Systematic Errors in Video Analysis: Camera Placement and Scale Location are Important.

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Video analysis is growing in popularity as a lab tool. It is a great way to simultaneously show multiple physical models, such as graphical and mathematical, and help students to be able to connect these models. Readily available software such as that embedded in Vernier's LoggerPro or PASCO's Capstone, and the free Tracker (reference - http://www.vernier.com/products/software/lp/ ,http://www.pasco.com/family/pasco-capstone/index.cfm , http://www.cabrillo.edu/~dbrown/tracker/) are fairly easy to learn and students enjoy working with them. However, we have found some students' results show significant systematic errors (such as finding $g = 11.59 \pm 0.02\ m/s^2$ when fitting the equations of motion to a tossed ball). This led us to carefully look at sources of systematic error due possible situations such as the reference length being at a different distance from the camera than the object being analyzed and due to effects of having the camera not perpendicular to the plane of interest.

For all measurements, we used our lab cameras which are Canon PowerShot A1200 digital point and shoot cameras capable of taking video clips. This camera has a modest 4x optical zoom, with a lens effective focal length range of 5.0 mm – 20.0 mm (35 mm camera equivalent of 28 mm – 112 mm) which varies from wide angle to telephoto. In our consideration of systematic errors we made measurements at the minimum and maximum focal length settings as well as halfway between them (normal). For each of these settings we positioned the camera to have the same field of view.

For our first set of measurements, we made the target shown in Figure 1. Each of the black line segments is 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 focal lengths used, we adjusted the camera-target distance to have the target fill the frame vertically and centered horizontally with the camera at zero degrees from normal incidence and shot a video clip. We then moved the camera to the side so that the angle from the normal increased in five degree steps up to twenty degrees, taking a video clip at each position.

Each video clip was analyzed using Vernier's LoggerPro 3.8.6. The center horizontal segment was used as the reference distance and the apparent length of each of the segments was measured with respect to the reference. To simplify understanding the graphs of the results, we normalized the data by setting the reference distance to be unity.

To emphasize the systematic errors seen, not all data are plotted. The largest variation is seen in the segments in the corners of the target which are plotted. In each of the graphs, the label 'top' and 'bottom' are used for the horizontal segments, and 'upper' and 'lower' are used for the vertical segments. Figure 2 is the plot of apparent length versus angle from normal incidence for the camera in its wide angle setting (which is the default setting when the camera is turned on). Figures 3 and 4 show the results with the camera at its most extreme telephoto setting and at its 'normal' setting (determined by placing the camera distance from the target halfway between the wide angle and telephoto distances).

As the plots show, there is little variation in apparent length when the camera is carefully centered on the target, i.e. there were no inherent distortions due to the lens being less than ideal. The scatter seen at zero degrees on each of the plots is consistent with the repeatability of length measurements. 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 twenty degrees 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.

Parallax can also produce systematic errors in video analysis results. To study this effect, we set up an array of meter sticks, as shown in Figure 5. The sticks are separated by 0.20 m horizontally and are offset slightly vertically to make them all visible from a camera centered on the center stick. Once again we shot video clips with the camera set at wide angle, telephoto, and normal settings. The distances from the center meter stick to the camera were the same as in the previous set of measurements. Using the center meter stick as the reference length and measuring the apparent length of the others, we produced the plot shown in Figure 6. In this graph, negative distances refer to the sticks closer to the camera and positive distances are further away.

Once again, the wide angle setting produces the greatest systematic errors, ranging from +40% for an object 0.40 m closer to the camera than the reference and slightly more than -20% for an object 0.40 m further away.

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. Both problems can be reduced by being further away and zooming in on the object of interest.

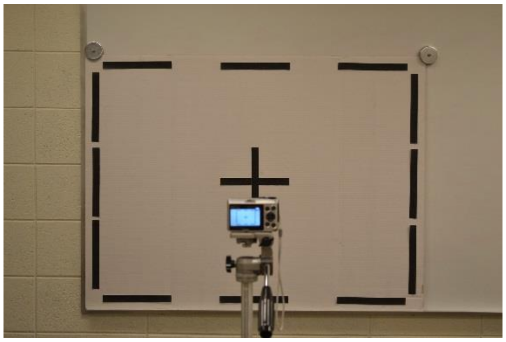


Figure 1. Target used to study variations in apparent length of segments located in different parts of the field of view.

