# Using PhysLogger to Investigate Nonlinear Dynamics with a Magnetic Pendulum

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## Scope

PhysLogger is a versatile data logging and control device that allows users to measure, manipulate, and analyze quantities around them. In this experiment, PhysLogger will be used to study the non-linear and chaotic dynamics of a magnetic pendulum. This setup is called PhysMag and details of the experiment can be found at: https://physlab.org/experiment/physmag-nonlinear-dynamics-with-a-magnetic-pendulum/.

PhysLogger is connected to two PhysInstruments: Qosain General Stepper Motor Controller (SMC) and PhysCompass. The driver frequency of the pendulum will be varied through the SMC, whereas PhysCompass will be used to collect and plot the angular displacement readings for the pendulum. These readings can be quickly visualized and manipulated in PhysLogger Desktop for a qualitative analysis. Furthermore, the readings can be exported from PhysLogger Desktop App and imported into an advanced software, e.g., MATLAB, for an involved mathematical analysis.
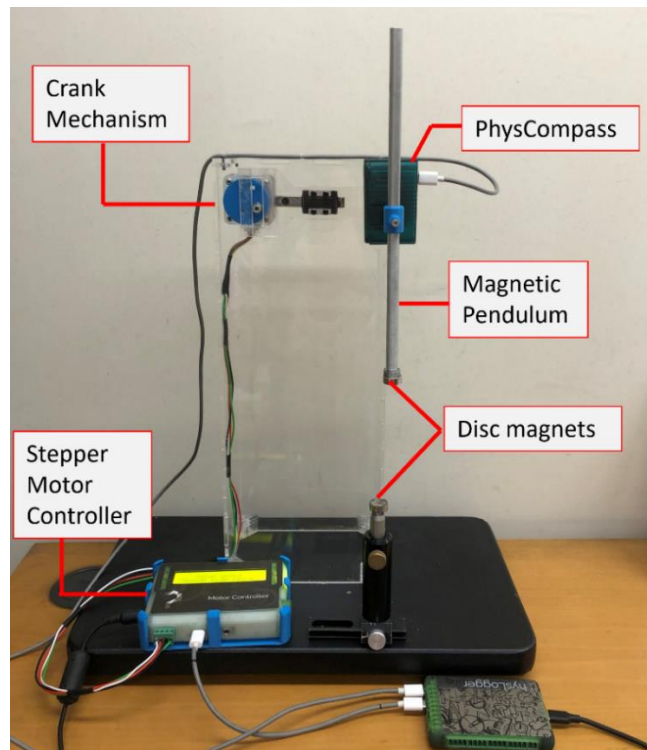
## Experimental Setup



Figure 1: Experimental setup for investigating nonlinear dynamics with a magnetic pendulum (PhysMag). The magnetic pendulum has an adjustable height and detachable permanent disc magnets. The pendulum is suspended from a vertically

mounted PhysCompass that is connected to PhysLogger. The pendulum and PhysCompass are attached to a slotted crank pin mechanism that is driven by a stepper motor. This motor is controlled by the Stepper Motor Controller (SMC). SMC is also connected to PhysLogger.

## Procedure

## Making all connections

1. Set up the apparatus, as shown in Figure 1.
2. Initially, it is ensured that the distance between both magnets is sufficiently large (> 10 cm) so there is minimal magnetic force on the pendulum. This distance is adjusted by changing the height of the vertical post below.
3. Connect the stepper motor of the crank mechanism to SMC via the motor terminal block on SMC, as shown in Figure 2 (a).
4. Connect a 12 VDC, 2 A power adapter to SMC via the DC power jack on SMC as shown in Figure 2 (b).
5. Plug the DC power adapter to a power source and press the ON button on the side of SMC. The LCD screen of SMC should light up.



