. **DO NOT connect the encoder cable to the amplifier!**

8. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder* connector on the *y*-axis SRV02 panel to *Encoder Input # 1* on the terminal board, as depicted by connection #6 in Figure 20 and Figure 21. This carries the *y*-axis load shaft angle measurement and is denoted by the variable $\theta_{l,y}$.
9. Connect the FireWire connection on the camera, shown in Figure 19, to a FireWire port on the PC.

Cable #	From	To	Signal
1	Terminal Board: Analog Output #0	Amplifier "Amplifier Command 0" connector	Control signal to the amplifier driving the *x*-axis SRV02.
2	Terminal Board: Analog Output #1	Amplifier "Amplifier Command 1" connector	Control signal to the amplifier driving the *y*-axis SRV02.
3	Amplifier "To Load 0" connector	SRV02 X "Motor" connector	Power leads to the DC motor of the *x*-axis SRV02.
4	Amplifier "To Load 1" connector	SRV02 Y "Motor" connector	Power leads to the DC motor of the *y*-axis SRV02.
5	Terminal Board: Encoder Input #0	SRV02 X "Encoder" connector	Encoder *x*-axis load shaft angle measurement.
6	Terminal Board: Encoder Input #1	SRV02 Y "Encoder" connector	Encoder *y*-axis load shaft angle measurement.
7	Terminal Board: DIO #0 Header	Amplifier “Enable”	Enables the amplifier.
8	Camera FireWire Connector	PC FireWire Port	Camera image.

Table 4 2DBB system wiring summary.

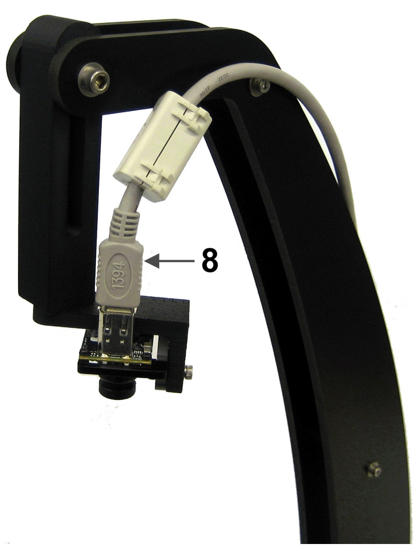


Figure 19: 2DBB camera connections.

