Digitized Video Images as a Tool in the Physics Lab

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Consider the following two physics laboratories:

1. Standard Projectile Motion Experiment: Student sets tabletop ball launcher at a certain height, shoots the ball several times, notes where the ball hits the table, raises the launcher, measures the launcher's height, shoots the ball, and continues this process for several different launch heights. Upon completing the experiment, student walks away with a table of data containing horizontal displacements of the ball, launch heights, and perhaps launch angles and uncertainties in measurements. Student is expected to prove that the horizontal speed of the balls is constant, under the assumption that the vertical speed of the ball changes at a rate of 9.8 m/s^2 (the assumption being backed up by experimentally observing that a ball launched horizontally and a ball dropped vertically at the same instant from the same height will hit the ground simultaneously).

Data acquisition takes up most of the lab period. Students must analyze the data largely outside of class. Throughout the lab the student's focus is on measuring launcher heights and ball impact points—not on the flight of the ball. The lab produces good numerical results, but there has always been some question as to whether the student really sees and understands the continuous motion of the projectile.

2. Radically Different Projectile Motion Experiment: Student places a couple of metersticks on a wall and throws a large steel ball in front of them. Throw is recorded on videotape. Separate images from the videotape are compiled into an image such as the one shown in Fig. 1. Upon completing experiment, student walks away with a full record of the projectile's flight.

Throughout the experiment and data analysis, the student's attention is focused on the projectile and its trajectory, which is seen in detail. Data acquisition takes less than a quarter of the lab period, so analysis begins while the instructor is present to provide assistance. The constant horizontal speed of the ball is immediately evident, and its vertical motion explicitly measured (no assumptions needed). The student clearly sees the continuous motion of the projectile.

In the spring of 1994, we began using a digitized video image system at Jefferson Community College that now allows us to conduct this radically different projectile experiment. The system we use is simple and flexible. Although the concept is not totally new (David Wagner described a similar

