VIDEO ANALYSIS OF SPORTS

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Abstract

The physics of events in national sporting competitions is analyzed using the analysis features of Tracker. A posted YouTube video of an event in a football game is used to determine the force between two players during a tackle. The video used was not taken for the purpose of performing the analysis. The Tracker analysis involves defining a coordinate system, appropriately scaling the video, and measuring the location of the players involved in the play. With such data, the momentum-impulse equation is then used to solve for the normal force between the players during the tackle. The analysis serves as an example of how the physics of virtually any YouTube video can be analyzed.

Introduction

Analysis of the science of events recorded on video has been the subject of recent science literature [1]. Computer software from various sources has been designed to perform such analysis. The attraction of such analysis is the ability to study events in nature that are not the idealized creations typically encountered in a classroom. Students benefit from real-world analysis because they are familiar with the event, and can now analyze the science of such an event. Thus, the idea of video analysis bridges the gap between the idealized situations of the classroom and real-world events. This bridge can be both exciting for the students and pedagogically advantageous for instructors.

Mostly, such computer software is used to analyze the basic mechanics of events. Thus, things such as force, acceleration, velocity, impulse, momentum, work, and energy are the typical quantities of interest. These quantities are an integral part of introductory physics courses at all levels and thus the relevance of such analysis applies to any student of science studying introductory physics.

There are two possible scenarios that would allow for the analysis of the physics of an event. The event could be staged, and filmed for the purpose of analysis. For example, a video camera could be used to film a person throwing a football for the purpose of analyzing the motion of a projectile. The camera angle, distance to the thrower, and scale could all be nicely arranged so that the analysis of the video could be done. This approach to using video analysis is effective. However, this approach in part suffers the pedagogical disadvantage of having the event of interest being staged. For example, students wishing to perform their own analysis would have to stage things in the same way, or design their own staging for an event of interest. Staging the event adds to the complexity of asking students to perform a project. In addition, the staging is in some ways simply a different way of idealizing the problem.

A different approach would be to be able to take an arbitrary unstaged video of a sporting event posted on a website such as YouTube, and be able to perform the physics analysis. Imagine the excitement of a student watching Tom Brady or Peyton Manning throw a touchdown pass to win a game and then being able to perform a scientific analysis of the play. The computer program written by Douglas Brown titled Tracker allows for such analysis and is used in this paper [2]. There are many impediments to performing the analysis of video that is not staged for such a purpose. Among them are poor camera angle, zooming or panning during the video, and resolution. Tracker has several features that can overcome these problems.

A play in the Michigan vs. South Carolina Outback Bowl game on January 1, 2013 has been used as an example of how Tracker can be used to perform an analysis [3]. The first step in performing the analysis is to convert the video from YouTube to an appropriate file to be imported into Tracker. Then, the analysis can proceed. In the play selected the force between the two players is analyzed. Because the play shows a significant football “hit,” it is natural to ask the question about the force involved in such a hit. The analysis in Tracker answers this question. This is a satisfying result for the student of physics.

General Procedure for Analysis

There are several different paths an investigator can take to perform the analysis of an ordinary YouTube video of a sports play. The path taken in this analysis is as follows:

a) Find the clearest YouTube video of the play of interest and copy the URL,

b) Run the web-based application keepvid.com by pasting the URL into the program, and then selecting convert video. This process will convert the YouTube file into an mp4 file recognized by Tracker. Save this file to your computer.

c) After downloading the Open Source Tracker [2] program, import the video into Tracker.

d) Isolate the portion of interest of the video using the ‘video clip’ option from the menu bar,

e) Set up a coordinate system, orient properly, and calibrate the video (i.e. set the video scale),

f) Track the position of objects of interest using the tracking feature,

g) Bring the Tracker data into Microsoft Excel to find the appropriate kinematic quantities needed to perform the physics analysis.