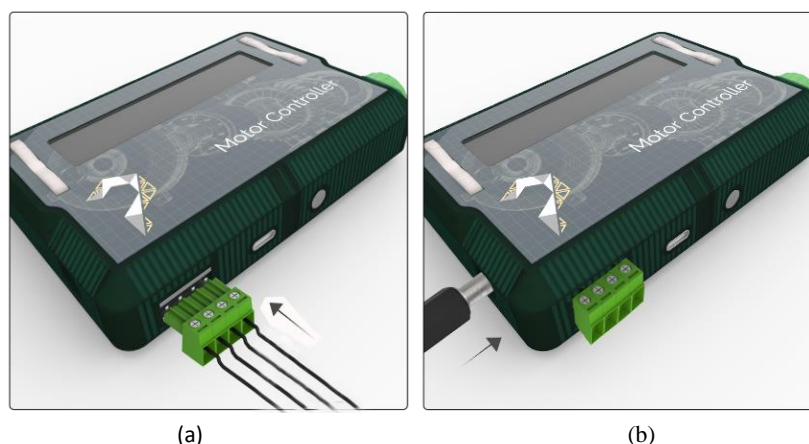(a)                                           (b)

Figure 2: (a) The stepper motor is connected to the motor controller via the motor terminal block on SMC and (b) the motor controller needs to be connected to a DC power adapter to be switched on.

6. Using a USB C to C cable, connect SMC to a digital channel of PhysLogger.
7. Connect PhysCompass to another digital channel of PhysLogger.
8. Connect PhysLogger to your PC by inserting the provided USB cable to the USB (•←–) port of PhysLogger.

## Beginning the Experiment: Calibrating and Taring PhysCompass

PhysCompass is used to measure the angular displacement $\theta$ of the pendulum.

9. PhysCompass is powered on as soon as the PhysLogger device is connected to PC,. This is signified by a red LED on PhysCompass being switched on.

10. Moments after being switched on, PhysCompass automatically calibrates itself. Slightly swing the pendulum suspended from PhysCompass to allow proper calibration.
11. Locate and open `PhysLogger2` application on your PC.
12. Click on `Measure > Rotation > Make a LivePlot now.`
13. To confirm that PhysCompass has been properly calibrated, oscillate the pendulum and observe how the angular displacement $\theta$ varies. Figure 3 shows a comparison between an uncalibrated and calibrated PhysCompass.
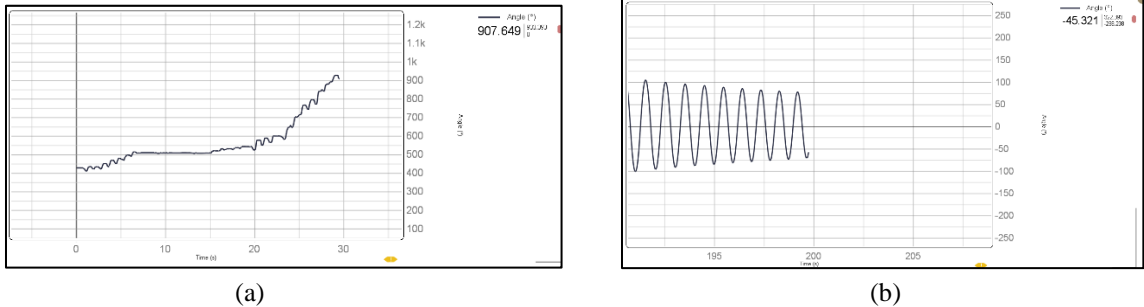


(a)                                          (b)

Figure 3: (a) An odd graph such as this for an oscillating pendulum clearly indicates an uncalibrated PhysCompass. (b) A correctly calibrated PhysCompass will generate a LivePlot such as this when the pendulum is freely oscillated.

14. In case your PhysCompass was not automatically calibrated and shows an abnormal behavior such as that shown in Figure 3 (a), calibrate PhysCompass using any of the following methods:
    a. Unplug PhysCompass from PhysLogger (ignore any warnings given by the application) and plug PhysCompass back into PhysLogger. Repeat Step 9.
    b. Go to `Quantities Panel > PhysCompass > Calibrate.` Swing the pendulum. Refer to Figure 4 and Figure 5.
15. When the pendulum is at its stationery mean position, tare PhysCompass readings. This can be done by pressing and holding (for at least 3 seconds) the hardware `Tare` button on PhysCompass or using the software `Tare` control, as shown in Figure 5. The angular displacement $\theta$ readings are zeroed once PhysCompass has been tared.

