McGill University

Department of Electrical and Computer Engineering

Control and Robotics Laboratory – ECSE 493 Lab Manual

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Winter 2016

1. **<u>Introduction and Objective:</u>**

The main goal of this manual is to introduce you to the robotics setup, which is being used in ECSE-493 labs [Fig - 01]. This setup consists of hardware (the pendulum and IP02 servo (Cart), Data Acquisition board, and the power amplifier) and software (MATLAB / Simulink).

Fig - 01

Hardware components and wirings are discussed in the next section. In the third section we focus on the real-time control software (Simulink - MATLAB) and, within two fundamental examples, the method of sending voltage to the cart and the task of reading the data from position and angle encoders are explained in detail in order to prepare you for using the systems in Control and Robotics Lab.

2. <u>Main Components (Hardware):</u>

2.1. Linear Motion Servo Plant (Quanser IP02):

First turn on the computer. Before turning on the power module (Section 2.3) you should make sure all the wires are connected correctly. Quanser IP02 consists of a DC motor that moves the cart along the x- axis. There is a shaft encoder sensor connected to the DC motor shaft whose output is the cart position that is sent to the data acquisition board via Channel-0 [Fig-02].

There is an angular position encoder connected to the pendulum's shaft that sends the shaft's angular position to the data acquisition board via channel-1.

The input to IP02 (Load – Black Wire) is the voltage applied to the DC motor. This voltage can have any form (e.g. functions of time like sinusoid, square, etc. or functions of the system data i.e. feedback). One can define the nature (Amplitude, Shape, Frequency, etc) of the load signal in Simulink and apply it to the DC motor using the data acquisition board. Make sure that the voltage signal's amplitude does not exceed 5 volts by putting a saturation for the generating signal.

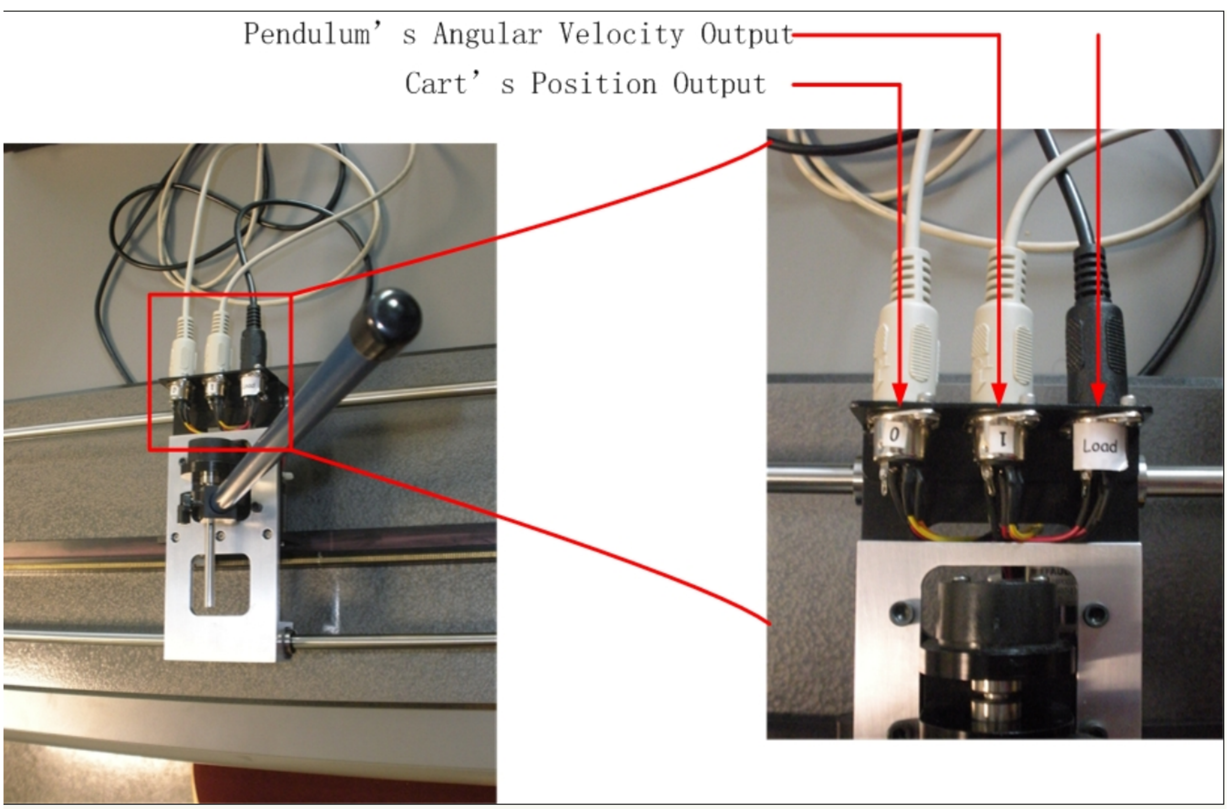

Fig-02

2.2. Data Acquisition Board (DAQ):

All stations in the lab are equipped with QuaRC DAQ boards of type Q4 [Fig-03]. This need to be manually selected in your Simulink models as explained in the next section (as Q8 is the default mode in Simulink). There is DAC (Digital to Analog Converter) on each board which generates the required analog signal and feeds it to the DC motor through the power module. The digital input to the DAC is determined by the user in Simulink, for example (Simulink => Source => Signal Generator).