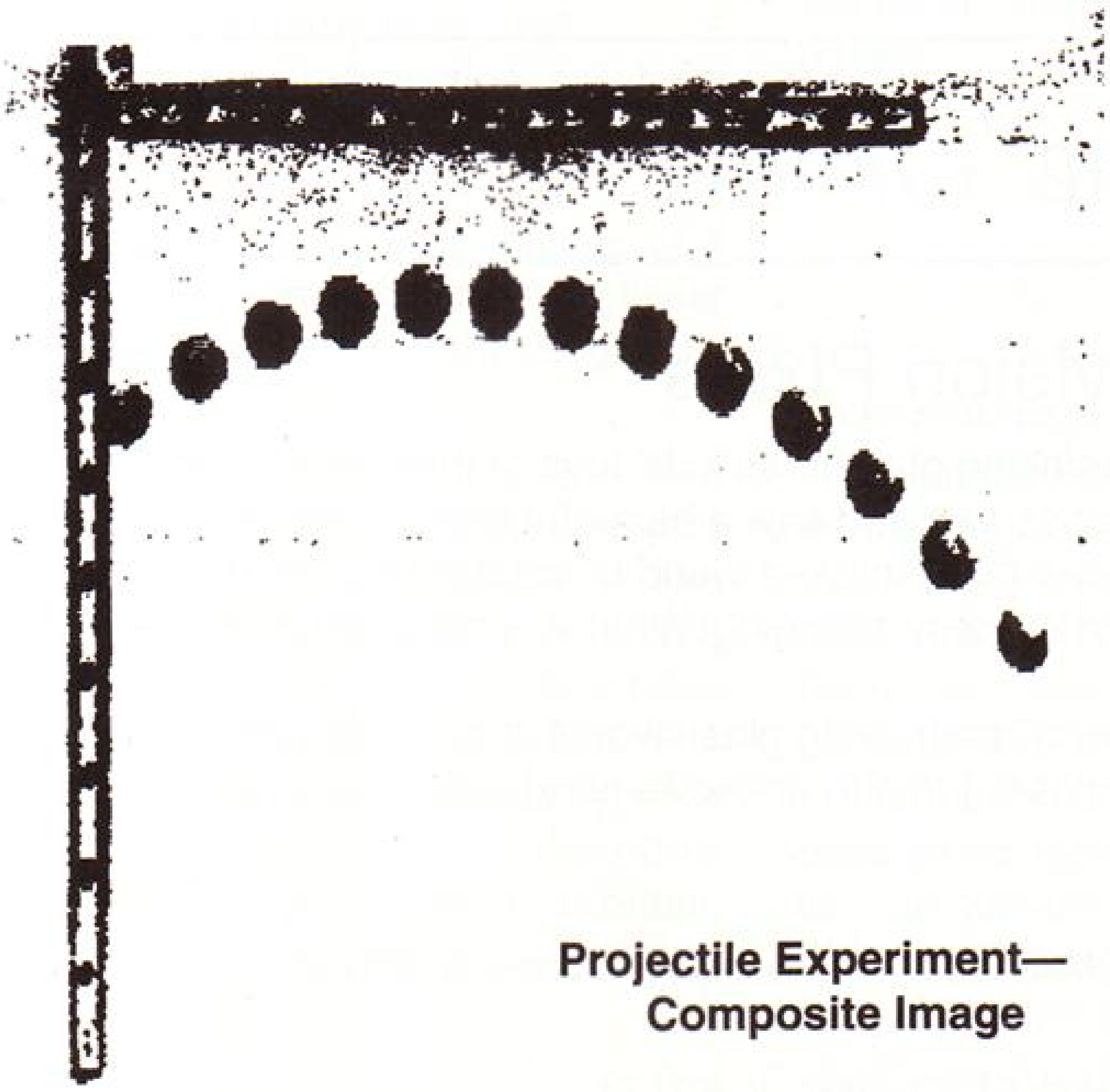

Fig. 1. What the student works from.

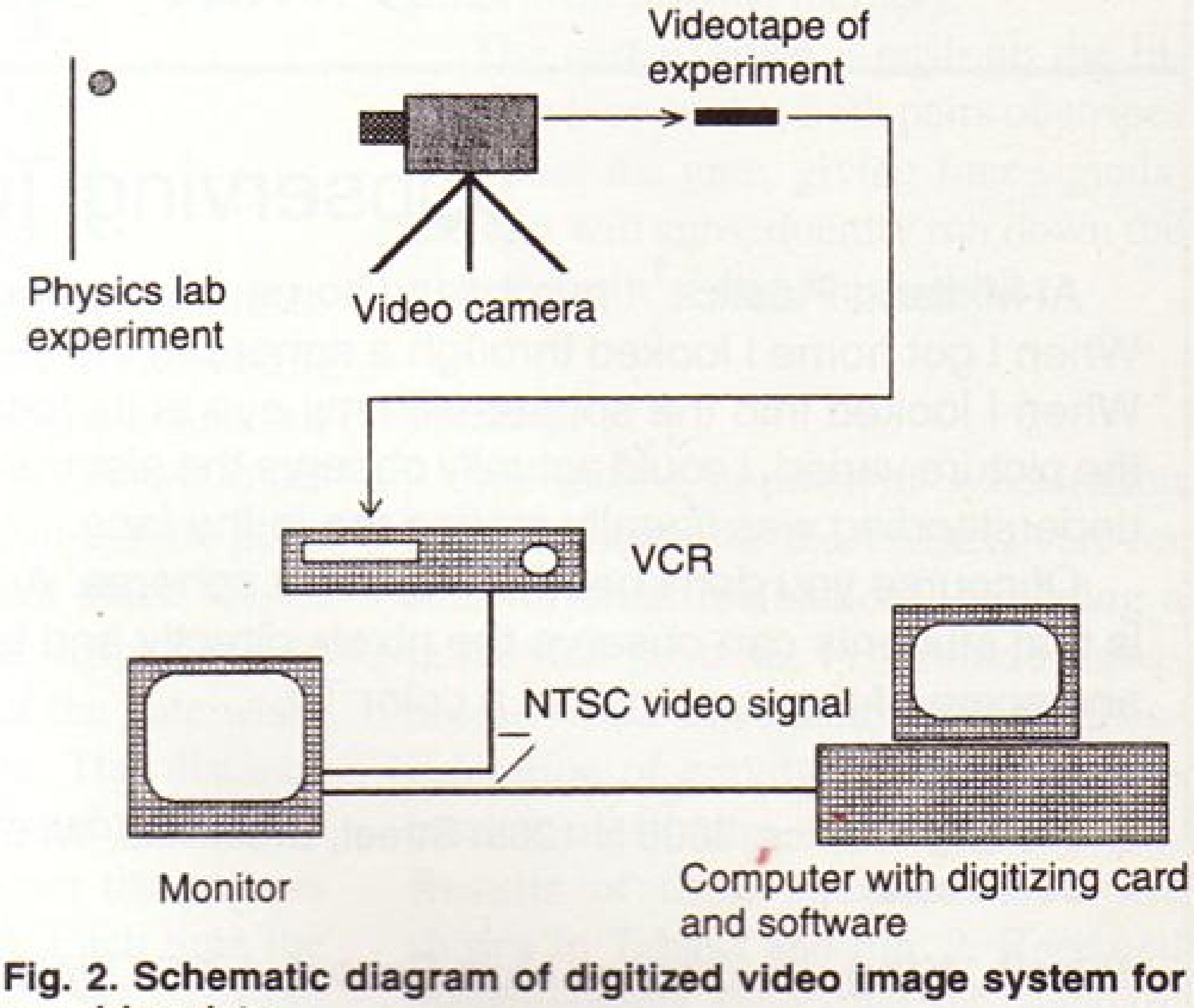

Fig. 2. Schematic diagram of digitized video image system for acquiring data.

technique in *TPT* recently[1]), our overall approach is different.

