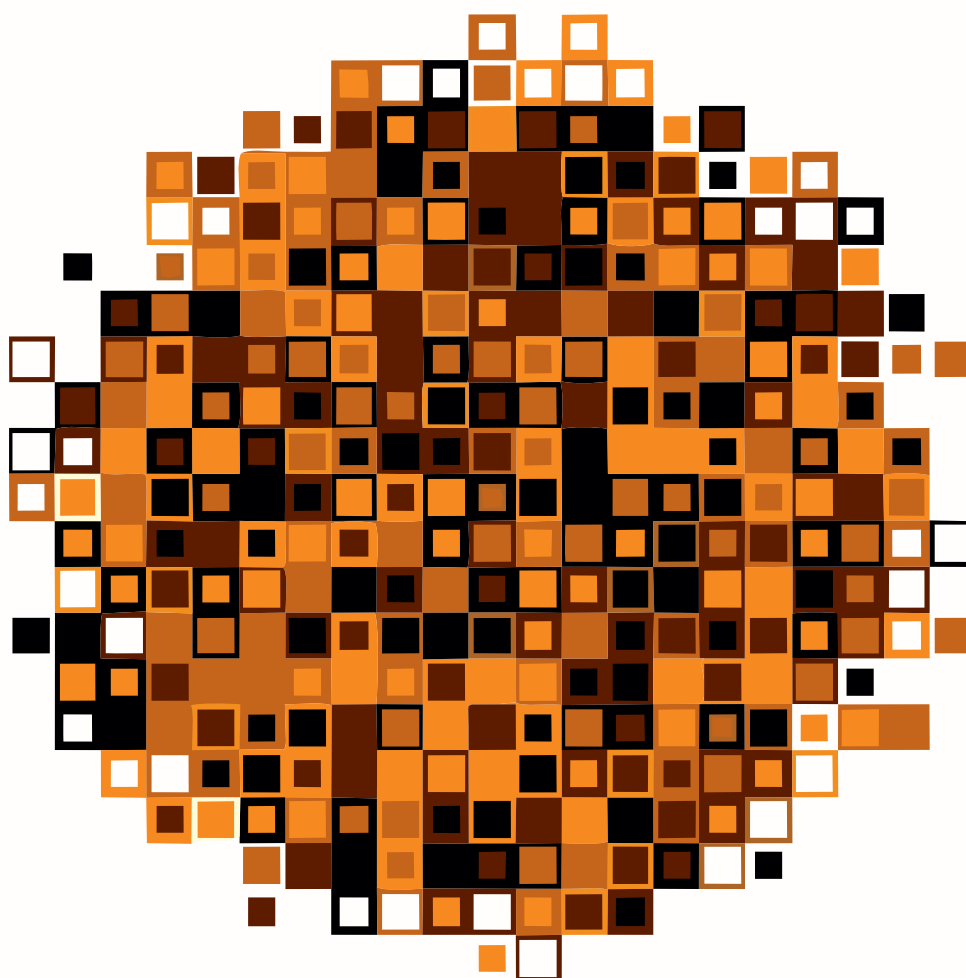


SNE SIMULATION NOTES EUROPE

Modelling in/for Education - Modelling, Simulation and E-Learning
SNE Special Issue



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Societies and Groups in EUROSIM





EUROSIM 2013

8th EUROSIM Congress on Modelling and Simulation

The City Hall, Cardiff, Wales, United Kingdom 10-13 September 2013



EUROSIM Congresses are the most important modelling and simulation events in Europe. For EUROSIM2013, we are soliciting original submissions describing novel research and developments in the following (and related) areas of interest: Continuous, discrete (event) and hybrid modelling, simulation, identification and optimization approaches. Two basic contribution motivations are expected: M&S Methods and Technologies and M&S Applications. Contributions from both technical and non-technical areas are welcome.

Congress Topics

The EUROSIM 2013 Congress will include invited talks, parallel, special and the poster sessions. The Congress topics of interest include, but are not limited to:

Intelligent Systems and Applications
Hybrid and Soft Computing
Communication Systems and Networks
Case Studies, Emergent Technologies
Workflow Modelling and Simulation
Web-based Simulation
Security Modelling and Simulation
Computer Games and Simulation
Neural Networks, Fuzzy Systems & Evolutionary Computation
Autonomous Mental Development
Bioinformatics and Bioengineering
Circuits, Sensors and Devices

e-Science and e-Systems
Image, Speech & Signal Processing
Human Factors and Social Issues
Industry, Business, Management
Virtual Reality, Visualization and Computer Games
Internet Modelling, Semantic Web and Ontologies
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Systems Intelligence and Intelligence Systems
Adaptive Dynamic Programming and Reinforcement Learning

Methodologies, Tools and Operations Research
Discrete Event /RT Systems
Mobile/Ad hoc wireless networks, mobicast, sensor placement, target tracking
Control of Intelligent Systems and Control Intelligence
Robotics, Cybernetics, Control Engineering, & Manufacturing
Energy, Power, Transport, Logistics, Harbour, Shipping and Marine Simulation
Semantic & Data Mining

Congress Venue / Social Events

The Congress will be held in the historic and magnificent City Hall in the heart of Cardiff, the capital city of Wales. The Gala Dinner will be held in the main hall of the National Museum of Wales. Social activities include visits to Cardiff Castle and Caerphilly Castle.

Congress Team: K. Al-Begain, A. Orsoni, R. Zobel, R. Cant, D. Al-Dabass; kbegain@glam.ac.uk

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Modelling in/for Education – Modelling, Simulation and E-Learning

The SNE special issues on *Modelling in/for Education – Modelling, Simulation and E-Learning* looks on modelling and education from different views. Modelling and simulation was very early used in education in technical applications – training simulators learned engineers how to operate complex technical systems. On the other side, education in modelling and simulation is necessary in order to qualify experts in modelling and simulation: here modelling and simulation is as well goal of education as well as tool for education. In the last three decades a lot of electronically supported tools for training have been released, and in principle computer games belong to these tools. These tools started the era of e-learning, where differences between modelling in education and education with models are vanishing.

The perhaps biggest promoter for modelling and simulation in and for education is the internet. In the present WWW modelling and simulation of any kind plays active and passive roles – from computer games for mining via tutorials for mathematic calculus to engineering design – and for the coming new web these roles will strongly increase.

This SNE special issue presents eleven contributions which discuss some of the fore-mentioned aspects of modelling, simulation and education. The contributions are modifications, extensions or revised versions of contributions presented at special sessions on modelling, simulation and education at MATHMOD 2009, 6th Vienna Conference on Mathematical Modelling (Vienna, February 2009), or at EUROSIM 2009, 6th EUROSIM Congress on Modelling and Simulation (Prague, September 2010); and the discussions on this topic will be continued at forthcoming events.

Nowadays, for modelling and simulation in / for education an electronic environment, or at least an electronic support seems to be a must, but good ‘analytical’ approaches for teaching and learning purposes may be as effective as electronic tools (or even better). Therefore we have framed the contributions in this issue by such ‘analytical’ approaches.

