**Hands-on Lab:**

**LabVIEW – Simulink Testing**

Previously, one captured both the step and free fall response of the LEGO Damped Compound Pendulum (DCP). Using the logarithmic decrement equation and the DCP’s physical measurements, one calculated the damping ratio, coefficient of friction, and moment of inertia (**Figure 1-1a**). Such system identification can now be used to determine the DCP (i.e. plant) transfer function. Equipped with this transfer function, one can use simulation tools, like Simulink, for future controller design.

**Concept 1:** **Calculating the DCP transfer function**

**Figure 1-1a**: DCP free body diagram (left) and both physically measured and calculated values (right)

thrustTesterFbd012905

|  |  |  |
| --- | --- | --- |
|  | Pendulum Length | 0.265 [m] |
|  | Pivot to CG distance | 0.1325 [m] |
|  | Mass of Pendulum | 0.0137 [kg] |
|  | Damping ratio | 0.033 |
|  | Natural frequency | 7.32 [rad/s] |
|  | Moment of Inertia | 0.00033 [ |
|  | Coefficient of Friction | 0.00016 [] |
|  | Steady-state angle | at 50% motor power |

A second-order system is characterized by the equation (1):



(1)

From the free body diagram, the motor-prop generates a torque. Thus dynamic equilibrium is given by (2):



(2)

Linearizing (2) where for small, and matching coefficients in equations (1) and (2) reveals the following relationships

(3a)

(3b)

Taking the Laplace transform of (2) yields

Hence

(4)

In block diagram form, (4) looks like **Figure 1-1b**. The torque results from the thrust force applied to the DCP’s lever arm (i.e. the pendulum’s length). This thrust is a result of a voltage applied to the motor-prop and prop size. The NXT Brick creates this voltage using a power command (in units of %) ranging from 0 to 100. Let represent this motor power.

**Figure 1-1b:** Block diagram relating the motor power input, to the DCP’s angle output



One could analytically use the prop’s dimensions (e.g. diameter, number of blades, and pitch) to calculate lift. If can assumeandare linearly related and use a proportionality constant (motor gain) for the relationship as in (5)

(5)

To determine one can recognize that at dynamic equilibrium, when the DCP is at its steady-state angle, (2) becomes:

(6)

In the previous lab, as shown in Figure 1-1a (last row of table), for a step input, yielded a . Substituting this into (6) and (5) yields

(7)

Using the values from (7) and the table in **Figure 1-1a**, the resulting block diagram is given in **Figure 1-1c.**

**Figure 1-1c**: Transfer function relating the motor input (as a percentage) and angle output (in radians)



**Exercise 1:**

* 1. Redo the table in Figure 1-1a, using the values you observed and calculated
  2. Using 1.1, calculate the motor gain
  3. Sketch Figure 1-1c, using and answers to 1.1 and 1.2

and and The resulting block diagram

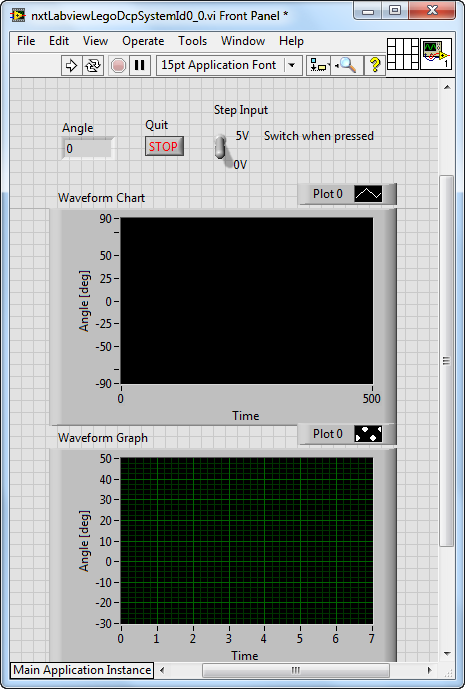
**Step 1:** Create Front Panel and Initial Block Diagram