To utilize this system you will need a video camera (camcorder) to record the experiments, a television or other video monitor, a video cassette recorder (VCR), and a computer. A couple of metersticks serve as position references. A little paint might be handy to give contrast to some moving objects. Our system is depicted schematically in Fig. 2. The VCR should be a four-head model with frame-by-frame advance feature that can hold a good still image. The computer must be outfitted with a video digitizing card.

Detailed Example

In a well-lighted room, place two clearly marked metersticks (one horizontal, one vertical) on a wall. Toss a ball in front of and close to the metersticks. With a video camera on a tripod about four meters from the wall, record the toss on tape. (Tossing the ball close to the wall while having the camera set back a good distance helps minimize parallax errors.) Set the video camera's shutter speed at a moderately high setting to minimize blurring (typically 1/100 to 1/500 s, depending on light level). Remind students that regardless of the shutter speed, a VHS video camera records at a rate of 30 frames per second (a standard set by the National Television Systems Committee and known as the NTSC signal), so consecutive frames will be 1/30 s apart.

After the toss is captured on tape, the student removes the tape from the camcorder, places it in the VCR, and rewinds to the point where the event begins. The first frame on the

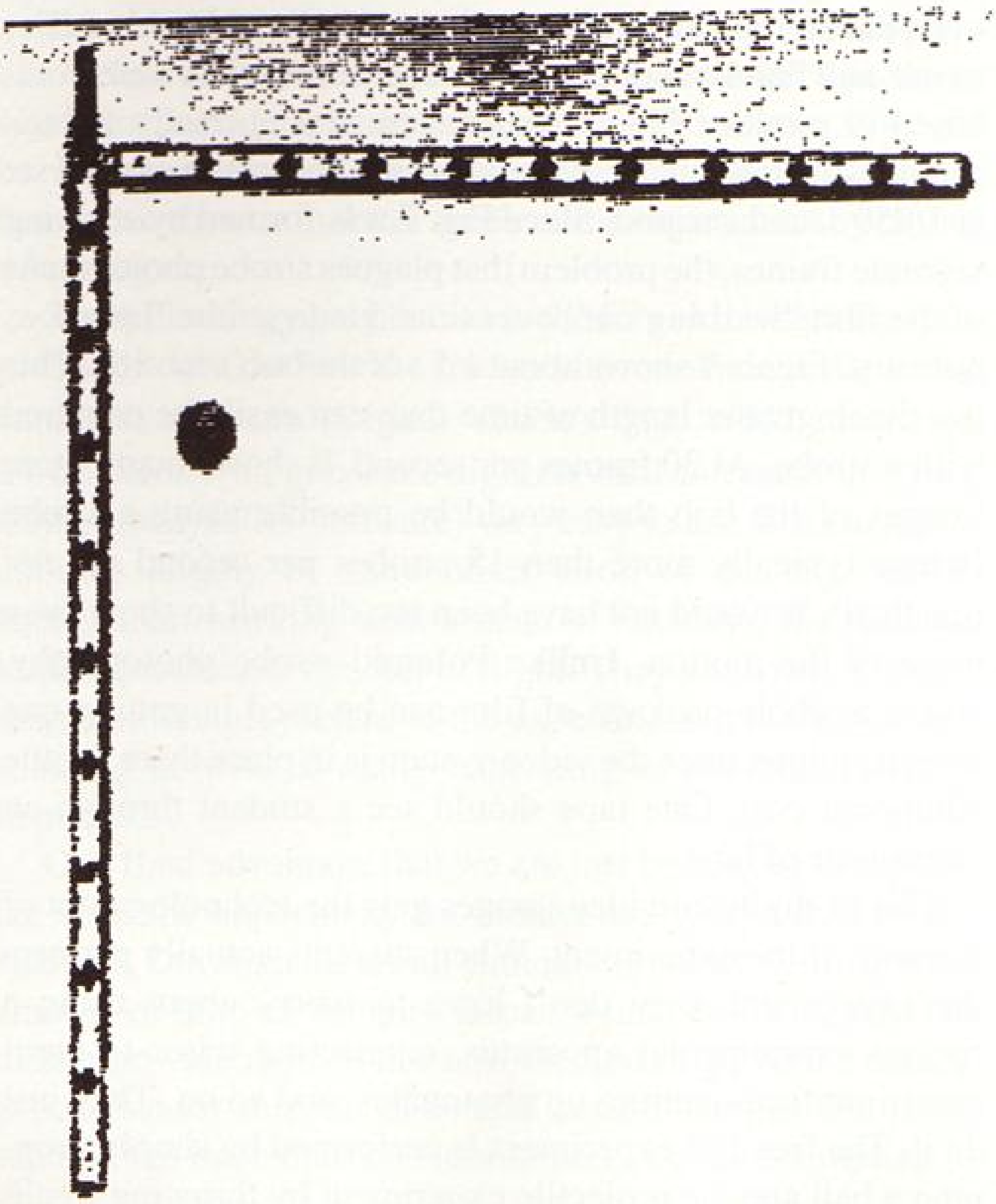

Fig. 3. Image of a single frame from a projectile motion experiment, showing projectile (ball) and reference metersticks. Note the "noise" at the top of the image.