The first contribution (H. Siller, Univ. Salzburg, Austria) shows a stepwise modelling cycle for a daily objects, an egg, could be done in teaching - all by means of ‘education-suited’ formula! The last contribution (P. Klán et al., Prague) presents a very well elaborated second-order plus dead-time model for the characterization of a self-regulating process - all by means of ‘education-suited’ formula!

The second contribution (S. Corovic et al., Univ. Ljubljana) sketches a web-based e-learning application for collecting, organizing and providing the knowledge and experience about cell and tissue electroporation. This e-learning application for physiology is based on a system E-CHO, a personalised e-learning environment, introduced in the third contribution (M. Papić et al., Univ. Ljubljana). The fourth contribution (P. Saccomani et al., Univ. Padova) shows how global identifiability can be tested within a computer algebra system for identification purposes – as well for operation as well as for teaching. Computer algebra software is also topic of the fifth contribution (A. Körner et al., TU Vienna), where implementation and complex grading methods for the e-learning environment Maple T. A. are presented. The sixth contribution (D. Matko, Univ. Ljubljana), reports on a successful new grading method: students are graded according to the success achieved in a competition in controller design.

The seventh contribution (M. Atanasijević-Kunc, Univ. Ljubljana) introduces a teaching and learning environment for modelling and analysis of SISO and MIMO processes. Also the next contribution (S.

Winkler et al., TU Vienna) sketches a web-based e-learning system for teaching and learning mathematical modelling and mathematical engineering, which also trains implementation of mathematical models.

The ninth contribution (P. Cafuta, Univ. Maribor) is a special one – it deals with modelling and training, but from a different approach: it presents a mechatronic model for the dynamics of exercising with a ‘physical’ wrist exerciser – an interesting counterpoint. The tenth contribution (G. Antonelli et al., Univ. Cassino, Italy) presents an open source simulator for education in robotics.

The editors would like to express their gratitude to all authors for their co-operation and efforts, e.g. for sending revised versions. We hope that the selected papers present a good overview and state-of-the-art in modelling and simulation in / for education and give a short glance at e-learning and blended learning.

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Editorial

Dear Readers – With SNE Volume 21 we are continuing the change of SNE. What readers see at the first glance is a new layout, and a new cover page. We are glad, that Vlatko Cerić, past president of CROSSIM, is providing his algorithmic art as design for SNE Volume 21 cover pages. The artist choose the series ‘Compositions’ (see below), and each SNE issue’s cover shows a specific algorithmic art print from this series - for SNE 21(2) we have decided for a print of this series in shade of brown. The change of title – from ‘NEWS’ to ‘NOTES’ meets on the one side the historic development of SNE, and at the other side it comes along with full electronic publication, contributions with DOI for citation, and open access Online SNE.

We also are glad to continue with SNE 21(2) the SNE Special Issue Series, with subject ‘Modelling in / for Education - Modelling, Simulation and E-Learning’. The contribution selected by the Special Issue Editors range from classic preparation of complex models for teaching purpose until web-based fully integrated e-learning applications and gives an insight into the relevance of modelling in / for /with education.

I would like to thank all authors and all people who helped in managing this SNE Special Issue, especially the Issue Editors Mrs. Maja Atanasijević-Kunc, Univ. Ljubljana, and Mr. Nikolas Popper, dwH Simulation Services, Vienna

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SNE - Simulation Notes Europe (SNE) is advised and supervised by an international editorial board. This board is taking care on peer reviewing and handling of *Technical Notes*, *Education Notes*, *Short Notes*, *Software Notes*, and of *Benchmark Notes* (definitions and solutions). At present, the board is increasing:

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Mathematics and Eggs – Do Those Two Terms have Something in Common?

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Abstract. Modelling of objects of daily life is a topic which could be a motivating and fascinating access to mathematics education. For this reason the paper shows a possibility, how an object which is common to all students in school, the egg, can be an item for an exciting discussion in schools. Based on two mathematical definitions a figure is constructed. Based on those the description in polar-coordinates and Cartesian implicit equations is developed. This stepwise modelling cycle shows the way how modelling of daily objects could be done in school and demands of curricula could be implemented.

Introduction

The concept of modelling for education has been discussed for a long time. It is a basic concept in all parts of sciences and in particular in mathematics. This concept is a well accepted fundamental idea (see [14]), in case of the preliminary-definition of Schweiger [12] is used:

A fundamental idea is a bundle of activities, strategies or techniques, which

- 1. can be shown in the historical development of mathematics,*
- 2. are sustainable to order curricular concepts vertically,*
- 3. are ideas for the question, what is mathematics, for communicating about mathematics*
- 4. allows mathematical education to be more flexible and clear*
- 5. have a corresponding linguistic or activity-based archetype in language and thinking.*

Therefore it is not remarkable that the concept of modelling can be found in a lot of different curricula all over the world. For example in the Austrian curriculum for mathematics in grammar-schools you can find a lot of quotations for it [7].

By interpreting those quotations in the curriculum modelling can be seen as a process-related competence.

That means:

- translating the area or the situation to be modelled in mathematical ideas, structures and relations
- working in a given or constructed mathematical model
- interpreting and testing results

Those process-related competencies have been described by many people, e.g. Pollak [10], Müller and Wittmann [8], Schupp [13], Blum [1]. Regarding to all the developments in modelling Blum and Leiß [2] has designed a modelling cycle which is designed by a more cognitive point of view.

1 Problems in Realm of Students' Experiences in Mathematics Education

Problems of real-life, like problems in environment, sports or traffic, are often a starting point for calculations and applications of mathematics. But before using mathematics in such fields it is necessary that the problem is well understood. This asks for a lot of time and dedication, because it is necessary to translate the problem from reality to mathematics and back to reality. Therefore models are used as an adequate description of the given situation. Modelling through problems in realm of students' experiences means creating an image of reality which allows describing complex procedures in a common way. Creating such an image has to observe two directions as Krauthausen [4] quotes:

- Using knowledge for developing mathematical ideas.
- Developing knowledge about reality by its reliance on mathematics.

If such problems are discussed in mathematics education it will be possible that students are more motivated for mathematics. But there are a lot of other arguments why such problems should be discussed. They

- help students to understand and to cope with situations in their everyday life and in environment,

- help students to achieve necessary qualifications, like translating from reality to mathematics,
- help students to get a clear and straight picture of mathematics, so that they are able to recognize that this subject is necessary for living, and
- motivate students to think about mathematics in a deep going way, so that they can recall important concepts even if they were taught a long time ago.

If a teacher is concerning the listed points, then he will be able to find a lot of interesting topics which he/she is allowed to discuss with students. Exemplarily I want to show the motivation problems in realm of students' experiences by observing an egg.