The Physical Analysis

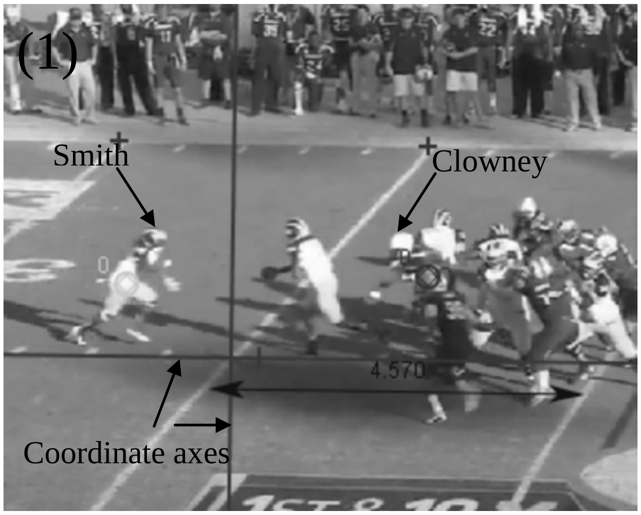
The particular play selected to illustrate the technique for using Tracker involves the collision of two players. Thus, the physics of collisions is the relevant theory necessary to obtain the force of collision between the players. The collision occurs approximately in one-dimension, and the players stick together after the collision. Thus, the collision can be categorized most simply as a one-dimensional completely inelastic collision. The system (both players) momentum is not conserved however since one of the players continues to push on the ground with significant force during the collision.

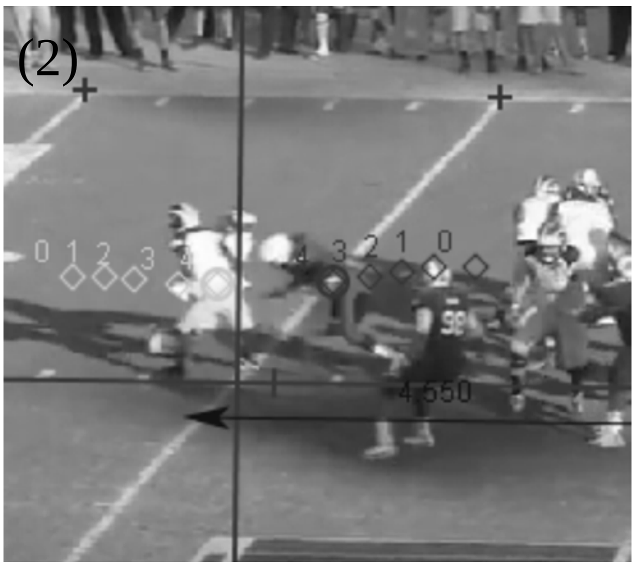
The momentum-impulse version of Newton’s 2^{nd} law can be found in any introductory textbook in physics [4]:

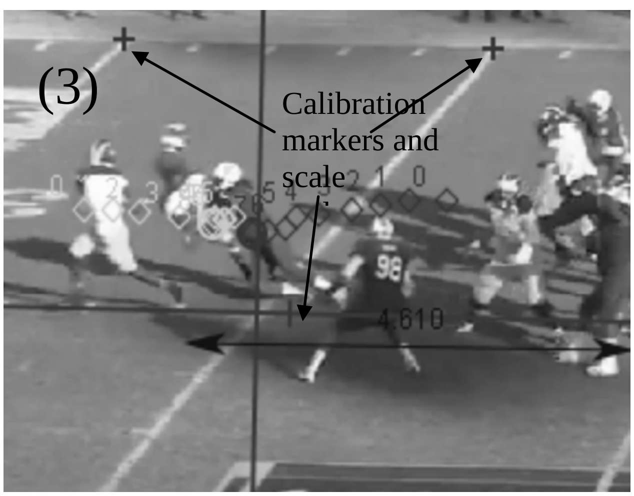
$$Ft = MV_f - MV_i \tag{1}$$

where F is the net force acting on a mass M, t is the time over which the force acts, and V_f, V_i are the final and initial velocities of mass M. As can be seen from the equation, if the mass of an object is known along with the initial and final velocities and the time over which the force acts, then the net force can be computed.

The Tracker program has a feature that allows the user to mark the position of an identifiable object for every frame of the video. In this case, the position of two objects (the two players) is desired. Figure 1 shows several frames in succession for the play of interest. The Michigan player (Vincent Smith) is running toward the line of scrimmage, and the South Carolina player (Jadeveon Clowney) is pursuing him after breaking through the line of scrimmage. The players meet and the tackle is made. Viewing the play in real-time shows that Smith is driven backward by Clowney. The earliest time is frame (1) of Figure 1. The coordinate system used for measurement is shown by the labeled coordinate axes, the positions of the players of interest are indicated by track symbols, and the indicators used to calibrate the video are labeled.







