Capturing the Real World in the Classroom

by André Heck and Peter Uylings

Universiteit van Amsterdam, AMSTEL Institute, Kruislaan 404, 1098SM, Amsterdam, The Netherlands.
heck@science.uva.nl, uylings@science.uva.nl

Practical investigation tasks are part of the Dutch examination programme of senior secondary education. In mathematics and science, pupils are expected to develop a broad range of research skills, which includes connecting a real world phenomenon with the scientific world, understanding the problems at hand and asking the right questions, making a project plan, designing and carrying out an experiment, and collecting, representing, analysing, and interpreting information. Pupils need ICT tools that make such investigation tasks feasible and that enable them to work at an appropriate level. In this paper we report on a classroom experiment in which pupils in pre-vocational secondary education develop and practise research skills by carrying out a small investigation task using digital video technology. We also discuss how one can deal with three particular problems experienced in practice, viz., perspective distortion of images, the complexity of recording video clips, and the amount of time needed for collecting data.

1. IMPRESSION OF PUPILS' WORK

Pupils in the third year of the theoretical learning pathway in pre-vocational education (age 14/15 yrs.) work in teams on recording a video clip about a subject of their own choice. They use things that they brought from home, direct webcams, set the video software in capture mode, and go ahead and shoot a video clip. Darts throwing, rope-skipping, flying paper airplanes, bouncing balls, descending balloons, a handstand, and so forth (see Figure 1). Many things happen inside and outside the classroom.

After this comes the excitement of watching the recorded video clip and making sense of it. A lot of questions are raised: is the video clip a success? What interesting points can one focus on? Are there angles or distances to measure, or are there timings of events to make that reveal an interesting aspect of the recorded motion? How do graphs connected with the motion look like? Pupils use the computer learning environment Coach (Heck, 2002) for this type of small investigation. They print the graphs that they have found, annotate the diagrams, write short explanations, and hand this in as a short report.

2. SETTINGS AND OBJECTIVES

The scenario just described is an impression of the video measurement project which is part of the School Examination Programme of the VMBO-TL3 classes at Bonhoeffercollege in Castricum. VMBO is an acronym for pre-vocational education, which is meant for practically inclined students, following their primary education. It takes four years of study and pupils passing the final examination may go on to senior vocational education and prepare for a particular profession. Our classroom study took place in the

Figure 1. Examples of video activities in the classroom: darts throwing and rope-skipping.

theoretical learning pathway (TL). It prepares pupils for middle management and secondary vocational education.

There undoubtedly exists some contradiction between 'vocational education' and 'theoretical learning pathway'. In general, we notice a tendency to keep a tight rein on pupils in the classroom, as the only way to make pupils learn anything and to keep them motivated. Clarity and discipline in classroom activities are the key words. How appropriate such an approach may be in itself, it can also lead to a situation that practical investigative work by pupils, which is essential in science education, is offered in the same closed, fixed manner as theory. This is a pity because learning by doing and through lab work has much more appeal for pupils than theory lessons and therefore stimulates them to put more effort into their learning. We think it is possible to use practical work to entice VMBO-TL pupils to a more active, self-responsible, and self-controlled way of learning. Furthermore, we believe that ICT can contribute much to the realization of challenging practical work. This classroom study is one of our experiments to investigate this view of education.

Eighty pupils in three classes in the theoretical learning pathway did the video measurement project in the school year 2003/2004. The main objective of this project was to let pupils carry out a short investigation on a self-selected type of motion, at their own educational level. Exploring attitude and adequate practical skills were assessed in this project. Focus was on preparation, implementation, and completion of the investigation, as well as effective collection, processing, and presentation of data that were obtained from self-made video clips. The pupils did not have much experience with Coach: they had seen it being used by the teacher, and they had occasionally carried out measurements with sensors. A school network with a sufficient number of computers and a well-equipped science lab was available at the school. At the time of the project, five webcams were available, and a teaching assistant helped the pupils, if needed. The project work was done under the responsibility and guidance of the pupils' own physics teacher. There were three teachers with different backgrounds involved: one of the teachers, one of the authors of this paper, was experienced in video measurement activities. Another teacher was familiar with computer supported lab work and demonstration experiments but had not used video before. The third teacher had almost no experience with Coach and adopted the approach of the innovative teachers. The most experienced teacher started the project, and the other teachers followed in their classes, taking advantage of the first findings.

