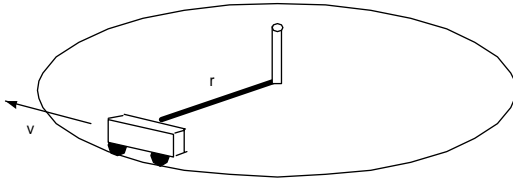


Hands-on Lab

Open-Loop Response: System Identification



Motorized tethered cart

A step or impulse response provides useful information that characterizes the system. With such data, one can then begin to analytically design a controller. This lab explores system identification by working with a motorized tethered cart. One will apply a step response to identify the rise time, damping ratio and system Type.

Concept 1: Experimental Open-Loop Step Response

The motorized tethered cart operates on ± 10 Volts. The motor driver board uses a 3 Amp power supply and interfaces to the USB-6211. This board consists of H-bridges and a power op-amp. The net effect is that one can actuate the cart's rotational direction (i.e. clock or counter-clockwise) and rotational speed (current is proportional to voltage).

An encoder (US Digital E4P, also used in a previous lab) monitors the cart's rotational angle. A LabVIEW program will be created to capture cart velocity. Plotting this velocity will reveal the cart's transient and steady-state behavior.

Step 1: Create the Front Panel and Block Diagram

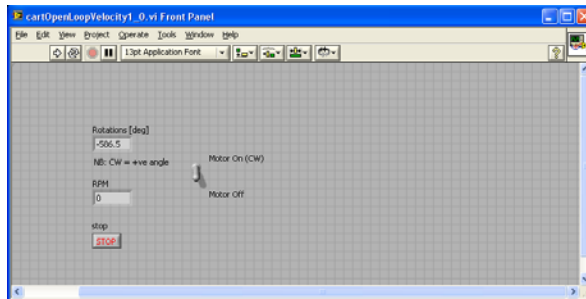


Figure 1-1A: Step Response Front Panel

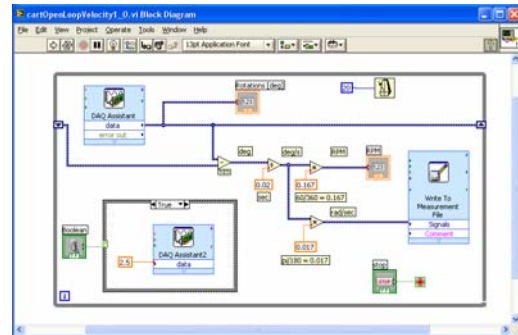


Figure 1-1B: Block Diagram

The front panel (**Figure 1-1A**) consists of 2 numeric indicators and a toggle switch. The indicators display the cart's rotational position (in degrees) and velocity (in RPM).

The block diagram (**Figure 1-1B**) consists of 3 DAQ Assist Controls. The first one monitors the encoder. A shift register and 20 millisecond timer are used to calculate cart velocity. Constants are applied for measuring this velocity in RPM or rad/sec. The second one captures the cart velocity in rad/sec. The third one works with the toggle switch to apply 2.5 Volts to the cart. This on-off toggle moves or stops the cart.

Save the file as: `cartOpenLoopVelocity1_0.vi`

Encoder DAQ setting:

- Counter: ctr1
- pulses/rev: 300; initial angle: 0; units: degrees
- Decoding type: X4
- Acquisition mode: 1 Sample (On Demand)

Voltage DAQ setting:

- Channel is ao0
- Min and max voltages are -10 and 10 volts respectively
- Generation mode: 1 sample (On Demand)

Measurement DAQ setting:

- File Format: Text (LVM)
- Segment Headers: No Headers
- X Value Columns: Empty time column
- Delimiter: Tab
- Action: Save to one file (suggested filename: `cartOpenLoopResponse.lvm`)
- If a file already exists: Overwrite file

Step 2: Apply step response and plot data

Caution: The tether will bind if the cart rotates more than 3 revolutions (i.e. there is no slip ring). Binding is bad because it slows the cart down (so cart characteristics will be inaccurate) and fatigues the cable. As such, when executing `cartOpenLoopVelocity1_0.vi`, do not let the cart rotate more than 3 times.