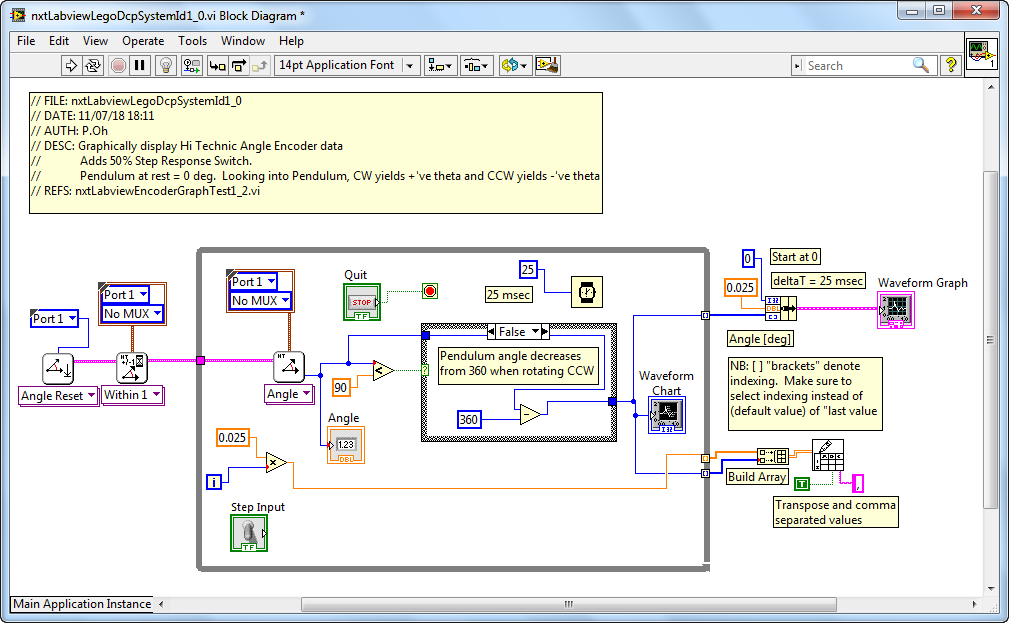
From your Angle Sensor lab open the file nxtLabviewEncoderGraphTest1\_2.vi. Recall that you wrote this file in Exercise 2-2. This Labview program consisted of a waveform chart, an XY chart, and wrote angle data every 25 milliseconds to a CSV file.

Save this file as nxtLabviewLegoDcpSystemId1\_0.vi. Note **Errata 1 and Errata 2** in **Figure 1-1A right**.

Add a toggle switch (MINDSTORMS Robotics – Boolean – Vertical Toggle Switch) to the Front Panel and add text to this switch (**Figure 1A left**). Right click this switch to make sure that the Mechanical Action is set to Switch When Pressed. In the Block Diagram, drag the toggle switch so that it is inside the while-loop (**Figure 1A right**).

**Figure 1-1A:** The toggle switch is in the Front Panel (left) and inside while-loop of Block Diagram (right). **Errata 1:** The block diagram incorrectly compares the angle to 90. **This should be 180**. Also, **Errata 2**: the numeric indicator should be re-wired to be after the Case Structure (e.g. next to the waveform chart). Refer to **Figures 2B and 2C**, which are correct

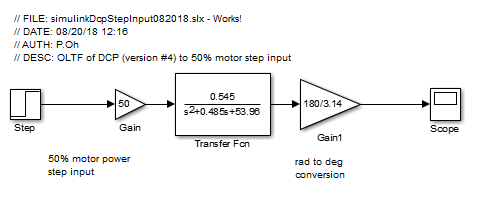




**Step 2:** Add a Motor Block to the Block Diagram

The toggle switch serves as a step input to the motor; when flipped on, a 50% motor power command will be fed into the motor. To achieve this, first add the NXT motor block (MINDSTORMS Robotics – I/O – Move Motors) into the while-loop. By default LEGO Mindstorms calls this block Power. Right click on the Power block and select Create Constant. Hovering over the created constant, select NXT Motor 1 (**Figure 1-2A**).

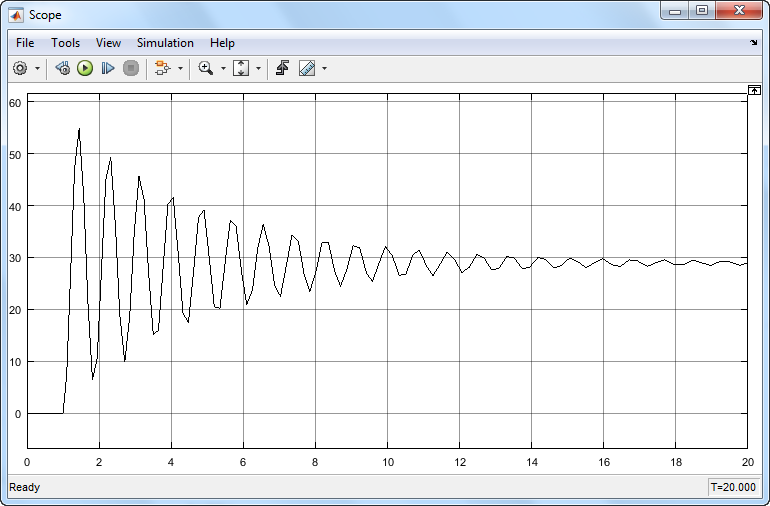
**Figure 1-2A:** Motor added to block diagram (called Power) with constant NXT Motor 1 as the assigned port. NB: The figure is incorrect, recall **Errata 1** and **Errata 2** from Figure 1A. Refer to **Figures 2B and 2C**, which are correct