3. RESEARCH QUESTIONS

In this classroom study we tried to find answers to the following questions: Were the VMBO-TL3 pupils able to deal with the open task given to them? How much responsibility could be taken by the pupils, and when should the teacher bring structure to the activities? What level of performance was reached by the students? How could the quality of the pupils' work be graded? Did the pupils' recording of the video-clips have additional value, or could one have used prepared video clips instead? Did the investment of time and energy bring pupils some understanding of mathematics and science? How could the instructional setting and the computer learning environment be improved to a smoother implementation and optimization of pupils' results?
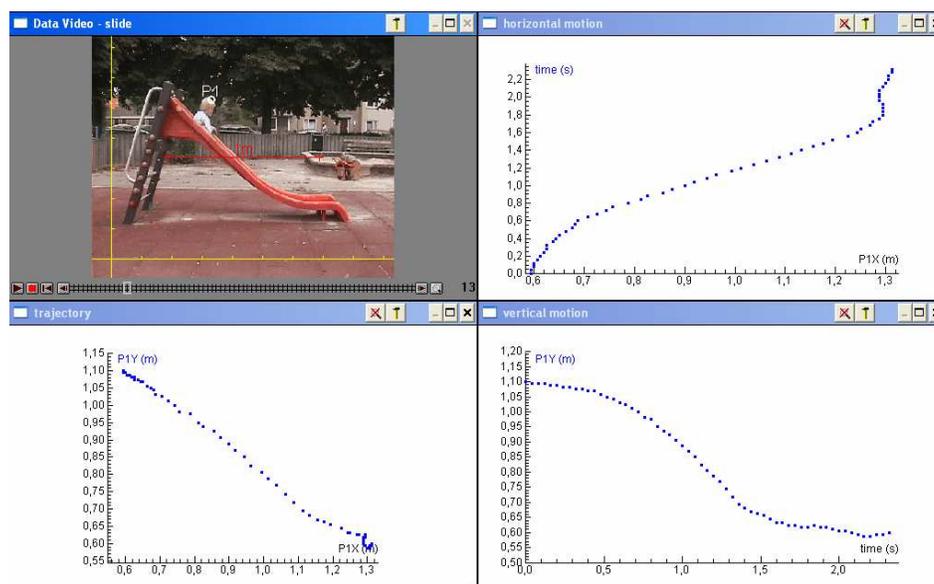

Figure 2. Sample video activity of a toddler on a slide in a playground.

4. DESIGN AND IMPLEMENTATION OF THE LESSONS

In this section we describe both the design of pupils' project work, planned for five lesson hours of forty-five minutes, and the implementation of the lessons by the most experienced teacher.

Lesson 1. Introduction to video capture and measurement

At the start, the teacher explains what the lesson is about and what the goals of the pupils' project are. He gives a live demonstration of using the video software VirtualDub (www.virtualdub.org) to capture a video clip with a webcam. There are many technicalities and things to take into account, but the idea of the demonstration is to show that any pupil is able to do this as well; it is not only for "whiz kids". When the teacher gives the second example of video capture, the pupils make their own class notes. They are expected to rely on their own notes when they themselves capture a video clip; no manual is provided. Next, it is the turn of two pupils to capture a video clip in front of the class. If all goes well, this gives each pupil the feeling that he or she will have success, too.

This recording of video clips takes about half an hour. So there is still some time left to practise measuring on a video clip. After a short demonstration, the pupils can practise with video activities that have been prepared for this purpose (pupils only have to trace a point by mouse clicking; the measurement settings and diagrams are preset). It is important that the sample video activities are appealing. A great success, especially with the girls, was the activity of a toddler on a slide in the playground (see Figure 2). Video clips with a sweet toddler are more effective than video clips

that are undoubtedly oriented towards physics, such as movies of falling balls, collision of balls, or motion of objects on an air track.

Lesson 2. How to make a useful video clip?

Pupils get five video clips with problems in capturing and measurement (see Figure 3). They must answer the following questions:
1. What is wrong or problematic with the video clip?
2. Can you fix this afterwards with the video software? If yes, carry out the repair!
3. How could you have prevented the mistakes?

Figure 3. Problem with perspective distortion.

In this lesson, time and attention is paid to the fact that the plane of motion is best perpendicular to the camera direction. The pupils must also decide now what phenomenon they want to capture and write down their plans of how to set up their experiment.

Lesson 3. Video measurement explained

The teacher demonstrates how to create a Coach video activity from scratch, how to embed the captured video clip, and how to carry out a measurement on the movie. Things that pass under review are the coordinate system and calibration, video compression, plane of motion and camera direction, display of collected data in diagrams, and so on. Actually, the teacher used in the classroom the video clip about darts throwing, which was recorded before by two pupils, as an inspiring example. This demonstration also serves another purpose: it gives the teacher once more the opportunity to explain the pupils what is actually expected from them.

Lesson 4. Video capture

Pupils capture their video clips using a webcam. They can get help from the teacher and/or his assistant if necessary, but they are expected to work as much as possible on their own, using their own class notes or getting help from fellow pupils.

Lesson 5. Collecting data and writing a report

Pupils carry out a measurement on their self-made video clip, create relevant diagrams, annotate graphs with relevant information, and finally write a short report. This report may be a screen shot of the Coach activity with some words of explanation and conclusions (see Figure 4).
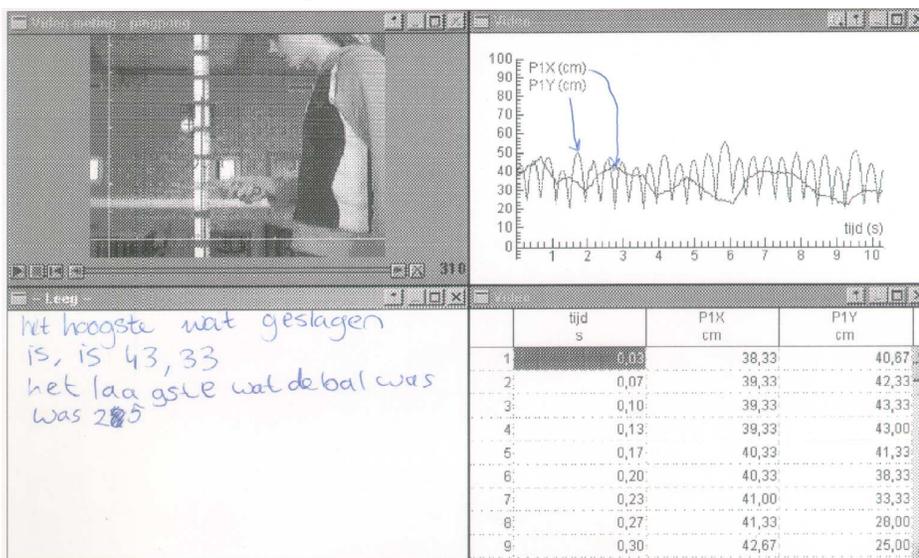

Figure 4. The full report of Irene and Nanda about table tennis.

