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Using *Tracker* to Engage Students' Learning and Research in Physics

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ABSTRACT

Information and communication technologies (hardware and software), have become an important part in classroom learning because they allow diversity in learning styles and make learning more flexible. This study focuses on *Tracker,* a free video analysis and modeling software, which offers an alternative route to discuss concepts that are otherwise difficult to grasp. Using the popular game, *Angry Birds*, we demonstrate the ongoing research on the application of *Tracker* in three cases: 1) motion of exploding projectile, 2) free fall with air resistance, and 3) calibration of a home-made spectrometer. Findings reveal that such visualizations can offer an alternative way to explain concepts that are otherwise rather difficult to grasp in Physics. Findings from these experiments open up exciting possibilities on the need for future research in more advanced research themes like determining diffusion coefficient and absorption spectra of materials.

Keywords: Tracker, parabola, momentum conservation, air resistance, spectrometer, physics

INTRODUCTION

Technologies have become an integral part of classrooms these days; they serve not only as an alternative way to make active learning in classroom but also as a tool to deliver concepts more clearly (Kozma, 2003; Freeman, et al., 2014). The technologies cover a wide range of spectrums, including, but not limited to, mobile apps, tablets, and computer software. Recent developments have embraced using social media to teach Physics in classrooms (Page, 2015).

In this paper, we focus on *Tracker* (Brown, 2015), an image and video analysis software, which is suitable as a teaching aid to deliver Physics concepts in classrooms. The power of *Tracker* lies in the fact that one is able to visualize the concept in question in

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real time. We have picked two concepts that are often misunderstood by the students (the law of momentum conservation in exploding projectile and the effect of air resistance on falling objects) and we demonstrate how *Tracker* is employed to help students understand those concepts. We also investigate using a simple exercise in calibrating a home-made spectrometer using *Tracker* and discuss how *Tracke*r can be used to deliver advanced concepts beyond high school level.

EXPLODING PROJECTILE

Consider the motion of a projectile under gravity. Ignoring the effect of air resistance, the projectile will have a trajectory of a parabola. Let us assume at some point the projectile explodes into several fragments. A typical problem of this sort involves finding the trajectories of these fragments after the explosion happens. If we consider the earth-projectile system, then there is no external force acting on the system and total momentum is conserved. i.e. $\boldsymbol{P}_i = \boldsymbol{P}_f$, where $\boldsymbol{P}_i$ is the initial momentum of the projectile + earth and $\boldsymbol{P}_f$ is the total momentum of the fragments + earth after the explosion. The fact that the earth is much more massive than the projectiles, allows us to ignore the earth's recoil effect and consider it stationary. Thus the trajectory of the center of mass of the fragments after the explosion would follow the trajectory of the original projectile if there had not been any explosion (Thornton & Marion, 2003).

The calculation for this problem is straightforward: by applying the center of mass theorem or conservation of momentum, one can easily solve the exploding projectile problem (Holics, 2011). However, the formal machinery may pose challenges to the students' understanding so that they may fail to fully grasp the concept behind it. One of the approaches to circumvent the difficulty in understanding concepts in Physics is through visualization (Robinett, 1995; Dori & Belcher, 2005; Cataloglu, 2006). We revisit this classic problem and use the popular game "Angry Bird" (Google Play, 2015) to visualize the physics of exploding projectiles. We focus on The Blues (Angry Birds Wiki, 2015) which have the property of splitting into three birds. We record The Blues in action and use *Tracker* to extract the coordinates of the bird(s) before and after explosion for analysis.

A snapshot of the tracker window which consists of three major components is shown in Figure 1. The left side of the window is where the user uploads the video and performs the analysis which includes setting the coordinate system, determining the scale, and tracking the object. The right side of the window allows the user to choose what parameters/variables to plot. The numerical values of the variables are given in the table below the plot. The red symbols on Figure 1 mark the traces of the objects from which the coordinates are recorded.

Tracker allows us to visualize the conservation of momentum in the exploding projectile problem process. We show that $(P_i)_x = (P_f)_x$ and $(P_i)_y = (P_f)_y$, where $\boldsymbol{P}_i = m\boldsymbol{v}$ and the final momenta of the birds are

$$(P_f)_x = m_1(v_1)_x + m_2(v_2)_x + m_3(v_3)_x$$

$$(P_f)_y = m_1(v_1)_y + m_2(v_2)_y + m_3(v_3)_y,$$

where we assume that the original bird splits into three birds with equal mass. Figure 2 shows the momentum per unit mass of the bird before the explosion (black) and the total momentum per unit mass after the explosion (blue) as calculated from the above equations. Had there not been any explosion, the original bird would have the momentum per unit mass as shown in orange. By comparing the total momentum per unit mass after the explosion (blue) and the momentum of the bird if there had not been any explosion (orange), one can verify that the momentum is indeed conserved in the process. The momentum per unit mass of the individual birds after explosion is also shown in the figure (red, green, yellow) for completeness.

