

A Web-Based Video Digitizing System for the Study of Projectile Motion

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Bio mechanics of human movement, broadly defined as the science concerned with the internal and external forces acting on a human body and the effects produced by these forces,¹ is one of the required courses for most students majoring in kinesiology, exercise science, and physical education. In this course, students must learn basic mechanical concepts before they can apply them to the analysis of human movement. Practitioners such as physical education teachers and coaches are also interested in the effects of forces acting on implements manipulated by humans in exercise or sports situations.

Projectile motion, the motion of a body in the air, is an important fundamental topic because it occurs with considerable frequency in many games and sports. Shot putters, golfers, and baseball, basketball, and volleyball players project objects (i.e., a shot or different kinds of balls), and jumpers, divers, and gymnasts project themselves into the air. In all these cases, the outcome depends largely on the performer's ability to control or to predict the result of the projectile motion involved. It is therefore important that students have some knowledge of the mechanical characteristics of projectile motion.

Video images are commonly used for the quantitative analysis of human movement. While students in an undergraduate biomechanics course are not expected to learn the details of

biomechanical motion analysis, an introduction of elementary measurement techniques is useful. Exposure to measurement techniques provides students an appreciation of how biomechanical data is obtained and introduces basic measurement concepts such as scaling. For example, when acquiring spatial measurements from video images, a conversion must be made from video-image size to real-life dimensions. For two-dimensional motion analyses, a recording of an object of known dimensions (e.g., a meterstick) placed in the plane of motion allows students to determine a conversion (scaling) factor for converting the length measured from the video image to a real-life distance.

Laboratory sessions are valuable for reinforcing mechanical concepts introduced in lectures. In the past, we used the traditional "Polaroid camera and strobe" technique for a projectile motion laboratory. Students used a desktop digitizer to extract coordinates of a projectile from a photograph obtained using a stroboscope and a Polaroid camera (see sample in Fig. 1) to complete a laboratory report. However, with advances in video technology, digitized video images have become popular in projectile-motion laboratories in the last decade.^{2, 3} A video-based system has several advantages over the "Polaroid camera and strobe" technique:

- **Improved image size.** For the same field of view, images obtained by a video camera are

greater in size, unless the Polaroid pictures are enlarged.

- **Higher quality.** Video images have better quality because the problem of "washing out" over time due to strobe flash does not exist.
- **Greater time resolution.** The video system provides more images for a given time (30 frames per second). Most commercially available strobe units have maximum rates of 10 flashes per second or lower.
- **Ease of use.** The digital video image technique is considerably easier to use and much more effective. Unlike the "Polaroid camera and strobe" technique, where a whole package of film can be used in getting one decent picture, once the video system is in place there is little additional cost.

To minimize the need of using laboratory equipment and to maximize the accessibility of video images to students, we developed a World Wide Web (WWW)-based digitized video system for a projectile-motion laboratory. We describe here the implementation of such a system.

IMPLEMENTATION OF A PROJECTILE MOTION LABORATORY

Preparation of Video Images

Instead of using a stroboscope and a Polaroid camera, a S-VHS camcorder (Panasonic AG455) was used

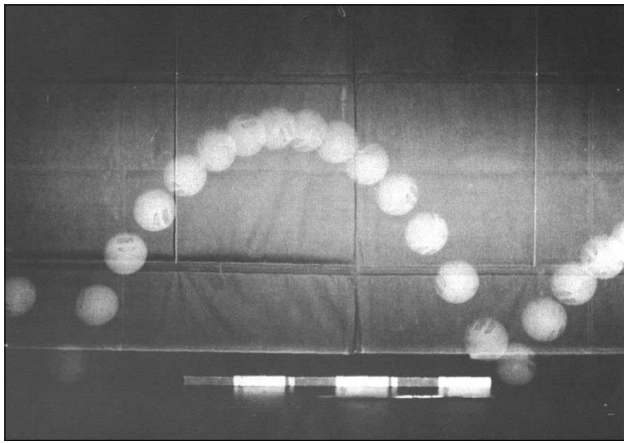


Fig. 1. Stroboscopic photography of a projectile motion taken at 21.5 flashes per second.