5.   FINDINGS

Let us begin with the unforeseen technical problems that we encountered the first time that we did the classroom activity. Although every team succeeded in making a useful video clip, capturing and embedding the video clip in a Coach activity was hindered by the following things:

- Because some pupils forgot to use video compression they flooded the computer network at school with files of 60 MB or larger, which essentially meant a collapse of the network. Without serious video compression, e.g., MPEG-4 Video Codec V2, the files were also too big to use diskettes as transport media.

- The network installation of Coach at school prohibited that pupils could save video clips in a Coach project; these rights were only reserved for teachers. Transport of video clips from a laptop to the school computer via a memory stick could also be done only by the teacher or teaching assistant.

Each team spent about twenty minutes capturing a video clip. Most of the time was required for finding one's way in the menu items of VirtualDub to specify correct settings of the software. Consequently, pupils paid less attention to setting up the experiment in an adequate way. Many of them wanted to capture immediately and hardly did a test run to see whether the quality could be improved. Also, pupils often forgot about a measuring stick in the movie clip for calibration purposes. If the teacher had stressed in the previous lessons that the best camera direction is perpendicular to the plane of motion (in order to avoid perspective distortion), then the pupils did this well. However, if the teacher had not emphasized this, pupils sometimes made less useful video clips. While capturing, pupils seemed to forget their research questions; they simply recorded the phenomenon without consulting their notes. The lesson we learned from this is that one should require from pupils a better plan for their work.

Our conclusions about capturing a video clip with VirtualDub by TL3-pupils is that, despite its success, it was a bit too time-consuming to do with the whole class at once. It involved too many technicalities that distracted the pupils from setting up their experiment in an appropriate way, and it made them rely on teachers and assistants for help. In common practice there is not many staff available to support a lesson or lab session. For this reason, the video module of the Coach software has been redesigned to make the process of capturing and measuring a video clip easier. We will come back to this in Section 6.1.

The experience of the teacher with the learning environment and with video measurement, as well as the availability of laptop computers and the choice of location to capture the video clips, had a great impact on the scenes recorded. The least experienced teacher chose a setting with which he felt most comfortable, viz., the science lab and a limited choice of subjects to record: rolling balls (12 teams) and bouncing balls (3 teams). However, two of his pupils, Marlotte and Kirsten were nevertheless more inspired and recorded a cutting motion with their fingers. Figure 5 shows part of their report.
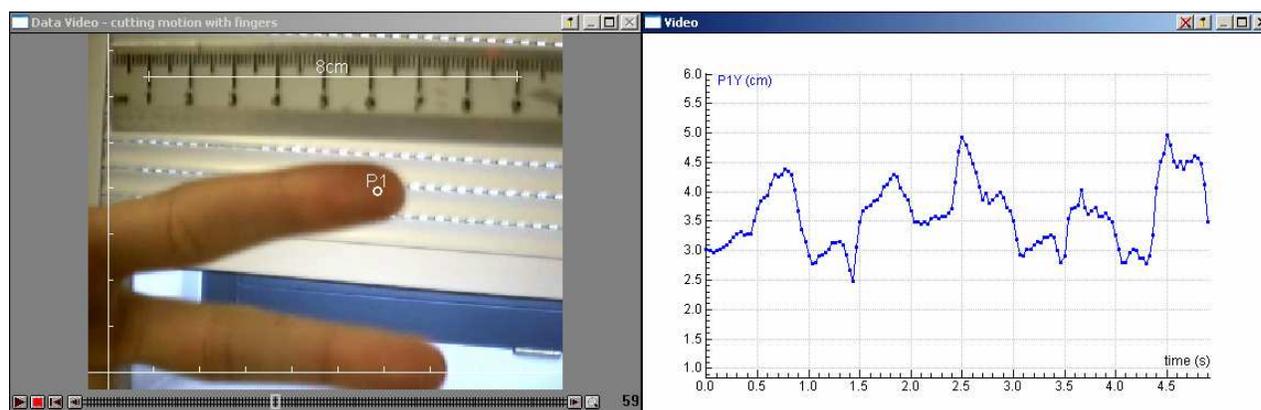
This graph is more readable. You see that the finger goes up and down, because we made a cutting movement. The movement is irregular, because the finger goes sometimes faster. The height is measured on the y-axis, the highest point is 5 cm. The time is measured in (s). The total time of the graph is 5 seconds. The initial point of the graph is (0, 3.0). The end point of the graph is (5, 3.5)

Figure 5. Part of the report of Marlotte and Kirsten on a cutting motion with fingers.

