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Systematic Errors in Video Analysis

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Systematic Errors in Video Analysis

Abstract

Video analysis helps students to connect physical, mathematical, and graphical models with the phenomena that the models represent and improves student kinematic graph interpretation skills. The wide-spread availability of easy to use software packages like Logger Pro (Vernier), Capstone (PASCO), and Tracker have led to many introductory physics courses adopting video analysis techniques in the classroom. Such uses include high-speed cameras to study rocket launches and other innovative applications. In this paper, we will look at ways in which some common systematic errors can affect outcomes.

Keywords

cameras, parallax, errors, video recordings, students

Disciplines

Physics | Science and Mathematics Education

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Systematic Errors in Video Analysis

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Video analysis helps students to connect physical, mathematical, and graphical models with the phenomena that the models represent and improves student kinematic graph interpretation skills.[1] The widespread availability of easy to use software packages like Logger Pro (Vernier), Capstone (PASCO), and Tracker have led to many introductory physics courses adopting video analysis techniques in the classroom. Such uses include high-speed cameras to study rocket launches and other innovative applications.[2,3] In this paper, we will look at ways in which some common systematic errors can affect outcomes.

A common problem using video analysis

When performing numerical fits to data to extract physically significant values, we have had mixed results. Video analysis in carefully conducted experiments can result in reasonable parameter values. However, students frequently find substantially different values than expected, even when least-squares fitting measures are good. For example, a two-dimensional ball toss might have a good quadratic fit for the vertical position as a function of time, yet the value of the acceleration due to the gravitational force g from the curve fit can be far from the accepted value. For example, in Fig. 1(a), we have a value of $g = 11.74 \pm 0.02$ m/s^2. This value is not only too high, but its uncertainty is too small to explain this high value. A second example [Fig. 1(b)] is a case where the vertical position curve fit yields a value for g that is 12.2 ± 0.3 m/s^2, but the horizontal position data show a non-zero acceleration.

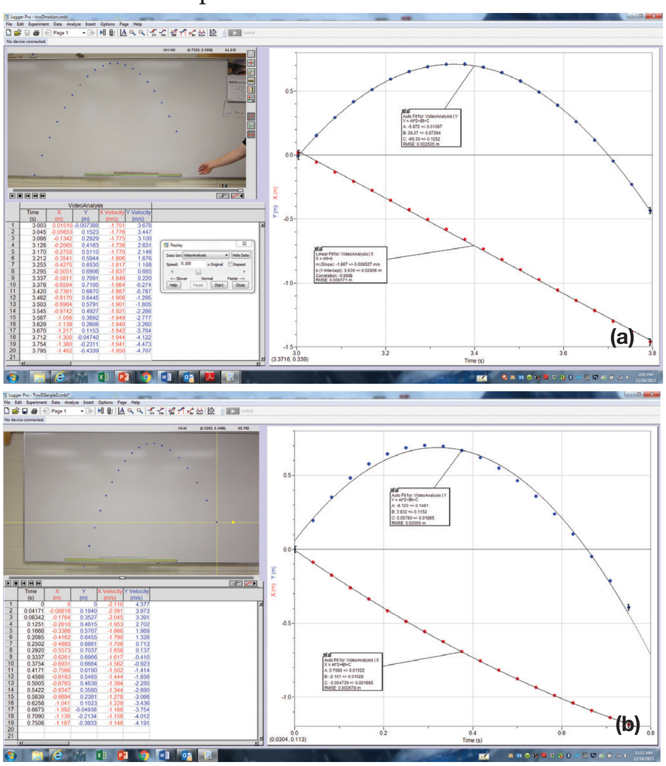

Fig. 1. Screenshots of two projectile motion video capture and analysis results.

What, then, are the factors that lead to these non-realistic values in an experiment like the two-dimensional tossed ball experiment?

