USING VIDEO ANALYSIS TO INVESTIGATE CONSERVATION IMPULSE AND MECHANICAL ENERGY LAWS

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***Abstract**: Video analysis provides an educational, motivating, and cost-effective alternative to traditional course-related activities in physics education. Our paper presents results from video analysis of experiments "Collision of balls" and "Motion of a ball rolled on inclined plane" as examples to illustrate the laws of conservation of impulse and mechanical energy.*

***Keywords**: physics, laws of conservation, video analysis, engineering education.*

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Introduction

Visualizations and simulations of physical phenomena have always been and will be important tool for illustrating and understanding of physics concepts. Via visualizations techniques, such as demonstrations, simulations, models, real-time graphs, films and video, scenarios that are otherwise too difficult to be carried out experimentally can be explored, and processes that are not normally visible can be presented [Belcher, 2007]. The combination of video with computer display and analysis has led to a powerful and sophisticated tool based on visual information about real physical phenomena [Lawrence, 1996; Zollman, 1994; Wagner, 1994]. Video analysis provides an educational, motivating, and cost-effective alternative to traditional course-related activities in physics education. Software engineers are now developing programs similar to these that are compatible with portable handheld technologies, which should greatly increase the versatility of video analysis as an instruction method. Such products meet the most important guidelines for the appropriate use of technology in science and mathematics study, and the use of these products should be an element in courses for preservice science and mathematics teachers and in professional development sessions for in-service teachers [Roth, 1992].

In our paper we use the advantage of Coach 6 system for video analysis of experiments "Collision of balls" and "Motion of a ball rolled on inclined plane" as examples to illustrate the laws of conservation of impulse and mechanical energy. Presented examples illustrate some of the possibilities of video analysis and show a new alternative for checking the conservation laws.

Advantages of video analysis

Video analysis programs are powerful ways for students to analyze different physics phenomena. A number of relatively inexpensive video analysis programs are currently available, including VideoPoint, Tracker, VideoGraph, Physics ToolKit (formerly known as World-in-Motion), LoggerPro, Coach and Measurement-in-Motion [Bryan, 2004].

The main advantages of video analysis are:

- Video analysis methodology eliminates the most common barriers to incorporating real-world investigations into math studies and economically facilitates authentic investigations and applications of graphical, mathematical, and numerical representations to realworld problems and data.
- Digital video analysis has a number of virtues. At present it is one of the few readily accessible methods for doing quantitative studies of electrostatics, thermal phenomena, and two-dimensional motions that are not too fast to be recorded at 30 frames per second.

- A major advantage of computer-based video analysis is ease of use. When students use analysis software to scale video frames and locate points of interest frame-by-frame, they are required to make judgments and understand the analysis process. In addition, video software takes a great deal of the tedium out of recording data and frees students to concentrate on the physical phenomena under study.
- Another advantage is that position measurements made by video-analysis software on video images tend to have less relative uncertainty than other types of measurements made in laboratories. Distances are measured in pixels (short for picture elements) and then scaled into real meters using an object of known length found in the image. Standard digital images are currently 320 pixels wide by 240 pixels tall, so uncertainties in position measurements are only about 1%.
- The versatility of video analysis is also an important feature. Any object(s) in any location that can be, or has been, videotaped can be analyzed. Computer technology today even makes possible the video analysis of any clip of motion “captured” from any available recording in videocassette (VHS), compact disk (CD), and digital video disk (DVD) formats.
- There is a wealth of video material showing motions that occur outside the laboratory: NASA launches, sports events, dance performances, movie stunts, and cartoons. Students can “mark” the position of an object in each frame of a video clip to obtain position information, and then quickly and easily produce informative graphs of position, velocity, acceleration, force, impulse, and energy with just a click of the mouse button. Students may either analyze video clips that are supplied by these programs, import video clips from other sources, or produce their own video clips.
- Video-analysis programs can also be configured to calculate the center of mass of a system of objects, or a nonrigid object, based on assigned masses of system elements.
- Students can analyze digital videos in many settings including residence halls, computer classrooms, laboratories, or even under trees using laptop computers. Not still photographs, but too short to be considered movies, these “live photos” can be played on a computer monitor at any speed, backward or forward, at the will of the user [Teese, 2007].
- If free or inexpensive software is used, video analysis can even be incorporated into homework assignments or distance learning. The videos used in this technique are normally very short. They should be long enough to show a phenomenon completely, but compact enough for students to analyze with a reasonable effort.

There are three important advantages of video analysis [Bryan, 2004] over probes and sensors.