In the class of the teacher who already had experience with Coach, but not with video measurement, work was also done within the science lab only. However, pupils were stimulated to make a subject choice of their own. This led to a variety of video clips: rolling and bouncing balls, springs, a pendulum, jumping from standing position, hitting each other, hand waving, and the moving second hand of the clock in the science lab. The subjects in the class of the most experienced teacher, who also used two laptops in order to be able to capture anywhere, were the most variable: flight of a paper airplane, rope-skipping, darts throwing, throw-in of a soccer ball, projectile motion of a table tennis ball, skipping, and doing a handstand are nice examples. The creativity of the pupils was certainly switched on.

In all classes, pupils did their best to obtain accurate data in their video measurement, explain the graphical representations, and link up the graphs with the phenomenon in the real world that they had recorded. They used mathematics and physics beyond their expected level. Note in the fragment of the report shown in Figure 5 that the pupils read out coordinates of points without any mistake and paid attention to units of quantities. Marlotte and Kirsten sought an explanation for the irregular graph in terms of the real world motion. In Figure 6, which shows a fragment of the report of Rianne and Kim on a bouncing ball, there is a similar attempt to explain the form of the graph in physical terms.

We experienced that TL3-pupils were easily satisfied with one graphical representation of collected data, regardless of its suitability. To make sure that pupils used all standard diagrams of motion, we set out in later lessons a Coach activity with three diagrams (see Figure 2). We required that pupils reported explicitly on all three graphs. Since in the first classroom session we experienced that TL3-pupils had difficulty with understanding horizontal displacement on a vertical axis, we plotted later on time against horizontal position (shown in the upper right window of Figure 2).
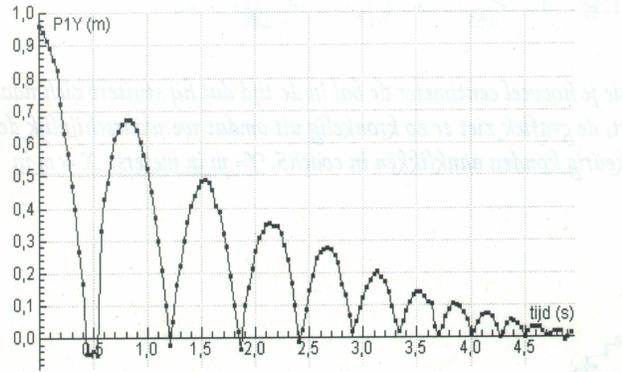
In this graph are arcs, these arcs arise because the ball is bouncing all the time. In the beginning the arcs are high because the ball has a high speed because it is released at a height of 1 meter. Hereafter the arcs get smaller because the ball reduces speed. This is a uniformly decelerated movement. Y=m in meters, X= time in seconds

Figure 6. Part of the report of Rianne and Kim on a bouncing ball.

6. IMPLICATIONS FOR THE RE-DESIGN OF THE VIDEO ANALYSIS TOOL

Video analysis means that a video clip is captured with a webcam or digital camera, data of a moving object are collected by clicking with the mouse in video frames, and finally the recorded motion data are analysed. Three potential problems experienced in the classroom experiment and in other practical work (Heck & Holleman, 2003) are that in video capture care must be taken of many technical details to obtain a useful video clip, manual data collection can be too time-consuming, and perspective distortion can interfere with useful video analysis. In this section we present how the computer learning environment Coach has been redesigned to deal with these issues. Examples illustrate that point tracking in video clips and perspective correction of images of planes broaden the scope of video and image measurement in practical work.
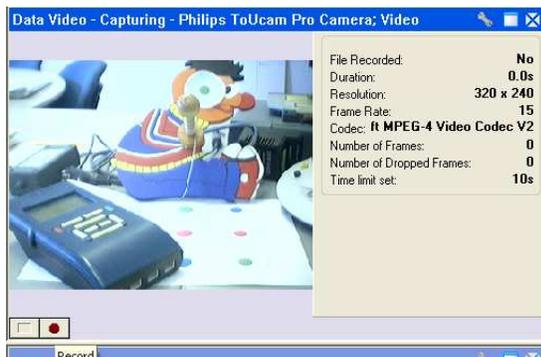
6.1 Capturing a video clip

Figure 7. The redesigned video capture window

Coach has been redesigned to make it possible to capture a video clip with a digital camera or webcam from within the learning activity. The main advantage is that many camera settings can be specified beforehand by the author of the activity so that the pupil can concentrate on more important issues. In this way, the recorded video clip is also immediately available in the activity for data collection and processing (see Figure 7). Furthermore, synchronized data collection with sensors and video capturing of the phenomenon under investigation is possible in this design. In future, when automatic recording of video data by point tracking has been professionalized, a webcam can be a special sensor to measure position(s) which can be used in combination with other sensors.

6.2 Point tracking

In Figure 6, which is part of the report of Rianne and Kim on a bouncing ball, the graph reveals that the pupils recorded the position of the ball many times. For getting acquainted with video analysis, such manual recording is a good approach, but when it comes to a research project of pupils, this might become too time-consuming and the commitment of students is put to a severe test. We quote two secondary school students, who investigated in another setting human gait patterns at various speeds and inclination angles (see Ellermeijer & Heck, 2002, for more information about gait analysis in students' projects).