There are two inputs to the board (white wires) coming from IP02 module. One of them is connected to channel-0 (for the cart position) and the other one is connected to Channel-1 (for the pendulum angular position). The output wire (black) which is the DAC output is connected to the Load-Channel of the IP02 module (cart).

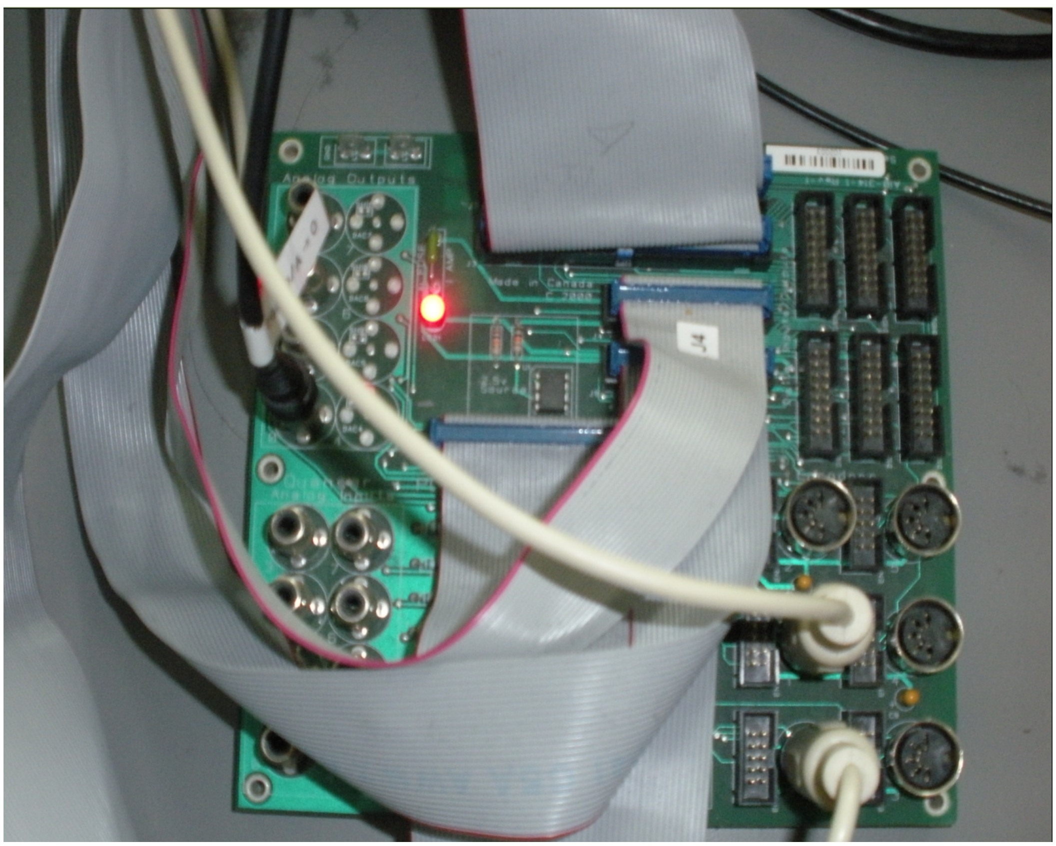

Fig-03

2.3. Power Module (Quanser UPM 1504):

Make sure all the wires are connected before turning on the power module [Fig-04]. The next step is to use MATLAB / SIMULINK to write programs to control the cart and pendulum.