- Video analysis allows for study of two -dimensional motion, such as revolving objects or projectiles.
- More than one object can be analyzed in any video, which can lead to detailed comparisons of multiple objects that are in the same system.
- Video analysis can be performed without all of the cumbersome wires and sensors associated with MBLs.

Coach Learning and Authoring Software Environment

Coach is the software package of the multifunctional interface Coach Lab, which offers the possibility to measure and control with a computer. The Authoring System Coach 6 gives opportunities to create multimedia activities for students starting at primary level up to undergraduate. A Coach Activity can consist of windows with: rich texts with teacher instructions and student reports; pictures with illustration of experiments and equipment; video clips to illustrate phenomena or to analyze frame by frame; data presented in forms of graphs; tables; meters or digital values; graphical or numerical models which theoretically describe science phenomena; programs to control devices and simple control systems and web-pages to bring extra resources for students. The program is delivered with many ready-to-go exemplary Activities. Coach with all its powerful facilities in one package is a unique environment for use in Biology, Chemistry, Physics, Mathematics and Technology with many different curricula. [Coach]

"Collision of balls" and "Motion of a ball rolled on inclined plane" as examples for video based experiments with Coach

The video measurements in Coach can be performed on digital video clips (format AVI, MOV or MPG), or on single images (format BMP, GIF or JPG). The optimal video resolution requirements of 320 x 240 allow using a web camera. After compression the captured video clip is open in data video window in the main window of the current project (coach activity) file cam or car. The real life phenomena video measurements are a possibility to apply the problem- based learning strategy with help to the computer. This paper describes how inexpensive video analysis technology makes possible the investigation of types of motion with detail and precision that would be incredibly difficult, if not impossible, without the use of this technology.

The main Learning objectives are: investigation the problem of collision of balls; progressive and rotational motion, laws of conservation of impulse and mechanical energy.

The experiment "Collision of balls" usually concerns the case of equal mass collision; the two objects just exchange velocities. During the impact these internal forces of interaction develop impulses equal in magnitude and opposite in direction. The impulse of the ball is transferred through the system, and the ball on the other end reacts accordingly. Generally, the impulse of the excited ball(s) will be transferred down the line on balls, exciting an equal amount of balls at the end. For example, one ball given an initial impulse will cause one ball at the opposite end to have the same impulse after collision (Fig.1.)

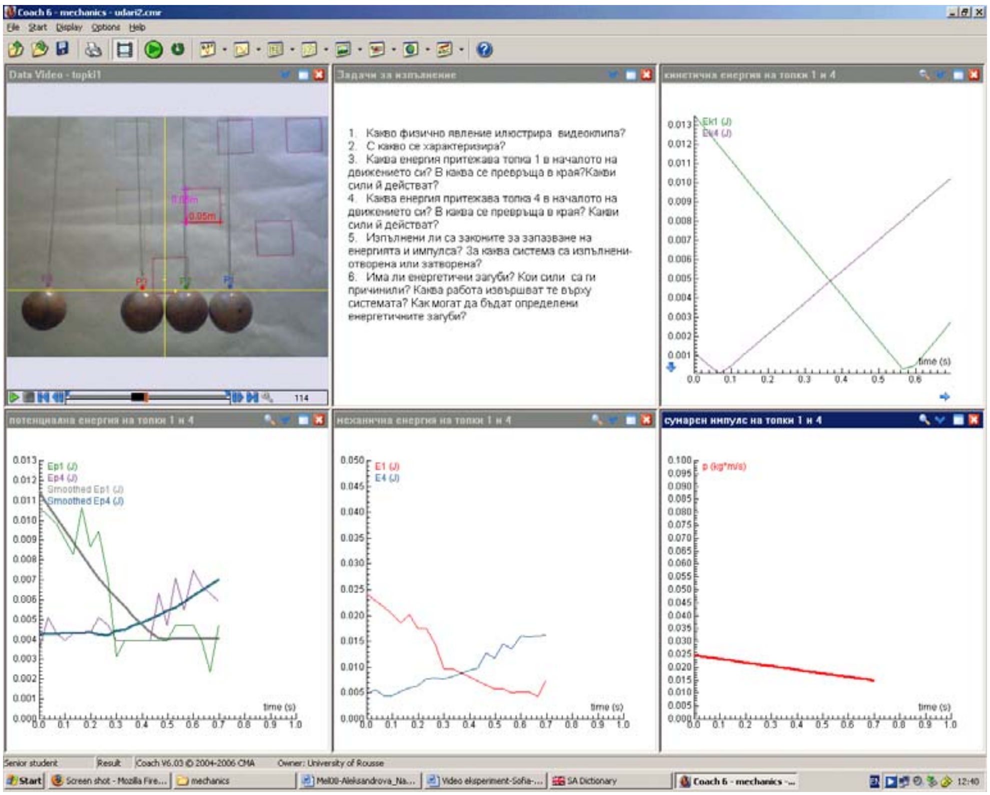

Fig.1. Screen shot of a video analysis activity – "Collision of balls"