> *"...Furthermore we had to click three points in each video frame: the knee, the ankle, and the hip. We have looked at two steps for each variation of speed and inclination On average 19 1/3 frames per step, times two because we do two steps, times four for the degrees, times three for the speeds, times two because we did everything twice, times three for the number of mouse clicks. This is a total of 2784 clicks per subject. Just because of the careful recording of the results it took an hour per subject. When you click for one hour, you make mistakes sometimes, so that this will also have led to inaccuracies."*

The students' complaint is pertinent: collecting data in this kind of research work is too time-consuming, extremely boring, error-prone because the concentration on careful mouse-clicking diminishes, and it limits the number of experiments in an investigation. What is needed is the possibility to track the motion of an object, e.g., a marker or an eye-catching point, and to record automatically the coordinates of the moving object in subsequent frames of the video clip.

Point tracking has been implemented in Coach as a DirectShow transformation filter which can be thought of as a program that connects a source, e.g., a video clip or a streaming video of a webcam, with the video window, while at the same time passing the recorded position data to the computer application. The algorithm used in the tracking filter is composed of two parts: (1) finding the best match of a given model template in a subsequent frame, i.e., locating the area that resembles most a specified area, and (2) limiting the search area in order to reduce computing time or to avoid ambiguity. The template that will be tracked and is selected by the user at the start of the tracking process has been chosen to be an area bounded by a circle with a user-specified radius. The comparison of an area with the model template is based on pixel intensities in the three channels of the RGB colour model. More specifically, the sum of squared differences of intensities between image and model template is used as a function that must be minimized in the search algorithm. We have chosen this algorithm for template matching after testing various commonly used algorithms on sample video clips; the chosen algorithm performs well in spite of its simplicity. The search area for the subsequent frame has been chosen to be a rectangle, of user-specified dimensions, centred on the position that is found for the current frame.

Let us illustrate point tracking in Coach by an example in which the leg motion of a student on an exercise bike in a fitness centre is investigated in much the same way as we described for gait research (Ellermeijer & Heck, 2002; Heck & Holleman, 2003).

During cycling, the coordinates of the hip and the ankle of one leg with respect to the knee joint are recorded via point tracking. So, we work with a moving coordinate system in which the origin always coincides with the knee joint. The origin is tracked in the video clip after selection of its model template in the first frame. In the first frame we also select the hip and the ankle for point tracking. The positions of the hip and knee joint are recorded in polar coordinates as well. We will only use the information about the angles to compute the knee angle during the cycling motion. Figure 8 is part of a screen shot of the video activity. To the left is the video window with three rectangular search areas for the points that are tracked. To the right is the graph of the measured knee angle versus time, together with a sinusoidal fit of the data. This fit gives students cause for reflection.
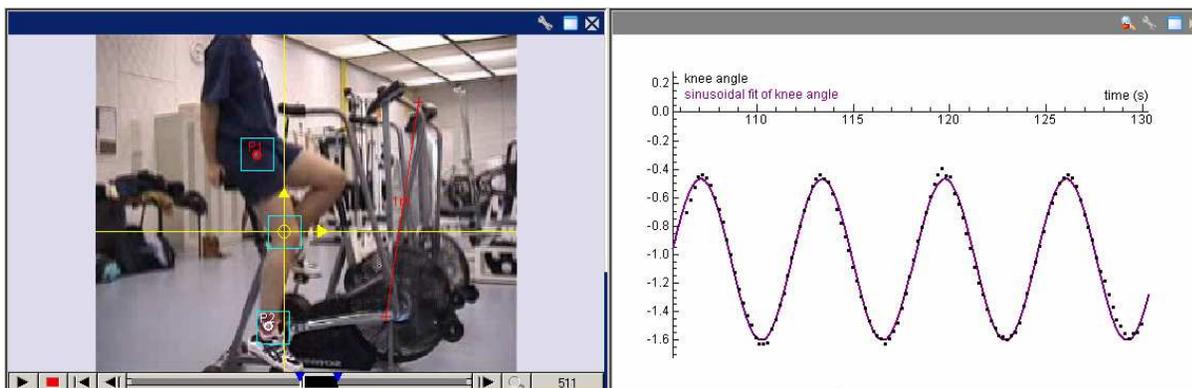

Figure 8. Screen shot of a video activity about fitness cycling with point tracking..

Some features of point tracking in Coach are:
- Point tracking can be combined with manual video measurement.
- A moving coordinate system can be selected and its origin tracked.
- When point tracking fails, it can be interrupted and moved to the first frame where the tracking algorithm has failed, and the model template can be reinitialized or its settings and/or the dimensions of the search area changed. After this point tracking can be continued from this frame, using the new settings.
- Point tracking can be combined with other video filters that have been implemented, such as change of brightness and contrast, and/or correction of perspective distortion.

The main advantages of point tracking in video activities are:
- When a manual video measurement takes more than 100 mouse clicks, it becomes monotonous and risky regarding repetitive strain injury (RSI).
- The automatic video measurement of 3 points in 137 frames in the example of a student cycling takes about 20 seconds on a PC with a 2.0 GHz Pentium 4 processor. So, collection of data is done in much less time than can ever be achieved by manual recording.
- Because of the lengthy process of collecting video data by hand, one becomes easily distracted, loses concentration, and too often makes mistakes. Point tracking allows a more objective way of collection data, in which accuracy of measurement is the same for each frame of the video clip.

This does not mean that point tracking is free of problems. At the current stage of development of Coach, video clips must match the following requirements for successful point tracking:

- Tracked objects may not change much in size, shape, or colour. This limits, for example, the usage of many television recordings of sport events.
- Markers of circular shape are preferable because of our choice of a circular-shaped model template (so that rotating objects can be tracked). Such markers should better have a colour distinct from the background scene in the search areas in order to minimize errors in tracking.