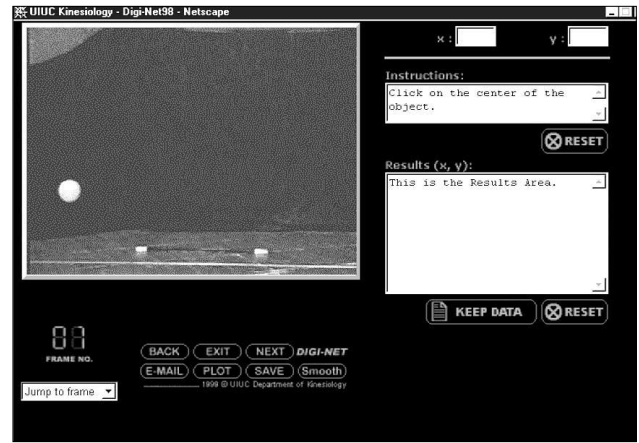


Fig. 2. Screen layout of the Digi-Net System for the digitizing of a projectile.

to record the projectile motion shown in Fig. 1. In front of a dark background, a volleyball was manually projected downward at an angle to the floor and landed next to the left end of a linear scale. The ball bounced off the floor and traveled toward the right and landed near the right end of the linear scale. After a number of trials, we selected those where the ball traveled in the vertical plane above the linear scale. The video recordings of the selected trials were digitized at 30 frames per second using a personal computer equipped with a video capture card⁴ and Adobe Premiere Software.⁵ In this way, we obtained a series of bitmap image files showing the ball locations starting about five frames before the first landing and ending about five frames after the second landing for each selected trial. To minimize the file size, the image files were resized from 640x480 to 500x375 pixels and saved in grayscale mode and as JPEG (.jpg) format using Adobe Photoshop software.⁵ The video images were then saved on a server connected to the Web.

The Digi-Net System

The Digi-Net (for *Digitizing on the Network*) system, first developed in 1997, is a web-based educational application for the study of motor coordination and biomechanics

(www.kines.uiuc.edu/digi-net98). The system aims to provide the capability of performing digitizing (extraction of coordinates from an image) without using specialized equipment in laboratory settings (e.g., desktop digitizers). The current version of Digi-Net utilizes the latest programming techniques in WWW client-server technology. The system is based on a combination of JavaScript 1.1 on the client side and Microsoft Active Server Pages technology on the server side.⁶⁻⁸ In addition to digitizing, Digi-Net also performs computations on the coordinate data the user digitized (e.g., data smoothing) and plots the results. At the request of the user, the system will send the results to the user's e-mail address.

Laboratory Procedures

The general procedures of this laboratory are outlined in a handout given to students. During the laboratory sessions, the technique used to gather data with the aid of a camcorder and a linear scale is demonstrated. This is followed by instructions on the use of Digi-Net to obtain the coordinates of the projectile. After the laboratory session, students complete the digitizing on any computer that has access to the Web by following the instructions in the handout. (See box for introductory portion of handout. A complete hand-

out is available at www.kines.uiuc.edu/courses/kines255/projectile_motion.pdf.)

To begin a digitizing session, the user is required to supply his/her name and e-mail address. After selecting one of the image sets, the first image of the series is displayed (Fig. 2). The first task for the user is to digitize the ends of the linear scale. To digitize a location, the user moves the cursor to the location of interest and clicks the mouse button. The x - and y -coordinates (in pixels) of this location are displayed. Because the length of the linear scale is known, the coordinates of the ends of the linear scale will allow the user to determine a conversion factor for converting pixels to meters. The next task is to digitize the center of the ball for the flight phase between the two landings. Once this is completed, the user selects the *Smooth* function to fit a second-order polynomial (quadratic curve) to the digitized y -coordinate versus frame number data, and the smoothed coordinates are displayed in the Result Area. The user then has the option of plotting the projectile motion on the screen and sending the raw and smoothed coordinate data to his/her e-mail account.

The handout details the data reduction procedures. Using the location data (x - and y -coordinates) they sent to themselves, students compute selected kinematic characteristics of

Lab 1: Projectile Motion

Purposes

The purposes of this laboratory are: (a) to acquaint you with some elementary measurement techniques used in biomechanics; and (b) to review some basic concepts of projectile motion.

Data Collection

The procedures used to gather data with the aid of a Panasonic Super-VHS camcorder, a volleyball, and a linear scale will be demonstrated.

