Studying a free fall experiment using short sequences of images

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Abstract. We discuss a new alternative for obtaining position and time coordinates from a video of a free fall experiment. In our approach, after converting the video to a short sequence of images, the images are analyzed using a web page application developed by the author. The main advantage of the setup explained in this work, is that it is simple to use, no software license fees are necessary, and can be scaled-up to be used by a big number of students in introductory physics courses. The steps involved in the full analysis of a falling object are: we grab a short digital video of the experiment and convert it to a sequence of images, then, using a web page that includes all the necessary javascript, the student can easily click on the object of interest to obtain the (x,y,t) coordinates, finally, the student analyze motion using a spreadsheet.

1. Introduction
We have implemented a new alternative to track coordinates of a moving object[1], that allows to easily analize a sequence of images obtained from video. After a short description of other setups commonly used to track coordinates, we will discuss the main steps involved in the analysis of a simple free fall experiment, using our approach.

2. Traditional setups to study the motion of falling objects
Attach a strip of paper to your object and use a vibrating nail to produce ticks equally spaced in time in the paper, then analyze the points grabbed in the strip. This is a very simple and intuitive solution but the main disadvantage is flexibility, think for example in using this setup for the study of a pendulum. In the previous setup, every time the oscillator ticks on the paper it apply a force to your moving object. To make this effect small, there is a setup where you use an oscillating high voltage between two wires, put a strip of paper parallel to them, and let your metallic object to fall. In this setup an electric arc will be produced between the wires at regular time intervals, the arc pass over your object and burns a mark in the strip of paper. In a typical optical solution, you illuminate your object using stroboscopic light and take a photo using a reflex camera, transfer the image to paper and analyze the combined photograph of your object for several positions. The main disadvantage of this setup are that you need a dark room for each group of students, you need also some extra time to reveal the photos, you have to dispose some chemicals, etc.
3. Modern solutions to analyze motion
Photogates and chronographs let you to measure position and time. You can also attach a strip to your object and pass this strip through a pulley, then using a photogate, the pulley can send pulses to a digital counter, the counter state and time can be recorded using a computer. Using an ultrasonic sensor[2] you can detect position and time using a computer, this mainly one dimensional solution, is very elegant, but it is expensive if you want to scale the solution for several groups. An optical solution[3] that gets a one-dimensional image of your illuminated objects from the side, can let you obtain one-dimensional positions for your object using a computer, this solution get more significant frames per second that the ultrasonic solution, but is also very expensive. A few years ago appeared in the market an optical solution, that using two video cameras, lets you get time and three-dimensional positions for your objects[4], but discussing the analysis of three dimensional data is beyond the scope of this work.

4. Solutions using video for data analysis
You can just take your video, open the file in a video editing software, advance each frame of interest annotating the pixel position for your object, when you are done save positions in a file and analyze them using a spreadsheet. Other alternative is to buy a license of a software for video motion data analysis[5]. One simple alternative to approach the commercial solution using free software, consists in converting your video to a video in flash format, and then use a web page[6] that uses a flash program that allow you to extract data from your video, do simple plots and copy the data for analysis using a spreadsheet.

Our own approach reported in this paper is similar to the example using a flash plugin to get data from video, the main characteristics of our implementation are: it is simple to use; once you learn how to convert your videos towards a sequence of still images, you do not need to worry about video codecs; it is a web page that can be used from nearly all modern internet navigators; it is very lightweight so any normal computers can be used; there is no need for programming because you only need to fill a directory with your sequence of images, and after changing a few parameters you are ready to begin the analysis locally or through the internet; you can make a library of short sequences of photos and share with anyone, again no need to worry about formats; it is easy to navigate between frames and you can restart from a previous frame or advance forwards skipping frames; because all the intelligence in the program reside in
Figure 2. Y vs t plot for a mass of 27.7 gr in a free fall experiment

your brain, you can analyze any complex one- or two-dimensional motion of objects; you can track up to four points (without programming any line of code); finally, the code is open source, so you can change it to make more complex things, but we recommend to maintain the program simple because it gives you more flexibility. We recommend to make the analysis of your data using a simple spreadsheet\[7\], because your students can analyze moving objects from home without installing additional software.

5. Obtaining a short sequence of photos for your free fall experiment
We recommend to buy a digital camera that grab short digital videos at a resolution of 640\times480 and 30 fps using a known codec, with this camera you have the freedom to shot videos everywhere and afterwards move the videos to your PC, convert to a sequence of photos and use them for analysis. Other alternative is to attach a webcam to your PC and obtain directly a sequence of photos from your experiment. There are also expensive fast digital cameras, that connect directly to the computer (via a firewire port for example), you can use the vendor software or you can use coriander in linux to obtain your sequence of images, at frame rates that other cameras can not reach.

To convert from video to a sequence of photos you can use almost any video editing software, we have tested VirtualDub\[8\] in windows and ffmpeg\[9\] + imagemagick\[10\] in linux, these programs are free to use and work very well. To convert your video to a sequence of images using VirtualDub, load your movie, rotate the scene to compensate for a bad tripod position, trim the movie to the time region of interest, trim the scene to the region of interest, export your selection to a sequence of jpeg images. To convert your video to a sequence of images using ffmpeg + imagemagick in linux, you can use the following commands: To convert a quicktime .mov movie to a sequence of images use /usr/bin/ffmpeg -an -i yourmovie.mov foto%02d.jpeg, delete images outside the time region of interest, then rename and resize the images using convert -resize 600 *.jpeg foto%02d.jpg, or crop an image region using convert -crop 200x200+0+0 *.jpeg foto%02d.jpg.

6. Getting coordinates from your sequence of images
The web interface to track coordinates for a free fall experiment is shown in fig. 1, to use the web page, copy any example from the project home page\[1\] to a directory in your computer, move
your sequence of images inside this directory, and change some few parameters at the beginning of the html page using a text editor. To track coordinates, load the web page and click on the object of interest, the image will automatically change to the next frame so you can click again on the same object, when you have finished just click on the Data button to see the coordinates and copy to the clipboard using the mouse or ctrl-c.

After you have copied your data into a spreadsheet, you have an index for the frame number and columns for up to four (x,y) coordinates. Insert a x-y graph into your worksheet to plot for example y versus frame number, if you know that your movie gives you 30 frames/s then you can multiply the frame number column by 1/30 and make the same plot again to obtain a y versus time graph.

In figure 2, we show a plot of y vs t for a free fall experiment, we used a sphere of mass 27.7 gr, and the marks on the side have a separation of 5 cm. We have intentionally maintained the original system of coordinates used for images (the origin of coordinates is at the top left corner of the image), the student can change the y-coordinate by adding a new column and writing a simple formula. The web page has no tools to calibrate distances, if you want this feature, track some points on the lateral marks for the first frame, then revert to the number of points that you want to track. As you can see, the results are very good, you can see more example in the Moving Objects home page[1], you can obtain videos from several sites on the internet[11, 12, 13, 14, 15], and you can also contribute your own videos to the community.

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