

A MODEL BASED PROJECT FOR 3D ANIMATION

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Abstract: As the computer game market is expanding, the demand for qualified programmers is increasing. Therefore more and more universities invest in education in this field, giving the students a broad knowledge in programming and graphics. What the students often miss is a competence in physical modelling that makes the simulation of the system close to reality.

This paper presents the achievement of a project course where students are asked to model, simulate and animate a physical system. Physically based modelling is used and it has been very successful as it is shown by the excellent results produced during the course. Two examples are described: they are both based on physical modelling but two different approaches for implementation are used. First the animation of a golf strike is illustrated. The mathematical model is implemented in Simulink and the Virtual Reality Toolbox of Matlab together with 3D Studio Max have been used for the 3D visualization. The animation of an axial fan is also illustrated. In this case both the model and the 3D animation are implemented in C++. *Copyright© 2005 IFAC*

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1. INTRODUCTION

Physical modelling of real dynamic processes is a challenging task (Wellwstead, 1979; Cellier, 1991) and it has acquired an increasing importance from an educational point of view. Students should become familiar with the different methodologies and learn to solve the related problems. In this case no specific textbooks are necessary but a good training tool is to make students face the problems by implementing a model of a real system. Physically based animation is an area that has had a big development in the last decade. It is used in computer graphics and it can also be a very good tool in education, especially to make students understand the need of a good

physical model in order to have a realistic animation (Sweeney *et al.*, 1991; Lelouche, 2000). Using physics to determine the motion of objects adds realistic effects to animations. Physical laws are used to produce animations and communicate information about how different models interact in a simulated environment. It is possible to obtain real time animation of systems with good graphics rendering for the object under study. Nowadays engineers are more and more asked to build mathematical models of the studied object and to simulate the behaviour by the use of computer graphics. It is, therefore, important that students become familiar not only with building mathematical models of physical systems but also with the idea of how models can be used to aid

the graphical representation of the system. This is the aim of the *Modelling project* course given to the students of the *Media Technology and Engineering* Master of Science program at Linköping University. The paper describes how the project is carried out and it focuses on the work produced by two groups. Sec. 2 introduces the modelling problem and the approach to solve it. The organization of the *Modelling project* course is presented in Sec. 3. Two examples of the results produced by the students are shown: in Sec. 4 the animation of a golf strike is illustrated while Sec. 5 deals with the animation of an axial fan. The course is evaluated in Sec. 6 both from the teacher and students' point of view. Finally Sec. 7 concludes the paper.

2. ANIMATION OF PHYSICAL SYSTEMS

Many components are needed in a system for computer animation. It is necessary to create the model of the object to be animated, to simulate the model and finally to create an image and render a frame in the animation.

2.1 Modelling

The construction of a mathematical model is based on the insights of how the system actually works. Experts of the field help in this first stage. The second step represents the task the engineer is asked to solve: transfer this knowledge into a useful model. A wide range of literature is available on this topic, the students of this project have already attended the *Modelling and simulation* course based on the book by Ljung and Glad (Ljung and Glad, 1994) and are familiar with these concepts. The models built for the examples described in Sections 4 and 5 are both based on physical laws. In the first example the equations are then represented in terms of block schemes so that the model can be implemented in Simulink. The second example, instead, uses the equations in forms of differential equations as they are implemented directly in C++. In both cases some approximations are taken into account but nevertheless the resulting animation is good and has a behaviour very close to the real system.

2.2 Simulation

Equations for forces and torques are written down and the acceleration of the system is determined. In order to get the position of the system at any time, integration must be carried out. This involves well-known numerical problems (Hairer *et al.*, 1987), among which to determine the best

integration method and the step size. The choice of the numerical method depends on many factors such as the complexity of the system and the accuracy requested by the application. When simulation is used in real time applications, the choice of the integration interval plays a relevant role and it must take into account the frame rate of the graphical implementation.

