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Opportunities in Physics Education: Low-Cost Position Tracking for Use in Kinematics Labs

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Abstract

Traditional introductory physics kinematics laboratories utilized a few different instruments for locating objects in motion, all of which have shortcomings. Some provide only timing data, which heavily restricts trajectories and data collection. Some instruments provide more measurements but restrict object shapes, orientations, and textures. Still others require extensive pre-processing. None of these traditional instruments provide two- or three-dimensional position data. New, low-cost, local positioning technology, based on radio frequency wireless communications, is available that enables novel redesigns of physics laboratories. This technology provides two- and three-dimensional position measurements, continuously, at data rates of 10 Hz or faster, from any object to which it can be affixed. Our research group at Portland State University is exploring how this technology can be applied to reconstruct and improve introductory laboratories, making them easier to perform while increasing the amount of usable data gathered. Additionally, we seek to enhance model-based learning experience in labs by confronting students with more diverse models than traditionally encountered. For example, we are pursuing applications in free-fall experiments, aerodynamic friction, two-dimensional motion, two-dimensional collisions, tug-of-war competitions, as well as Astronomy applications such as retrograde motion.

Motivation

The Physics Education Group at Portland State University seeks advancements in the design and implementation of introductory laboratories that improve student learning outcomes. While traditional laboratory courses contain some modern pedagogy, such as active and model-based learning practices, some laboratory activities fail to live up to the expectation of educators [1, 2]. One of the perennial sources of frustration for the laboratory instructor is the quality and usability of laboratory equipment. For example, some instruments are of high quality, but are too difficult to operate or too expensive in a large introductory course in which many devices are needed. Conversely, some instruments are designed for such settings, but are so specialized that the experimental design becomes highly restricted and instrument-focused. Furthermore, all of these devices operate in one-dimension (1D). Arrays of these devices are needed to achieve two-dimensional (2D) positioning.

Clearly, the choice of measurement apparatus is critical, since each bestows its own advantages and disadvantages. For example, the photogate is often used for timing objects moving on tracks. (See Figure 1.) While accurate, ranging devices such as this limit the trajectory and orientation of objects under study. Furthermore, each photogate measures at one position.

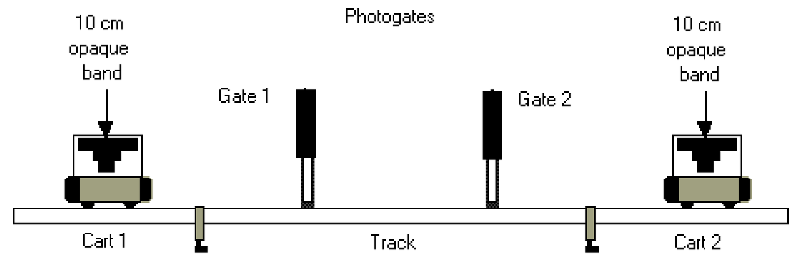

Figure 1: Diagram of a typical photogate-based experiment [3].

Another common instrument used in kinematics labs is the range sensor, based on ultrasonic or infrared reflection technology. These are accurate and produce more measurements than the photogate, but can only measure strictly linear displacement, and also restrict the tracked object's shape, orientation, and texture. (See Figure 2.)

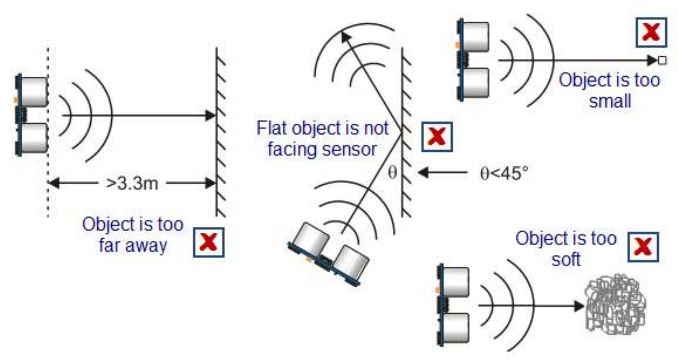

Figure 2: Unusable configurations for ultrasound sensors [4].

Our recent work focuses on new opportunities provided by low-cost, local positioning system (LPS) devices. Based on ultrawide-band (UWB) radio frequency time-of-flight technology, these LPS platforms produce continuous position, origination, and environmental data, in one-, two-, and three-dimensions, up to 40 m in range. In fact, the product we use is even tolerant of limited attenuation, permitting it to be completely enclosed inside a foam ball, as shown in Figure 3.

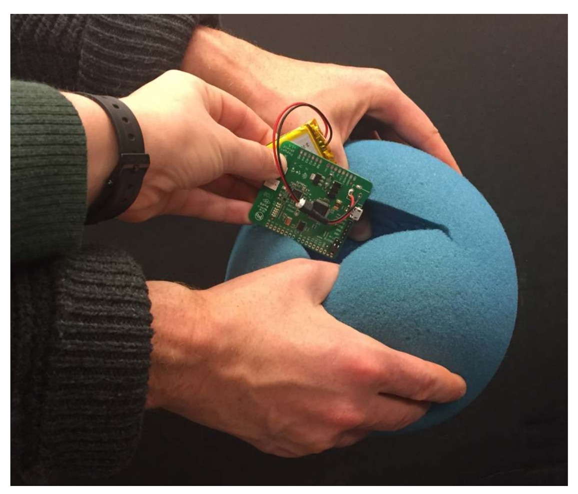

Figure 3: Insertion of an position tracking device into a foam ball.