Figure 4: If both PhysInstruments (SMC and PhysCompass) are properly connected to PhysLogger, they should appear in the Quantities Panel as shown above. If an instrument is connected to PhysLogger but does not appear here, scan the busses of PhysLogger using [icon].
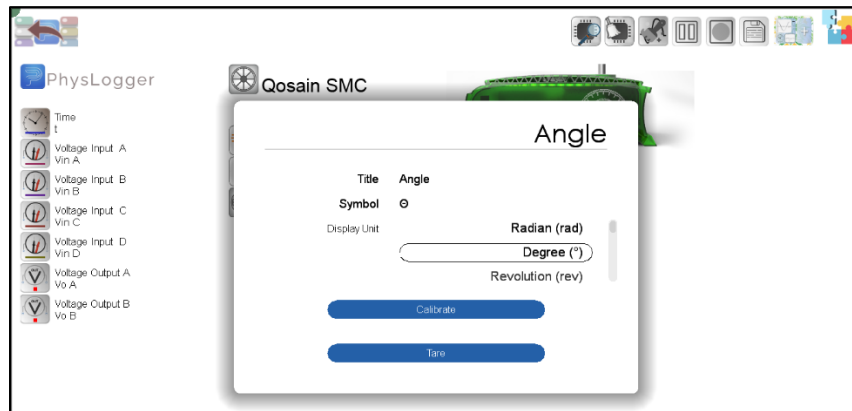


Figure 5: PhysCompass can be calibrated and tared anytime by clicking on its icon in the `Quantities Panel`.

## Controlling Driver Frequency: Configuring the Stepper Motor Controller (SMC)

16. From the `Quantities Panel, go to` `Qosain SMC > Working Mode > Speed`.
17. In `Speed` mode, select a display unit for motor parameters (rad/s in this case).
18. In `Source`, create a graphical control widget, such as a horizontal slider. This will allow you to vary the driver frequency i.e., speed of the motor in run time from the workspace.
19. You may rename your motor speed controller slider (we named it `Motor Speed`). Figure 6 shows how the SMC is set up in the application.
20. Specify the range of the horizontal slider by clicking on the minimum and maximum value of the slider. By default, the slider has a maximum and minimum value of -1 and 1, respectively. We changed it to 0 rad/s to 12 rad/s (Figure 7).
21. To operate the SMC from PhysLogger Desktop, enable `Power` (its value will be set as 1).
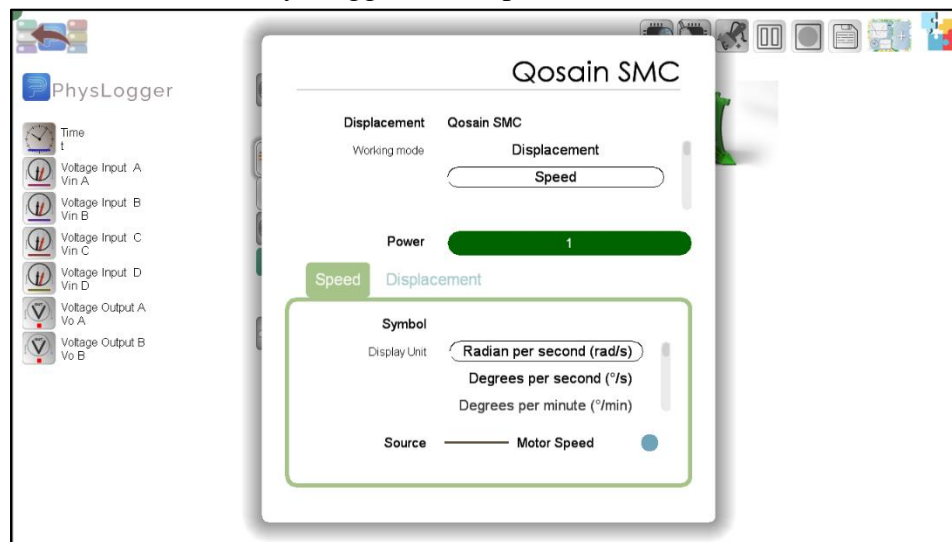
Figure 6: Setting up an adjustable slider (named `Motor Speed`) and other parameters of SMC in PhysLogger Desktop to control the speed of the stepper motor.

# Determining the Resonance Frequency

In the experiment, the motor is driven at about 70–80% of the pendulum's resonance frequency $\Omega_o$. Thus, the resonance frequency $\Omega_o$ needs to be determined first.