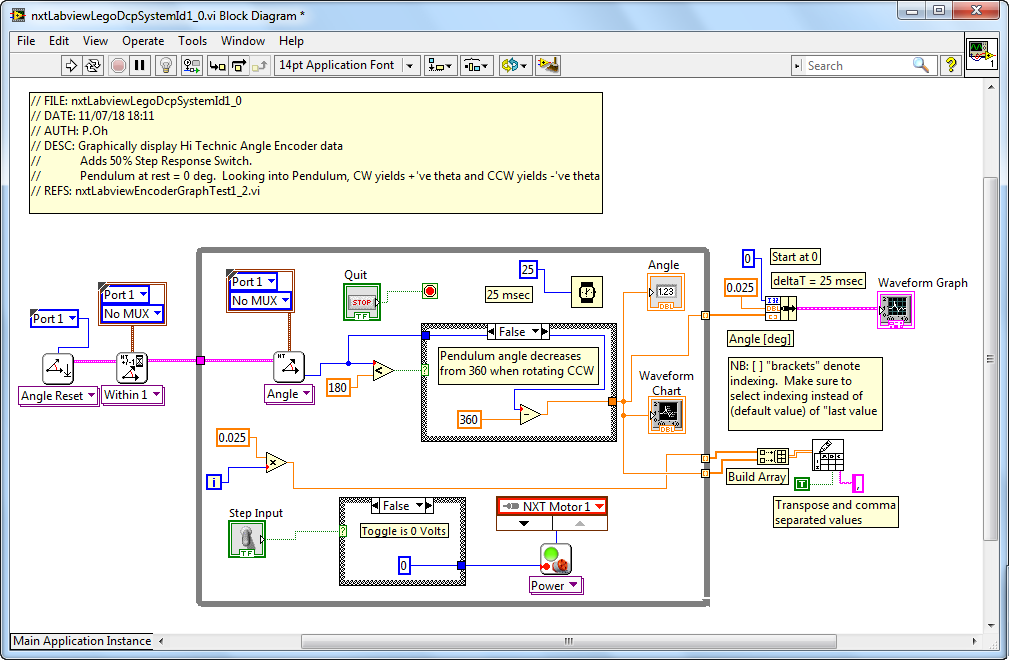
Next, place a Case Structure between the toggle switch and motor. For the True condition, add a numeric constant. Set this constant to 50, and wire it thru the Case Structure and into the motor’s Power input (**Figure 1-2B**).

For the False condition, add a numeric constant with the value of 0. Wire this constant to the Case Structure (**Figure 1-2C**). The net effect is when the Labview program is played toggling the switch will set the Case Structure to True and consequently issue a value of 50 into the motor power (and thus activating the motor). Conversely, when the switch is False, 0 is fed into the motor power (essentially deactivating the motor).

Save your program (called nxtLabviewLegoDcpSystemId1\_0.vi).



**Figure 1-2B:** A Case Structure is added into the Block Diagram. For the True condition, the numeric constant is fed into the input of the motor (Power block). The toggle switch is wired to the Case Structure. NB: NB: **The figure here is correct**; it incorporated the aforementioned errata



**Figure 1-2C:** For the Case Structure’s False condition, a numeric constant of zero is fed into the motor input (Power block). NB: **The figure here is correct**; it incorporated the aforementioned errata