2 The Egg

If we have a closer look at an egg, we will see that its shape is very harmonic and impressive. Considering a hen's egg it is obvious that the shape of all those eggs is the same. Because of the fascinating shape of eggs I tried to think about a method to describe the shape of such an egg with mathematical methods. Searching the literature I found some material from Münger [9], Schmidt [11], Malina [6], Wieleitner [17], Loria [5], Timmerding [16] and Hortsch [3]. The book of Hortsch is a very interesting summary about the most important results of 'egg-curves'. He also finds a new way for describing egg-curves by experimenting with known parts of 'egg-curves'. The modality how the authors are getting 'egg-curves' is very fascinating. But none of them has thought about a way to create a curve by using elementary mathematical methods. The way how the authors describe such curves are not suitable for mathematics education in schools. So I thought about a way to find such curves with the help of well known concepts in education. My first starting point is a quotation of Hortsch [3]: 'The located ovals were the (astonishing) results of analytical-geometrical problems inside of circles.' The second point of origin are the definition of 'egg-curves' found by Schmidt [11] and presented in Hortsch [3].

2.1 First Definition (Schmidt [11])

Schmidt quotes: 'An 'egg-curve' can be found as the geometrical position of the base point of all perpendiculars to secants, cut from the intersection-points of the abscissa with the bisectrix, which divide (obtuse) angles between the secants and parallel lines in the intersec-

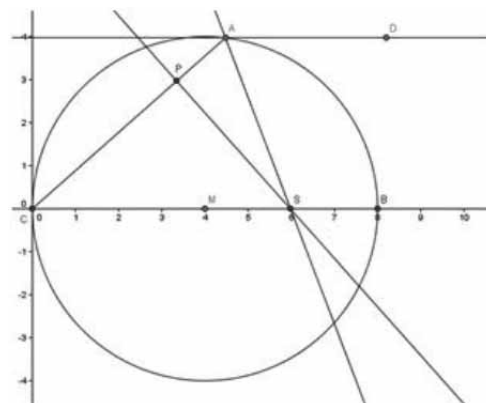


Figure 1. Translating the definition of Schmidt to the DGS

tion-points of secants with the circle circumference in halves. The calculated formula is $r = 2a \cos^2 \varphi$ or $(x^2 + y^2)^3 = 4a^2 x^4$.

In education the role of education is gaining in importance. Different systems, like computer-algebra-systems (CAS), dynamical-geometry-software (DGS) or spreadsheets, are used in education. With the help of technology it is possible to design a picture of the given definition immediately. In the first part I use a DGS because with its help it is possible to draw a dynamical picture of the given definition. The DGS I am using is GeoGebra. It is free of charge and very suitable in education because of its handling.

First of all we construe the one point P of such an egg as it is given in the definition, as shown in Figure 1.

According to the construction instruction I have first construed a circle (center and radius arbitrarily), then a secant from C to A (points arbitrarily). After that I have drawn a parallel line to the x-axis through the point A—

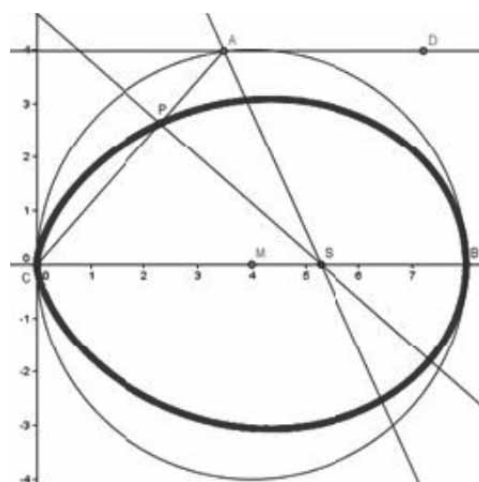


Figure 2. Egg-curve construed by DGS

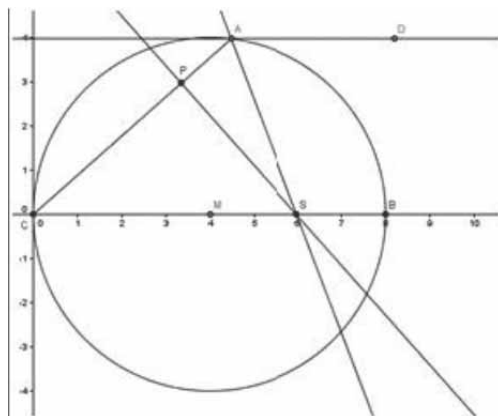


Figure 3. Initial situation for calculating the equations of the egg-curve.

the intersection point of secant and circle—and determined the bisecting line CAD, which is cut with the x -axis. So we get point S. Now we draw the perpendicular to the secant through S. The intersection point of the secant and the perpendicular is called P and is a point of the ‘egg-curve’. Now I activate the ‘Trace on’ function and use the dynamical aspect of the construction. By moving A towards the circle the ‘egg-curve’ is drawn as Schmidt has described it. This can be seen in Figure 2.

Now we have to find a way to calculate the formulas $r = 2a \cos^2 \varphi$ and $(x^2 + y^2)^3 = 4a^2 x^4$ as mentioned above.

Let us start with Figure 3: We know, because of the construction that the triangle CPS is right-angled. Furthermore we can recognize that the distance CP and PS is the same and that the triangle CAB is also rectangular, because it is situated in a semicircle. This can be seen in the following figure, where I have also drawn the real ‘egg-curve’ as dashed line (Figure 4).

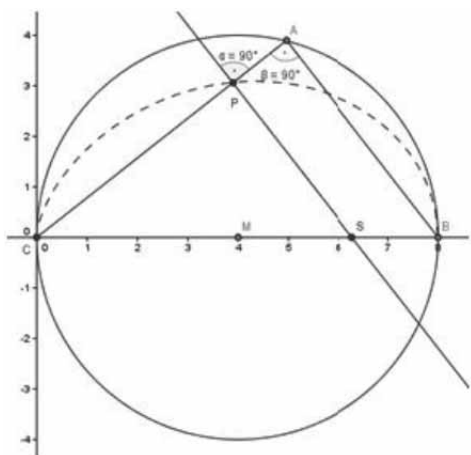


Figure 4. Affinity of the triangles

Because of the position of the points C (0, 0), A (x, y), B (2r, 0) and the construction instruction the coordinates of point S and P can be calculated. Therefore only a little bit of vector analysis is necessary. The calculation can be done in the CAS Mathematica.

First of all I have to define the points and the direction vector of the bisecting line w:

$$\begin{aligned} & \{c = \{0, 0\}, a = \{x, y\}\}; \\ & a - c \\ & \{x, y\} \\ & 1/\text{Norm}[a - c] (a - c) \\ & \left\{ \frac{x}{\sqrt{\text{Abs}[x]^2 + \text{Abs}[y]^2}}, \frac{y}{\sqrt{\text{Abs}[x]^2 + \text{Abs}[y]^2}} \right\} \\ & w = -1/\sqrt{(x)^2 + y^2} \{x, y\} + \{1, 0\} \\ & \left\{ 1 - \frac{x}{\sqrt{x^2 + y^2}}, -\frac{y}{\sqrt{x^2 + y^2}} \right\} \\ & w = \left\{ 1 - \frac{x}{\sqrt{x^2 + y^2}}, -\frac{y}{\sqrt{x^2 + y^2}} \right\}; \end{aligned}$$

Now I can calculate the equation of the normal form of the bisection line, cut it with the x -axis and define the intersection-point S.