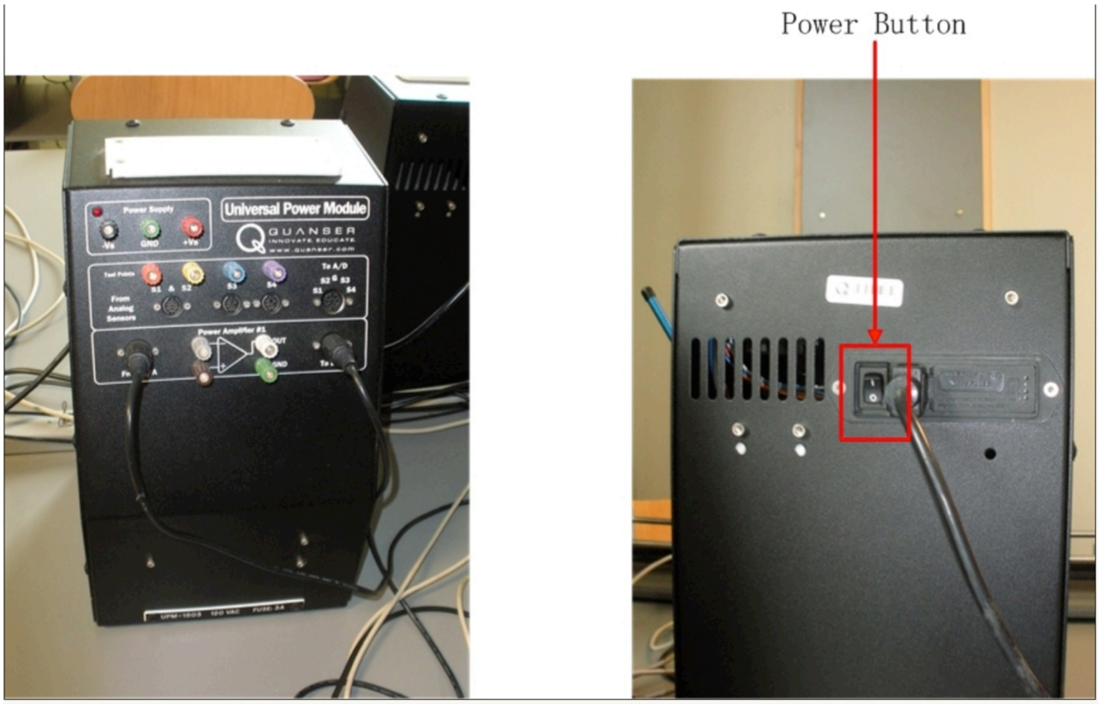

Fig-04

3. <u>SIMULINK (software):</u>

3.1. Applying voltage to the DC motor that moves the cart

In this section you will create a SIMULINK model to apply a sinusoidal signal to IP02 (DC motor). **The steps are explained for students with minimum knowledge in Simulink.** Follow the steps described below:

Step 1: Start MATLAB,

Step 2: Launch the Simulink Library Browser (by typing the command "simulink" or by clicking on Simulink icon shown in Fig – 05) and open a new model.

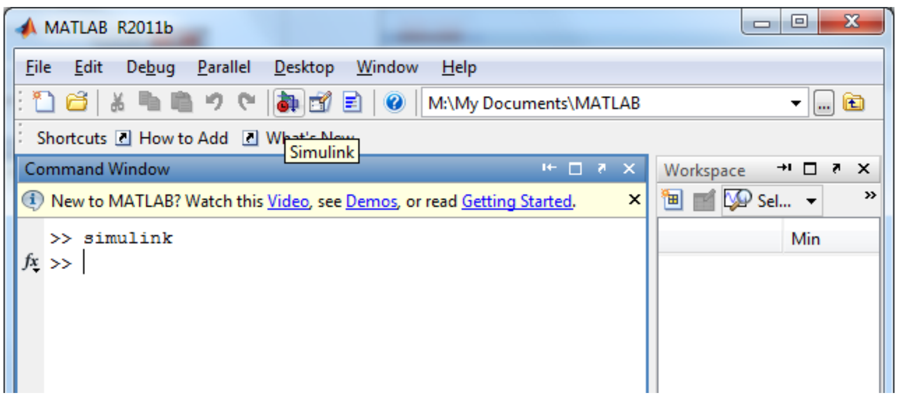

Fig-05

Step 3: In Simulink Libraries section (left column) find "QUARC Targets", then select "Data Acquisition", and then "Generic" and finally "Configuration". In this window select "HIL Initialize" module (Fig-06) and drag and drop it on the blank Simulink model that you just created.

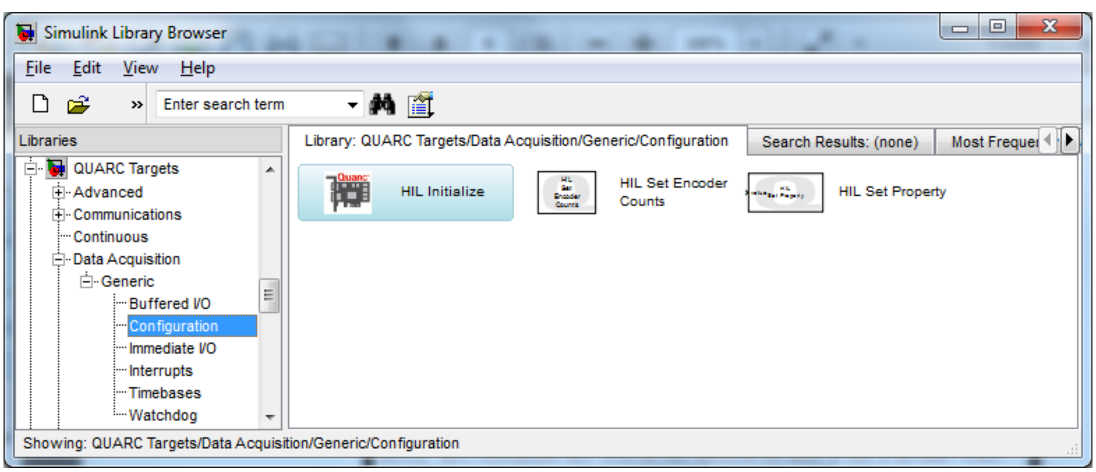

Fig-06

Step 4: After placing the “HIL Initialize” Module on simulink model, double click on it and make sure that board type is “q4” (Fig-07). Having this block is necessary for all your simulink models since it introduces the board to the computer.