This demonstrates conservation of impulse in a collision involving several bodies. In practice the central collisions of identical balls can be observed with the aid few balls on stand. All the balls are suspended on long strings and the task is reduced to consideration of their paired collisions. Outermost balls will be pushed consequently with identical velocity and deviated by identical angles, while all the balls between them will be in rest. It is necessary to note, that above mentioned consideration is true only for the case of absolutely elastic central collision of the balls when there is no loss of energy. Actually, the total energy of the system will decrease due to air dumping, heating of the balls, excitation of acoustic waves, etc. Therefore, the amplitude of extreme balls deviation decreases with time and the central balls are set into the oscillatory motion. The experiment of central collisions of identical balls can be used as example of the conservation of mechanical energy. After a ball is tossed upward, it loses kinetic energy Ek and gains gravitational potential energy Ep as it rises; and then loses gravitational potential energy and gains kinetic energy as it falls, such that the total mechanical energy E = Ek + Ep remains constant at every location during the trip. Fig.1 is a screen shot of the video analysis activity and shows the original video clip of the experiment “Collision of balls”, student’s tasks and graphical results of measuring – kinetic and potential energy of ball 1 and ball 4, mechanical energy and total impulse with respect to time. Additional graphs present the position on the axes x and y, velocities, impulse and accelerations components.

Students will analyse impulse and energy transformation graphs, to check the conservation laws and define and explain the losses of energy.

The experiment “Motion of a ball rolled on inclined plane” can be used for the same purpose – to check the conservation laws. A small steel ball is rolled down an inclined plane (fig.2). For small angle the motion of the ball on the inclined plane is a sum of progressive and rotational motion. If ball is rolling down on inclined plane it tends to accelerate downward, but since it may not be free to move straight down, the acceleration (change in velocity) proceeds in the direction that decreases its height most quickly. The plane itself pushes against it, canceling some of that acceleration, and it goes accelerating in the direction free to it that decreases the height most quickly. Initially, the ball has only potential energy (the ball is not moving initially). Later, some of the potential energy is transformed into kinetic energy. As it loses height, the ball gains speed, and always in such a way that the speed gained depends only on the height lost. In this case the motion is more complex. The kinetic energy now consists of two components connected with progressive and rotational motion.