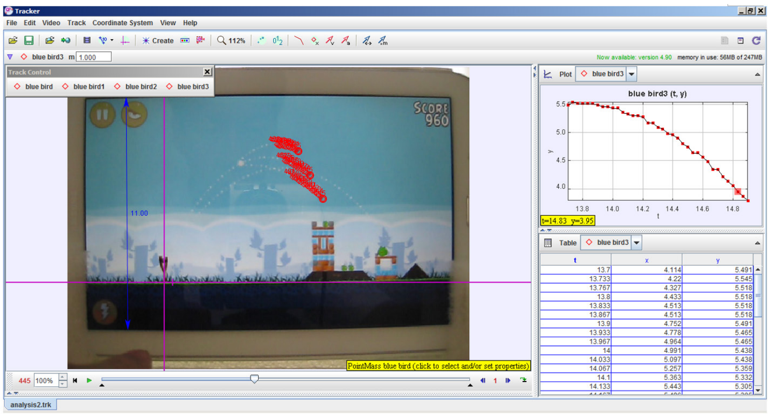

Figure 1. Tracking the coordinates of the bird(s) from which relevant quantities are extracted and calculated. We define the frame of reference (purple lines) along with the calibration measurement (blue line) to allow us to extract and record the data. The red marks show that the birds are tracked by *Tracker*. The Top panel shows the trajectory of the original bird before explosion and the bottom panel shows the trajectories of the birds after explosion. The user can choose the plots and numerical values to show at the right side of the window as shown in the figure above.

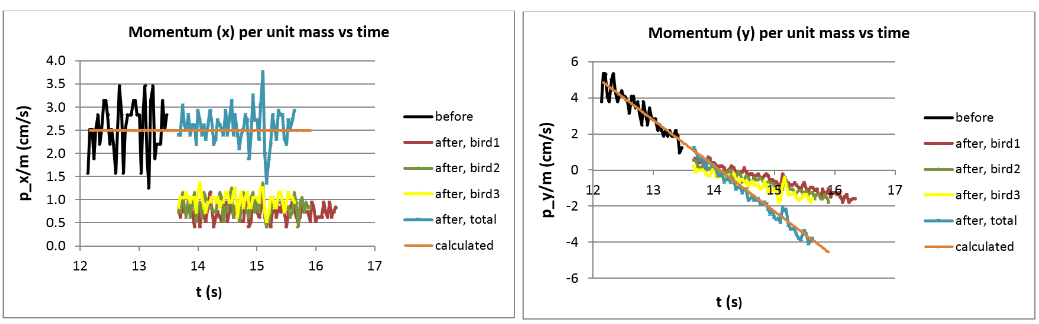

Figure 2. Momentum analysis of The Blues before and after the explosion along the x −(top panel) and y −(bottom panel) which demonstrates the conservation of momentum. The momentum per unit mass if there had not been any explosion (black and orange) matches the total momentum of the 3 birds after explosion (blue), indicating that momentum is conserved. The momentum per unit mass of the three birds after explosion, from which the total momentum is calculated, are shown in red, green, and yellow.

The trajectories of The Blues before (black) and after explosion (red, green, and yellow) are shown in Figure 3. The top (bottom) panel of Figure 3 shows the horizontal (vertical) position of the birds. We show the trajectory of the center of the mass after the explosion (blue) by performing weighted average. We also plot the calculated trajectory of the original bird if there had not been any explosion (orange). The analysis clearly shows that the trajectory of the center of mass after the explosion agrees with the calculated trajectory of the original bird if there had not been any explosion.