- Tracked points must stay within the view field as much as possible. If a tracked point temporarily disappears from the view field and later reappears, then it is not guaranteed that the point of interest is always found. In this case the user must reinitialize the model template and continue from the frame where the point reappears in the video clip or start over again with a larger search area.

6.3 Perspective correction of images of planes

The image of a plane from a three-dimensional setting captured by a camera may experience perspective distortion. The picture in the left side of Figure 9 shows an image of such two planes, a photograph of two external walls of a building. Observe that the rectangular features, such as the windows, do not appear as rectangles in the image: the apparent geometry of the Figure has undergone a transformation that distorts Euclidean properties such as length, angles and parallelism. The picture in the right side of Figure 9 shows a perspective-corrected front of the building, where the geometrical relationships are those which would be seen had the original photograph of the plane of interest been taken with the camera situated fronto-parallel to the wall. Such image rectification of planes is useful before data collection in a digital image or in video clip where an object moves in a plane.
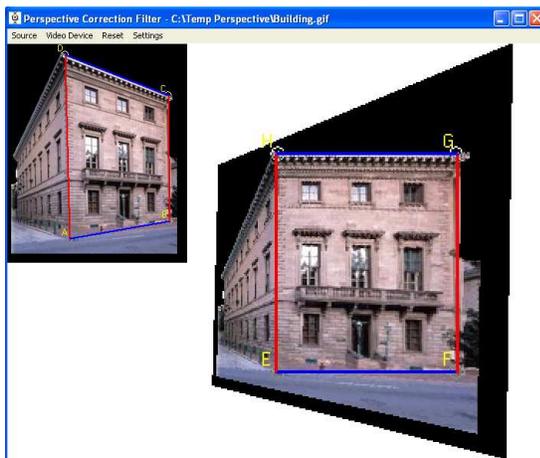

Figure 9. Perspective correction of the image of the front of a building.

Rectification of planes in digital images is part of the discipline that is known as computer vision. Projective geometry lays the mathematical foundation of this discipline. For example, the map between the world plane and the perspective image is a plane projective transformation, i.e., a 2D homography. Correcting perspective distortion is a matter of determining the eight degrees of freedom of the homography. The rectifying homography is computed from scene geometric information, specifically parallelism, angles between lines, and ratios of length along lines in different directions. A full description of the mathematics of image rectification of planes can be found in (Liebowitz, 2001; Liebowitz & Zisserman, 1998) and in many textbooks on computer vision.

We will use Figure 9 to exemplify in what way the perspective distortion of a plane can be corrected in Coach. Our plane of interest will be the front of the building. In reality, the edges of the front wall are two pairs of parallel lines. However, this is not the case in the photograph of the building. The image transformation that restores this property is determined by mapping the four corners of the front wall with a homography to the corners of a rectangle in a new image. Actually, the orthogonality of two pairs of parallel lines determines the plane rectification up to an unknown aspect ratio. This scaling can be specified in Coach, if necessary. In Figure 9, the result is shown on the right side. Actually, the basis of the method, which is also used in (Liebowitz & Zisserman, 1998; Liebowitz, 2001), is that any projective transformation can be uniquely written as a composition of three transformations, viz., a perspectivity P that maps a 4-gon into a rhombic figure (which consists of two pairs of parallel lines), an affine mapping A that transforms the rhomb into a rectangle, and finally a similarity transformation S with isotropic scaling that rotates, translates and / or scales the rectangle. For measurements in a rectified photograph or video clip it suffices to find appropriate transformations P and A.

We end this section with two educational applications of image rectification.

6.4 Clifton Suspension Bridge

In mathematics textbooks one often sees a photograph of a bridge in a distorted perspective with the message that the shape of the suspension cable is a parabola. This might be true, but not if one collects data from the photographs in the book and applies a quadratic fit to the data. Figure 10 is a screen shot of an image measurement activity applied to the picture of the Clifton Suspension Bridge in Bristol, UK. The measured positions on the cable do not lie on a parabola: the right diagram shows the best quadratic fit and it does not match well with the data.

Figure 11 is a screen shot of the activity in which the plane formed by the piers and the left side of the road (as seen from the camera position) is rectified to a fronto-parallel view. The cable is in this plane and via the rectifying transformation it becomes a parabola. The diagram to the right shows the best quadratic fit. This does not necessarily mean that this is really the shape of the cable: a sinusoidal fit will do as well, and perhaps the shape can be modelled as an ellipse. Only physics and knowledge about bridge building can help students to understand which model is most appropriate (Heck & Holleman, 2002).