2.3 Animation

Graphical animation makes it possible to represent how a system behaves over time. In this context, the term system denotes not only the object itself but the object together with its environment. This implies that animation can be used to represent how an object moves in time. The computer renders the scene and displays all changes in rapid succession creating in this way the illusion of motion. *Motion control* is the way how these changes are specified to the computer. There exist several different ways of achieving this control (Fishwick and Porr, 1991); among these, *physically based modelling* has become very successful in recent years. This is the approach used in this project: physically based models are incorporated into the animation; the objects are given mass and inertia, then forces and torques are applied to achieve a certain motion.

3. MODELLING PROJECT

In the modelling project course students work in small groups (4-5 students per group) and they decide together the system they are going to work with. The first step is, therefore, to analyze a physical system and try to understand the possible difficulties that might arise while the task is carried out. In the beginning some assumptions on the behaviour of the system are made in order to get a simplified model and the graphical representation of this simple model is implemented. For instance, if the aim is to animate a car, the students will start with the model of the dampers and a mass will be represented moving along a given profile of the road. Step by step some of the simplifying assumptions are removed and a more complex system is obtained. Most of the students choose to work with systems they are familiar with so that they can also use their own experience to evaluate the correctness of the model.

The course gives 3 points; this implies that the working load for the students is not very demanding: each student should spend 3 working weeks for the project. The limited amount of time makes it impossible to request the students to follow well established project models such as LIPS (Linköping Interactive Project

Steering)(Svensson and Krysanter, 2003). Nevertheless, at the beginning of the work each group writes down the specifications for the physical system and how they intend to implement it. Even if the students are not supposed to write down a detailed documentation of how the work is being carried out, the supervisor meets each group weekly so that it is possible to follow the on-going work process.

At the end of the project, each group is asked to write a technical report so that there is documentation of the work done together with a manual that allows everybody to run the animation. All the projects are stored in a server (Pro, 2004) and they are available over Internet. An oral presentation is given by each group as conclusion of the work. It is in form of a short seminar and it is intended to a general public. The students must therefore decide which part of the work to present and to some extent they evaluate their work themselves.

3.1 What's new

Although the different topics described in the previous section do not represent a novelty in the area, the way how they can be used together as an educational tool is worth to be mentioned. Different teachers are involved in the project but experience has shown that the word *model* can have quite a broad meaning and it can sometimes be misunderstood. It is therefore important that the project is supervised by people with a system theory background. The aim of the modelling phase must be a set of differential/difference equations which are implemented during simulation by means of a numerical method.

The purpose of the course is not to achieve very advanced models and/or animation but to make the students perform all the different steps necessary so that they become aware of the related problems. This is achieved with relatively short time spent for the work (3 working weeks).

On the other hand, the fact that the students are not supposed to write down each single step carried out during the work, it implies that they must learn to make a good use of the time. The students have approximately three months to carry out the project. During the weekly meetings, the supervisor discusses with the group the achievements and the problems encountered during the work. It is completely up to the students to decide how to spread the working load. Some groups concentrate most of the work in three full weeks while others decide to dedicate to the project one day per week

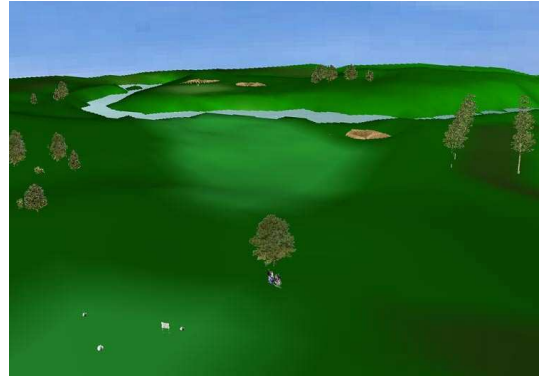


Fig. 2. Virtual world used for the 3D visualization of the golf court.