Data Reduction

Sequential images were captured from the video recordings of the projectile motion of a ball and have been placed on the Internet. The data will be reduced to a series of numerical values (coordinates) using the Digi-Net System available on the Web. Follow the steps below to gather the required data:

1. Go to a PC that has Netscape Navigator 3.0 or Microsoft Internet Explorer 4.0 or later.
2. Double-click on the *Netscape Navigator* or *MS Explorer* icon.
3. Type in the location: <http://www.kines.uiuc.edu/digi-net98> or use the link to Digi-Net on Kines 255 home page. This will take you to the Digi-Net home page.
4. Click on the Image to enter Digi-Net. Click on Continue. . . .

the ball during the flight phase (e.g., speed and angle of release, vertical velocity and acceleration during the flight phase, etc.) and enter the results on the Answer Sheet provided.

Comments

This laboratory provides students with hands-on experience on the kinematic analysis of a planar motion, which is one of the fundamental techniques used for motion analysis in biomechanics. In terms of mathematical skills, the only prerequisite for our first-level biomechanics course is entry-level college algebra. Those who have no prior knowledge of plane analytic geometry learn the basics of rectangular coordinates, which is the foundation of any image-based motion analysis. They also gain an understanding of scaling—converting measurements from digitizer units (pixels in this case) to real-life units. They also acquire greater insight into the differences between the computation of “average” and “instantaneous” velocities in video analysis. For the students, use of a web-based digitizing system gets much of the laboratory-specific

equipment out of the way of learning. They do not need to learn the operational procedures for using a desktop digitizer, digitizing software, or video cassette recorder (VCR), which can be different from one manufacturer (or model) to another. Indeed, the students do not need to use any equipment in our laboratory, which is normally not available during evenings and weekends, to complete the image analysis.

For some students, one of the difficult concepts to grasp in projectile motion is the constant vertical acceleration of a projectile. When a body is projected upward in the air, the body (a projectile) will ascend to a peak location and descend afterward. Some students mistakenly think the vertical acceleration of a projectile is zero when it reaches its peak height because the vertical velocity is zero at that instant. This laboratory *demonstrates* that the vertical acceleration of a projectile is constant throughout the airborne phase. This helps students understand the concept that “zero velocity does not necessarily imply zero acceleration.”

To minimize copying of data

among students, each student is required to turn in a hard copy of the e-mail message containing the coordinate data along with the Answer Sheet. Our long-term goal is to have enough image sets in the system so that each student will work on his/her own image set.

To evaluate the effectiveness of the Digi-Net system for the projectile-motion laboratory, we prepared a questionnaire. It included a brief introduction of the Digi-Net project and some background information, along with a list of proposed advantages. It should be mentioned that few of our students had previous experience with a desktop digitizer. Consequently, the advantages of digitizing on the Web may not have been obvious to them. However, in general, most students found the Digi-Net system to be very effective for the study of projectile motion. They enjoyed the flexibility in terms of when and where to perform the digitizing. Some complained that the digitizing took too long to complete, partly because of the waiting time when moving from one frame to another—a limitation of the speed of the Internet connection the user has and the speed of the video display card in the user's computer. Suggestions by students for making the system more user-friendly include the addition of on-line help and audio instructions.

For us, the primary function of the web-based Digi-Net system is to allow users to quantify the motion of an object or the human body by acquiring coordinate data from video images. This paper describes the use of this system for the learning of mechanical concepts related to projectile motion. But such a system can be used in a variety of applications. We are also currently using the system for the study of movement coordination.⁹ In addition to acquiring coordinate data, we are planning to include features such as area measurement in the future. It is apparent that the Digi-Net system, or a system

of similar capabilities, has tremendous potential to be a valuable instructional tool in physical science.

Acknowledgments

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Physics Trick of the Month

A Pebble Curiosity

For this experiment you need a supply of marbles of two different sizes. Any kind of small spheres will do also, such as spherical bubble gum and candy. Assuming you are using marbles, fill a glass to the brim with the small marbles, and fill another glass to the brim with the larger marbles.

Question: Which glass has the larger volume of empty space?

You may think the glass with the larger marbles has more empty space because the spaces between marbles are larger. Actually, the volume of empty space is the same in both glasses. It is close to 40 percent of the glass's volume. To prove this, fill one glass to the brim with water, then pour the water into the other glass. It will fill the other glass exactly to the brim.

The fact that the ratio of empty space between randomly packed spheres to the total volume of the spheres is a constant is related to an important geological fact. Random packing of pebbles, even though their shapes are not spheres, has the same constant ratio of space to solid matter regardless of pebble sizes. As a consequence, if water is moving underground through a strata of pebbles, it flows at the same rate regardless of the sizes of the pebbles.

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