We are currently investigating five applications of LPS devices for the introductory kinematics laboratory:

1. Free-Fall vs drag in projectile motion
2. Friction and Newton's third law in the Tug-of-War
3. Retrograde motion in orbital dynamics
4. Walking kinematics exercises
5. Two-Dimensional collisions

In addition, we developed an application that collects and visualizes the data as it is produced.

Projectile Motion: Free-Fall or Drag?

A fruitful application of LPS is projectile motion. We measured the position of a 20 cm diameter foam ball dropped from a three story building, which is not achievable using conventional senors due to range and alignment limitations. The data is better fit using a drag-enhanced model of projectile motion than the free-fall model, represented by a coefficient of drag of zero ($C_d = 0$) in Figure 4. This suggests more realistic models, and hence more model-based learning, can be tackled using LPS technology in this experiment.

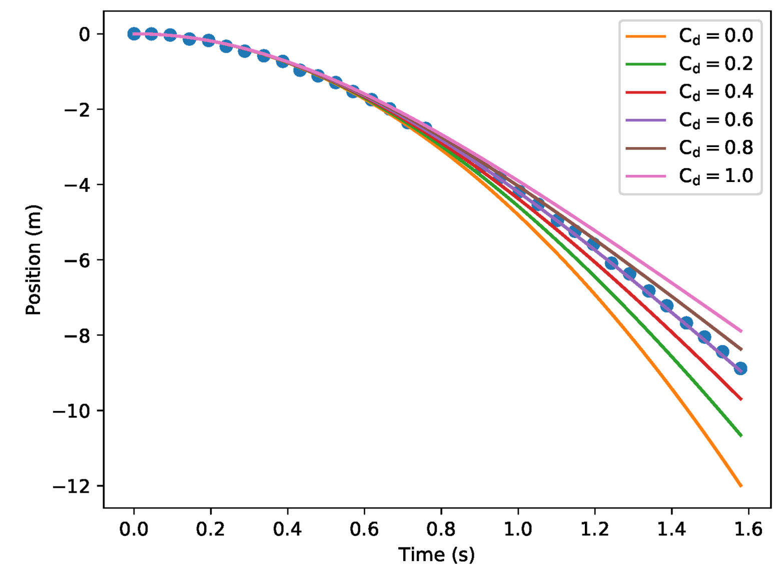

Figure 4: Foam ball displacement measurements, as points, overplotted with model curves for different coefficients of drag (C_d).

Tug-of-War, Friction, and the 3rd Law

How does one win a game of tug-of-war? We are investigating this question, as well as how students understand the role of the friction force and Newton's action-reaction law. The LPS device we use allows us to track the position of the rope, continuously, during the game.

Walking Kinematics Exercises

We designed several kinematics lab activities in which students are challenged to act-out and match motion and velocity graphs given in the instructions. Traditional sensors require students to walk linear paths and hold large, flat, reflective objects. The LPS devices expand these activities to 2D.

Orbital Dynamics: Retrograde Motion

A novel application of LPS is planetary motion, as 2D data is difficult to obtain using traditional instruments. In our example activity, two students walk in concentric "orbits," simulating two planets orbiting a common center, such as Earth and Mars, while their positions are recorded. Plotting the vector displacement between the inner and outer "planet" reveals retrograde motion, as predicted from the heliocentric model of the Solar System and shown in Figure 5.

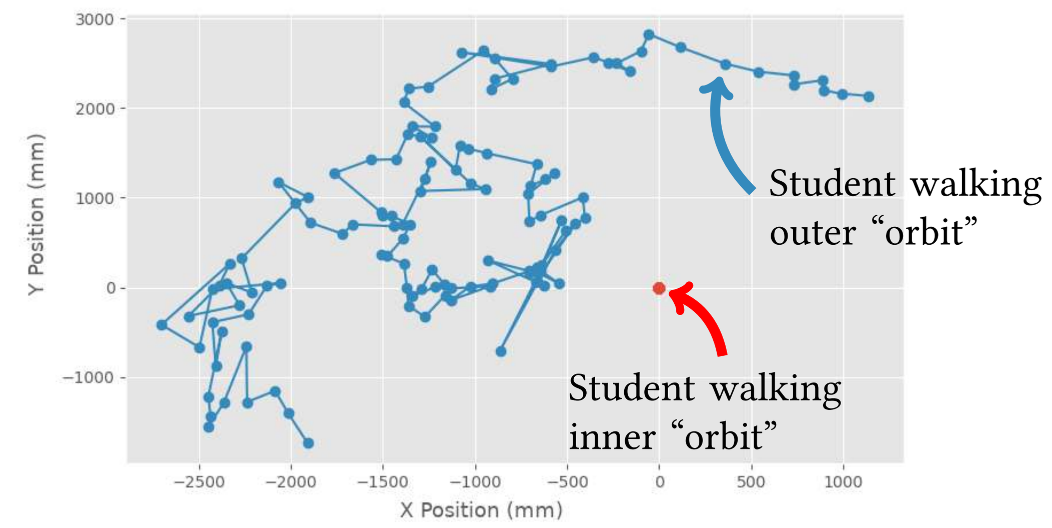

Figure 5: Retrograde motion is apparent in this plot of the displacement between two students walking concentric "orbits."

Future Work

The 2D capabilities of the LPS, as well as it's versatile placement, provide new opportunities for teaching multidimensional conservation of linear and rotational momentum. Our team is working to redesign the momentum conservation laboratory, often taught in 1D only.

Finally, the performance of these new laboratories will be measured. We will design assessment tools to probe student learning outcomes produced by the aforementioned activities based on LPS technology.

Conclusion

Recently commercialized Local Positioning Systems provide motion tracking for many lab activities that traditionally require specialized instruments. They have the potential to change the way kinematics laboratories are designed due to their versatility.

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