22. To find the resonance frequency of the system, the magnets are positioned sufficiently further apart such that there is negligible force between them.
23. Using the horizontal slider created earlier, gradually vary the speed of motor and observe how the amplitude (angular displacement $\theta$) of the pendulum varies.
24. You may plot a LivePlot of angular displacement $\theta$ against motor speed to identify the resonance frequency. (Add a new LivePlot by navigating to `Extensions Menu > Build from scratch > Widgets > LivePlot`.)
25. The resonance frequency $\Omega_o$ is the motor speed at which the angular displacement $\theta$ is the maximum. Refer to Figure 7 to see how we identified the resonance frequency.
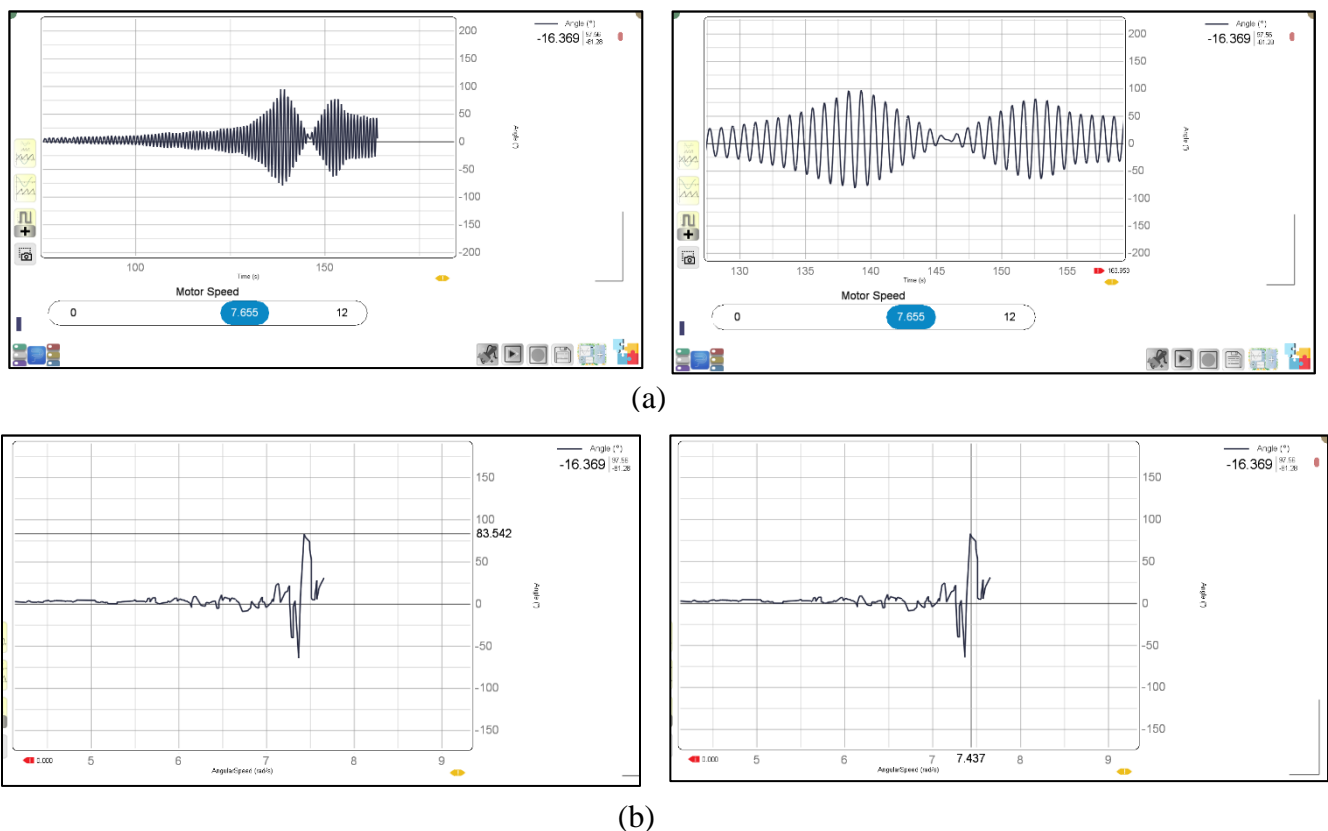


(a)



(b)

Figure 7: To identify the resonance frequency $\Omega_o$ of the system, vary the `Motor Speed` using a horizontal slider you created. (a) Identify the speed (position of horizontal slider) at which the amplitude of oscillations is the maximum. For better precision you may also (b) plot angular displacement $\theta$ against `Motor Speed` and note down the motor speed at which the amplitude of the pendulum is the maximum (in this case the resonance frequency $\Omega_o$ was found to be 7.437 rad/s).

