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Teaching classical mechanics using smartphones

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A number of articles published in this column have dealt with topics in classical mechanics.[1,2,3] This note describes some additional examples employing a smartphone and the new software iMecaProf.[4] Steve Jobs presented the iPhone as "perfect for gaming."[5] Thanks to its microsensors connected in real time to the numerical world, physics teachers could add that smartphones are "perfect for teaching science." The software iMecaProf displays in real time the measured data on a screen. The visual representation is built upon the formalism of classical mechanics. iMecaProf receives data 100 times a second from iPhone sensors through a Wi-Fi connection using the application Sensor Data.[6] Data are the three components of the acceleration vector in the smartphone frame and smartphone's orientation through three angles (yaw, pitch, and roll). For circular motion (uniform or not), iMecaProf uses independent measurements of the rotation angle θ, the angular speed $d\theta/dt$, and the angular acceleration $d^2\theta/dt^2$.

We have systematically identified where iMecaProf can be used in lab/demonstration exercises in a course on classical mechanics. We then note different levels in iMecaProf that define a pedagogical progression. **Level 0** is somewhat reminiscent of a Steve Jobs show[5]—a virtual representation of the real smartphone on a visual display with no added scientific tool. Manipulation of the real smartphone controls the virtual one's orientation. Only changes in 3-D orientation are reproduced on the screen and not the translations. One can directly visualize how the Moon rotates and the existence of its dark side. **Level 1** adds frames and unit vectors to level 0. Fixed unit vectors are associated with the lab frame (**O,X,Y,Z**) and rotating unit vectors to the smartphone frame ($\mathbf{O}$, $\mathbf{x}_{iPh}$, $\mathbf{y}_{iPh}$, $\mathbf{z}_{iPh}$). **Level 2** splits the screen into four parts as shown in Fig. 1: the upper left displays an image of level 1 while the three other parts show projections of unit vectors attached to the smartphone. Users can practice orienting a real smartphone to obtain different projections of unit vectors $\mathbf{x}_{iPh}$, $\mathbf{y}_{iPh}$, and $\mathbf{z}_{iPh}$ in the planes OXY, OXZ, and OYZ. One can try to have the three projections of unit vectors $\mathbf{x}_{iPh}$, $\mathbf{y}_{iPh}$, $\mathbf{z}_{iPh}$ equal in all three planes OXY, OXZ, and OYZ. A game associated with this level proposes that the user control the orientation of the real smartphone so that its artifact is always aligned with a second virtual smartphone whose orientation is controlled on screen by the computer. In **Level 3**, iMecaProf enters dynamics: acceleration **a** and velocity **v** vectors are shown on screen and in real time, in the lab frame, and in the smartphone frame. Level 3 options are designed to specifically offer a detailed study of cases most often studied in basic mechanics. In the 2-D option, movements are rotational: circular motion (uniform or not) and pendulum oscillations. In the 1-D option, displacements include free fall or elevator movement and 1-D oscillations to experimentally explore mechanical resonance. The screen on visual display is then split into four parts as shown in Fig. 2. The upper left part is again the level 1 image. The upper right shows in lab frame the unit vectors of both frames (lab and smartphone), acceleration **a** and velocity **v**. The lower right shows in rotating smartphone frame the associated unit vectors plus acceleration **a** and velocity **v**. The lower left is used to plot (versus real time) the potential energy, the kinetic energy, and their sum, the total mechanical energy. In the 1-D case, acceleration and velocity vectors are displayed in real time as arrows. Their values are plotted in real time on a single graph. A second game has been introduced here so that the user can play with acceleration. The computer defines a 1-D oscillating movement with period from 0.5 s to 2 s and amplitude between 10 cm and 50 cm. The user tries to move the phone back and forth in the defined way. We managed to reasonably control smartphone movement by hand to reproduce period and amplitude. We hope readers will achieve better results as far as phase is concerned.

Levels 0, 1, and 2 require no specific material or setup to

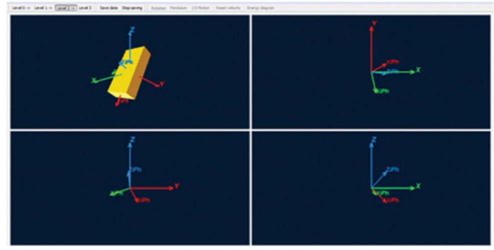

Fig. 1. The upper left corner shows an image of level 1 (see text) while the three other parts show projections of unit vectors attached to the smartphone (x_{iPh}, y_{iPh}, z_{iPh}) in OXY, OZY, and OXZ planes defined in the lab frame.

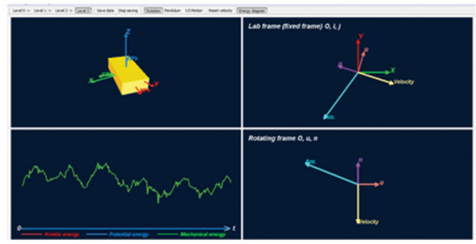

Fig. 2. iPhone on a rotating swivel chair with nonuniform circular rotation. The upper left part is again a level 1 image (see text). The upper right shows in the lab frame the unit vectors of both frames (polar vectors u and n used here in the smartphone frame are rotating), acceleration a and velocity v. The lower right shows in the rotating smartphone frame the associated unit vectors u and n (now stationary) plus the acceleration a and velocity v. The lower left is used to plot (versus real time) the potential energy (here equal to zero), the kinetic energy, and their sum, the total mechanical energy.

use iMecaProf as described above. The smartphone is in the user's hand. The setup used in level 3 is very minimal. Circular motion can be studied using a swivel chair, a pendulum using the smartphone charge cable, and oscillation by putting the smartphone into a plastic bag attached to an elastic rubber- band?. Use of the smartphone in a more sophisticated setup can easily be considered as long as smartphone size is not an issue and if its movement is not too fast.

In conclusion, motivations to develop iMecaProf are : 1) Using a personal computer and a smartphone, it provides a complete teaching environment for experimental activities associated with a classical mechanics course. This is based on a visual, real time, and interactive representation of measured data using the formalism of classical mechanics; 2) Using smartphones is more than just using a set of sensors. iMecaProf shows students some real applications of important physical concepts they are learning; and 3) It provides a practical introduction to mechanical microsensors that are nowadays a key technology in advanced trajectory control.

The first version of iMecaProf is now ready to be used and will be tested this academic year at the Université Joseph Fourier (Grenoble, France).

References

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