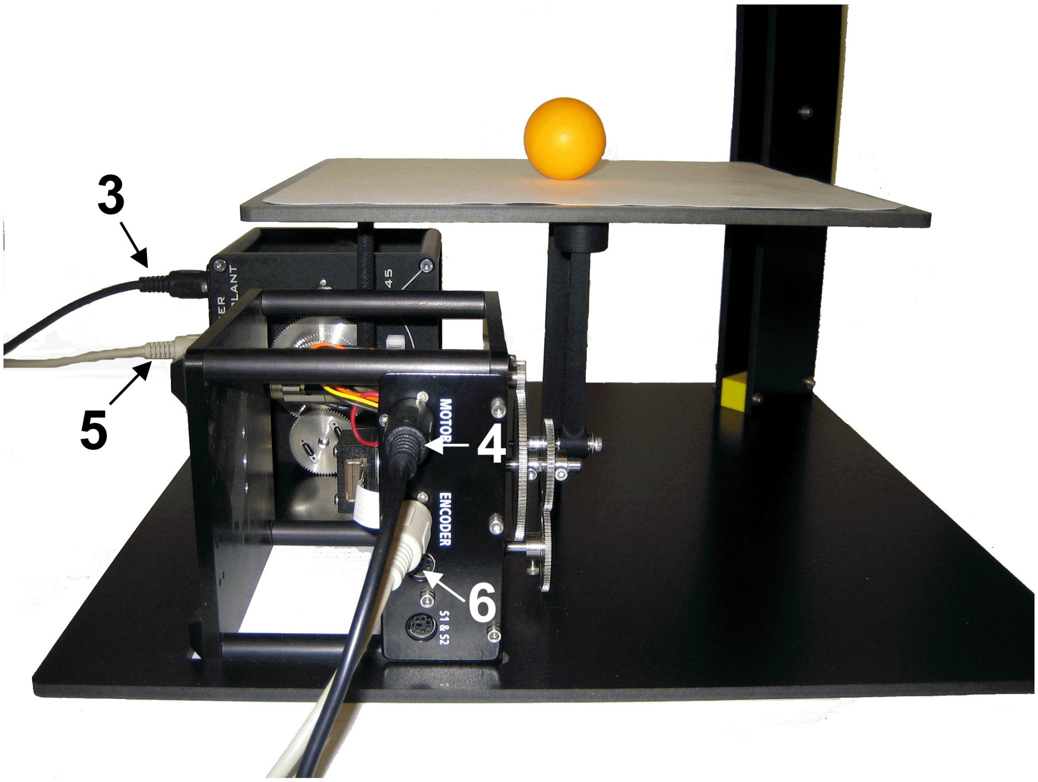


Figure 20: 2DBB SRV02 connections.