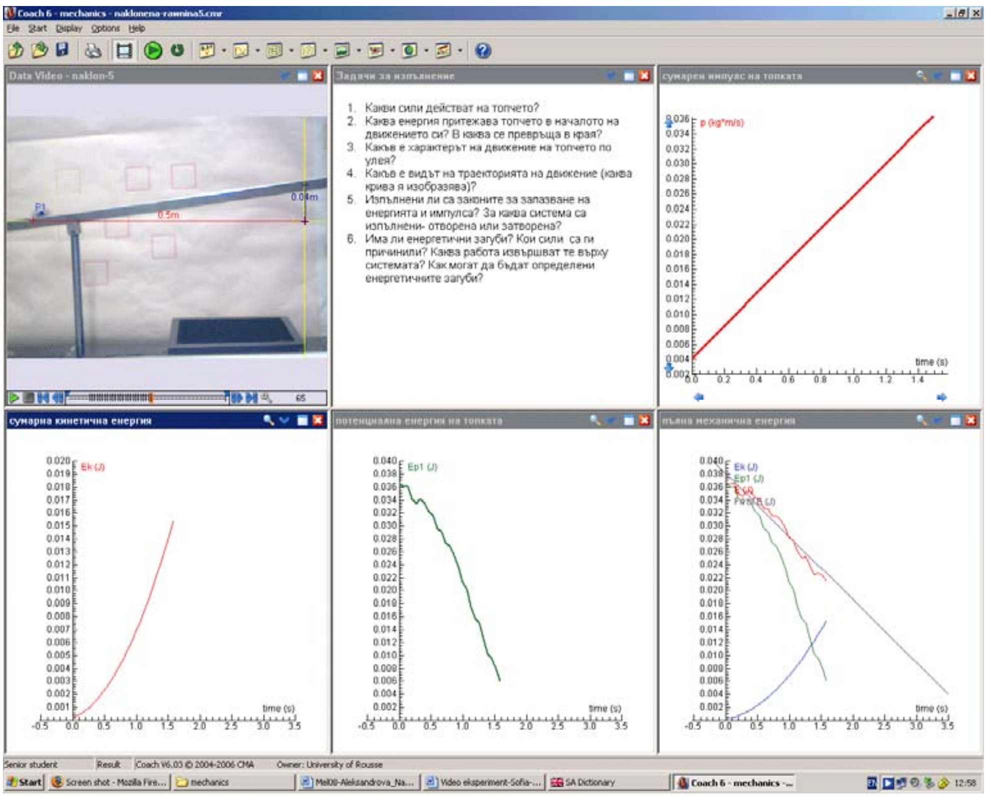

Fig. 2 Screen shot of a video analysis activity – “Motion of a ball rolled on inclined plane”

Fig.2 is a screen shot of the video analysis activity and shows the original video clip of the experiment “Motion of a ball rolled on inclined plane”, student’s tasks and graphical results for total impulse, potential, total kinetic energy (a sum of kinetic energy connected with progressive and rotational motion) and mechanical energy of rolling ball. Additional graphs present the position on the axes x and y, velocities, impulse and accelerations components, kinetic energy of progressive and rotational motion.

Students will analyse complicated motion of the ball (define the progressive velocity components, moment of inertia and angular velocity), investigate different types of kinetic energy graphs, the forces that act on the ball, work done, impulse and energy transformation, check the conservation laws, determine and explain the losses of energy.

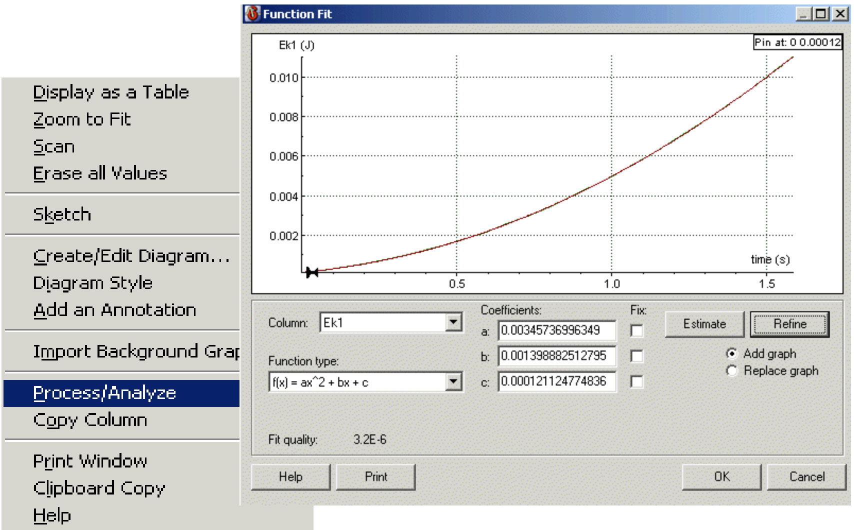

Fig.3. Screen shot of process analysis and function fit

The video analysis allows active and deeper investigation of to the processes and phenomenon, captured in the video clip. Students can use the additional tools for analyzing the collected data- scan results, smooth (filtering results), derivative and integral operation, signal analysis (Fourier transform), different kind approximation (Function Fit), statistics and etc (Fig.3). From the basic data for the position and time can define other derivative physics quantities as velocity, acceleration, force, impulse, energy and etc. Students can directly connect the real phenomena and its analytical and graphical representation, investigate correlation between quantities, make predictions and test them. Do this, students precise define which of the physics quantities are scalars or vectors.

Conclusion

Video analysis provides a significant pedagogical tool for the physics teacher. The motion detailed video analysis enhanced by the discussion and active student’s participation could help to improve understanding of studied phenomena. It also brings the real experiment into mathematics and physics education in an attractive way. Presented examples illustrate some of the possibilities of video analysis and show a new alternative for checking the conservation laws. Students can be actively involved in the process of finding solutions to investigated problem. In addition to its obvious benefits for physics investigations, video analysis software can be an effective addition to mathematics instruction. Motivating the students with solving of real-world problems combined with computer usefulness, visualizes graphs and functions that are constructed as models of real-world phenomena are utilities to develop conceptual understanding and achieve pedagogical approach.

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