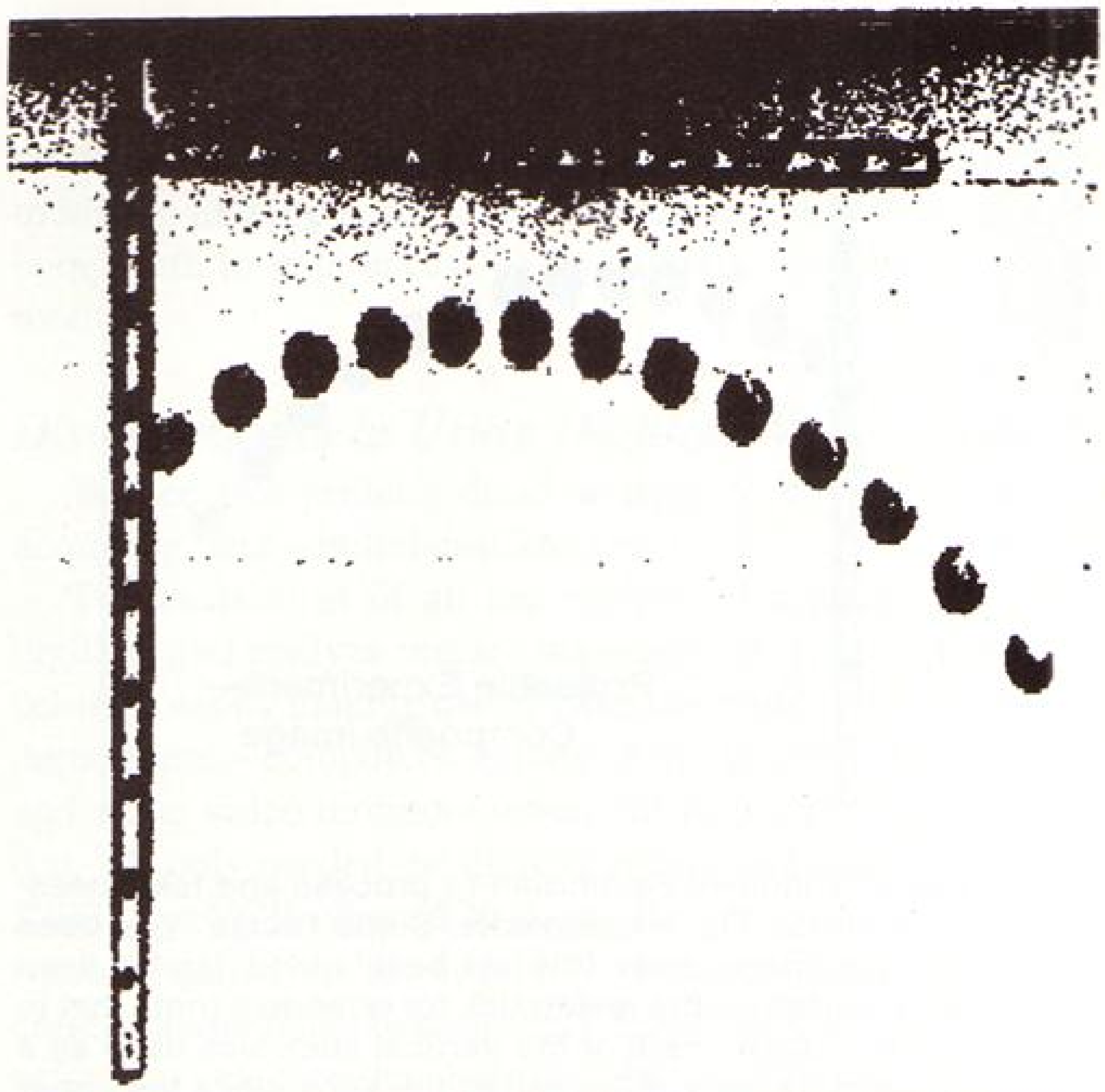

Fig. 4. Composite image from projectile experiment. "Noise" from many images has added up to produce the black smear at the top of the image. The metersticks are less clear than in Fig. 3, but can still be distinguished, as can the major markings on the sticks.

tape is "frozen" and loaded into a bit-mapped image file on the computer, using the digitizing card and accompanying software. The VCR is advanced one frame and that image loaded. The process is repeated until enough images are recorded to trace out a good portion of the ball's flight. The image loading process takes about five seconds per frame. We usually set the digitizer to give high-contrast, black-and-white images (these images take up the least disk space and are easy to make measurements from). A digitized image of a single frame is shown in Fig. 3.