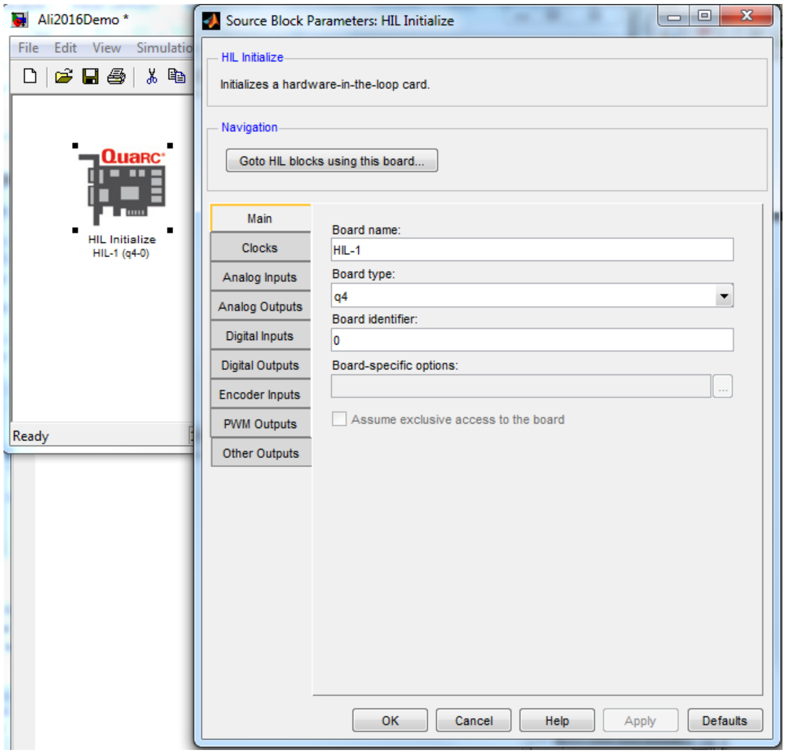

Fig-07

Step 5: In order to send the voltage signal to the DC motor (and move the cart) you need “HIL Write Analog” Model to connect a signal generator to it. Go to “QUARC Targets”, >> “Data Acquisition” >> “Generic”, then click on “Immediate I/O” and finally select “HIL Write Analog” and place it on Simulink model (Fig-08).

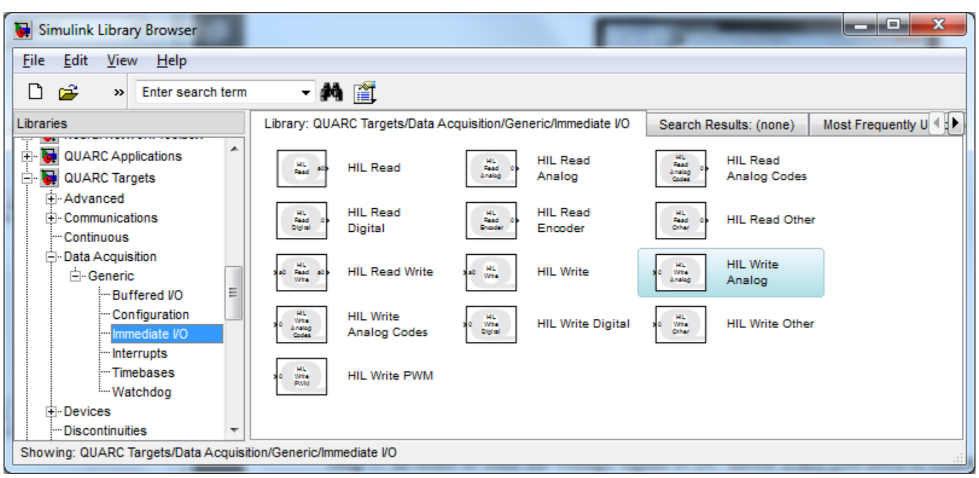

Fig-08

Step 6: You can apply any type of signal to the cart (via e.g. a Signal Generator). In Simulink Libraries section (left column) find “Sources” and select “Signal Generator” or “Since Wave” block (Fig-09) and place it on the model. You can double click on the module to change the signal amplitude or frequency or even signal type. Leave other parameters unchanged for this example