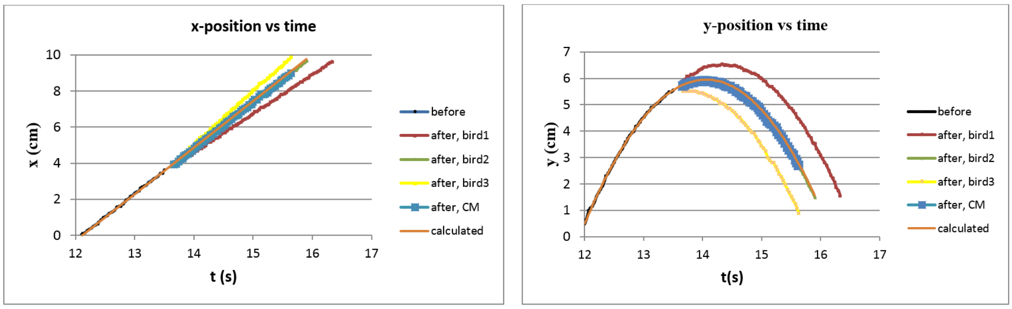

Figure 3. The trajectories of The Blues before (black) and after (red, green, and yellow) the explosion: the horizontal position (top panel) and vertical position (bottom panel) as the function of time. We assume that a single blue bird splits into three birds (bird1, bird2, bird3) with equal masses after the explosion. The trajectory of the center of mass (blue) after the explosion is obtained by averaging the trajectories of the individual birds (red, green, and yellow). The calculated trajectory if there had not been any explosion is shown in orange. The analysis confirms that the trajectory of the bird if there had not been any explosion (orange) follows those of the center of mass of the birds (blue).

Here we have shown how visualizations can offer an alternative way to explain concepts that are otherwise rather difficult to grasp. We use a simple and free tool and combine it with a popular game to discuss the application of momentum conservation and center of mass in the exploding projectile problem.

THE PHYSICS OF FALLING OBJECTS

In this section we discuss the physics of falling objects under gravity. The equivalence between inertial and gravitational mass (Pendrill, et al., 2014) implies that, in the absence of air resistance, all objects will fall with the same acceleration, i.e. gravity. A hammer and feather will fall at the same time dropped from the same height in a vacuum, or on the Moon (NSSDCA, 2008). The situation changes when one considers the drag force which arises from air resistance. The drag force will oppose the motion of the falling objects and will change the kinematics.

We contrast the cases where the effect of air resistance is negligible and is important. In the absence of air resistance, where the only force acting on an object is the force of gravity, the vertical position is quadratic with time and the vertical velocity is linear with time. The presence of air resistance is usually modeled by a velocity-dependent force, $f = bv$, at low speeds (Landau & Lifshitz, 1959). The parameter $\boldsymbol{b}$ is a constant which depends on the surface area of the object and v is the instantaneous velocity at a particular time. The velocity of the falling object, with mass m, in the presence of air resistance will then be given (Alonso & Finn, 1992):

$$v(t) = \frac{mg}{b}\left[1 - e^{-bt/m}\right];$$

at short times, the force of air resistance is small and plays little role in modifying the kinematics; the object obeys the kinematics of free fall. As time increases, the force of air resistance grows and opposes gravity, thus decreasing the effective acceleration. At long times, the velocity of the object saturates (terminal velocity) because the force of air resistance balances the force of gravity. The vertical position is no longer quadratic in time but grows linearly with time.

We performed a simple experiment to see how air resistance affects the motion of falling objects. We used two sheets of tissue paper, one tightly crumpled and another one loosely crumpled, as the objects, dropped them separately from a height of approximately 3 meters, and recorded the motions. *Tracker* was used to analyze the motions of the tissue papers. This is shown in Figure 4.

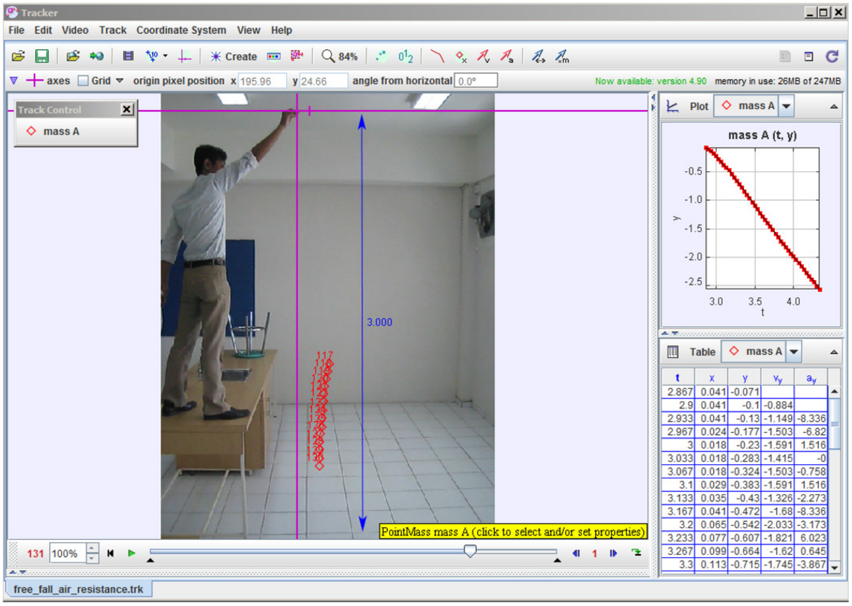

Figure 4. Video analysis of a sheet of tissue paper dropped from a certain height above the floor. We set up the frame of reference (purple lines) and calibration (blue line) to enable data collection of the motion. Red symbols are the tracked data in the motion. The right panel shows the plotted graph on a vertical position along with the numerical values on the table below it.