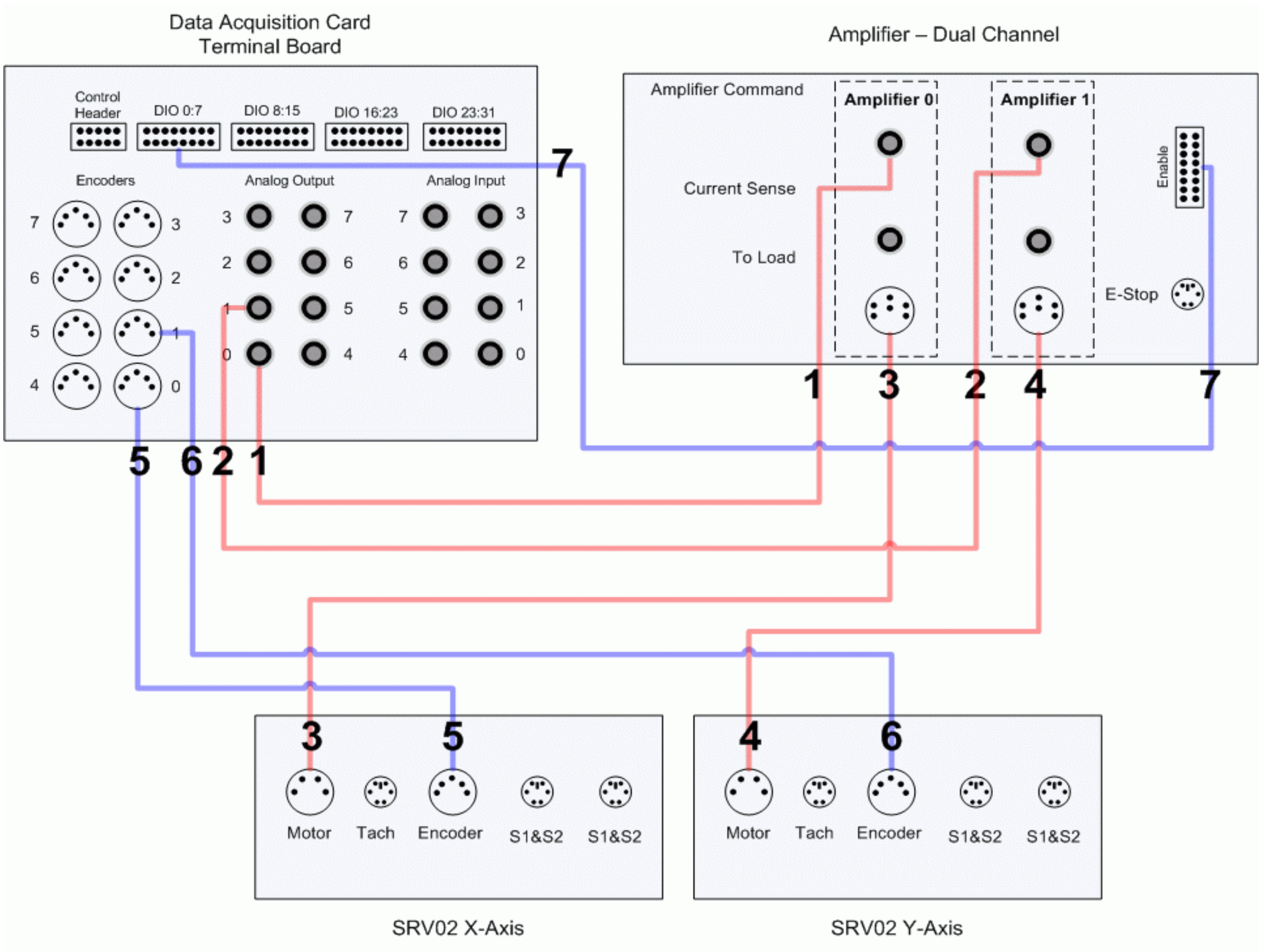


Figure 21: 2 DOF Ball Balancer connection diagram

5.3. Typical Q3 ControlPAQ-FW Connections

This section describes the typical connections used to connect the 2DBB plant to the Quanser Q3 ControlPAQ-FW data-acquisition and amplifier board. The wiring is described in detail in the procedure below and summarized in Table 5.

Follow these steps to connect the 2DBB system:

1. It is assumed that the Quanser Q3 board is already installed as discussed in the Reference [1].
2. Make sure everything is powered off before making any of these connections. This includes turning off your PC and the Q3.
3. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN from *MOTORS 0* connector on the Q3 to the *Motor* connector on the x-axis SRV02. See connection #1 shown in Figure 22. The cable transmits the current that is applied to the *x*-axis SRV02 motor and is denoted $I_{m,x}$.

4. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN from *MOTORS 1* on the Q3 to the *Motor* connector on the y-axis SRV02. See connection #2 shown in Figure 22. The cable transmits the current that is applied to the *y*-axis SRV02 motor and is denoted $I_{m,y}$.
5. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder* connector on the *x*-axis SRV02 panel to *ENCODER 0* on the Q3 board, as depicted by connection #3 in Figure 20. This carries the *x*-axis load shaft angle measurement and is denoted by the variable $\theta_{l,x}$.
6. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder* connector on the *y*-axis SRV02 panel to *ENCODER 1* on the Q3 board, as depicted by connection #4 in Figure 22. This carries the *y*-axis load shaft angle measurement and is denoted by the variable $\theta_{l,y}$.
7. Connect the FireWire connection on the camera, shown in Figure 19, to a FireWire port on the PC.