In the corrected, fronto-parallel view of the bridge, the scaling in horizontal and vertical direction is not the same. This causes a strange ratio of height and span of the bridge. However, this does not matter for the mathematical shape of the curve of the cable: it is still a parabola. But do students also understand this? An interesting investigation task would be to sort out under what familiar planar mappings parabolas remain parabolas.
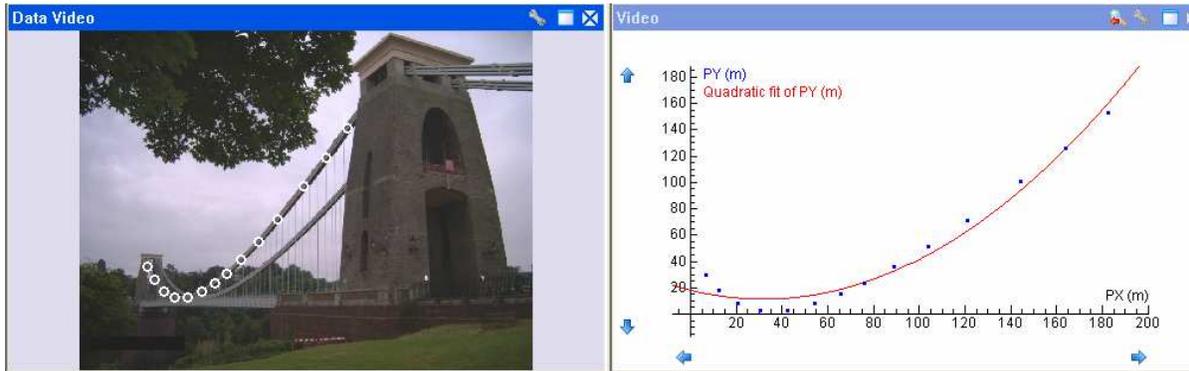
Figure 10. Screen shot of a photogrammetry activity on the Clifton Suspension Bridge.
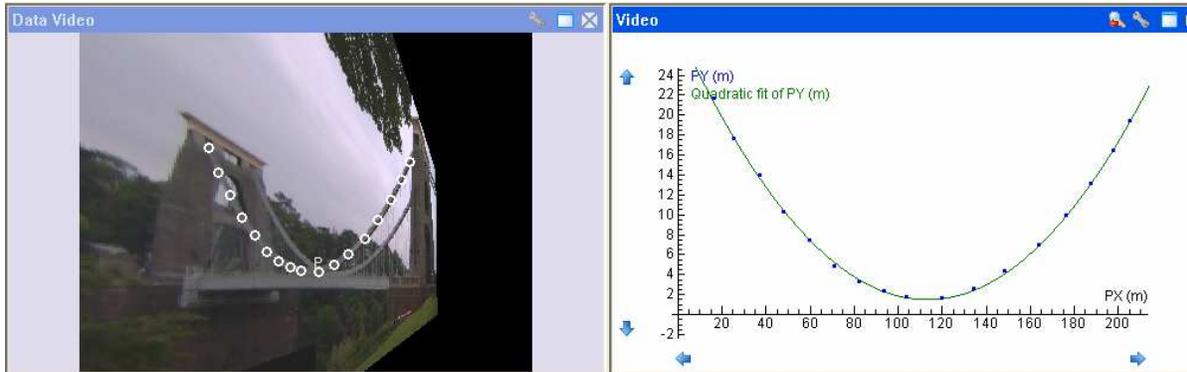

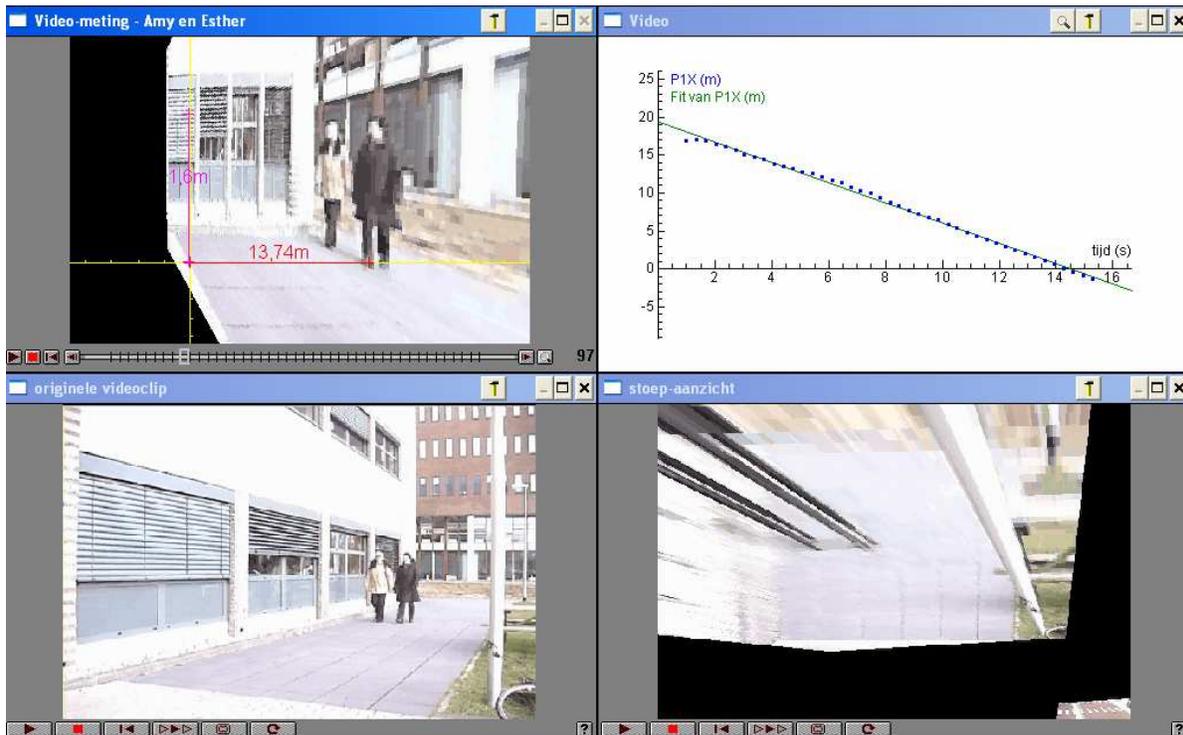Figure 11. Screen shot of the bridge activity after image rectification

Figure 12. Screen shot of a video activity with students walking in a straight line.

