PARTICLE TRACKING FOR A SIMPLE HARMONIC MOTION

A linear restoring force that brings back a body to the equilibrium position may cause harmonic oscillations. *Harmonic* means that position, velocity and acceleration can all be described by sinusoidal functions of time. A pendulum or a spring are good examples of this motion, provided that the departure from the equilibrium position is small. A simple pendulum (a point pass hanging from a thin thread of length $\boldsymbol{l}$) will be considered in this laboratory session. The period of such oscillations can be shown to be $\boldsymbol{T} = \boldsymbol{2\pi}\sqrt{{}^{\boldsymbol{l}}/_{\mathbf{g}}}$. Therefore $\boldsymbol{g} = {}^{\boldsymbol{4\,\pi^2 l}}/_{\boldsymbol{T^2}}$, and so a measurement of the period $\boldsymbol{T}$ will provide a value of the gravity constant $\boldsymbol{g}$.

You are requested to take this measurement using two procedures. The first will be done manually, with a chronometer. The second one is an automated procedure in which you will use a technique known as *particle tracking*, that involves image processing of a video recording to detect the position of the pendulum mass.

A. MEASUREMENT OF THE PENDULUM PERIOD BY HAND

The pendulum length $\boldsymbol{l}$ can be chosen arbitrarily. Measure it as precisely as you can with a tape measure. Then measure $\boldsymbol{T}$ with the chronometer. Find $\boldsymbol{g}$ and its error.

Remark.- The reaction time of a person imposes a limit on the measurement precision of $\boldsymbol{T}$. The expedient is to measure several $\boldsymbol{T}$ in a row (five or six periods, for instance), then divide by the number of periods. (The reaction time error is then proportionally reduced). Repeat ten times to find the average and standard deviation.

B. MEASUREMENT OF THE PERIOD BY PARTICLE TRACKING

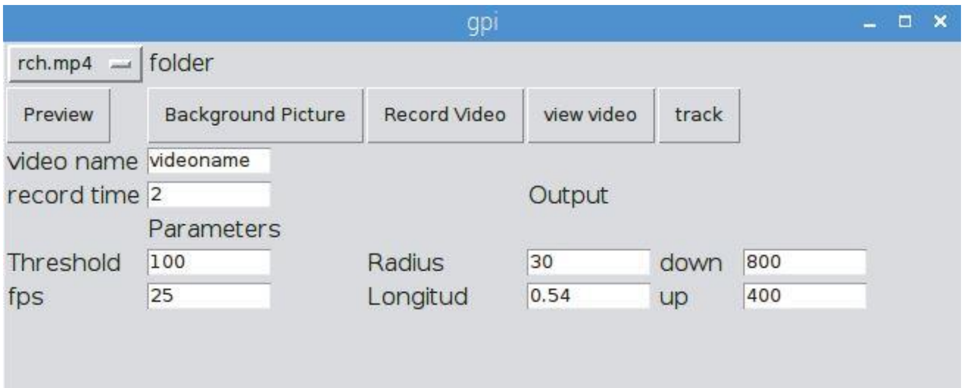
You will now use a nanocomputer (a Raspberry Pi), with a camera, to capture a video, identify the body of interest in the recording, track it along time, and measure the period of the pendulum. Hopefully, you will only need to perform minor adjustments.

Preparation.- The camera is focused at 50 cm. Place the camera at such a distance from the pendulum. Set the white screen behind the pendulum. Lighting is of crucial importance; use natural light if possible and avoid the shadow of the sphere as much as possible.

You will take an image of the background, without the pendulum. After that, you will want a short (~4 seconds) video to test that everything is working fine. Once you have fixed the system variables, you will record a longer (20 seconds) video. The program will then track the bead and provide you the measurements for the period.

Proceed by completing the following steps.

1. Open a terminal by clicking on the terminal icon: 
2. Type **`python3 gpi.py`** to launch the program. A window will appear with several buttons that will help you to accomplish the task:



3. Place the pendulum in front of the camera, at 50 cm. Put the white screen behind the pendulum. You can visualize the field by pressing the **Preview** button.

Once you are satisfied with the lighting, the image setting and framing, take care not to change the setup (camera, pendulum, light) until you finish. If you change it, you may have to start anew.

Close the preview window with this procedure: click on the window bar, press **q**, then close the window with the close button (the one marked with **x**).

Remark.- It is important that you close the windows that display graphical output once they are not needed any more. Leaving opened windows after a task is completed may cause the program to stop working.

4. Lift the thread of the pendulum to take it out of the image entirely and press **Background Picture** to take a still photograph of the background (it will take some seconds; the image will be displayed and automatically saved under the name *imagef.jpg*; you can see how it looks by double clicking on it). All the output will be stored in the folder **dataGPI**. Close the image preview by clicking the *close* button.