Systematic errors in video analysis

Two variations in the way that students set up and execute the 2D ball toss experiment suggest sources of systematic error that might adversely affect the results of the experiment. One common experimental setup places the reference meterstick and the tossed ball different distances from the camera (referred to below as reference length misplacement). A second experimental setup has the ball toss in a plane that is not parallel to the camera's lens plane (referred to as incorrect camera angle). While avoiding these problems is commonly recommended in places such as Vernier's Tech Info Library, we wanted to make systematic measurements to determine the size of the errors introduced.[4] In addition to these two common setup errors, we wanted to consider the effect of focal length choice for our zoom lens cameras, recognizing that images taken with extreme wide-angle focal length lenses can show significant distortion effects. As described below, we have made measurements to determine the level of systematic errors that these introduce. These are not an exhaustive set of systematic error sources, and it should be noted that the behavior of the digital shutter has been observed to play a role in measurement error as well.[5]

Experimental setup: Camera settings

For all measurements, we recorded video clips using a Canon PowerShot A1200 digital point and shoot camera. This camera has a modest 4x optical zoom, with a lens effective focal length range of 5.0 mm to 20.0 mm. In each experiment, we used three different focal lengths: wide angle, normal, and telephoto. In keeping with the language used in photography, the 5.0-mm focal length is considered wide angle due to the field of view being wider than that normally seen by the eye, and the 20.0-mm focal length is a telephoto setting, and a normal setting midway between these two, which yields an image close to what the eye sees. It should also be noted that whether the lens is considered wide angle or not depends both on the focal length of the lens as well as sensor/film size. The equivalent focal length range for a 35-mm film camera would be 28 mm to 112 mm. All video clips were analyzed using Logger Pro 3.8.6 (Vernier).

Reference length misplacement

Misplacing the reference length is effectively a parallax problem, since apparent object size is relative to its distance from the camera. For example, if the meterstick was placed closer (than the tossed object) to the camera, the tossed object would appear to travel a shorter distance than it actually did. We simulated this effect by creating an array of horizontal metersticks, with each meterstick an additional 0.2 m

Fig. 2. Meterstick array used to study parallax.

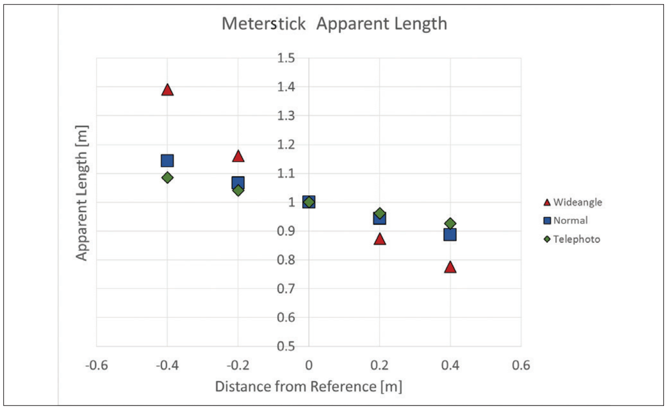

Fig. 3. Apparent length change due to distance from the camera. Negative distances refer to metersticks that were closer than the reference to the camera.

farther away from the camera with a slight vertical offset to make them all visible to the camera (Fig. 2). Video clips were recorded with the camera set at wide angle, normal, and telephoto settings. For each focal length setting, the distance from the camera to the array of metersticks was adjusted to produce an image of the sticks that nearly filled the viewfinder. The center stick was used as our reference length, meaning that it was selected as 1 m using the set scale tool. The apparent length of each of the other metersticks was measured using the measurement tool. Metersticks that were closer (than the reference) to the camera appeared larger than one meter (Fig. 3), while metersticks that were farther from the camera appeared shorter. A reference length offset of 0.2 m in either direction affects the apparent length by approximately 5% when using either the normal or telephoto settings and by more than 10% with the wide angle setting. In the ball toss experiment presented at the beginning of this paper, this would result in a value of g that was off by 0.5 m/s^2 (normal or telephoto) to 1.0 m/s^2 (wide angle). The error becomes much more pronounced with the reference lengths that are offset by 0.4 m from the center length, with the wide angle view showing an error of as much as 40%. This is the effect that is responsible for the large value of g in the experiment shown in Fig. 1(a). It is interesting to note that the results are much more sensitive (i.e., greater errors occur) when the camera is at wide angle, which is the default focal length when the camera is first turned on. Very recently others studied parallax errors by a different method. Our results are consistent with theirs.[6]