Run your program and toggle the switch to run the cart. After about 2 rotations, toggle off and terminate the program. Use Excel to read the data file (e.g. `cartOpenLoopResponse.lvm`). Populate the first column with runtime. Data is collected every 0.02 seconds. Remove outliers if needed. Create a plot that looks like **Figure 1-2**

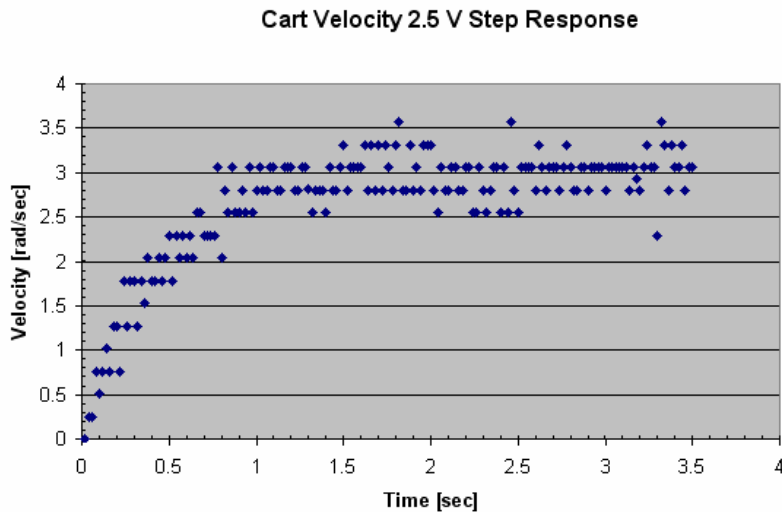


Figure 1-2: Cart's Open-Loop Step Response

Exercise 1: Identify the following from your open-loop step response plot

- 1.1. Steady-state velocity, Y_{ss}
- 1.2. Time constant, τ , i.e. time to reach 63.2% of steady state
- 1.3. Steady-state gain (i.e. $k = \frac{Y_{ss}}{A} = \frac{\text{Steady State Velocity} [\text{rad/s}]}{\text{Step Input Voltage} [\text{Volts}]}$)
- 1.4. Open-loop transfer function

Concept 2: Modeling and Simulation

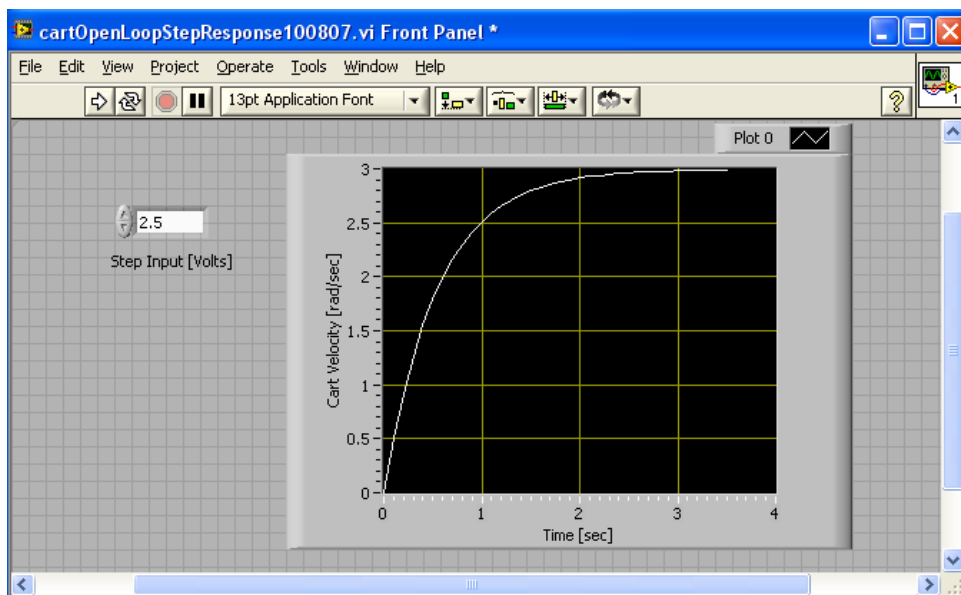


Figure 2: Simulation of cart open-loop step response. NB: looks similar to **Figure 1-2**