The result of the analysis is presented in Figure 5. The effect of air resistance is small for the tightly-crumpled tissue paper and thus it serves as a model for free fall situations where an object falls under the sole influence of gravity. The position and velocity are plotted in Figure 5 in red symbols. The time dependence of the position and velocity agree with that of theoretical description: quadratic in time for the position and linear in time for the velocity. The effect of air resistance on the loosely-crumpled tissue paper is large. The position and velocity exhibit time dependence consistent with the description of an object falling under gravity and opposed by the force of air resistance. At short times, the position and velocity agree with those of free fall, while at long times, the position is linear with time and the velocity saturates, a hallmark of terminal velocity. This simple exercise can bring a new level of understanding about the physics of falling objects in the absence and presence of air resistance.

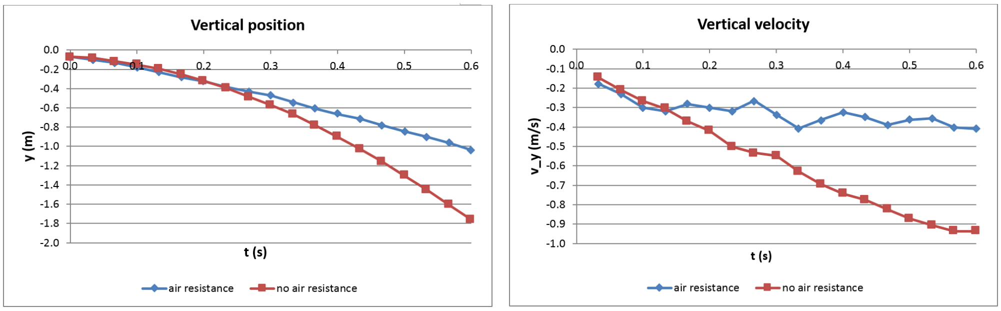

Figure 5. The position (top panel) and velocity (bottom) of falling objects in the absence (red) and presence (blue) of air resistance. When the effect of air resistance is negligible (red), the object follows free-fall kinematics where the object is falling under the sole influence of gravity: the position grows quadratically in time while the velocity grows linearly in time. When the effect of air resistance is large, the position grows linearly with time while the velocity is linear with time at short times and saturates at long time, a clear demonstration of the strong interplay between the force of gravity and force of air resistance.

CALIBRATION OF A HOME-MADE SPECTROMETER

In the last example, we show how to use *Tracker* to calibrate a home-made spectrometer based on known spectra of a mercury lamp (Philips Lighting, 2015). The spectrometer was made from household items such as cardboard, an unused mouse pad which was used as the entrance slit, and an old CD which served as the diffracting grating. Figure 6 demonstrates the calibration process and result. The calibration process is as follows: we used the entrance slit (white line on top panel of Figure 6) as the frame of reference from which the distance (in pixels) to the known spectra is measured. To determine the distance to the spectral lines, we used the line profile feature in *Tracker* to measure the spectral intensities along the line; the peaks in the observed intensity were marked as the distance to the said spectrum. Correlating the known wavelengths of the spectra with distance gave us the calibration curve shown in the bottom panel of Figure 6.

Equipped with the calibration curve, one can extract unknown wavelengths of observed spectra of a light source. We applied this to a commercial mosquito repellant lamp. Figure 7 shows the image of the observed spectra of such a light source which has 3 sharp lines. The calibration curve given in Figure 6 allowed us to extract the wavelengths of the spectra. The result is shown in Table 1. It is unfortunate that the commercial mosquito repellant light does not provide any information on the wavelengths of the emitted light. Thus it is not possible to compare our finding with the real wavelengths.