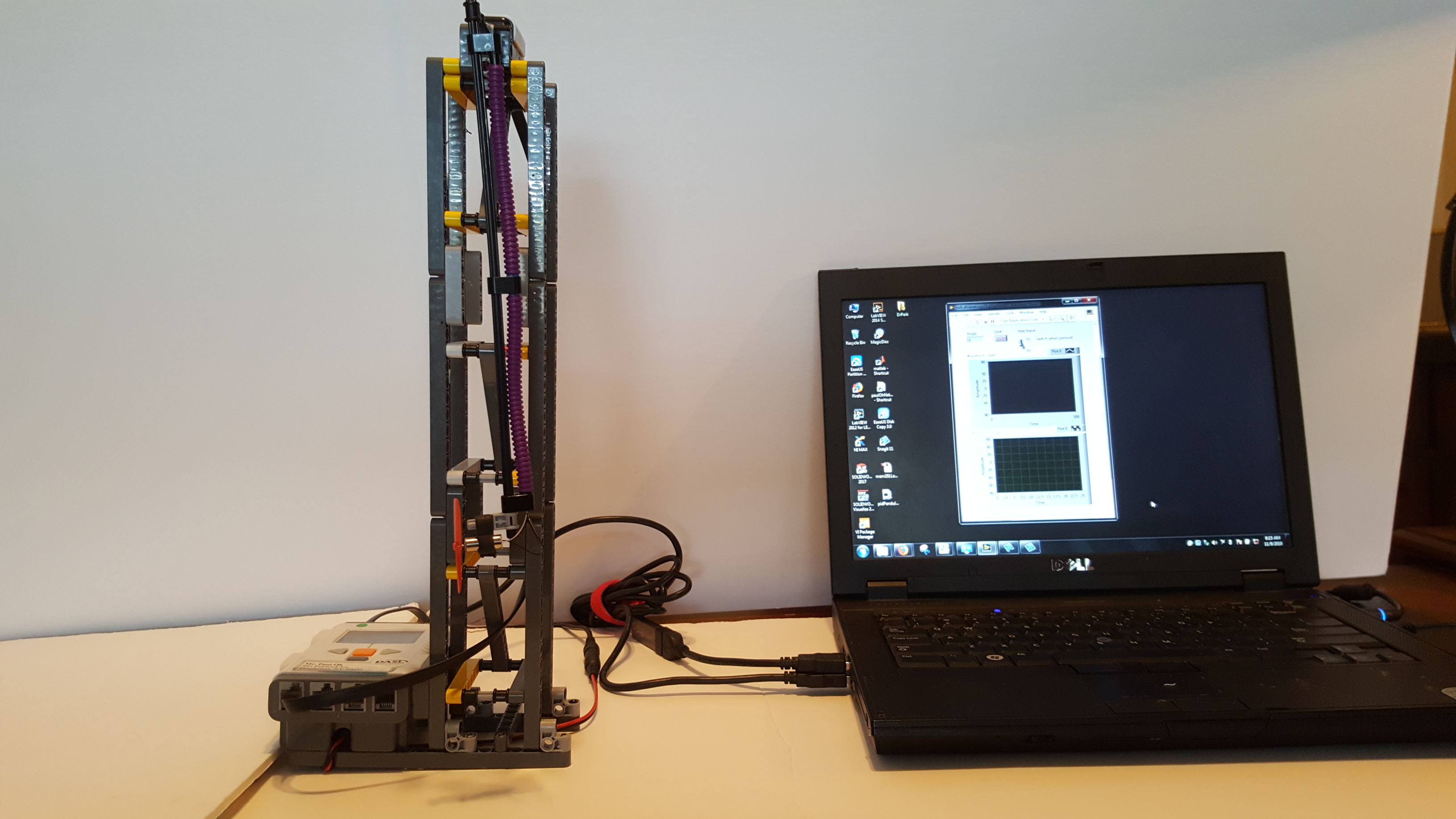
**Step 3:** Execution

A step response will be performed on the LEGO DCP (see **Figure 1-3A**). The above block diagram shows the angle sensor and motor connections. Thus, connect your NXT cable from the Hi Technic Sensor to the Port 1 of the NXT and your spliced NXT cable to Port A of the NXT.

Since this program will activate the motor-prop, make sure to clear any obstacles the pendulum could possibly hit. Execute the program (nxtLabviewLegoDcpSystemId1\_0.vi) and observe the waveform chart. Toggling on the switch will send 50% power to the motor and the pendulum will start to rotate clockwise. Toggling off the switch stops the motor. Repeat toggling on and off to ensure the LEGO DCP and your program is working as expected (**Figure 1-3B**).

Hit the front panel’s Stop button. A pop up box will prompt you to enter a file name. For example, saving as **systemId-110918-07H41M.csv** suggests the data was saved on 11/09/18 and 7:41 AM as comma-separated values (CSV) file format.

Opening this CSV file with Excel and plotting the values (**Figure 1-3C**) yields what was captured and displayed on the front panel’s XY chart

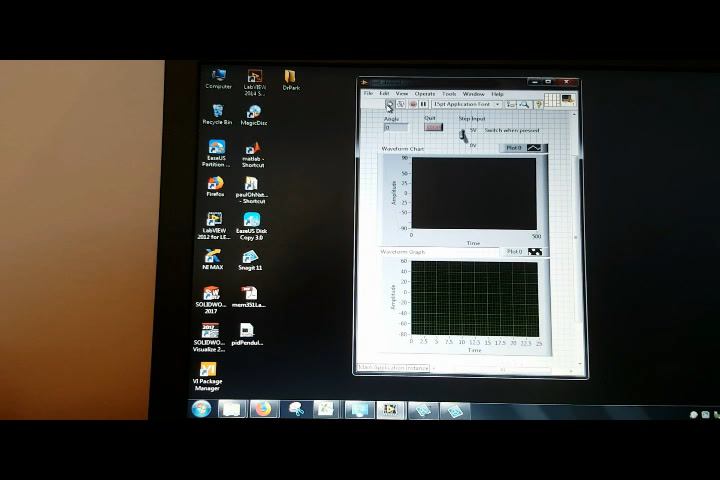


**Figure 1-3A:** LEGO DCP connected to laptop. Note: no obstacles in the pendulum’s pathway. Angle sensor and Motor are connected to the Brick’s Port 1 and Port A respectively.