$$\begin{aligned} & wa = \{y, \sqrt{(x)^2 + y^2} - x\}; \\ & wa.\{u, v\} == wa.a \\ & uy + v(-x + \sqrt{x^2 + y^2}) == xy + y(-x - \sqrt{x^2 + y^2}) \\ & wa.\{u, v\} == wa.a /. v -> 0 \\ & uy == xy + y(-x + \sqrt{x^2 + y^2}) \\ & \text{First}[\%] / y == \text{Last}[\%] / y \\ & u == \frac{xy + y(-x + \sqrt{x^2 + y^2})}{y} \\ & \text{Simplify}[\%] \\ & \sqrt{x^2 + y^2} == u \\ & s = \{\sqrt{x^2 + y^2}, 0\}; \end{aligned}$$

Now I can calculate the intersection point P of the secant and the perpendicular through S.

$$\begin{aligned} & \text{Solve}[\{xu + yv == (x) (\sqrt{(x)^2 + y^2}), -yu + (x)v == 0\}, \{u, v\}] \\ & \left\{ \left\{ u \rightarrow \frac{x^2}{\sqrt{x^2 + y^2}}, v \rightarrow \frac{xy}{\sqrt{x^2 + y^2}} \right\} \right\} \\ & p = \left\{ \frac{x^2}{\sqrt{x^2 + y^2}}, \frac{xy}{\sqrt{x^2 + y^2}} \right\}; \end{aligned}$$

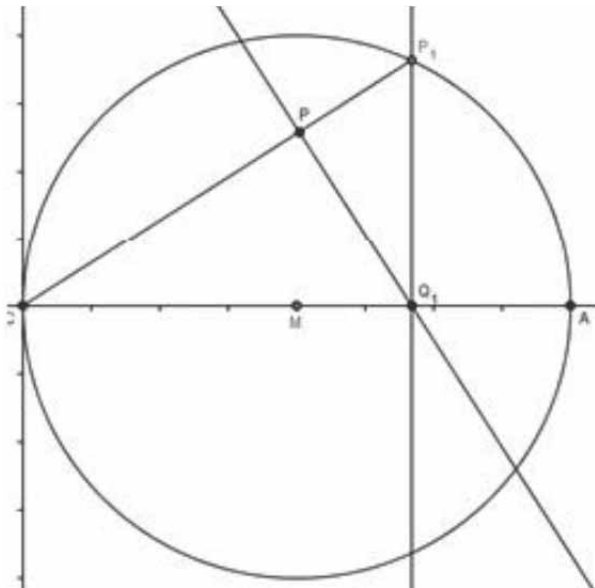


Figure 5. Translating the definition of Münger to the DGS

Now all important parts for finding the 'egg-curve' are calculated. Let us have a closer look at figure 4. It is easy to recognize that there are two similar triangles – triangle CPS and triangle CAB. The distance CP shall be called r and the radius of the circle shall be called a . The distance CB has now the length $2a$. The other two distances which are needed CA and CB has the length $\sqrt{x^2 + y^2}$. Now we can apply the similarity of the triangles:

$$\frac{CA}{r} = \frac{2a}{CS} \Leftrightarrow \frac{\sqrt{x^2 + y^2}}{r} = \frac{2a}{\sqrt{x^2 + y^2}} \quad (1)$$

Transforming this equation, delivers:

$$x^2 + y^2 = 2ar$$

Now I use the characteristic of the right-angled triangle CAB and call the angle ACB φ . For the cosine of this angle I get:

$$\cos \varphi = \frac{\sqrt{x^2 + y^2}}{2a} \Leftrightarrow 4a^2 \cos^2 \varphi = x^2 + y^2$$

By inserting this connection in the equation above I get:

$$4a^2 \cos^2 \varphi = 2ar$$

Shortening this equation, delivers:

$$r = 2a \cos^2 \varphi$$

By substituting r and $\cos \varphi$ it is possible to get the implicit Cartesian form, mentioned in the definition:

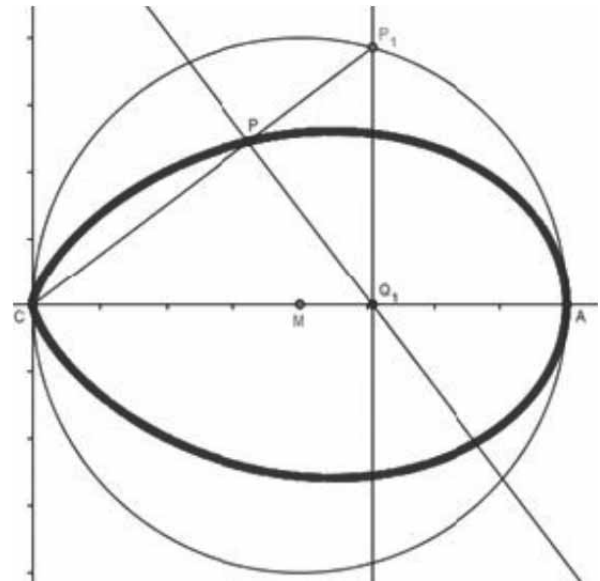


Figure 6. Egg-curve construed by DGS

$$\begin{aligned} \sqrt{x^2 + y^2} &= 2a \cos^2 \varphi \\ x^2 + y^2 &= 4a^2 \frac{x^4}{r^4} = 4a^2 \frac{x^4}{(x^2 + y^2)^2} \end{aligned}$$

respectively

$$(x^2 + y^2)^3 = 4a^2 x^4$$

As we have seen the 'egg-curve' has been modelled by elementary mathematical methods. Through using technology teachers and students get the chance to explore such calculations by using the pivotal of modelling. Through such calculations the necessity of polar-coordinates can get obvious.

2.2 Second Definition (Münger [9])

Another construction instruction is formulated by Münger [9]. He quotes: 'Given is a circle with radius a and a point C on the circumference. CP_1 is an arbitrarily position vector, P_1Q_1 the perpendicular to the x -axis, Q_1P the perpendicular to the vector. While rotating the position vector around C point P is describing an egg-curve. The equation of this curve is $r = a \cos^2 \varphi$, in Cartesian form $(x^2 + y^2)^3 = 4a^2 x^4$.'

As it is given in the construction instruction a circle (radius arbitrarily) and a point C on the circumference of the circle is constructed. Then we construe an arbitrarily point P_1 on the circumference of the circle. The perpendicular to the x -axis is construed through P_1 which is cut with the x -axis and delivers Q_1 . After that the perpendicular to the secant CP_1 through Q_1 is construed. All these facts can be seen in Figure 5.

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An E-learning Application on Cell and Tissue Electroporation

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Abstract. Electroporation is an electrical increase in cell membrane permeability by means of local delivery of short and sufficiently intense voltage pulses to the target cells or tissues for biomedical and biotechnological purposes. Electroporation is used as an effective technique for delivery of variety of therapeutic agents such as chemotherapeutic drugs, DNA or other molecules, which in normal conditions do not cross cell membrane, into many different cells either in vitro or in vivo. Electroporation is used in clinical electrochemotherapy of cutaneous and subcutaneous tumors, in non-viral gene electrotransfer for gene therapy and DNA vaccination purposes, in transdermal drug delivery and new medical applications are emerging at an increasing rate. In this paper we present a web-based e-learning application which was developed in order to collect, organize and provide the knowledge and experience about cell and tissue electroporation as well as about its medical applications. The e-learning application is based on HTML, JavaScript, ASP and Macromedia Flash technologies and integrated into an interactive e-learning environment (ECHO) developed at our institution. The ECHO enables authentication of users, statistical analysis, network traffic measurement, support for video streaming, as well as the use of various types of communications among users, such as forums, e-mail correspondence and videoconferencing.