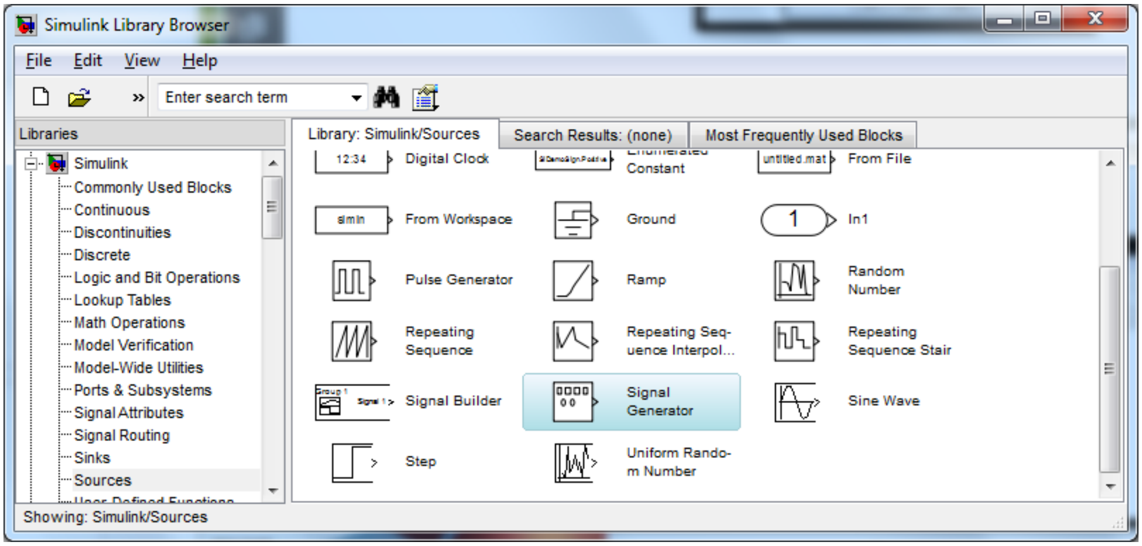

Fig-09

Step 6: For safety issues, it is highly recommended that you insert a “Saturation” block before the input to the “HIL Write Analog” all the time. Although the signal is manually selected in this part, “Saturation” is an essential block for all closed loop inputs. In Simulink Libraries section (left column) go to “Commonly Used Blocks”, find “Saturation” (Fig-10) and drag and drop to your model. Double click on the “Saturation” in your file and set the upper bound to “5” and the lower bound to “-5”.

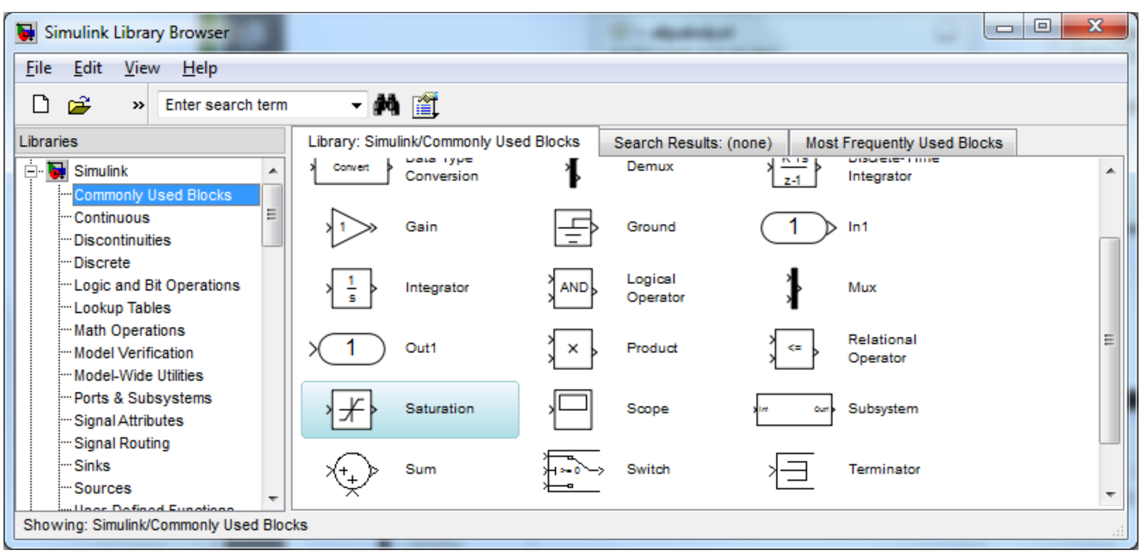

Fig-10

You can plot the input signal by adding a “Scope” from “Simulink” >> “Sink” (Fig-11). You can use other blocks as well, for example you can select to send “To Workspace” and “To File” in order to store them offline and then plot and analyse the data.

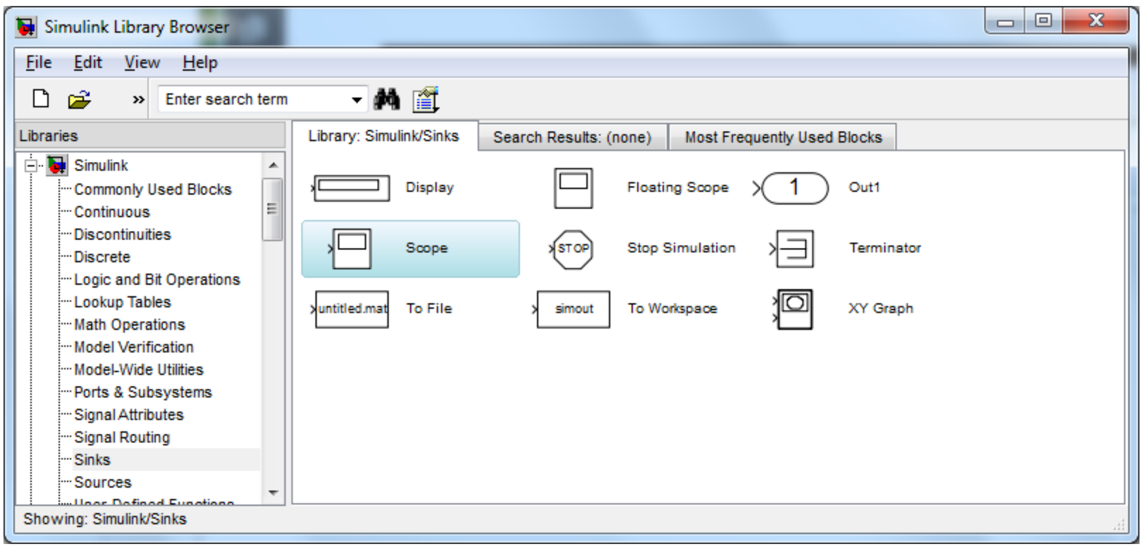

Fig-11

Step 7: Here is the final Step. Connect all the blocks as shown in Fig-12 and save the file (make sure your path (the Current Folder in the main MATLAB window) is set properly for example it can be “M:\My Documents\MATLAB”).