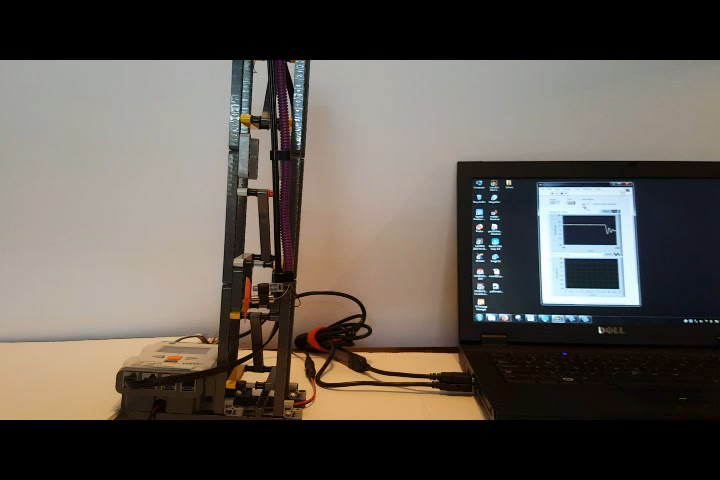
**Figure 1-3B:** Sequential photos from a video. Top Row: Program is executed (left); pendulum at rest (middle); and switch toggled on and activates motor-prop (right). Bottom Row: motor-prop generates thrust which raises pendulum and waveform chart provides real-time display of angle (left); toggling motor off, stops motor and pendulum returns to zero angle position (middle); toggling switch on again raises pendulum and waveform chart shows angle response (right).

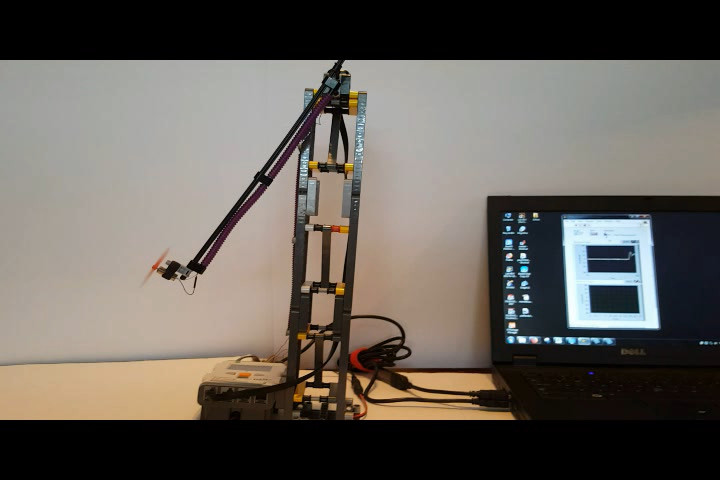




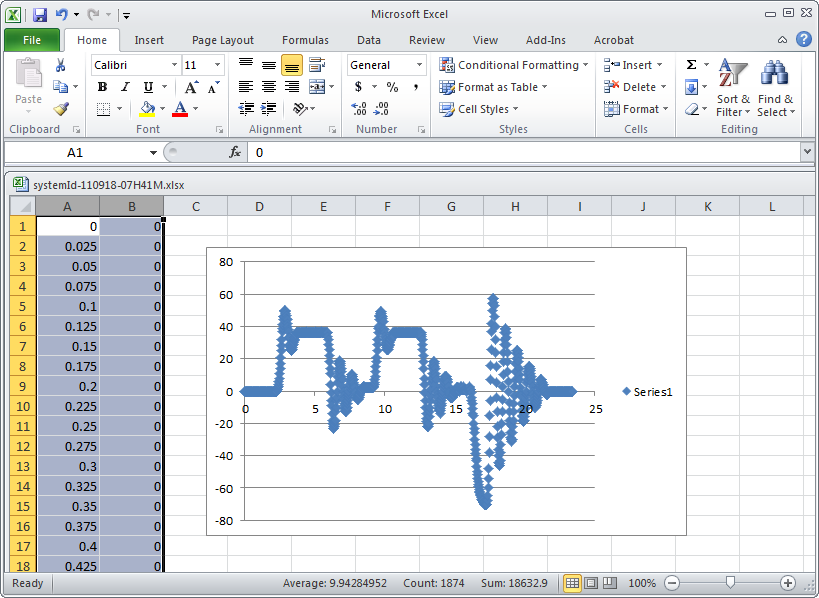








**Figure 1-3C:** Opening the CSV file in Excel, and performing a scatter plot, shows the LEGO DCP’s angular response to a step input. One sees (around 2.5 seconds) that apply 50% motor power (due to toggling the switch on), has the pendulum reach a peak angle (about 50 degrees) and oscillates to reach a steady-state angle of about 35 degrees.