Now the student can access the image files using any number of available drawing programs (we use Paintbrush, which comes free with Windows). With Paintbrush we line up the image files and stack them into a composite image that looks like, but is considerably less clear than, a strobe photograph (Fig. 4).

The student now enhances and analyzes the composite image. The drawing program can be used to add titles and text to the composite image or to erase extraneous things such as tables, chairs, and people's arms. With the "view cursor position" option of Paintbrush, the student can calibrate the picture and transform the cursor position into a position measured with respect to the metersticks seen in the image. This is done by first noting the cursor positions of the ends of the two metersticks. A little algebra produces two conversion equations—one to transform the horizontal cursor position into a position measured with respect to the horizontal meterstick, and one to transform the vertical cursor position into a position measured with respect to the vertical meterstick. The cursor is then placed on each image of the ball (Fig. 5). The ball's location is determined by noting the cursor position and converting that to position with respect to the

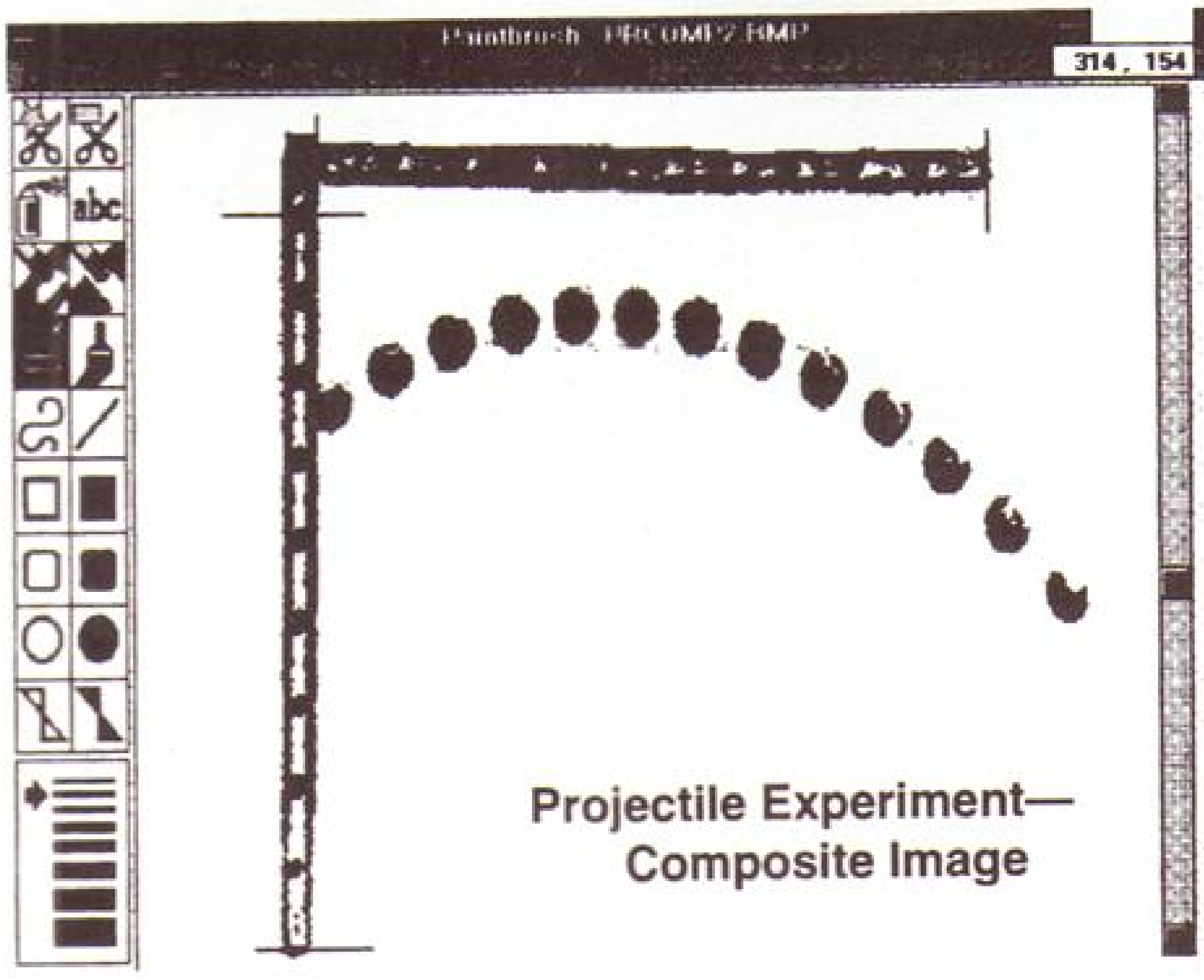

Fig. 5. Use of Windows Paintbrush to process and take measurements from the Fig. 4 composite. Some "noise" has been cleaned off the image, and a title has been added. Marker lines have been inserted on the meterstick for reference (note that in this image the 90-cm mark of the vertical stick was used as a reference point instead of the end of the stick since the upper end of the stick is not as clearly defined). Cursor position is shown at the upper right of the figure. What cannot be seen is the cursor itself, located on the center of the sixth ball image from the right.