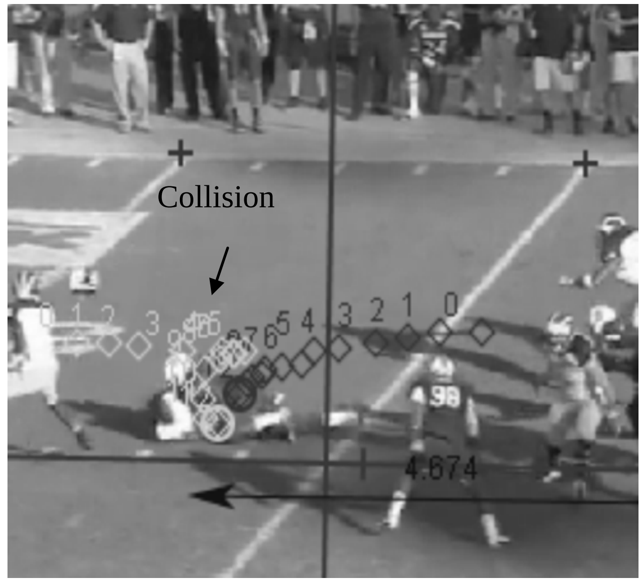


Figure 1: Several frames of the play of interest are shown. The earliest time is frame (1), and the latest is frame (4). Small arrows in (1) and (3) indicate the key players and Tracker features.

After marking the position of Smith in the video using Tracker, his position along his direction of motion (x-axis) is displayed as a function of time in the upper right of the Tracker program, and the numerical values used for the plot are displayed in the lower right portion of the Tracker program. The units of position are the units used to calibrate the video, which in this case are meters. The time is in seconds. The Tracker windows as displayed for Smith are shown here in Figure 2.

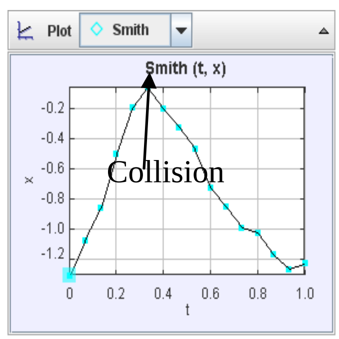
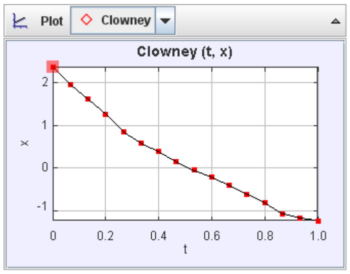


Table — Smith

t	x
0	-1.307
0.067	-1.076
0.133	-0.861
0.2	-0.498
0.267	-0.189
0.333	-0.05
0.4	-0.2
0.467	-0.318
0.533	-0.464
0.6	-0.725
0.667	-0.848
0.733	-0.99
0.8	-1.024
0.867	-1.172
0.933	-1.266
1	-1.231

Figure 2. The Tracker numerical data and plot for Smith.

Similarly, Figure 3 shows the Clowney data and plot from Tracker.



t	x
0	2.386
0.067	1.965
0.133	1.617
0.2	1.271
0.267	0.862
0.333	0.583
0.4	0.397
0.467	0.147
0.533	-0.05
0.6	-0.207
0.667	-0.401
0.733	-0.613
0.8	-0.802
0.867	-1.07
0.933	-1.164
1	-1.236

Figure 3. The Tracker numerical data and plot for Clowney

Tracker has curve fitting features and analysis tools. For this project, these were not used. Instead, data for both players was copied and pasted into Microsoft Excel. Using Excel made it easier to separate the data before the collision and after the collision. After separating the portions of the data into what occurred before the collision, and what occurred after the collision, the data were plotted in Excel. A linear best fit was then performed in each plot. Figure 4 shows the plots and best fit analysis in Excel. In the linear equations shown in the figure, the variable ‘x’ is position, and ‘t’ is time. Thus, the slopes of the various linear fits are the velocities of each player before and after the collision. Notice that Smith’s velocity abruptly changes direction, while Clowney’s speed slows a bit.