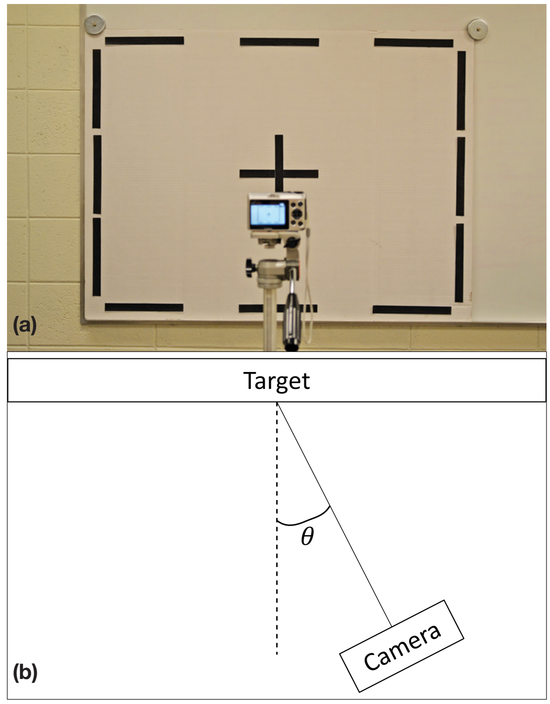

Fig. 4. (a) Target used to study variations in apparent length of segments located in different parts of the field of view. (b) Angle variations.

Incorrect camera angle

We simulated the effect of a ball toss that has a motion component away from the camera by rotating the camera a known amount relative to a fixed target (Fig. 4). The target is a rectangle containing an array of black line segments, each 0.250 m in length. The camera was placed on a tripod and set to be at the same height as the center of the target. For each of the three focal lengths, the camera-target distance was adjusted so that the target filled the frame vertically and was centered horizontally when the camera was at 0° from normal incidence. As shown in Fig. 4(b), we then moved the camera to the side so that the angle from the normal increased in 5° steps up to 20°, taking a video clip at each position. In each case the angle is changed such that the left side of the target is further from the camera than the right side. This mimics the variation in apparent distance traveled if an object moves with a component away from the camera.

The center horizontal line was used as the reference length, and the apparent length of each of the segments was measured with respect to it. We normalized the measured lengths for all segments by finding the percent difference from the reference length. The most extreme effects occur for the horizontal bars in the corners, with the lower horizontal bars' results being very close to the upper horizontal bars' results. Figures 5 through 7 are the plots of apparent length of the upper horizontal bars (right and left) vs. angle from normal incidence for the three focal length settings that we used.

As Fig. 5 shows, there is little variation in apparent length when the camera is carefully placed so that the target plane is parallel to the camera independent of focal length setting. The

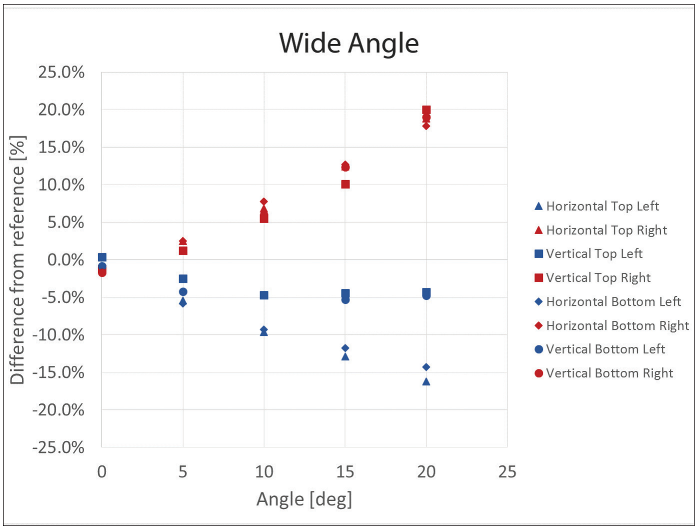

Fig. 5. Apparent length as a function of angle from normal incidence to the target with the camera lens at its wide angle setting.