Introduction

Electroporation is a phenomenon of cell membrane permeability increase due to local delivery of short and sufficiently intense voltage pulses via appropriate electrodes to the target cells and tissues [1]. Electroporation is used as an effective method for introduction of either small molecules (i.e. therapeutic agents such as chemotherapeutic drugs) or macromolecules (such as DNA) or other molecules which in normal conditions do not cross cell membrane. This method can be applied to many different types of human, animal or plant cells and tissues for different biomedical or biotechnological applications. In medicine this method is used in clinical

electrochemotherapy of cutaneous and subcutaneous tumors and in non-viral gene electrotransfer for gene therapy and new medical applications are emerging at an increasing rate [2].

The effectiveness of cell and tissue electroporation depends on one hand on the parameters of the applied pulses such as amplitude, duration, number and repetition frequency and type of electrodes used and on the other hand on the characteristics of the cell and tissues to be electroporated. Depending on the electric pulse parameters used the electroporation can be reversible or irreversible. Namely, when the electric pulses are applied a local electric field (E) is established within the treated cells or tissues. Since the electroporation is a threshold phenomenon magnitude of local electric field need to achieve the critical reversible threshold value (E_{rev}) in order to cause structural changes in cell membrane and to trigger the increase in its permeability. The phenomenon is reversible until the magnitude of local electric field reaches the irreversible threshold value E_{irrev} , which causes permanent damages of the cell membrane. The reversible electroporation regime has to be assured in all applications in which the viability of cells have has to be preserved, such as for example electrochemotherapy or gene therapy [1]. On the other hand, in some medical and biotechnological applications such as irreversible tumor tissue ablation, liquid food sterilization of water treatment, the irreversible electroporation is used as a method for efficient cell killing. The electroporation pulse parameters can also be designed so as to trigger electrofusion of cells with electroporated membranes in fusogenic state. [2]

The key role in electroporation effectiveness plays the local electric field distribution, which can be directly modified by electric pulses and electrodes [3]. Thus, for controlled use of the method in each particular electroporation mediated application the pulse parameters and electrodes need to be specifically optimized. Realistic mathematical models validated on corresponding experimental observations are valuable tool in designing the cell and tissue electroporation level/regime. Numerical

calculations of local electric field distribution in realistic mathematical models allow for optimization of pulse parameters and electrode geometry and their positioning. In electroporation mediated applications planning a multidisciplinary expertise is required. Namely, the collaboration and knowledge and experience exchange among the experts in the fields of medicine, biology and engineering is needed. The efficacy of electrochemotherapy can be improved with a good knowledge of parameters of the local electric field, being crucial for successful tissue electroporabilisation and subsequently for the best electrochemotherapy treatment outcome. In electrochemotherapy a close collaboration between oncologists and electrical engineers is of great importance. To make the therapy as efficient as possible it is of great importance to transfer that knowledge to the practicing clinicians who plan or perform the treatment.

To collect, organize and transfer the acquired knowledge web-based technologies are being an indispensable tool in modern teaching. The web-based e-learning programs offer more educationally effective and enjoyable learning and teaching methods compared to the conventional learning methods such as learning through listening to spoken words. Furthermore, the use of web-based e-learning techniques enables the simulation of the users' participation in "hands-on" learning activities, which is proven to be the most retentive learning method [4].

In this paper we present a web-based e-learning application which was developed in order to collect, organize and provide the knowledge and experience about cell and tissue electroporation. The educational content is based on previously published studies from a single cell level and simplified tissue models to complex biological tissues. In the first part of the e-learning application we explain basic mechanisms underlying electroporation process. Based on simple graphical illustrations we demonstrated the influence of each of the pulse parameters, such as pulse amplitude, pulse number and duration, on electroporation of cells with different sizes, shapes and orientations with respect to the applied electric field. By using 3D animation we visualized the aqueous pore formation in cell membrane, which is most widely accepted model, among different theoretical models that describe cell membrane electroporation [2].

One of the main objectives of the presented e-learning application is to demonstrate the importance of local electric field distribution for effective electro-

poration of treated cells and tissues. For this purpose we used combination of numerical calculations by means of mathematical modeling and simple graphical illustrations. We demonstrated how the pulse amplitude, electrode shape and electrode positioning influence on the local electric field distribution within the treated cells and tissues. We also illustrated how the electric properties of a treated sample can modify the local electric field distribution.

We further provide main medical applications of reversible electroporation with special emphasis on electrochemotherapy. We also provide a list of applications of irreversible electroporation in medicine and biotechnology. Electrochemotherapy treatment outcome is directly related to the local electric field distribution within the target tumor tissue and its surrounding tissues [3]. Therefore, this part of e-learning application was developed in order to provide an educational material about the parameters of local electric field being crucial to make the tumor treatment as efficient as possible. The main conclusions on influential parameters on local electric field distribution can be applied also for other electroporation based applications.

The e-learning application is concluded by a test on the presented educational material. The textual and graphical information was published using HTML and integrated into an interactive elearning environment (E-CHO) [5].

1 Methodology

The e-learning web application is based on HTML, JavaScript, ASP and Macromedia Flash web technologies.

For graphical illustrations and 3-dimensional visualizations of the electroporation process on the levels of cell membrane, cell and tissues a software package 3D Studio Max was used. Based on the numerical calculations of electric field distribution carried out with software packages COMSOL Multiphysics and Matlab, more simple 2dimensional and 3-dimensional illustrations using software packages 3D Studio Max, Macromedia Flash, PhotoShop and CorelDraw are designed. The educational content (textual and graphical information) is published using Hypertext Markup Language (HTML). The designed e-learning application is integrated into E-CHO elearning system developed at the Faculty of electrical engineering (University of Ljubljana) by the Laboratory of telecommunications [5]. The E-CHO e-learning system is an interactive e-learning

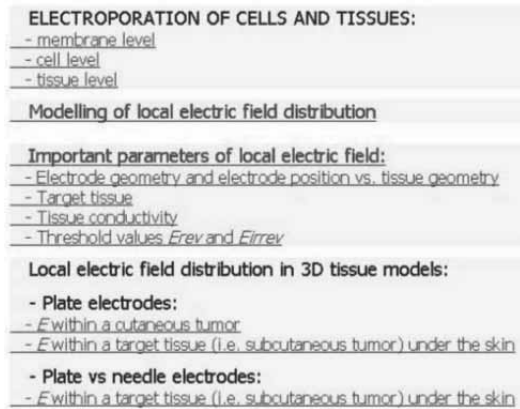


Figure 1. The structure of the e-learning application on cell and tissue electroporation

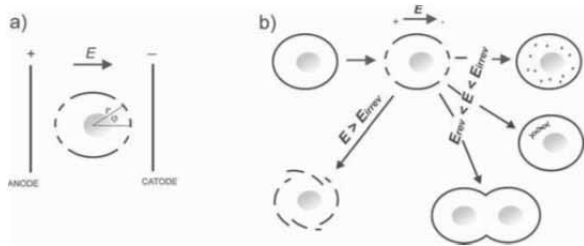


Figure 2. (a) The electroporation of cell membrane first occurs within the cell area facing the electrodes and (b) Different electroporation regimes: reversible $E_{rev} < E < E_{irrev}$ and irreversible $E > E_{irrev}$.

environment enabling the authentication of users, statistical analysis, network traffic measurement, support for video streaming, as well as the use of various types of communications among users, such as forums, e-mail correspondence, videoconferencing [5].