The masses of each player can be found on the respective websites for each team. They are:

a) Mass of Clowney = 116 kg

b) Mass of Smith = 79.5 kg.

The time of the collision is vital for the analysis. Perhaps here more than any other portion of the analysis estimation is clearly being used. The time between frames is calculated from the YouTube conversion by Keepvid. In this case it is 0.0333 sec per frame.

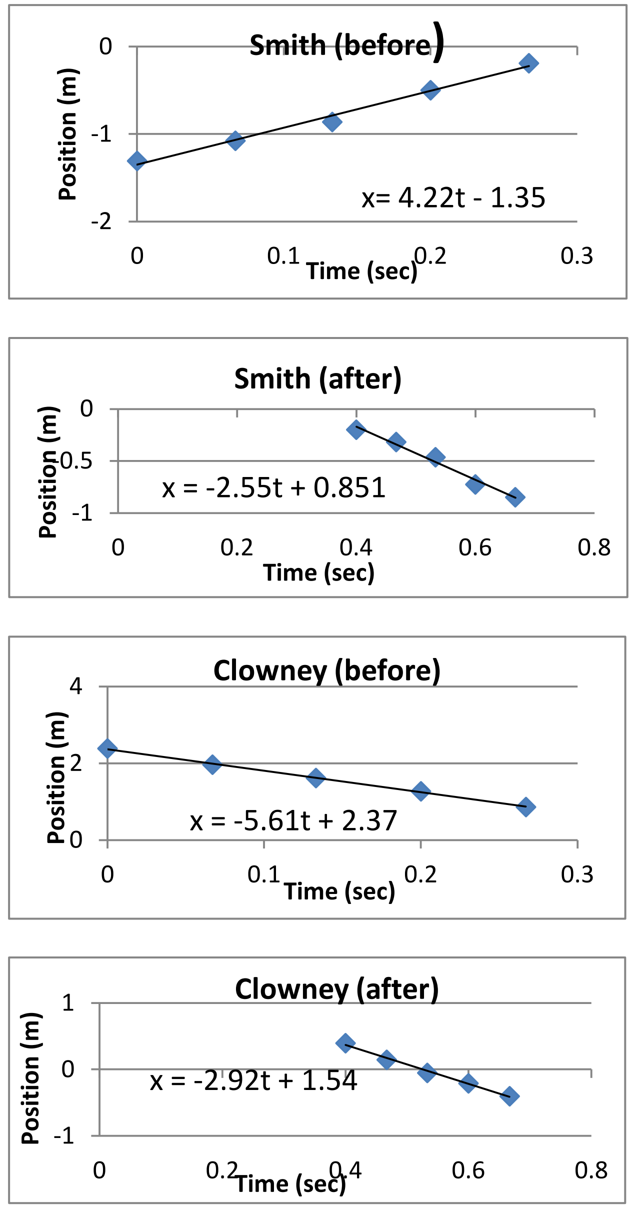


Figure 4. Plots and linear best fits for Clowney and Smith before and after the collision. In the plots, ‘x’ is position, and ‘t’ is time. Slopes of the equations are the respective velocities of the players.

By watching the video carefully, it was estimated that the collision took place over approximately 2 frames, so the ‘t’ chosen for use in equation 1 was 0.0667 sec. It is also noted in the video that Smith is lifted from the ground by the hit from Clowney. Thus, equation (1) applied to Smith is:

$$F_T\, t = M_S\, (V_s)_f - M_S\, (V_s)_I \qquad (2)$$

where F_T is the average force between the players during the tackle, M_S is the mass of Smith, $(V_S)_f$ is the final velocity of Smith, and $(V_S)_i$ is the initial velocity of Smith. The values from the Excel analysis yield an F_T = 8070 N = 1810 lb. Thus, this was a nearly 1 ton hit!

For Clowney, the equation must be modified to include the force between himself and the ground. Thus, equation (1) for Clowney is:

$$(F_T - F_G)t = M_C\, (V_C)_f - M_C\, (V_C)_i \qquad (3)$$

where F_G is the force between Clowney and the ground, M_C is the mass of Clowney, $(V_C)_f$ is the velocity of Clowney after the collision, and $(V_C)_i$ is the velocity of Clowney before the collision. Using the value obtained from (2) in the analysis of Smith for F_T and the velocities from the Excel plot, F_G = 3390 N = 762 lb.