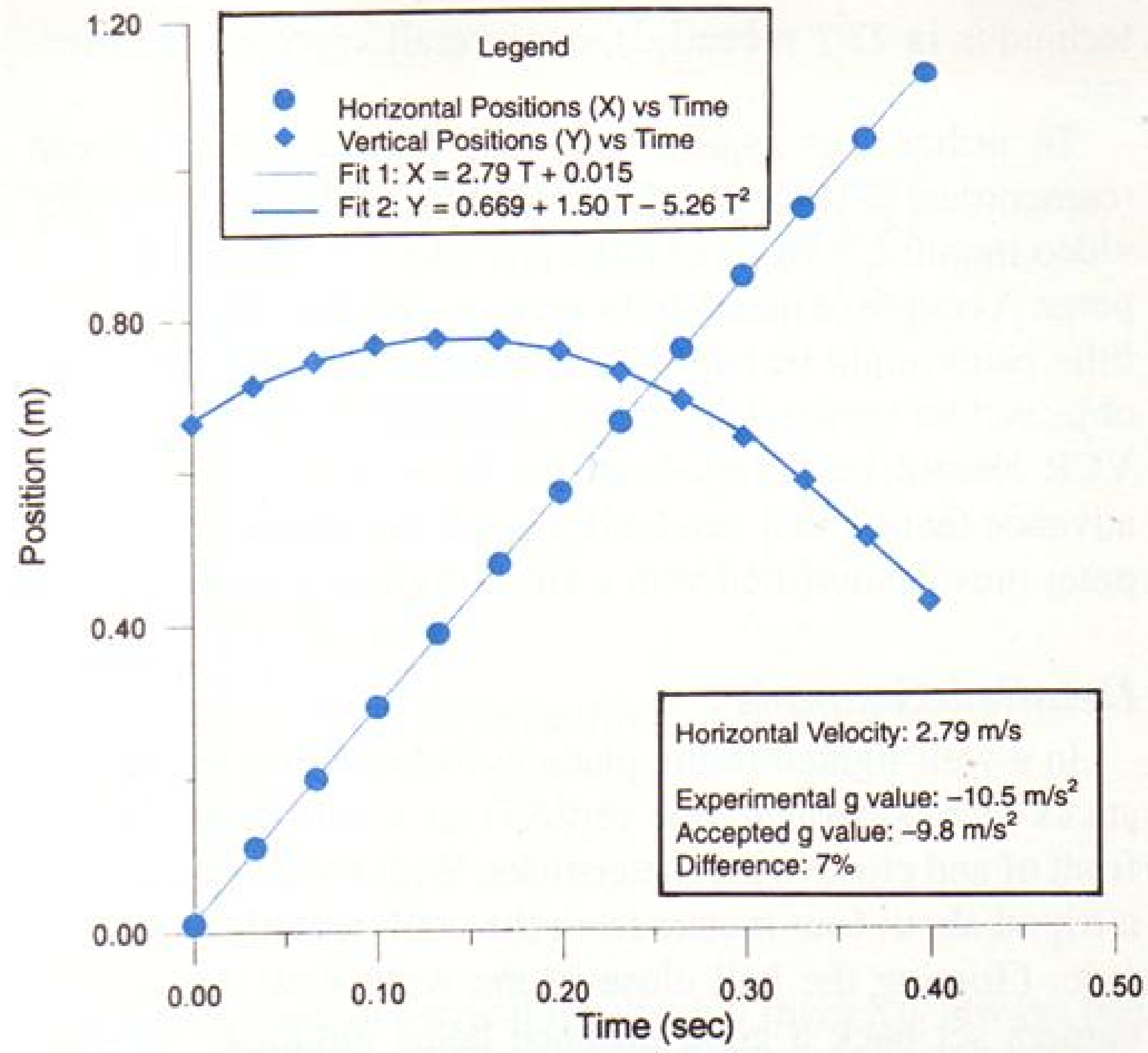

Fig. 6. Graphs of data extracted from projectile motion composite figure (produced with Golden Software's Grapher for Windows). Horizontal speed of the ball found by taking the first derivative of Fit 1; value for *g* found by taking the second derivative of Fit 2. Several different types of plots may be produced; this is given only as an example.

metersticks. This way, the problem of the composite image not being clear enough to directly read the metersticks is neatly bypassed. Furthermore, even the positions of those ball images that do not lie inside the area defined by the two metersticks can be determined with reasonable accuracy. The horizontal positions of the last two images are each greater than 1.0 m.