2 The e-learning application

The main structure of the e-learning application is given in Figure 1.

The first part of our web-based e-learning application brings together the educational material on basic mechanisms underlying electroporation process on the levels of cell membrane, cell and tissues as a composite of cells. Electroporated cell in a local electric field exceeding reversible threshold value $E > E_{rev}$ is represented by a simple graphical illustration in Figure 2a: The electroporation of cell membrane first occurs within the cell area facing the electrodes (dashed line in Figure. 2a), since the induced transmembrane potential is maximal at the poles of the cell in accordance Schwan's

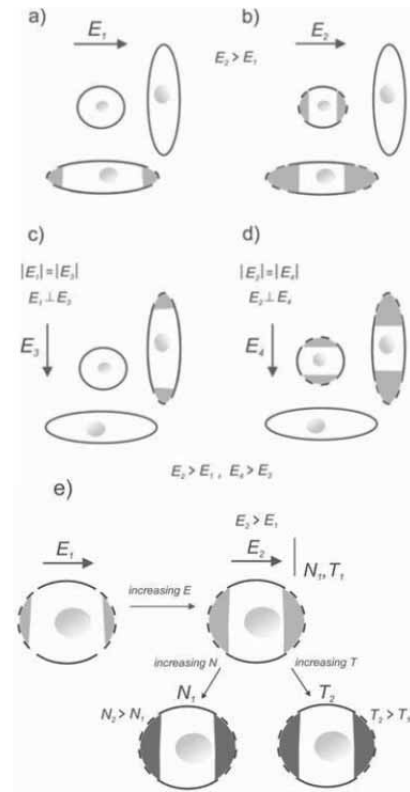


Figure 3. (a) Electric field parallel to elongated cell, (b) electric pulse amplitude is increased, (c) orientation of electric field is changed, (d) electric pulse amplitude is increased and (e) increasing the pulse amplitude results in larger area of membrane with smaller extent of electroporation, while increase in pulse number or duration does not affect the membrane area but increases the extent of electroporation.

equation: $U_{TI} = -1.5 r E \cos \varphi$, where r is the radius of the cell, E is the strength of applied electric field, and φ is the angle between the direction of the electric field and the selected point on the cell surface. Different regimes of electroporation process, depending on parameters of the electric pulses applied, are illustrated in Figure 2b: the introduction of small molecules, macromolecules and cells' electrofusion require reversible electroporation regime ($E_{rev} < E < E_{irrev}$), while the permanent cell damaging requires irreversible electroporation thus local electric field exceeding irreversible threshold $E > E_{irrev}$.

The value of induced transmembrane voltage and thus the cell electroporation depends on the cell size, shape, and the position of the cell with respect to the direction of applied electric field, which we represented in Figures 3a,3b,3c and 3d. For a spheroidal cell, maximum induced transmembrane potential strongly depends on its orientation with the respect to the electric

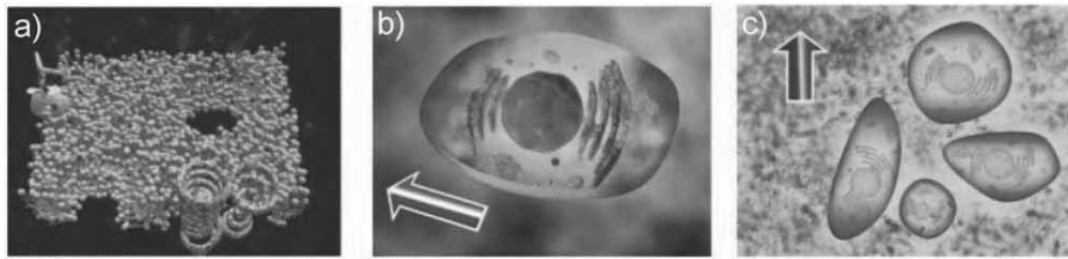


Figure 4. Introduction of small molecules (blue molecules) through a cell membrane (a) into an electroporated cell (b) and into the successfully electroporated cells within an exposed tissue (c)

field. It is maximum when the spheroidal cell is parallel to the applied electric field. In Figure 3e we illustrated that increasing the pulse amplitude results in larger area of membrane with smaller extent of electroporation, while increase in pulse number or duration does not affect the membrane area but increases the extent of electroporation. In order to visualize the electroporation process in three dimensions we used 3D Studio Max software. The animations of introduction of small molecules in 3D through an electroporated cell membrane, into an electroporated cell and into all successfully electroporated cells within an exposed tissue, which we included into the e-learning application, are shown in Figure 4.

The Modeling of local electric field distribution chapter provides an educational content about importance of visualization of local electric field distribution. The user is warned about possible errors that can be committed while performing cell or tissue electroporation, such as insufficient amplitude of electric pulses or inadequate electrode geometry, electrode positioning. This part of e-learning content is particularly intended as guidance to the practitioners who perform electrochemotherapy treatment of solid tumors. Namely, for successful tumor treatment all the clonogenic cells have to be destroyed, otherwise the tumor cell can regrow due to the insufficient magnitude of local electric field $E < E_{rev}$. This was in our e-learning application demonstrated with an example of unsuccessful the skin tumor treatment performed on a nude mouse, as shown in Figure 5. The Figure 5a shows the electrode position and the tumor geometry just before the treatment, while Figure 5b shows the negative result of the treatment: two new tumors regrew in the regions (marked with 1 and 2 numbers) where the tumor tissue was not exposed to the sufficient electric field $E > E_{rev}$.

By using simple graphical illustration we pointed out that the effectiveness of electrochemotherapy can be improved by: optimizing the applied voltage, changing electrode dimension or changing electrode orientation

and their position, which we previously predicted by means of numerical modeling.