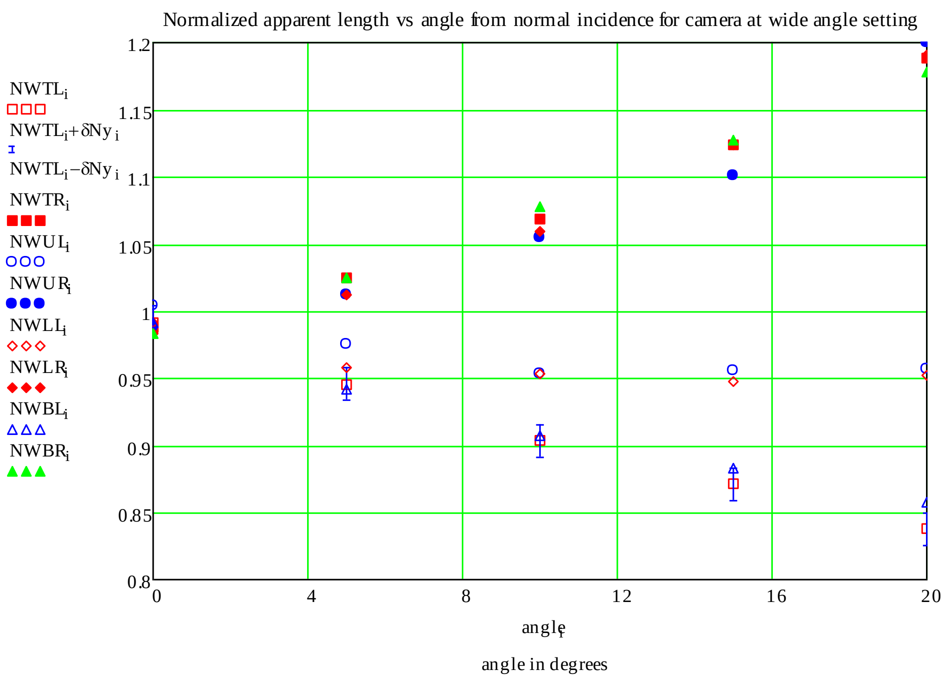


Figure 2. Apparent length as a function of angle from normal incidence to the target with the camera lens at its wide angle setting.

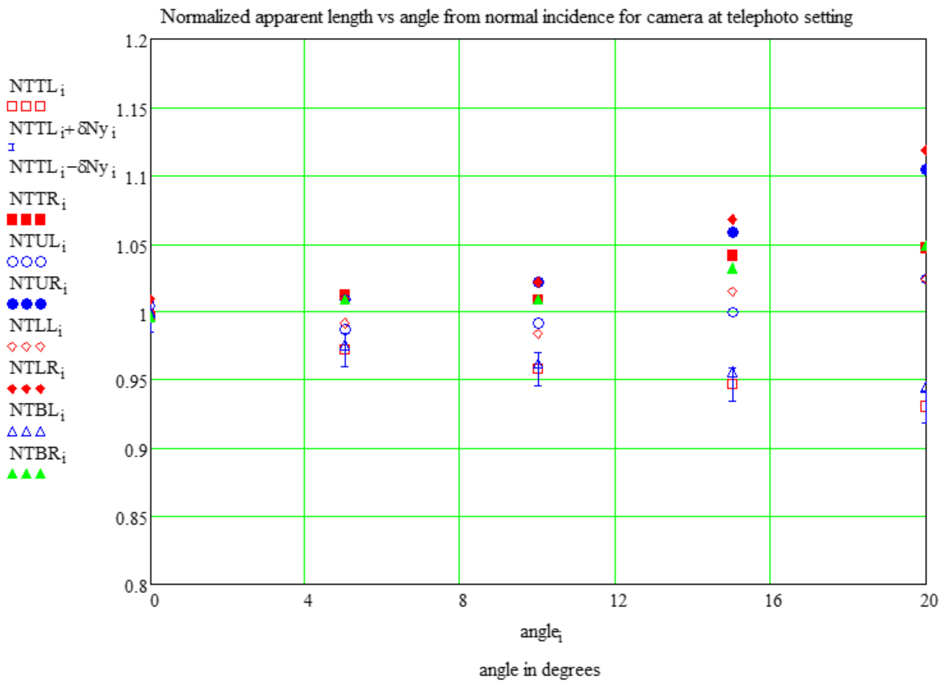
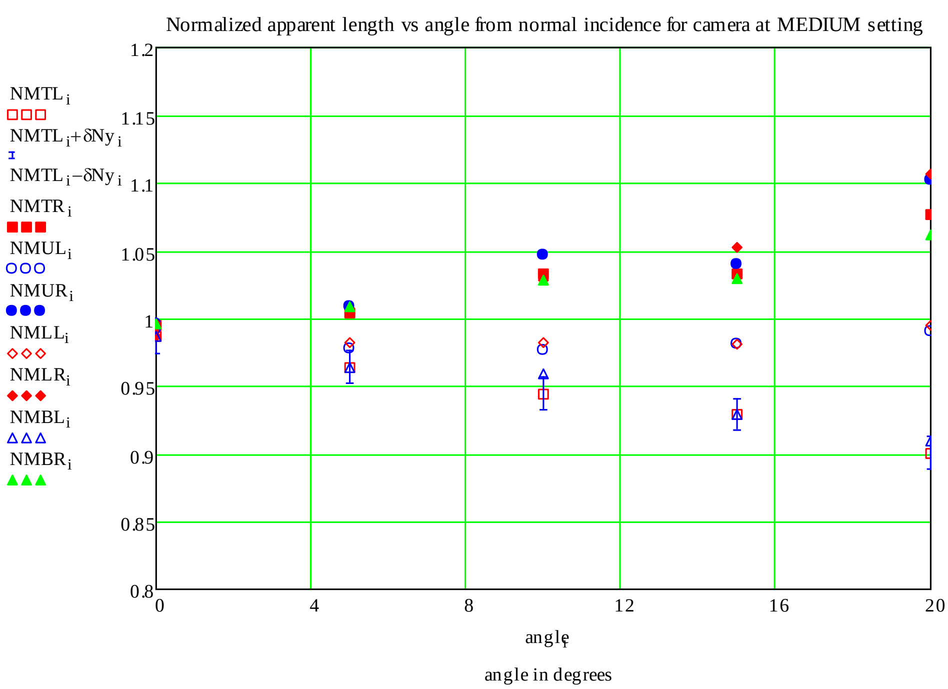