The student has acquired a table of horizontal and vertical ball positions, and knows that there is 1/30 s of time between positions. Now it is possible to go on to plot horizontal and vertical positions vs time, showing mathematically that the horizontal speed of the ball is unchanging, while the vertical speed changes at a rate of 9.8 m/s^2 (Fig. 6). Of course the fact that the horizontal speed is constant will probably already have been noticed simply because the horizontal positions of the ball are at regular intervals.

Advantages to Using Digitized Video Images

Among the advantages of using digitized video images to collect data, we mention the following.

The technique is very flexible. Our students have used the system for free-fall and projectile lab experiments. However, we have experimented with problems involving free fall with air resistance, simple harmonic oscillators (both linear and angular, damped and undamped), and air tracks. It seems possible to analyze in detail and extract good data from any experiment that can be videotaped! As an illustration, Fig. 7 shows a composite image of the motion of the bob of a spring pendulum. While this figure is included only for illustration, it would not be hard to clean up the picture with Paintbrush and take measurements of the bob's rather complex motion, something that might be tough to do using another data collection method.

An image such as Fig. 7 might be obtained using the "Polaroid camera and strobe" technique often used in physics labs during the mid-sixties through the early eighties. However, the digital video image technique is considerably easier to use and much more effective. The frames that were combined to produce Fig. 7 were taken in a normally lighted room, using a standard video camera with a shutter speed set at 1/250 s, and a tripod. Since Fig. 7 was formed by stacking separate frames, the problem that plagues strobe photographs of the film "washing out" over time due to strobe flash does not exist. Figure 7 shows about 1.5 s of the bob's motion. This is a much greater length of time than can easily be captured with a strobe. At 30 frames per second, it shows many more images of the bob than would be possible using a strobe (where typically more than 15 strobes per second are not practical). It would not have been too difficult to show even more of the motion. Unlike Polaroid strobe photography, 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. One tape should see a student through an entire year of labs.

Use of digitized video images gets the technology out of the way of the experiment. When students actually perform the experiment, they don't have to worry about using a special experimental apparatus, connecting wires to computer interfaces, setting up photogates, and so on. They just do it. The free-fall experiment is performed by simply dropping a ball and the projectile experiment by throwing a ball. Students don't need much assistance in setting up and using a camcorder or VCR.