LabVIEW Control Design and Simulation toolkit can be used to simulate response. The answers in Exercise 1 serve for system identification; the transfer function is a representation of the plant's input-output characteristics.

Step 1: Create the simulation loop

Drop a simulation loop in the block diagram as follows. In the block diagram, right click and select **Control Design & Simulation - Simulation - Simulation Loop** (see **Figure 2-1A**). Highlight the loop and right click - **Configure Simulation Parameters**. In the resulting pop-up box, choose the following settings:

- Final time: 3.5 seconds
- ODE Solver: Runge-Kutta 3
- Step Size (s): 0.1

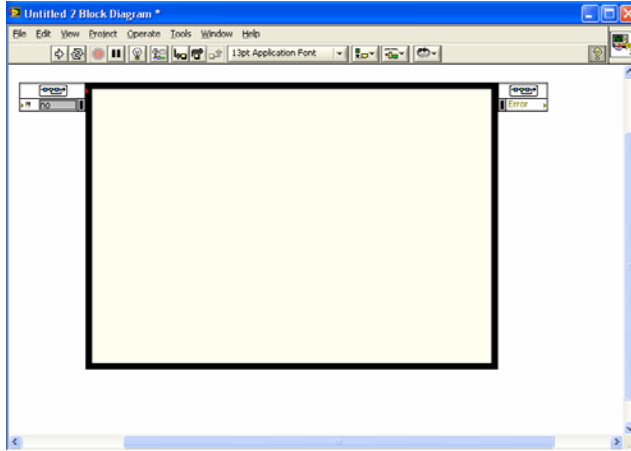


Figure 2-1A: Simulation Loop in Block Diagram

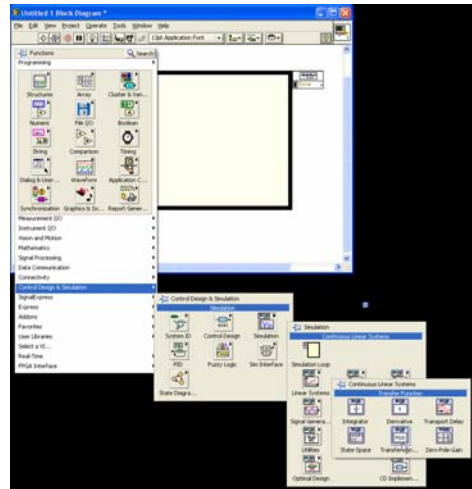


Figure 2-1B: Transfer function element

Next, drop a transfer function element into the simulation loop as follows: Right click for Control Design & Simulation - Simulation - Linear Systems - Transfer function (see Figure 2-1B). Insert this element into the simulation loop.

Double click the transfer function element. The resulting pop-up setting box (see Figure 2-1C) enables one to configure the transfer function's numerator and denominator. Configure the parameters with the transfer function found from Exercise 1-4. This will result in Figure 2-1D.