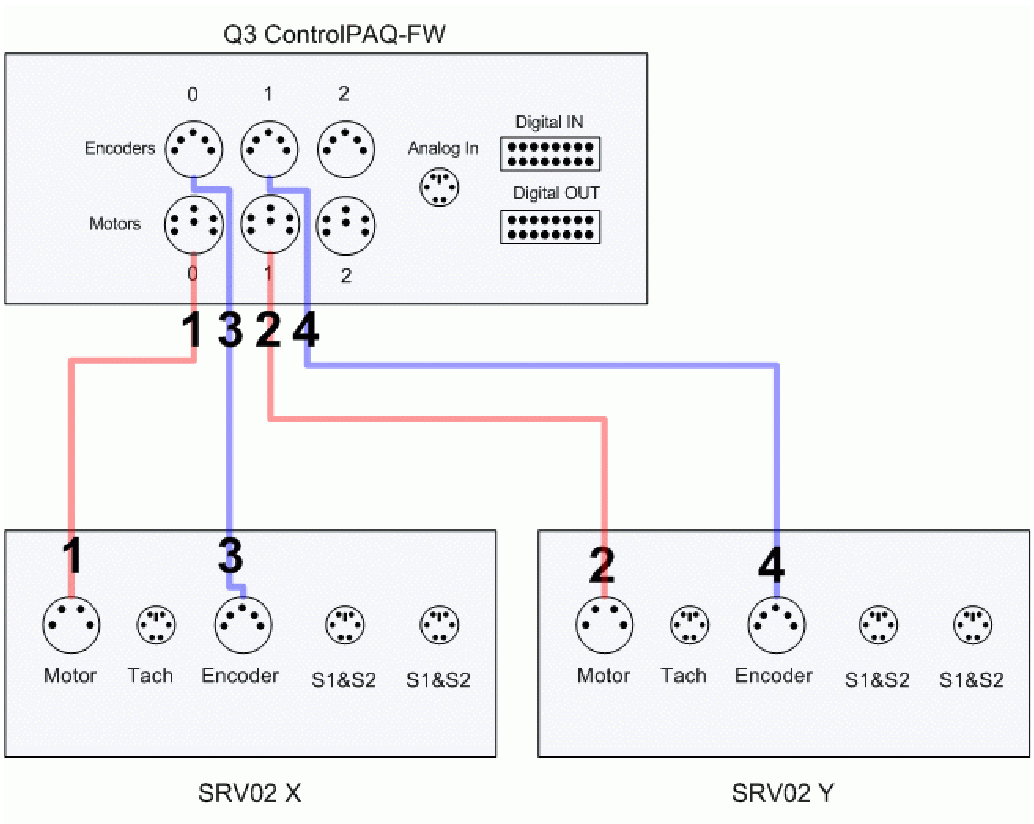


Figure 22: 2DBB connection diagram when using Q3

Cable #	***From***	***To***	***Signal***
1	Q3 "MOTOR 0" connector	SRV02 X "Motor" connector	Power leads to the DC motor of the *x*-axis SRV02.
2	Q3"MOTOR 1" connector	SRV02 Y "Motor" connector	Power leads to the DC motor of the *y*-axis SRV02.

Cable #	*From*	*To*	*Signal*
3	Q3 “ENCODERS 0” connector	SRV02 X "Encoder" connector	Encoder *x*-axis load shaft angle measurement.
4	Q3 “ENCODERS 1” connector	SRV02 Y "Encoder" connector	Encoder *y*-axis load shaft angle measurement.
5	Camera FireWire Connector	PC FireWire Port	Camera image.

Table 5 2DBB system wiring summary for Q3.

6. Testing and Troubleshooting

This section describes some functional tests to determine if the 2D Ball Balancer system is operating normally. It is assumed that the SRV02 is connected as described in the Section 5.2, above. To carry out these tests, it is preferable if the user can use a software such as QUARC or LabVIEW to read sensor measurements and drive the motor. See Reference [3] to learn how to interface the SRV02 with QUARC. Alternatively, these tests can be performed with a signal generator and an oscilloscope.

6.1. SRV02 Motor and Sensors

See Reference [2] for information on testing and troubleshooting the SRV02 separately.

6.2. Testing the 2D Plate Balancer

6.2.1. Testing

Run the *FlyCap.exe* program supplied with the camera to ensure a video feed can be received.

6.2.2. Troubleshooting

Follow the steps below if the experiments are not behaving correctly:

- Before running the experiments, make sure the FireWire is properly connected between the camera and the PC and an image can be obtained using the FlyCap.exe software.
- If no image can be obtained with FlyCap.exe, then read through the supplied documentation or contact Point Grey Research. Technical support is available from PGR at the following website: http://www.ptgrey.com/support/index.asp
- If an image can be obtained but the experiments are not operating correctly, go through the camera calibration procedure again in Section 4.4. In particular, ensure the camera is properly focused and that the image size and offsets are correctly tuned. Also if another vision based program is used, make sure the image properties, i.e. image size and offsets, are defined in that program. If not calibrated properly, the ball positions extrapolated from the camera will not be

accurate and cause some issues with the control experiments.

7. Technical Support

To obtain support from Quanser, go to http://www.quanser.com/ and click on the *Tech Support* link. Fill in the form with all the requested software and hardware information as well as a description of the problem encountered. Also, make sure your e-mail address and telephone number are included. Submit the form and a technical support person will contact you.

For issues involving the digital camera, go to http://www.ptgrey.com/support/index.asp to contact Point Grey Research technical support.

Note: Depending on the situation, a support contract may be required to obtain technical support.

8. References

[1] DAQ User Manual
[2] SRV02 User Manual
[3] Rotary Experiment #0: SRV02 QUARC Integration
[4] Point Grey Research. Firefly MV Getting Started Manual