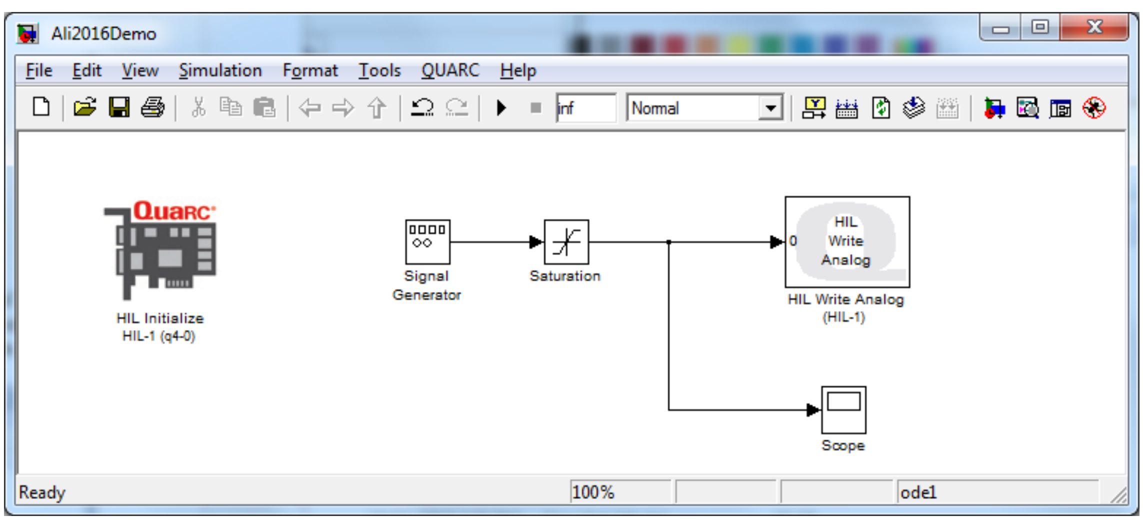

Fig-12

Unlike simulations and analysis which you normally do in Simulink, we need to set our simulation to "External" as we are sending (and later, also receiving) data to (and from) external sources. This step is shown in Fig-13.

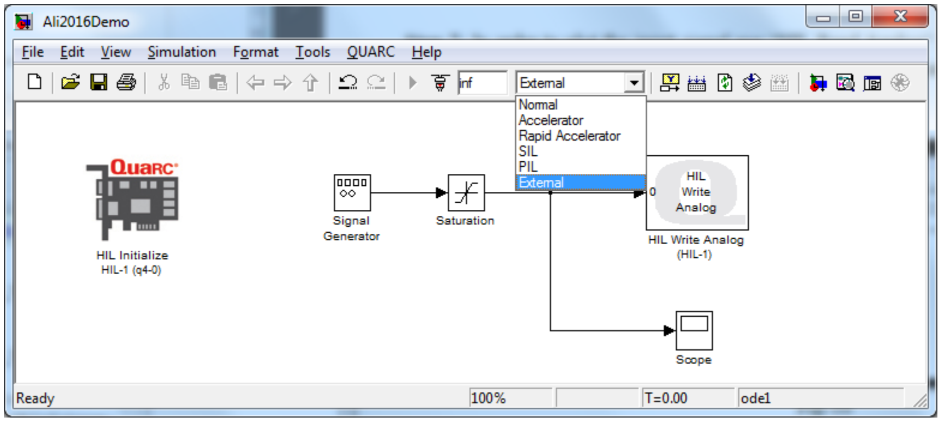

Fig-13

Now click on "Incremental Build" (Fig-14).

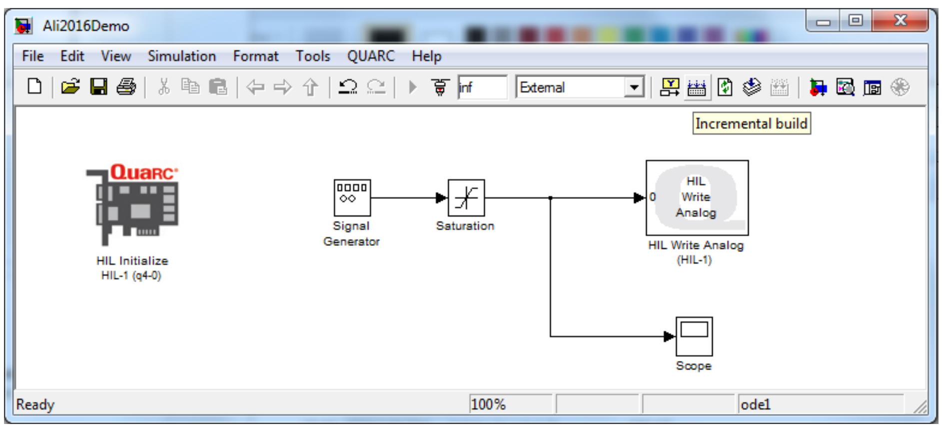

Fig-14

After building and debugging your model, click on "Connect to Target" (Fig-15). Then click on the "Play" button ► and the robotic system should start moving.