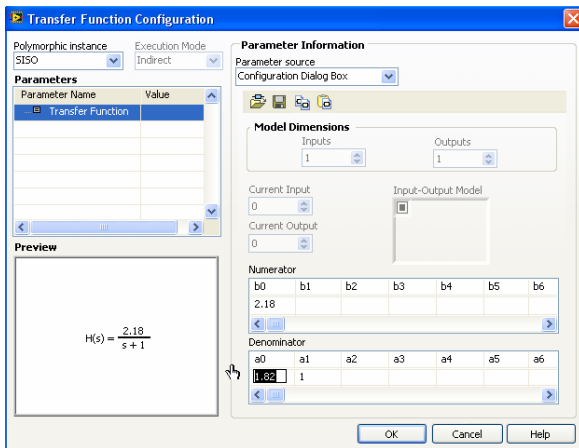


Figure 2-1C: Configuring the transfer function

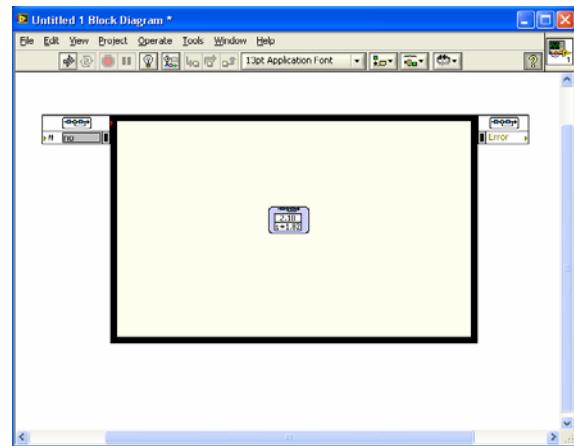
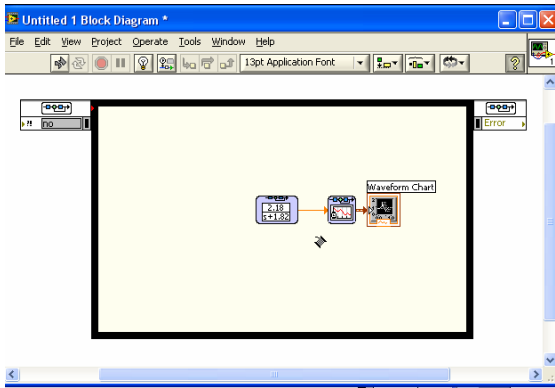
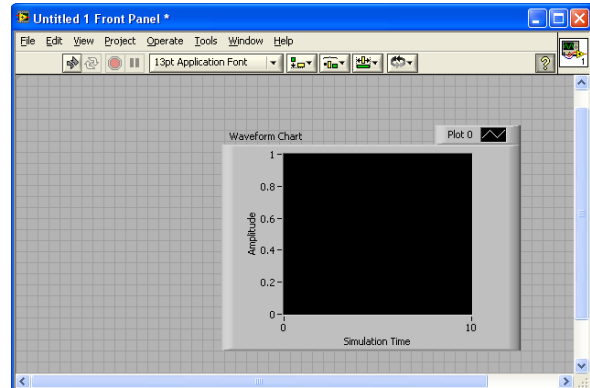


Figure 2-1D: Finished transfer function in loop

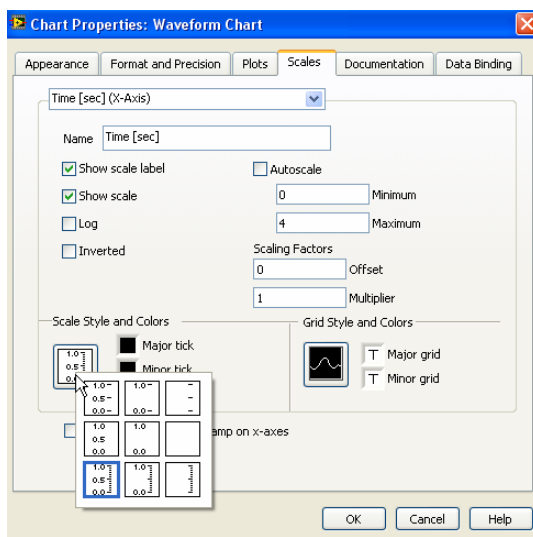
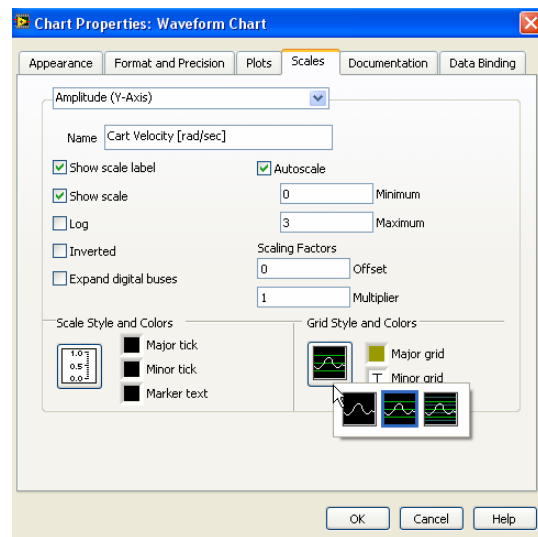
Step 2: Insert Simulation Time Waveform