## Experimental observation of the nonlinear motion and development of the phase portraits

A phase portrait is a two-dimensional system with the canonical coordinates being angular displacement ($\theta$) and angular speed ($\omega = \dot{\theta}$) of the magnetic pendulum. Non-linear and chaotic behaviors can be observed in these diagrams.

After setting $\Omega \approx 0.7\Omega_o$, the distance $d$ between the two magnets is varied by adjusting the height of the post on which the magnet is perched. As the distance is changed, and different phase portraits are obtained, remember to keep the initial conditions of the pendulum constant. The initial conditions include the motor speed and the initial angle from which the pendulum is displaced.

26. To calculate the angular speed $\dot{\theta}$ of the magnetic pendulum, you need to differentiate the angular displacement $\theta$ of the pendulum.
27. Go to `Extensions Menu > Build from scratch > Advanced > Differentiate`.
28. In the `Differentiate` window, specify the angle $\theta$ of the magnetic pendulum as the source. `Differentiate` utilizes four-point differentiation algorithm to compute the angular velocity $\dot{\theta}$ of the pendulum.
29. In a new LivePlot, plot this differentiated quantity (angular velocity $\theta$) on the vertical axis against angular displacement $\theta$ on the horizontal axis.
30. Gradually decrease the distance $d$ between the two magnets.
31. For each measurement of $d$, observe the changes that occur in the time course plots and the phase portraits of the pendulum.
32. For an advanced quantitative analysis of the data, save and export the readings.

A few sample phase portraits generated in PhysLogger are shown in Figure 8.
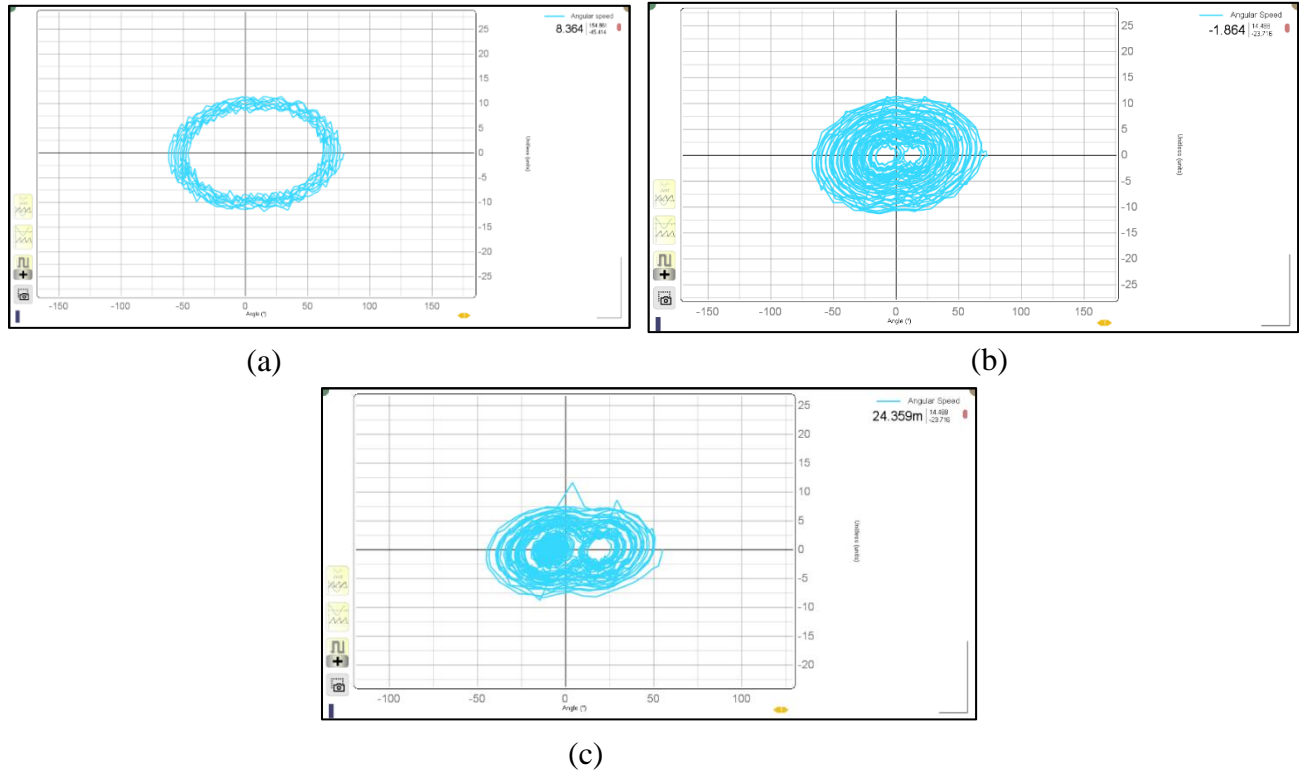
(a)