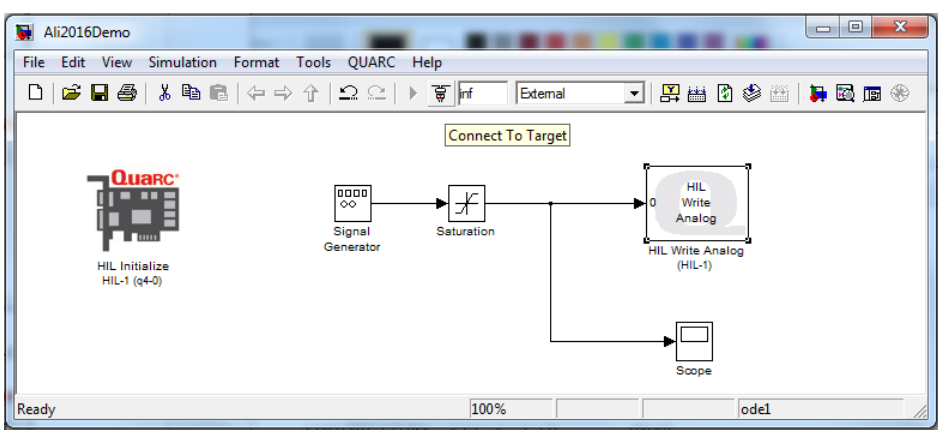

Fig-15

3.2. Measuring the Cart Position and the Pendulum Angle from the IP02 Encoders:

In this section the objective is to create a Simulink model to monitor and measure (in real-time) the actual position of the IP02 cart and the pendulum angle, as sensed by the encoders. For this purpose, follow the steps described below:

Step 1: Start Simulink and follow the steps 1 to 6 in the previous section. You can also use the file that you have already saved.

Step 2: In order to measure the real time cart position or pendulum angel you need "HIL Read Encoder Timebase", which can be found in: "QUARC Targets", >> "Data Acquisition" >> "Generic" >> "Timebase" (Fig-16).

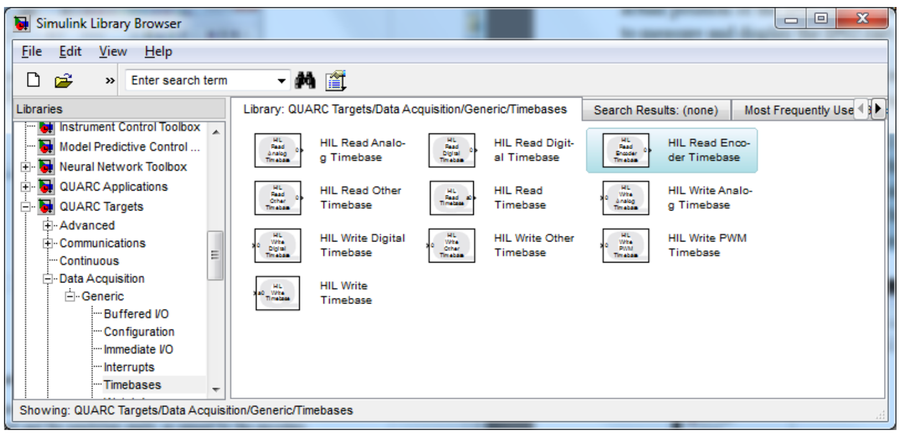

Fig-16

After placing the module in Simulink model, you can double click on it and select the reading "Channels". Channel "0" shows the cart's position and channel "1" monitors the pendulum's angle (check the connections first, it might be different). You can have both outputs simultaneously by inserting the vector [0;1] in the Channels setting (Fig-17).

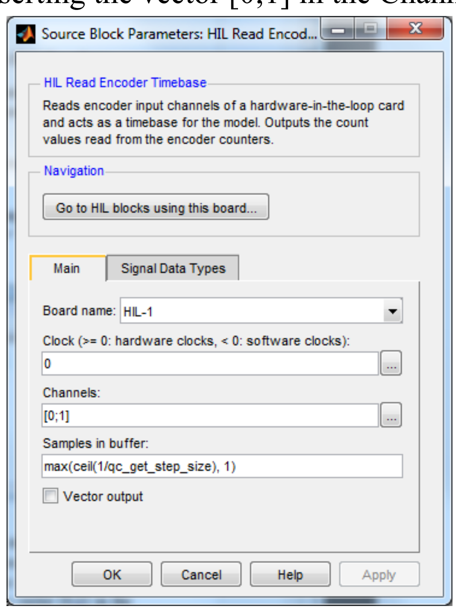

Fig-17

Step 3: The encoder provides the number of counts proportional to the angle of rotation, which in turn is proportional to the cart position on the rack if it's the position encoder, and if it's the angle encoder the number of counts is proportional to the pendulum angle (relative to the angle at the start of the simulation). The IP02 cart encoder resolutions are provided in Table 1, which must be entered in the "Gain" blocks following the Encoder Input block. You can find the "Gain" block in "Simulink" >> "Commonly Used Blocks" (Fig-18).