4. GOLF STRIKE

The model of a golf strike is simulated and a 3D animation implemented. The ball is hit with an initial force and it flies in an arc shaped trajectory. Wind and air resistance are also taken into consideration resulting in the following equation

$$m\mathbf{a} = \mathbf{F}_0 - \mathbf{F}_g - \mathbf{F}_{\text{air}} + \mathbf{F}_{\text{wind}} \quad (1)$$

where m denotes the mass of the golf ball, \mathbf{a} its acceleration, \mathbf{F}_0 the initial force applied to the ball by the strike, \mathbf{F}_g gravity force, \mathbf{F}_{air} air resistance and \mathbf{F}_{wind} the wind acting on the system (it can have both positive or negative effect). Eq. (1) is written in vector form and when the model is implemented in Simulink three separate models are created for the components along x , y and z axis. The Simulink model is reported in Fig. 1.

3D Studio Max has been used to model the golf court world and the Virtual Reality Toolbox in Matlab to link the model to the 3D world in Simulink. The world is fairly simple with as few polygons as possible to make the simulation smooth. An image of the virtual world is shown in Fig. 2.

A detailed description of the project is given in the technical report written by the students and available on the net at (Bajt *et al.*, 2004).

The physical model built for the golf ball flying after the initial hit represents a standard task for this project. The students have decided to put a big effort in making the animation look real. This depends both on the model itself and on the parameters used. At the beginning of the animation a graphical user interface opens and the user can choose which kind of club use for the strike and which kind of balls. The initial force, the direction of the hit together with the wind can also be entered by the user. This makes it possible to have the animation for many different situations. The graphical user interface is shown in Fig. 3.

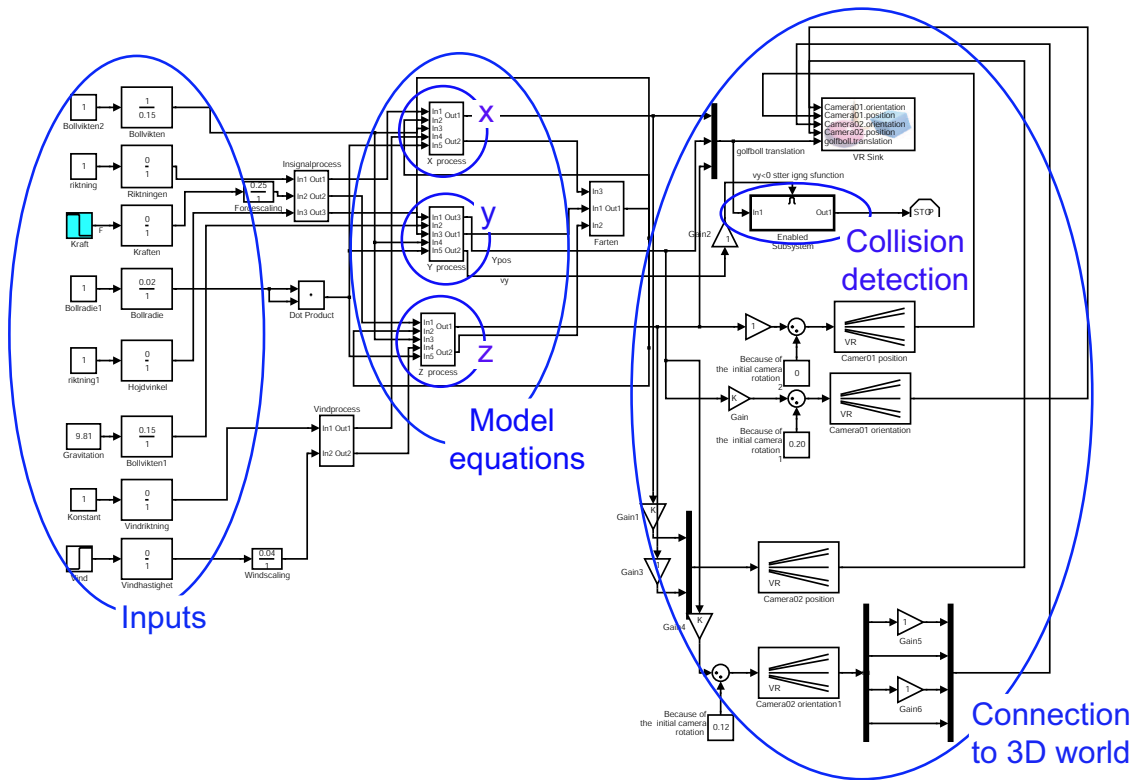


Fig. 1. Simulink model for the golf strike.