**Exercise 1:**

* 1. Complete the following table

|  |  |  |  |
| --- | --- | --- | --- |
| Your Step Response Input (i.e. motor power) [%] | | Your Steady-State Angle [deg] | |
| e.g. 50% |  | e.g. 29 deg |  |

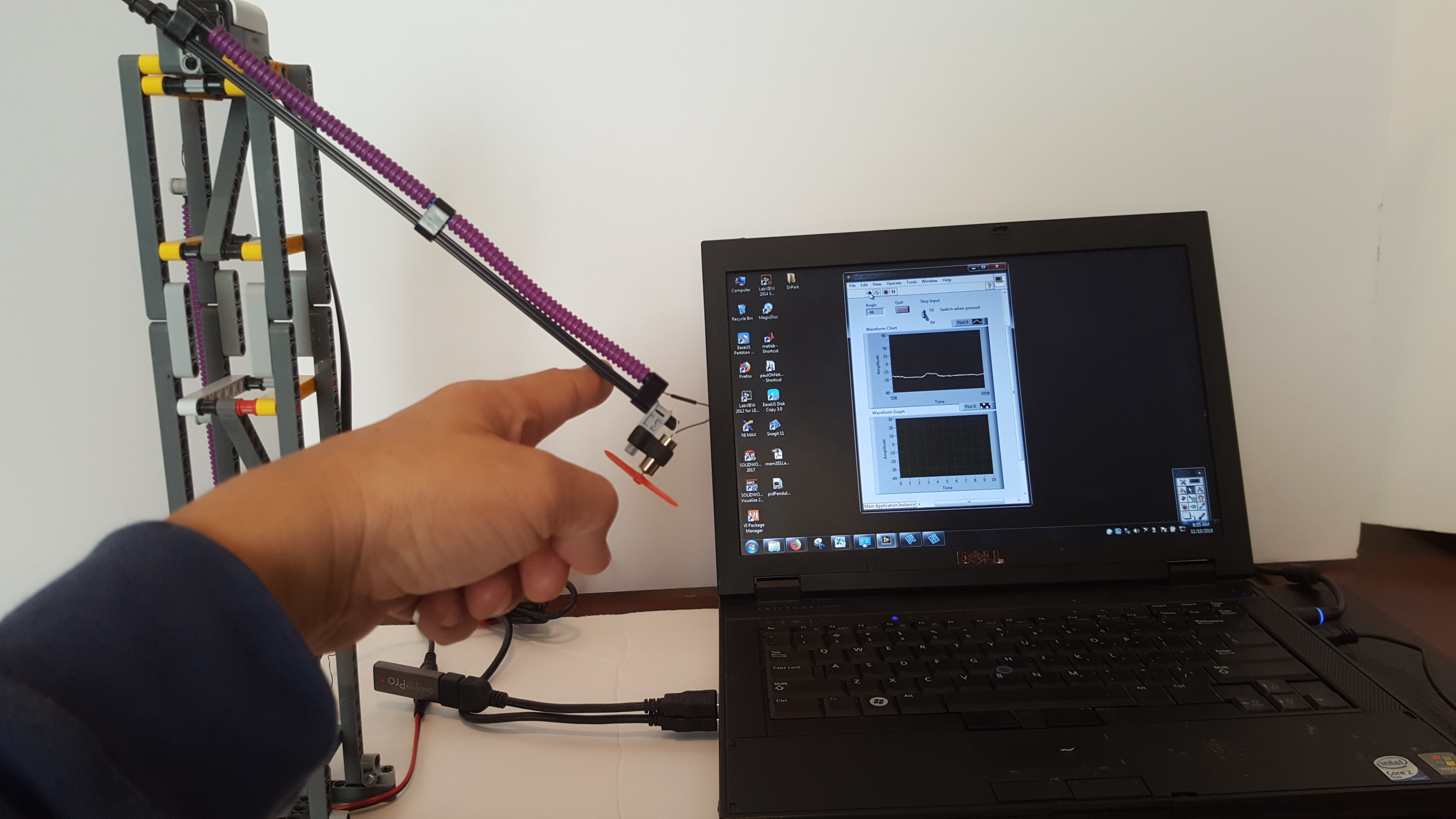
**Concept 2:** Free fall data capture and Logarithmic Decrement