Important Issues

It is worth mentioning again that the approach used here is not the only way to estimate the force of the collision. For example, one may try to estimate the distance over which the collision occurs and use the work-energy theorem rather than the momentum impulse relation. Any technique used will require decisions that render the whole process an estimation rather than a precision analysis. The investigator must make the determination regarding the value of such a process. In this case, the excitement generated by analyzing an actual play seems worth the sacrifice of estimation.

Perhaps the most important matter in the whole analysis is placing coordinate axes on the video, scaling the video, making sure the origin of the video does not move during the tracking of the objects, and that the scale does not change. This is particularly challenging when the video selected is either panning or zooming, or both. Tracker has several features that allow the user to pick reference points in the video and use them to reset the coordinate system origin to the same location for each frame. There are also a variety of calibration tools that set the video scale accordingly. The football field was particularly simple to scale since there are easily identifiable yard markers on the field of play. Scaling may be more complicated in other sporting events.

Another factor in the estimation is the choice of the position of an object that is not a point object. This was the case for this example as the players are not point objects. In this case, the waistline of each player was chosen as the point of reference to mark their position.

Software

The beauty of this computation is that the software for performing the conversion of the YouTube video, and the Tracker program used to perform the analysis, are free. Keepvid is a well-known web-based program used to convert desirable videos so they can be downloaded to a local computer and stored for future viewing. It is accessed by typing in keepvid.com in a web browser. Tracker was written by a physics professor (Douglas Brown) and is downloadable over the web. It is Open Source software and is thus free of charge. There is also a downloadable user manual for instructions on how to use the many features of Tracker. In addition, there are YouTube videos demonstrating its use.

Student Reception

The football play and associated analysis described in this paper have been the subject of a physics lecture given to students in introductory physics at Edinboro University. In each case the topic of the day was the momentum-impulse relation, and this analysis was used as an example of how to apply the equation to real-world situations. First, after setting the stage of the bowl game and the circumstances surrounding the play, the video was then shown. It turns out that South Carolina had been clearly the victim of a bad call by the referee on the previous play, thus, the drama that unfolded in the play analyzed herein was intense. In the video Clowney tackles Smith and recovers a fumble, thus South Carolina was vindicated. All of this peaks student interest during the lecture. This is followed by a discussion of the possible values of the force during the tackle. After showing the results of the Tracker analysis and the Excel plots, the calculation yielding the tackling force is performed on the marker board in the lecture hall. In at least one case, when the result came in, students reacted with astonishment. A peer observer invited to the presentation wrote afterward "… students began to anticipate the results and became completely absorbed in the computations. When the computation was complete, the class reacted with enthusiasm."

A student survey asking for comments and reaction regarding the effectiveness of the demonstration showed that more than 85% of the students felt the Tracker analysis enhanced their understanding of the momentum-impulse concept. In addition, more than 90% of the students felt that the analysis bridged the gap between classroom discussion and real-world application.

Thus, the student reception to using the Tracker analysis in the classroom was a huge success. Many students have mentioned that they would like to learn how to use Tracker to do their own analysis and thus it seems that the nature of the analysis captured their interest and motivated them to learn.

Conclusion

The ability to analyze the physics of a "garden variety" YouTube posting opens the door for a tremendous range of possibilities. In addition to the play described herein, analysis has been done for the acceleration of an Adrian Peterson cut-back, the force of a Ray Lewis tackle, the precision of a Russell Wilson timing pass, the air-resistance of a Joe Flacco long touchdown pass, and other plays of interest. The possibilities are nearly endless, but the central important point is the concept of taking a non-staged, non-idealized, prominent big-stage sports play, and performing a detailed, although estimated, physical analysis for the purpose of illustrating the laws of physics. This has been shown to capture students' attention which is vital to success in teaching.

Acknowledgement

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Biographical Information

James R. Kirk is a professor of physics and technology at Edinboro University of Pennsylvania. He earned his Bachelors Degree in physics from Rutgers University, a Masters Degree in physics from the University of New Hampshire, and a Ph.D. in Meteorology from The Pennsylvania State University. His background includes a diverse set of knowledge ranging from advanced electronics and digital signal processing to atmospheric physics.