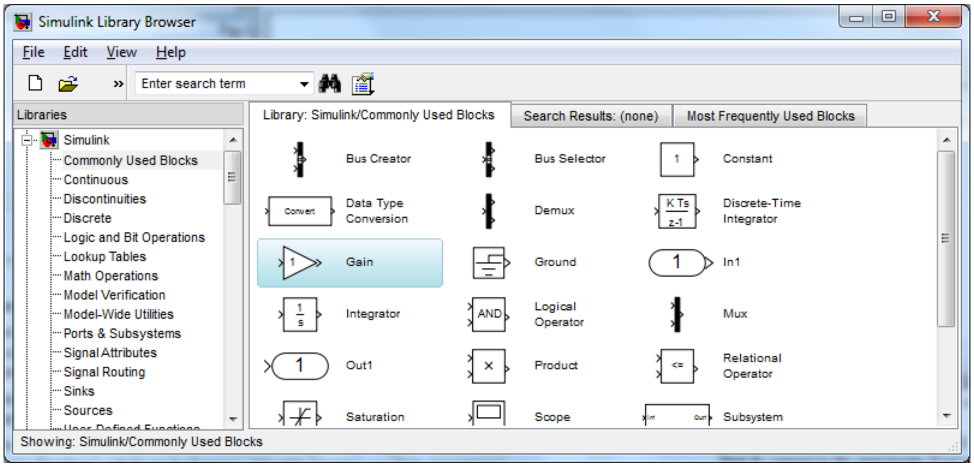

Fig-18

Step 4: In order to monitor the position you can use "Scope" and if you would like to see the numeric values you can use "Display" module which is found in: "Simulink">> "Sink". Once can also use "To Workspace" (simout) to send position values to the work space or use "To File" (untitled.mat) module to send values to a file.

Step 5: Now you should have a diagram similar to Fig-19.

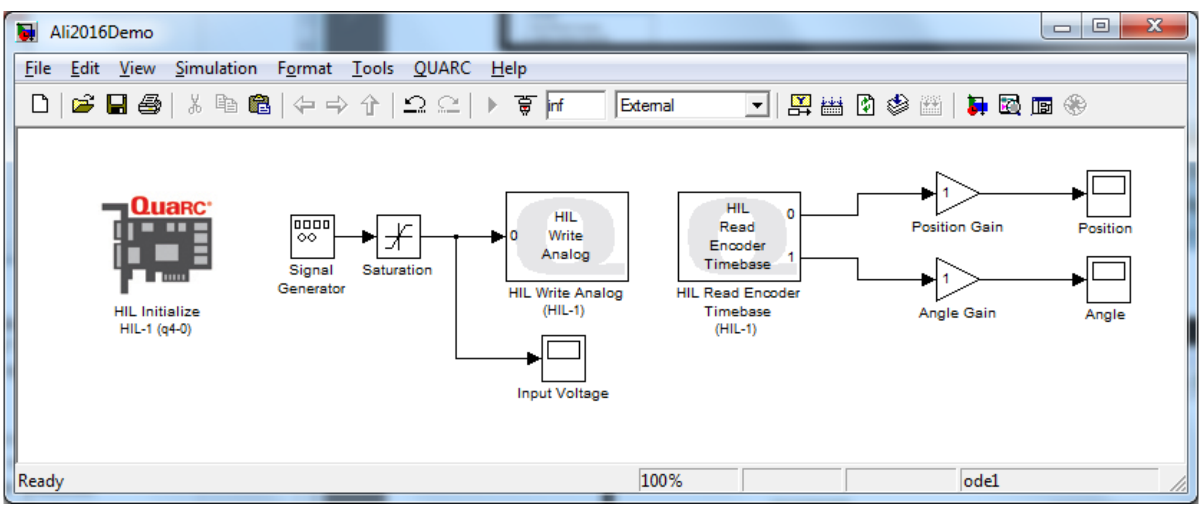

Fig-19

Build and connect to target as instructed in previous section and you can monitor the cart's position as well as the pendulum's angle (to see non-zero values for the angle, you can move the pendulum manually). Keep in mind that you don't need to have "Write Analog" block in order to use "Read Encoder Timebase".

Step 6: To measure the velocity of the cart, you can insert a derivative block after the position and angle values. Differentiation is a high pass filter operation resulting in a very noisy signal. You can post process the data offline or use a low-pass filter in your Simulink model. This part is left to you to decide based on the experiment you are making but to give you an idea, a transfer function block with, for instance, $G(s) = \frac{100}{s+100}$ or a Butterworth Lowpass filter (for example of order 8 and a Passband Edge Frequency 30 rad/s), etc. will all smooth out your signal.

Table 1: System Parameters

Parameter	**Symbol**	**Value**	**Units**
Motor Torque/ Constant Back EMF constant	Km	0.0077	N.m/amp V/(rad/sec)
Armature Resistance	Rm	2.6	Ohms
Armature Inductance	Lm	180	uHenry
Maximum Voltage	Vmax	5.0	Volts
Internal Gear Ratio	Kg	3.7 to 1	none
Motor Gear Radius	r	0.0064	m
Cart Mass	mc	0.526	Kg
Linear position gain	Kx	2.28 x 10E-5	m/counts
Pendulum angle gain	Kth	0.00153	rad/counts
Pendulum mass	mp	0.106	Kg
Distance to Pendulum COG	lp	0.168	m