5. Tilt a little bit the pendulum mass and release it, just like in a grandfather clock. Do it in such a way that the oscillation takes place in a plane perpendicular to the camera line of view.

6. Write a name for the video file in the *video name* box, type 4 seconds in the *record time* and take a video by pressing **Record Video**. You can view it once recording has finished by pressing **view video**. *The view and record windows must not be closed before finishing*. You have to wait until it ends.

7. Try to implement the tracking with this short video in the following way. First, select *up* and *down*, which are the location of the vertical sides of a rectangle that must encompass the pendulum motion (the camera vertical dimension is 1080 pixels). Then select a *Threshold* to separate the frames into black and white images so that the hanging mass is the only object visible. This is done by trial and error (threshold must be between 1 and 255). Press the **track** button to see the results. *The track window must not be closed before finishing*. Wait until tracking finishes and then close the window. Repeat until the tracking is successful.

Do not change *fps* as the camera is configured at 25 frames per second. *Radius* is meant to be the dimension of the body, and *Longitud* the length of the thread (it's not used here).

8. Once you are satisfied with the results, take a 20 seconds video recording by writing a different name in the *video name* box, enter 20 seconds in the *record time*, and press the **Record Video** button. View the video, and then perform the tracking. The program will produce several files. One of them is ***periods.dat***, which contains the measurements of the pendulum period.

9. You may now quit the program by clicking on the close button.

10. Insert a USB memory, and copy the files to the USB: Open a File Manager by clicking on the  icon. Copy all the files (***imagef.jpg***, ***periods.dat***, ***xvst.dat***, and your video) to your USB. Extract your USB.

With the data in the file ***periods.dat***, calculate ***g*** and its error.

A note on the hardware and software used

Particle tracking, or video tracking, is a powerful image processing technique that allows to detect moving objects. Its applications range from the military to the biophysics. It involves an image acquisition system and a computer allowing image processing. The software must *segment* the object of interest (meaning that the object must be detected and isolated in every video frame) and find its centre.

The device you are using is arguably the cheapest particle tracking system in the world. It was developed at the Department of Physics and Applied Mathematics, University of Navarra, Spain, and it relies on a Raspberry Pi nanocomputer. The software is written in *Python*, a popular programming language. Everything is **open source**, from the Raspberry Pi electronics to the program code.

If you are interested in owning a nanocomputer: You can get a Raspberry Pi for about 35 € in Amazon and other suppliers. The Raspberry Pi Camera is a 8 MP colour camera that retails for about 25 €. The box is optional. The camera support has been made with a 3D printer. A standard USB keyboard and mouse can be used, and video is output through an HDMI, so you can connect the Raspberry Pi to a TV set that accepts this input. The charger is standard (you do not need to buy one if you already have it). You will also need a microSD card with at least 8GB. The operating system is Raspbian, which is a Linux flavour, and therefore completely free. You can buy a 16GB microSD card with preinstalled Raspbian for about 25 €. If you already have a microSD card, you can download the Raspbian operating system from the Internet. Installing Raspbian on a Raspberry Pi is easy; just accept the default choices and it will be running in a few minutes. (You may also install other operating systems on a Raspberry Pi). The Raspberry Pi 3 B model comes with WiFi connection and Bluetooth. You will be offered the option to connect it to the Internet during installation.

Although the Raspberry Pi just has 1GB RAM, it is enough to run programs fairly acceptably. For instance, you can download a Web browser and surf the Internet, watch films with VLC or other video players, listen to music (either through HDMI or through the sound connector), install Office programs (LibreOffice is preinstalled in Raspbian), and so on. At the time of writing this, Mathematica is also given for free, along with Wolfram Alpha and some other applications.

The software you have used has been developed by three professors in the University of Navarra (I. Fonceca, D. Hernández and A. Garcimartín). It has been written in Python, a free programming language that is also included in the Raspbian distribution. You can download it from https://github.com/FisUnav/rasptracking. It uses OpenCV image libraries (also an open source code that can be downloaded for free). Image processing involves subtracting the video frame from the background, then the frame is binarized (converted to black and white, as specified by the threshold), and finally a standard morphological operation called *opening* is used to detect a white disk. The centre of the disk is obtained by averaging the positions of the white pixels. The time between successive crossings by zero, as found by interpolation, provides the period with a resolution better than one hundredth of a second.

A set of connections allows using the Raspberry Pi for data acquisition (other popular strategy is to connect an Arduino to the Raspberry Pi). Many projects along this line and other suggestions can be found in the official Raspberry Pi site: https://www.raspberrypi.org/. Just to mention one, British soldiers built a bomb disposal robot based on a Raspberry Pi.