In the block diagram, right click: Control Design & Simulation – Simulation – Graph Utilities – SimTime Waveform. Wire the Waveform and Transfer Function element as shown in **Figure 2-2A**. This will result in having a graph element in the Front Panel as shown in **Figure 2-2B**.

**Figure 2-2A:** SimTime Waveform element**Figure 2-2B:** SimTime Resulting Front Panel**Step 3: Configure Waveform Display Properties**

Refer to **Figure 2-3A**. From the Front Panel, right click and select Properties. The resulting pop-up box enables one to set parameters. Click the Scales tab. Under Name: type Time [sec]. Under Maximum: type 4. Click the Scale Style and Colors icon and choose the desired tick interval. Lastly, one can click the Grid Style and Colors icon for make the waveform more readable.

Refer to **Figure 2-3B**. Set the Y-axis. Under the Scales tab, use the pull-down menu to select the Amplitude (Y-Axis). Under Name: type Cart Velocity [rad/sec]. Under Maximum, type 3. Like before, one can set the Scale Style and Colors and Grid Style and Colors options to improve readability. The resulting front panel should look like **Figure 2-3C**.

**Figure 2-3A:** X-axis setting**Figure 2-3B:** Y-axis setting

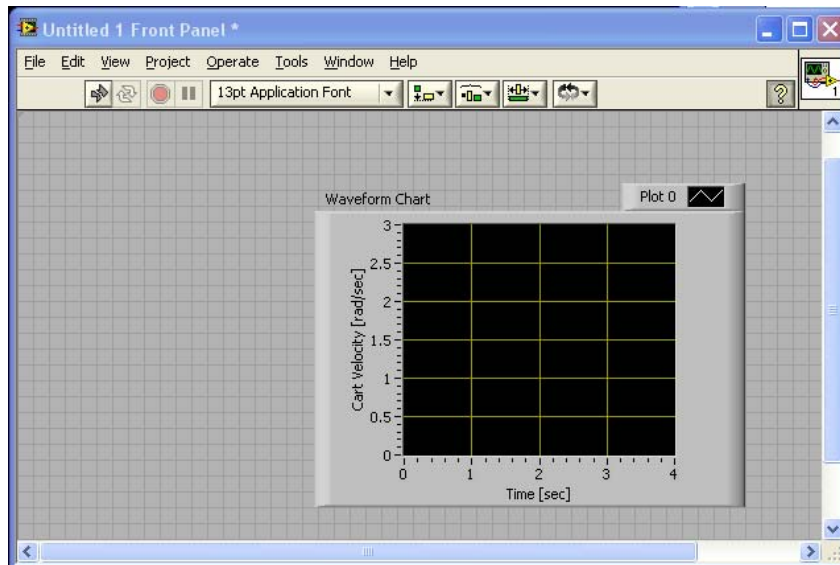


Figure 2-3C: Resulting Waveform

Step 4: Add Step Response value

Add a numeric control to the Front Panel and caption as “Step Input [Volts]”. This control will be used to set the step input voltage. Set the default to 2.5 as follows: right click on the numeric control – Data Range. Under Default Value: type 2.5. Click OK. To display the default value, right click the numeric control – Data Operations – Reinitialize to Default Value. This should result in **Figure 2-4A**.