The chapter Important parameters of local electric field provides a list of important parameters of the local electric field distribution that affect the electrochemotherapy outcome, such as: electrode geometry (needle or plate electrodes), dimension of the particular electrode (width, length, diameter), distance between electrodes, electrode position with respect to the target tissue, electrode orientation with respect to the target tissue, geometry of the target tissue, geometry of the tissue surrounding the target tissue, the contact surface between the electrode and the tissue, electric properties of the target tissue i.e. tissue conductivity, electric properties of the surrounding tissue, the voltage applied to the electrodes and threshold values of the tissue E_{rev} and E_{irrev} . Using mathematical modeling and graphical illustrations we stressed the fact that the local electric field within the treated tissue is markedly non-homogeneous due to the specific structure and electric properties the tissues (particularly target tumor tissue that usually has higher

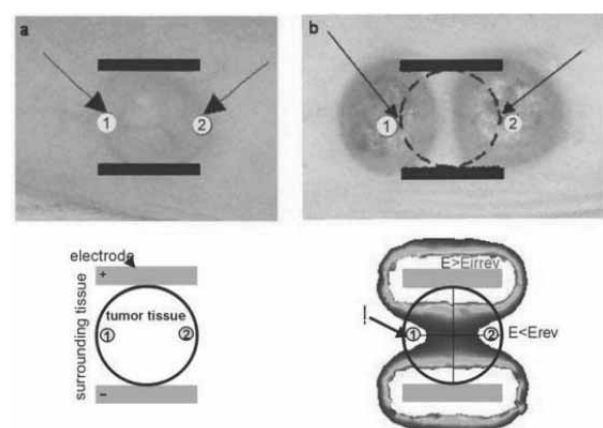


Figure 5. Unsuccessful tumor treatment performed on a nude mouse: a) The electrode position and the tumor geometry just before the treatment, b) after the treatment two new tumors regrew in the regions (marked with numbers 1 and 2) where the tumor tissue was not exposed to $E > E_{rev}$.

electric conductivity than its surrounding tissues).

The chapter Local electric field distribution in 3D tissue models provides 2D and 3D animations of local electric field distribution in models of cutaneous and subcutaneous tumors, which we previously numerically calculated using COMSOL Multiphysics software. We presented local electric field distribution in models of cutaneous protruding tumor and model of subcutaneous non-protruding tumor with skin.

The objective of this part of the e-learning application is to provide an interaction with the educational content in order to simulate the “hands-on” learning approach about the parameters of the local electric field distribution that have been previously explained. Namely, by varying different parameters (such as amplitude of electric pulses, electrodes’ dimensions and shape and distance between electrodes) in the navigation bar users have the possibility to shape the electric field distribution within the models (see the navigation bar in Figure 6). The local electric field distribution can be viewed in 2D model cross-sections or played as a 3D animation. The E is displayed in the range between E_{rev} to E_{irrev} .

In Figure 6 the local electric field distribution inside the cutaneous protruding tumor obtained with two different amplitudes of applied voltage (Figure 6a: $U = 300$ V and Figure 6b: $U = 600$ V) using two parallel plate electrodes is shown as example. By increasing the applied voltage (for the same tissue geometry, electrode size and position) the stronger local electric field is obtained. Similar effect can be achieved by increasing the electrode dimensions (electrode width) or changing electrode orientation, while by increasing the distance between electrodes the tumor is exposed to a lower local electric field intensity, as shown in Figure 6c and 6d.

The model of subcutaneous tumor gives the user an insight into the electric field distribution within the target tissue when electroporated through the skin. This model is composed of two layers; the upper layer representing skin tissue with lower specific conductivity compared to the underlying layer being more conductive. The electric field distribution is presented in two models with two different thicknesses of the skin layer: 1 mm (Figure 7a) and 3 mm (Figure 7b). Thus, the user can appreciate the influence of the skin thickness and its electric conductivity on the local electric field distribution within the target tumor and its surroundings. The key message is that in order to successfully electroporate the target tumor through the thicker skin layer (3 mm) a higher voltage need to be applied compared to

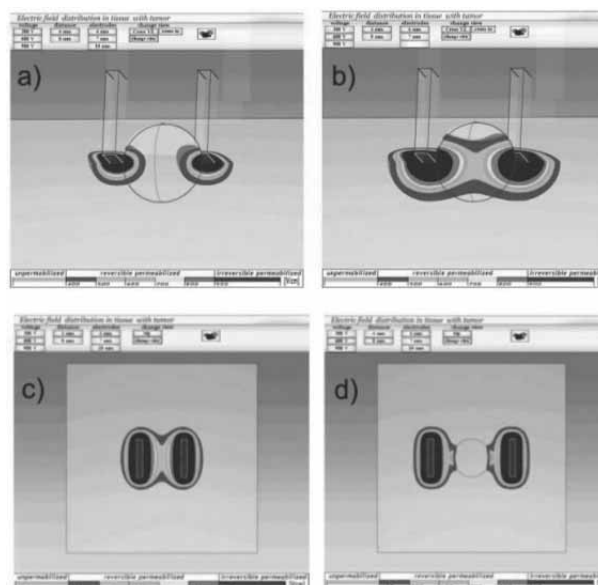


Figure 6. Electric field distribution inside the protruding tumor model for two different applied voltages on the electrodes: a) $U = 300$ V and b) $U = 600$ V. The electrodes are 4 mm wide and 4 mm apart in both cases. Electric field distribution inside the models for two distances between electrodes: c) $d = 4$ mm and d) $d = 8$ mm. The electrodes are 4 mm wide with the applied voltage $U = 600$ V in both cases.

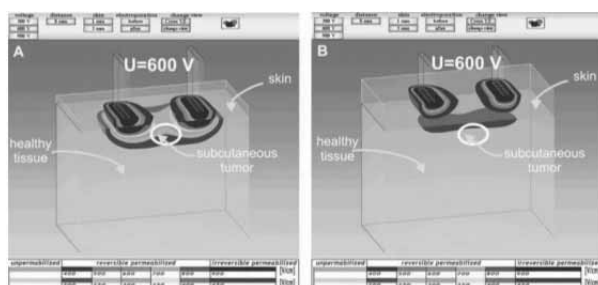


Figure 7. Electric field distribution within a model of subcutaneous tumors seeded below: a) a 1 mm thick skin layer; b) a 3 mm thick skin layer

the tumor electroporation through the thinner skin layer (1 mm). Based on this the user is offered a guideline on how to overcome the highly resistive skin tissue in order to permeabilize more conductive underlying tissues.

Based on the presented educational content in chapter Local electric field distribution in 3D tissue models the user can appreciate that the plate electrodes are more suitable for treatment of protruding cutaneous tumors, while for situations when the tumor is more deeply seeded in the tissue the needle electrodes are to be used and that by increasing the number of needle electrodes