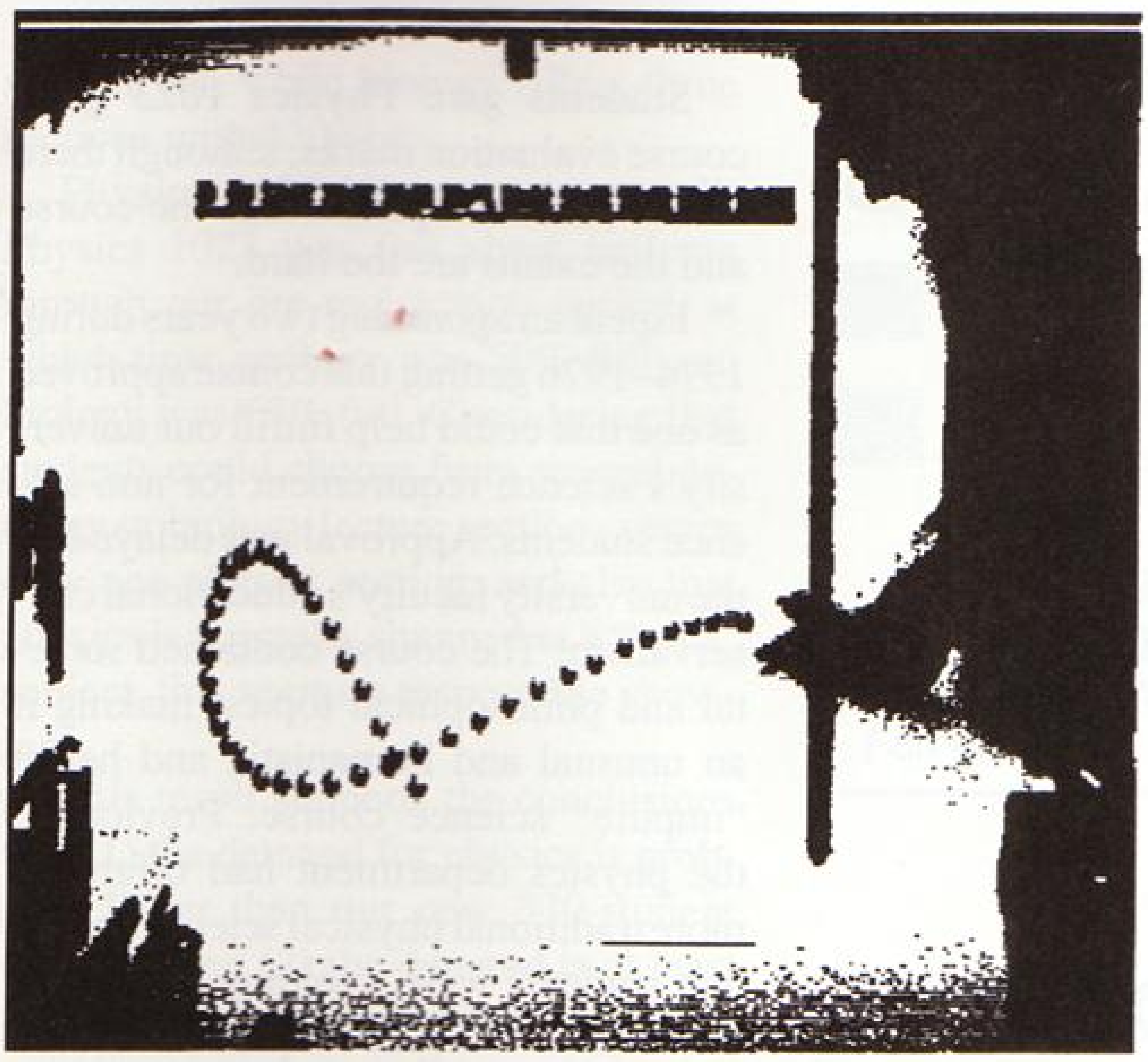

Fig. 7. Composite image of the motion of the bob of a spring pendulum. The string and spring from which the bob is suspended cannot be seen. Noise can be seen at the bottom. A table, chair, and other items are at the lower left. Author Graney's hand and body are at right, severely blurred by the process of stacking many images of a moving person one on top of another. Graney also made the mistake of getting in the way of the vertical meterstick! The complex path the bob follows is very clear, however. Over forty images were stacked to make this composite. It would be possible to have fewer images for the same time span by simply stacking every other image or every third image to form a composite. This would define the bob's motion less clearly, but would help avoid any overlap of images where the bob is moving slowly.

Because the technology is non-obtrusive, the experiments can be less contrived and much more "real world" than those often performed in physics lab courses. For instance, it would be very possible to do the projectile experiment by taping a horseshoe toss, or to do an acceleration experiment by taping a braking car.

The technology only comes to the fore in the data analysis part of the lab, but here the students have found the digitizing card and software (Digital Vision's 512 × 512 resolution 24-bit color/8-bit grayscale digitizer card and accompanying ComputerEyes/RT software) very easy to use. Data analysis consists largely of more observation of the experiment. Rather than working with a table of numbers, the students look at pictures of the ball in flight. They see a much larger, more continuous picture of the experiment, and their understanding of what is really happening in the experiment is increased.

One final advantage that we are just beginning to capitalize on is the opportunity for remote analysis of data by the students. Our students are all commuters, many with a limited amount of time on campus. Because images are captured to disk from videotape in this new method of gathering data, it is possible for students to do analysis off campus. For those who do not have their own computers, we are attempting to obtain some Windows-equipped laptop computers, which could be checked out and taken home. We are equipping the network of computers in our science building with two modems, making it possible for students to use their remote computers to gain access to on-campus computer analysis tools.

Disadvantages to Using Digitized Video Images

We see two primary disadvantages to this technique of acquiring data—initial cost and precision.

The initial cost of all the equipment needed to record, digitize, and analyze images is significant. However, we cut set-up costs by making use of what we could find around the department—computers, copies of the Paintbrush program, and some video monitors (even old Apple II monitors will do). We only needed the digitizing card and software (about \$300), the VCR (about \$200), and the camcorder equipment (more expensive, but currently we borrow this from the college audiovisual department). Equipment cost is partially offset by the fact that because the digitized video image technique is so flexible, once the apparatus is in place there is less need for specialized, expensive equipment for each individual lab.

The problem of precision is apparent in the rather crude images seen in Fig. 7 and the other images. However, we have found the digital video technique to be sufficiently accurate for students to feel that it "works" (in the free-fall experiment, g values are well within 10% of 9.8 m/s^2). The advantages of this system outweigh this disadvantage. Also, the digitizing cards are capable of greater precision than our images show. This comes at a cost of more disk space to store images and a more sophisticated program than Paintbrush to process them. Advancing technology may largely eliminate this disadvantage.

One thing that may be viewed as a disadvantage is that the students have to learn how to use the system and the software that goes with it. We devote one whole lab meeting early in the semester to acquainting the students with the system. Clearly that time could be spent doing experiments, but this is somewhat offset by the fact that the experimental procedures require less time, and once the system is learned, it is used throughout the semester.

Digitized Video Images in Use

Once our students became familiar with the system for the free-fall experiment they considered themselves virtual experts. We plan to introduce some new labs, especially in the area of rotational motion. The system is not perfect—we are only just beginning to explore its potential. We hope others will try this digitized video technique and let us know what successes and difficulties they encounter.

Reference

1. D. Wagner, *Phys. Teach.* **32**, 240 (April 1994).