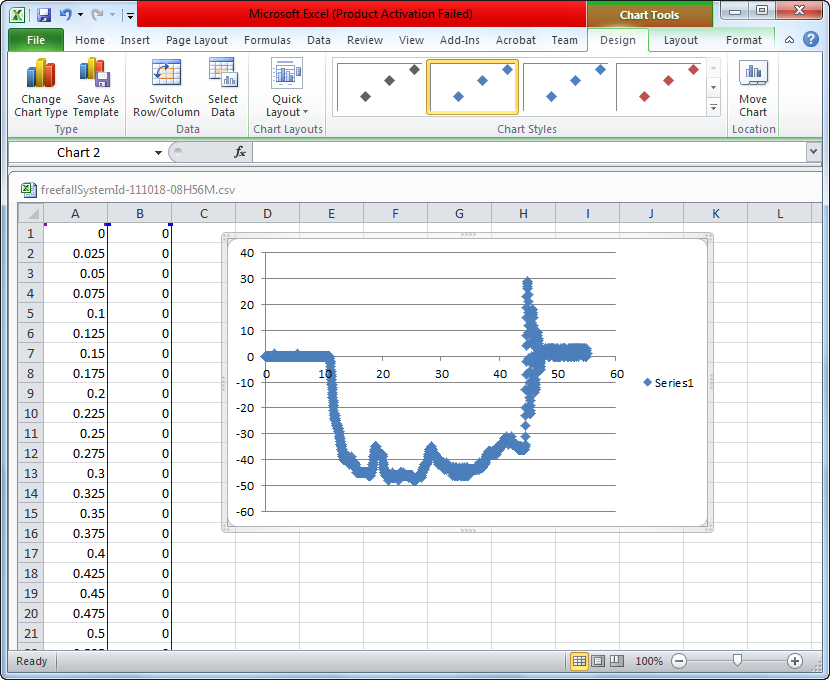
Pendulums, like the LEGO DCP, when released from an initial angle, will oscillate. The oscillations’ amplitudes become smaller as the pendulum swings back-and-forth, until the finally stop. This is a characteristic of damped second-order systems like the LEGO DCP. The amplitudes and period are related to the system’s damping constant and damped natural frequency. This relationship will be shown in this concept. Such system identification serves to find a mathematical model (called transfer function) of the system (i.e. plant).

**Step 1:** Execute nxtLabviewLegoDcpSystemId1\_0.vi

Here, toggling will not be used. Instead, run the program and rotate the pendulum counter clockwise (CCW) to an initial angle (e.g. -45 degrees) and release (**Figure 2-1A left**). Once the pendulum is motionless, hit the Stop button and save the data e.g. legoDcpFreefall-111018-08H56M.csv. Graph the data in Excel as a scatter plot (**Figure 2-1A right**).

**Figure 2-1A:** Program is executed on laptop and pendulum moved counter clockwise to about -45 degrees (left). Scatter plot of captured data in Excel (right).





**Step 2:** Label data points for peaks and calculate damping ratio and natural frequency

The data of interest in **Figure 2-1A right**, is the oscillatory peaks. Recall that the pendulum’s angle gets smaller as time elapses. The amplitudes of subsequent peaks are related to the pendulum’s damping ratio and natural frequency thru a logarithmic decrement (1):

(1)

Here, is the th peak and is the th peak (for any) are the amplitudes of subsequent peaks. The period of the oscillations is also related thru (2)

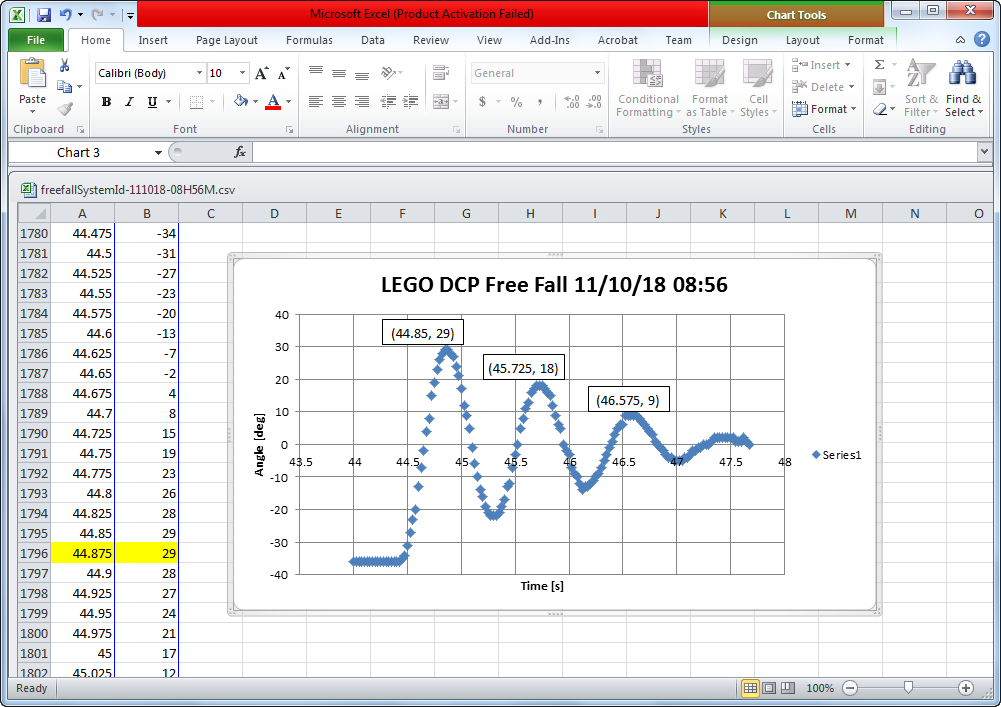
(2)