Fig. 3. Graphical user interface for the animation of the golf strike.

The world of the golf court consists of hills and valleys and therefore one of the main problem is represented by detecting the collision of the ball with the ground. Collision detection has been implemented with an S-function in the Simulink model. After the velocity of the ball has become negative, the function compares the coordinates

of the ball with the coordinates of the ground (in particular with the vertices of the meshes representing the ground) at every step. If the coordinates match, the ball has landed and it will land on the closest vertex of the polygons representing the ground.

5. AXIAL FAN

The other project illustrated in the paper is based on a more complex system. The system simulates multiple interacting spheres propagated by a fan, trapped in a cylinder and bouncing off the walls and the ground (Persson *et al.*, 2004). Many simplifications are necessary in this case and this is possible only after a full understanding of how the system works.

The axial fan (Bleier, 1997) in the simulation rotates at specific speed and moves air from an inlet through the cylinder out into free air. The velocity of the airflow created by the fan produces a force on the spheres in the cylinder. In order to simulate the reacting forces on the spheres and thus their movement, a model of the fan airflow velocity must be developed. The velocity produced by the rotating fan depends on several engineering parameters, for example fan rotational speed, fan radius, hub radius, blade twist, blade area, blade angle of attack and the number of blades. External parameters that affect the airflow velocity are

how fast air decelerates moving through air and turbulence. The engineering properties determine the amount of turbulence, the swirl created by the blades, and the volume of air moved in a specific time. The volume of air moved is often denoted CMS, cubic meters per second, and is the parameter that most affects the movement of the spheres in the cylinder.

The fan in the simulation has a radius of 0.3 m. The airflow velocity produced by an axial fan can be divided into two components, the upward airspeed in Y-direction, and the rotational velocity of the air in XZ-direction. By using the specified CMS the first component can be calculated. The average speed of the air upward can be regarded as the rate at which the air must flow in order to move the specified volume of air per second with the disc area covered by the fan.

$$V_{Y,average} = \frac{CMS}{A} \quad (2)$$

The CMS depends linearly on the speed of revolution, RPS, revolutions per second. In other words, a 30% increase of rotation speed results in 30% increased CMS. Thus the average upward airspeed is defined as:

$$V_{Y,average}(RPS) = \frac{CMS \cdot RPS}{A} \quad (3)$$

The upward air velocity also depends on the distance to the centre of the fan. In the middle of the fan there is a hub, covering the motor driving the fan. Over this area the airspeed will be low since no blades propel the air. The speed of the blades depends linearly on the radius from the centre. Thus more air should be propelled near the edge of the fan than near the centre. However, fan manufacturers try to compensate for this in order to obtain an even airspeed cross the radius. The compensation is made by smoothly changing the twist of the blades along the radius. Near the centre the blade angle of attack is high, approximately 30-50 degrees, and near the edge the angle of attack is low, approximately 10 - 25 degrees. The compensation is not perfect and consequently some variations along the radius will occur. The air velocity variation along the radius is not part of the specification and thus this property is approximated. Three different equations are used depending on the radius to express the air speed variation. The final value ranges from about 0.2 to 1.2 (see Fig. 4). These values are used to scale the average upward airspeed.

A detailed description of the project is given in the technical report written by the students and available on the net at (Pro, 2004).

An image of the 3D animation of the system is given in Fig. 5.