In the Block Diagram, complete wiring between the numeric control and the transfer function (see **Figure 2-4B**). Save as: **cartOpenLoopStepResponseSimulation.vi**

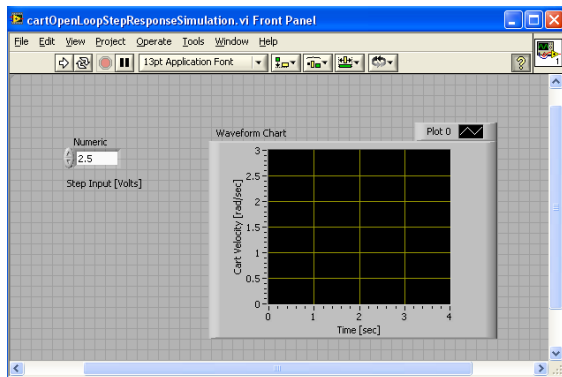


Figure 2-4A: Finished Front Panel

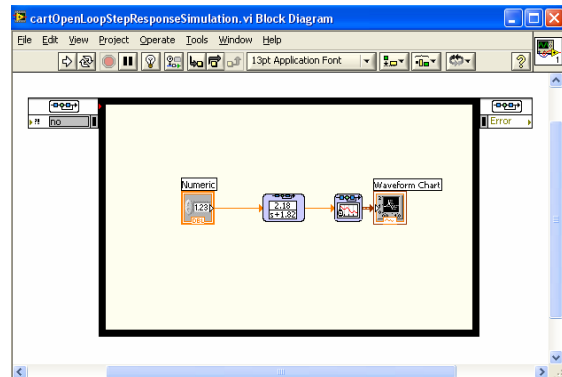


Figure 2-4B: Finished Block Diagram

Click the Run Continuously button to see the resulting open-loop step response (see **Figure 2-4C**). Adjust the Step Input level and note the change in the graph. For a 2.5 Volt input, note the similarity to data acquired experimentally (e.g. **Figure 1-2**).

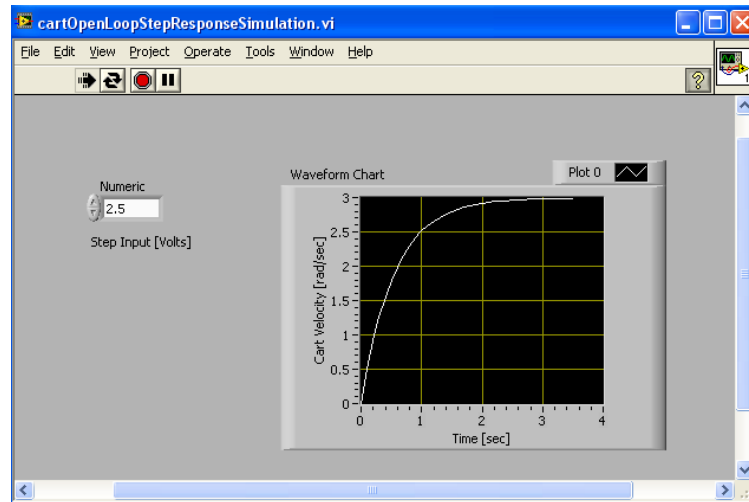


Figure 2-4C: Simulated open-loop step response

Exercise 2:

2-1: Add weight to the cart and repeat Concept 1. Identify the corresponding time constant. How does this value compare to the one found in Exercise 1-2? Explain the difference.

2-2: Repeat Concept 1 with a -3.0 Volt step input (i.e. negative voltage). Capture the angular data and identify the system's transfer function. Repeat Concept 2 with this transfer function and compare the simulated step response with the experimentally captured one.