6.5   Speed of walking students

Image rectification can be used to answer the question of how fast an object is moving towards the camera in a perspective view; see Figure 12 for a screen shot of such a video activity. In the lower left corner is the video clip of two students walking in front of a building, in a straight line fairly in the direction of the camera. This video was used in the second lesson of the classroom experiment to illustrate that the plane of motion is preferably perpendicular to the camera direction. The

question is at what speed the two girls walk. To get an answer to this question image rectification can be applied to one of the following planes: the perspective correction of the imaginary vertical plane in which the student to the right walks and the rectification of the plane formed by the paving stones. The result of the first image rectification is the video clip shown in the upper left corner of Figure 12. As vertices of the 4-gon which is in reality a rectangle we choose the left shoe and the head of the student to the right in two separate video frames that are far apart from each other. The rectification of the footpath gives the alienating video clip in the lower right corner. The rectified image of the vertical plane is used to measure the distance walked by the student. The data of this measurement are shown in the diagram in the upper right corner, together with a straight line fit. Apparently the student walks at a constant speed. The slope of the line implies a walking speed of 4.8 km/hr. Students can validate this answer by using the other rectified video clip for an alternative measurement and in this way practise good research methodology.

7. CONCLUSION

In summary, the authors and the teachers involved were quite pleased with the enthusiasm and performance of the pupils in their project work. The pupils were able to create interesting and useful video clips and they could carry out meaningful measurements. Also, they could link the recorded motion with graphical representations and physics concepts better than usual (if at all) with pencil and paper. The classroom experiment provided many ideas for improvement of the video analysis module in the computer learning environment and for the design of new video tools. It also provided useful information for the experimental physics exam with video analysis at school. It confirms that usage of computers in science exams constitutes an interesting development and is a good addition to the traditional written exams (Boeijen & Uylings, 2004). Results of computer-based exams are promising and have led to a definitive implementation into the Dutch curriculum. Examples in digital form can be retrieved from the website http://compex.citogroep.nl. Practical assignments like the one presented in this paper provide powerful training and preparation to the pupils, next to the exciting and challenging content itself.

REFERENCES

Boeijen, G., & Uylings, P. (2004). Exams of Tomorrow. In E. Mechlová (ed) *Teaching and Learning Physics in New Contexts,* Conference Proceedings of GIREP2004, Ostrava-Czech Republic. pp 153-154. University of Ostrava, Ostrava.

Ellermeijer, T., & Heck, A. (2002). Walk like a Physicist: An Example of Authentic Education. In *Proceedings of the GIREP 2002 Conference, Uppsala-Sweden*. Available: http://pinf.fysik.lu.se/abstracts/fullText/148.pdf

Heck, A. (2002). A Versatile Environment for Active Learners and Teachers. In G. Goodell, (ed), *Proceedings of ICTCM13.* pp 165-169. Addison-Wesley, Boston. See also the CMA website www.cma.science.uva.nl

Heck, A. & Holleman, A. (2002) Investigating Bridges and Hanging Chains. In T. Triandafillidis & K. Hatzikiriakou, (eds) *Technology in Mathematics Teaching,* Conference Proceedings of ICTMT6, Volos-Greece. pp 380-387. New Technologies Publications, Athens.

Heck, A. & Holleman, A. (2003). Walk like a mathematician. In: M. Borovcnik & H. Kautschitsch, (eds) *Technology in Mathematics Teaching*, Conference Proceedings of ICTMT 5, Klagenfurt, Austria. pp 409-413. Schriftenreihe Didaktik der Mathematick, v. 25. öbv&hpt, Vienna.

Liebowitz, D. (2001). Camera *Calibration and Reconstruction of Geometry from Images.* PhD thesis (chapter 3). Available: www.robots.ox.ac.uk/~vgg

Liebowitz, D. & Zisserman, A. (1998) Metric Rectification for Perspective Images of Planes. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition.* pp 482-488. Available: www.robots.ox.ac.uk/~vgg

BIOGRAPHICAL NOTES

André Heck took Master degrees in Mathematics and Chemistry at the University of Nijmegen. After research work in Lie Theory, his professional activities moved into the promotion of computer algebra usage in research and education. At present, at the University of Amsterdam, he is still much involved in the introduction of computer algebra and other ICT applications to students in mathematics and science. Besides his work in curriculum innovation at university level, he is actively involved in research and development at the AMSTEL Institute that aims for a computer learning environment for mathematics and science education at secondary school level. This environment will contribute to the realization of cross-disciplinary and challenging practical work .

Peter Uylings graduated in Physics and Mathematics at the University of Amsterdam. He obtained his doctorate in theoretical physics on the subject of electron correlation effects from the same university in 1985. He completed the first degree teacher training both in Physics and in Mathematics separately and he works part-time as teacher at a grammar school. His research interests include ICT applications like computer modelling, data video measurements, and technical automation for improving mathematics, science and technology education. From 2002, he constructs physics computer exams as an innovation in the nationwide curriculum.