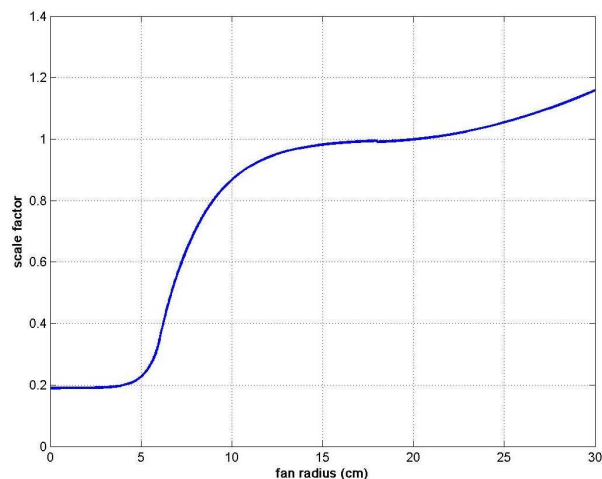


Fig. 4. Air speed scale factor along the fan radius.

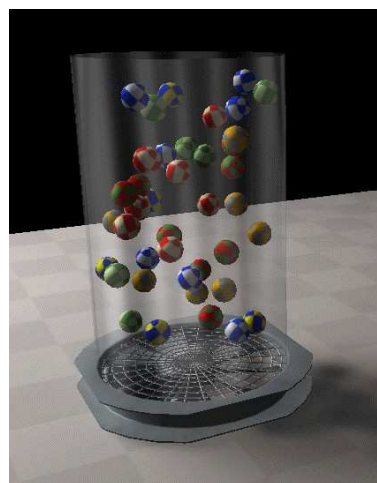


Fig. 5. Virtual world used for the 3D visualization of the axial fan

6. COURSE EVALUATION

The course works very well. The students enjoy their task and most of them work more than they are supposed. The most difficult part for the students is to understand how the system works from a physical point of view and write down the corresponding physical model. The students have taken only one course in physics so their competence in physics is rather limited. The teacher of physics is available for help so the students can meet him and discuss together the problems. Once the mathematical model is ready, then no much help is needed. The task of the supervisor is to check that all the different parts of the project are given a reasonable amount of time.

6.1 Master of Science in Media Technology and Engineering

The objective of the study programme (*Study Guide @lith*, 2004) is to educate students within

the broad field of media engineering. The education, that covers traditional as well as modern media technology, provides a comprehensive understanding for possible uses of different media and their technical and social limitations. In addition to the engineering subjects, the education also contains elements providing understanding for different creative expressions of design, colours and sounds.

The students that take part to this course are very skilled in programming and 3D graphics and hence they might focus their work on the graphical animation. It happens very seldom, indeed. On the contrary, once the animation starts taking form the students wish to improve the model in order to make the behaviour of the system as close as possible to reality.

6.2 Feedback from students

At the end of the course, the students are asked to fill an evaluation form on the net; it is not compulsory and it is usually half of them that do so. Moreover, all the students meet together and they discuss the course resulting in a written evaluation. This is handed to the course responsible who, eventually meet the student representatives for further discussion. The course is very much appreciated by the students. They like to have the possibility to put into practice theory learnt in several courses that seemed to have not much in common.

The fact that the whole course is run in form of a project implies that the students have much freedom in their work with also risk of missing the deadline. In spite of this, the students like this form of learning where they fill much more active. They agree that it shouldn't be possible to have this course earlier in their studies as they need to build a competence in several areas and it takes two years to do that.

One of the most common complains is the lack of help in programming, especially in 3D graphics. Resources that can be placed for the course are limited and the students have already good skills in programming. On the other hand graphical animation does not represent the main aim of the course but it is only a mean to visualize the behavior of the system. The experience of the past years shows that if a good mathematical model is built (and here is often necessary supervision), then the implementation is carried out without problems.

7. CONCLUSION

In this paper a project course is illustrated. The students are asked to model, simulate and animate a physical system. The aim is to make the students use what they have learnt on modelling and simulation in previous courses. Each group chooses the physical system to work on and starting from a simplified model, they implement the model and simulate it. Depending on which environment has been chosen to implement the model, it may be necessary to implement the numerical method as well. The project gives very good results as the students understand all the problems related to the modelling and simulation of real systems.

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