Figure 3. Apparent length as a function of angle from normal incidence to the target with the camera lens at its telephoto setting.

Figure 4. . Apparent length as a function of angle from normal incidence to the target with the camera



lens at its normal setting.

Figure 5. Meter stick array used to study parallax.

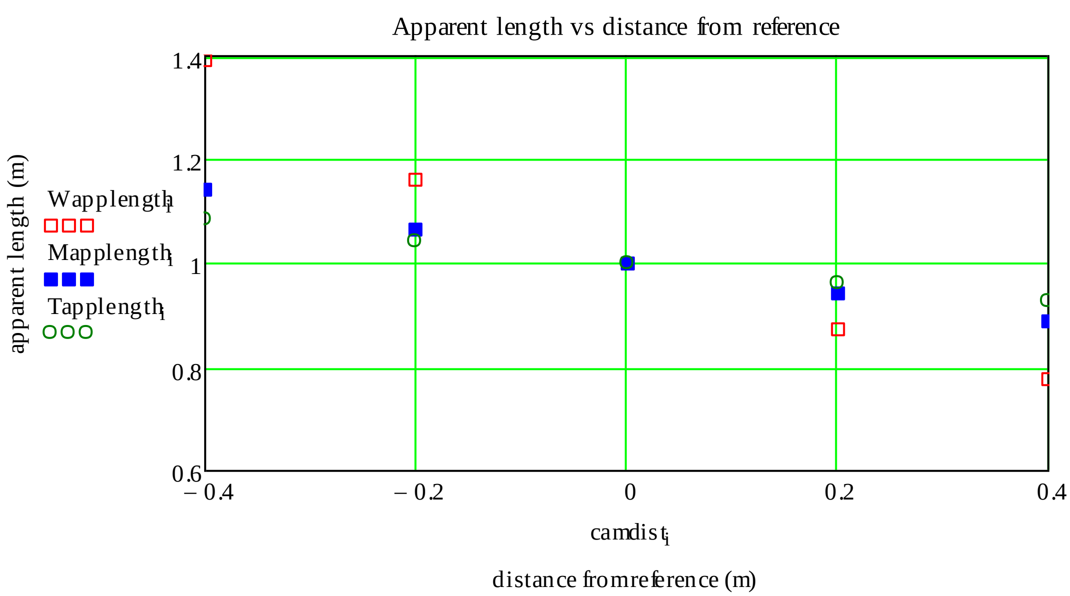


Figure 6.

Apparent length change due to distance from the camera.