Using (1) and (2) and with the definition of one can show (3)

(3)

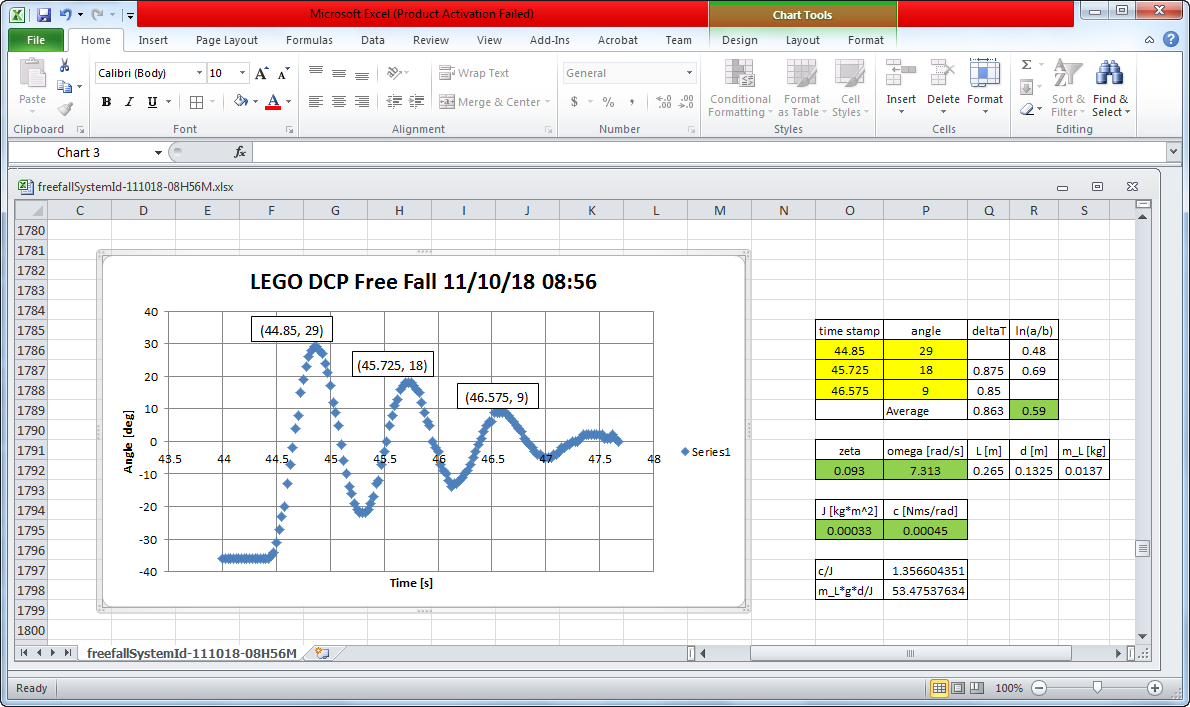
and

**Figure 2-2A** focuses the scatter plot on the oscillatory peaks. Point your mouse over each peak to reveal the associated angle and time. For clarity, these angles and times are added as text boxes over each peak. The plot’s title and axes are also labeled. **Figure 2-2B** implements equations (1)-(3) in Excel. Here, the average period and logarithmic decrement were used.



**Figure 2-2A:** From an initial angle of about -45 degrees, the pendulum oscillates for about 3 times. The angle and time of each peak was identified. The peaks are labeled with this data.

**Figure 2-2B:** Angles and times (yellow highlighted cells) were used to compute the average period and logarithmic decrement. These values were then used to compute and. Physical properties like mass and lengths are also shown and used to compute the DCP’s moment of inertia and damping coefficient.



**Congratulations: LEGO Damped Compound Pendulum System ID Completed**

**Exercise 2:**

* 1. Complete the following table

|  |  |  |  |
| --- | --- | --- | --- |
| Your Damping Ratio | | Your Natural Frequency | |
| e.g. 0.093 |  | e.g. 7.313 |  |
|  |  |  |  |

* 1. Referring to the free body diagram, complete the following table

thrustTesterFbd012905

|  |  |  |  |
| --- | --- | --- | --- |
|  | Pendulum Length [m] | e.g. 0.265 [m] | Your value |
|  | Pivot to CG distance [m] | e.g. 0.1325 [m] |  |
|  | Mass of Pendulum [kg] | e.g. 0.0137 [kg] |  |

**Exercise 2:**

* 1. Using compute the Moment of Inertia (e.g. 0.00033 )

* 1. Using compute the coefficient of friction (e.g. 0.00045 )