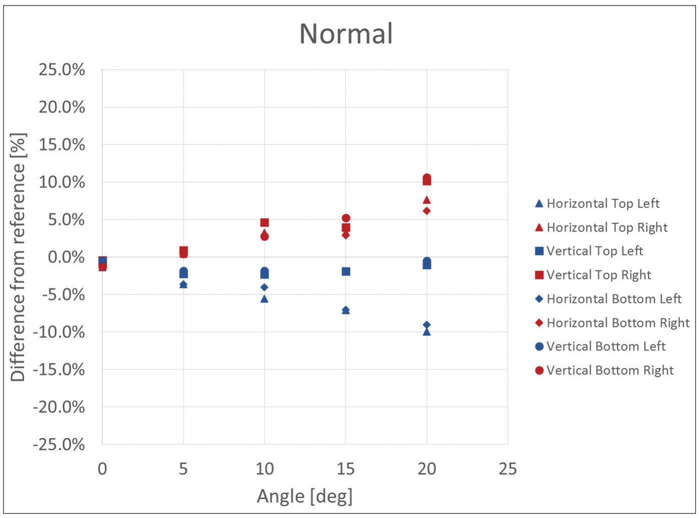

Fig. 6. Apparent length as a function of angle from normal incidence to the target with the camera lens at its normal setting.

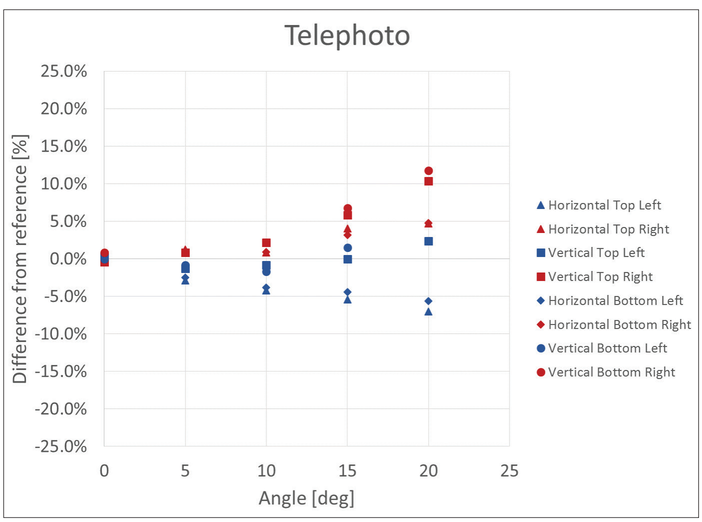

Fig. 7. Apparent length as a function of angle from normal incidence to the target with the camera lens at its telephoto setting.

scatter seen at 0° on each of the plots is consistent with the repeatability of length measurements when using the computer mouse to select segments. As the camera is moved from normal incidence, systematic errors in apparent length become significant. At its most extreme for the camera at its wide angle setting and 20° from normal, apparent length varies from –15% to +20% from the left side to the right side at the top or bottom of the field of view. An object moving with constant velocity horizontally across the field of view would appear to have a significant acceleration due to this effect. Telephoto and normal settings are better behaved. While not graphically displayed, other parts of the target show less variation in apparent length but roughly follow the trend shown in Fig. 5.

As these measurements show, care must be taken to minimize systematic errors that can result if an object's distance from the camera changes significantly or if the reference length is at a different distance than the object from the camera. If one is using a camera with a zoom lens, both problems can be reduced by using a longer focal length lens setting. When using a wide angle lens, such as that used in most cell phone cameras, particular care is needed when setting up the shot.

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Tim Martin *graduated with his undergraduate physics degree and continued his studies at Knox Seminary in Florida. Tim is currently the pastor at Fron Lutheran Church in South Dakota. He has a passion for seeing how God has revealed Himself through His marvelous work in creation.*

Kayt Frisch *currently serves as an associate professor of biomedical engineering at George Fox University in the Portland, OR area. Her research interests include using video motion capture to study the dynamics of the body during volleyball hitting and the creation and assessment of active, project-based learning experiences in undergraduate physics and engineering classrooms.*

John Zwart *is now professor of physics emeritus. He remains interested in physics pedagogy, especially in the design of lab activities for introductory physics courses.*
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