(b)



(c)

Figure 8: Some phase portraits generated in PhysLogger Desktop App. The distance *d* between the magnets was decreased from (a) to (c).

# Some further points of exploration

If curious and motivated, you may explore several controls and features of PhysLogger through this experiment. Tables can be made in the application, on-screen widgets attached to quantities, meaningful LivePlots with different readings generated, and an intuitive understanding developed of the many underlying concepts.

### Minimizing noise in the readings

For instance, you can try to minimize the noise in readings. If you spot erratic behavior in the angular speed readings of magnetic pendulum (i.e., the differentiated angular displacement), try minimizing this noise by applying a low pass filter to the readings (determine an appropriate cut off frequency) or experiment with various sampling frequencies. The **low pass filter** can be found in the `Extensions Menu > Build from scratch > Advanced`. **Sampling frequency** can be adjusted by clicking on the `Time` quantity.

Further, identify the possible reason behind these fluctuations. Is it inherent or due to some connected instruments? Can the four-point differentiation algorithm be a reason? You may also test if there is any change in the noise when motor is on and off.

The following figure shows an instance where we applied a low pass filter on the angular velocity of the magnetic pendulum. A noticeable reduction in noise can be observed. You may perform similar tests on your readings.
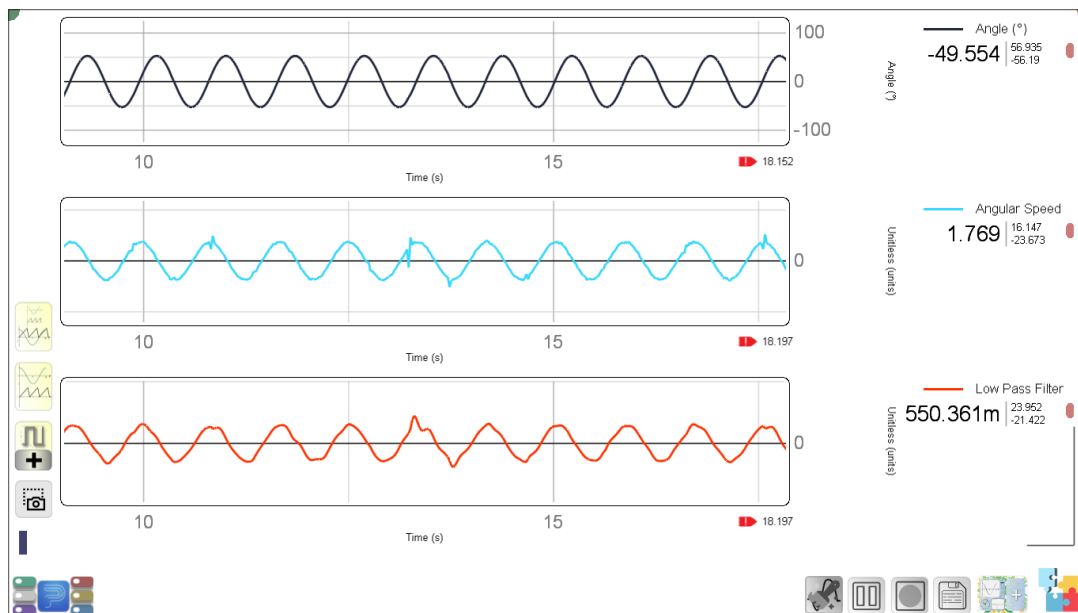
Figure 9: An example of how one can reduce noise in readings (angular speed of magnetic pendulum) by applying a low pass filter on the readings. This filter is present in the widgets menu of PhysLogger Desktop.