Table 1
The extracted wavelengths of the spectra of a commercial mosquito repellant lamp

Distance from entrance slit (pixels)	Calculated λ (nm)
665	384.6
838	507.2
888	542.6

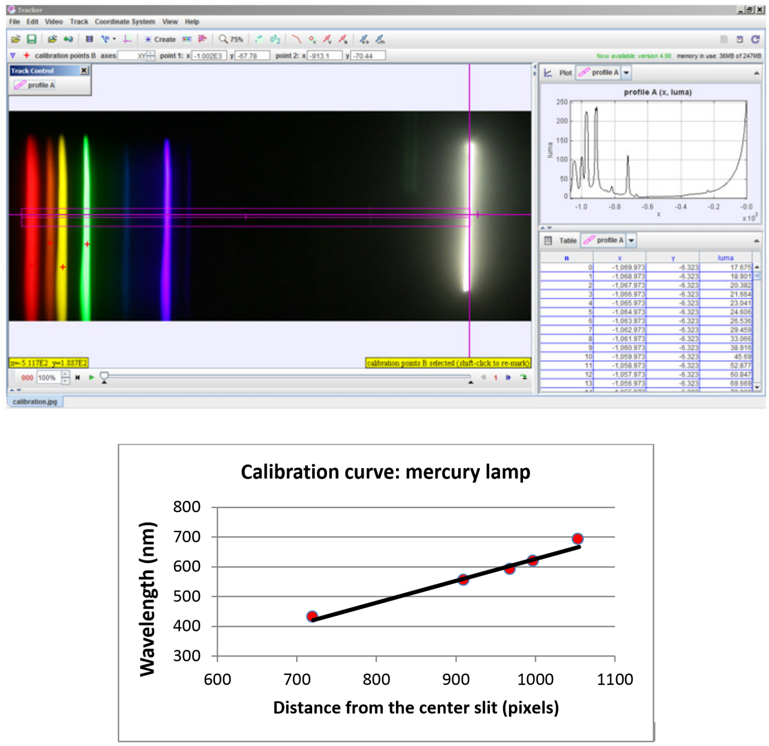

Figure 6. Calibrating a home-made spectrometer using a mercury lamp with known spectra. The top panel shows the tracker window where the calibration involves two processes: 1) setting up the coordinate system and 2) placing calibration points at spectral lines with known wavelength. The calibration points mark the distance (measured in pixels) from the reference point, which is taken as bright white line at the right. The bottom panel shows the calibration curve for the mercury lamp which is done by correlating the distance from the reference point with the known wavelength.

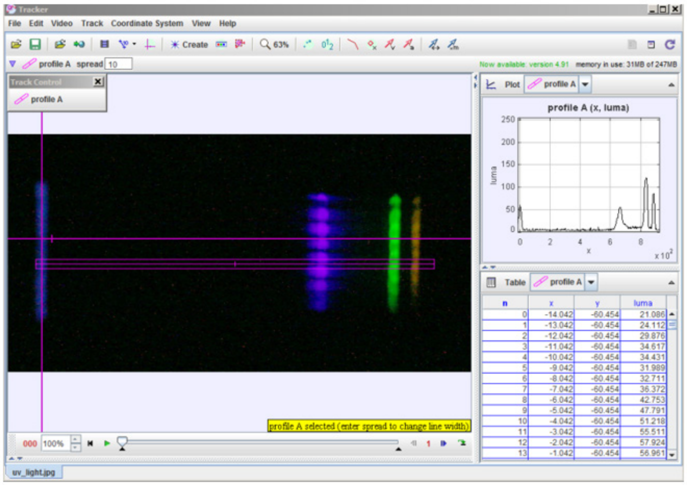

Figure 7. Measuring the unknown wavelengths of the spectra of a commercial mosquito repellant lamp. The entrance slit is used as a reference from which the distance to the spectra is measured. By comparing the measured distance with the calibration curve in Figure 6, one can extract the wavelengths of the observed spectra.

CONCLUSION

In this work we show how *Tracker* offers visualizations of concepts that are otherwise rather difficult to grasp. We discuss the application of *Tracker,* an image and video analysis software, in two different settings: mechanics and optics. In mechanics, *Tracker* was used to analyze videos of an exploding projectile, modeled by The Blues in the Angry Bird game, and a falling object in the presence of air resistance. The concepts of momentum conservation, center of mass, and terminal velocity in these exercises are presented by combining experiments, calculations, and visualizations. In optics, a home-made spectrometer was calibrated using *Tracker* by analyzing still images of the known spectra of a mercury lamp. The calibrated spectrometer can be used to extract wavelengths of unknown spectra. This simple exercise opens up an opportunity to introduce advanced concepts in modern Physics, such as energy band gap, at high school levels.

In the future, we would like to bring *Tracker* into the classrooms. One of the goals of this future study is to study the effectiveness of using visualizations in delivering Physics concepts. *Tracker* can also be used to study advanced topics beyond conventional topics in classrooms. For example, diffusion dynamics is one of the topics that is not typically offered at high school level; nevertheless we believe that students will be able study and grasp the concept using *Tracker.* Thus *Tracker* opens up wide range of possibilities for further (advanced) works.

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