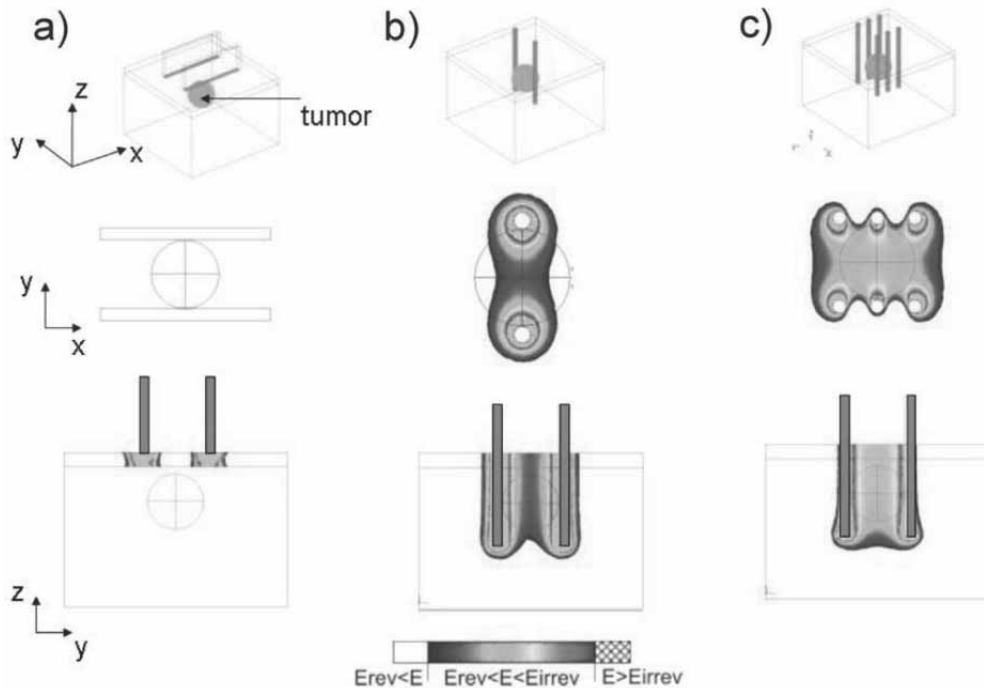


Figure 8. Local electric field distribution in subcutaneous tumor model using plate electrodes (a), a pair of needles (b) and three pairs of needles (c). The applied voltage in all cases is $U = 300$ V.

stronger local electric field in the tissue can be achieved, as shown in Figure 8.

3 Conclusions

We developed a web-based e-learning application that provides the educational content on important parameters that affect the effectiveness of cell and tissue electroporation. The e-learning application is particularly aimed at providing the knowledge about the adequate choice of local electric field parameters such as electric pulse amplitude, electrode shape and number or electrode positioning, being important in treatment planning of electrochemotherapy as well as in other electroporation based applications.

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Personalized Learning Environment E-CHO

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Abstract. Important features of the Knowledge Management Systems, based on the Information and Communication Technologies (ICT) are described in the first section. These features emphasize the importance of Web 2.0 concepts which foster user generated content development as well as effective content filtering and selection capabilities (e.g. Really Simple Syndication – RSS feeds). The most popular community portals (blogging, video, etc.) nowadays generate more content than ever before. This new paradigm, where users become active participants instead of passive observers, calls for improvements in quality assessment and demands the adaptation of user generated content, so that it could be used for the wider interested audience. On the other hand, corporate or academic environments do not benefit from the community oriented Web 2.0 advantages directly. Knowledge Management challenges in these environments lie in the meaningful and tight integration of the Learning Management Systems (LMS) into the existing knowledge resources and information systems. This enables creation of personalized learning environments for target users, which is described in the second section. Subsequently, some of the case studies, which are incorporated into the E-CHO Learning Management System at the Faculty of Electrical Engineering, University of Ljubljana, Slovenia, are presented. Conclusions of the paper describe future research and development work, based on our experiences and new learning paradigm, putting learners into the centre of the educational process.

Introduction

Introduction of e-learning into any business or academic environment facilitates studying activities as well as management and administration process. E-learning assists in extension and deepening of student's access to information, increased flexibility of study delivery and integration of student's learning experiences and knowledge. Aspects of e-learning initiation that are not directly correlated with the studying activities are also important. Students save time and money that would

otherwise be spent on travelling and accommodation expenses. Faculties with enrolment limitations due to lack of space (lecture rooms, laboratories, ...) can increase the number of enrolled students.

Because all learning materials are in electronic format, their upgrade, maintenance and distribution can be substantially simplified. This is significant in the natural and technical science studying fields where knowledge is modernized and upgraded all the time. Simplified distribution means the increase of use of the same learning materials in different faculties and studying programs. Systematic e-learning introduction also enables better time efficiency in the engagement of the pedagogues.

E-learning should reflect actual education process in academic environment and enhance educational possibilities in innovative way from the viewpoint of the course access, contents and level, in order to meet diversified needs of target groups. The only way to accomplish this is to support the following e-learning components:

- E-learning content commonly presented in HTML format, enriched by multimedia that is supported by Internet as well as real time audio or video streaming clips. Java applets are usually used to explain experiments.
- Management of the learning process consists of managing students, learning staff, learning content, different learning tools and dissemination of learner's statistical data as well as progress tracking.
- Collaboration between learners can be accomplished by forming of groups of learners, giving them common assignments and enabling them to have guided or non-guided discussions among themselves.
- Pedagogical support is achieved through tutor - learner communications via advanced communications channels. These can be asynchronous: e - mail, discussions and notice boards, or synchronous: chats or audio & videoconferences.
- Assessing knowledge in e-learning is not only about getting feedback on the learner activities and gained knowledge, but also about acquiring complete picture of the quality of e-learning. The most common model

to achieve this is through multi-level evaluation. This way we evaluate reaction of the learners, track learners progress and get the results of e-learning.

E-learning as described (in different variations) has been present for more than ten years or so. During that time, it has emerged from being hype to the mainstream ICT supported service in academic and corporate environments. Learning content that is used in e-learning today is represented in the set of learning objects that originate in the computer-based training (CBT) system. These are the smallest possible, independent, sets of content that could be put together or organized. Standardization bodies have redefined the concept of learning objects into a strict form and have provided specifications on sequencing and organization of learning object into online courses or course packages similar to e-books or training manuals. Therefore, the main software used in e-learning today is the Learning Management System (LMS), as described above. It organizes learning content in a standard way, as an online course separated into modules or lessons, supported with quizzes, tests, communication and collaboration features, mostly discussions. Most up-to-date LMS systems are integrated into the target environment information system.

However, internet as the main media used in e-learning and its users have begun to change rapidly. Some authors say that internet users are becoming »digital natives«, meaning, they learn, play and work in completely different ways [1]. Their most important features are quick and easy absorption of information presented to them, from multiple sources simultaneously in different formats (images, video text, etc.). The speed at which digital natives perform is faster than previously, additionally they expect instant response or feedback. They expect to be in constant and instant communication with their friends, they prefer accessing information on the random (or as needed) basis from different media or sources and they are very likely to create their own multi-media content. In learning, these trends can be described as the »Learner Centered« design [2]. This means that learners are put in the center of the learning process, where teachers act as moderators only. Learning today emphasizes greater autonomy for the learners and fosters active learning, with creation, communication and participation playing key roles [3]. Some authors speak about "connectivism" in learning [4]. Siemens states that today's knowledge workers derive competencies through formation of connections

in the chaotic world. Connectivism is in accordance with the well-known constructivism theories in the learning which foster understanding through process of meaning and constructing (making) afterwards. Meaning-making process and forming connections between specialized communities are both important activities. To clarify these statements we can look into modern internet services, commonly called "Web 2.0" and used in e-learning. Web 2.0 itself was transformed from "the Read Web" to the "Read-Write Web" [5]. Web changed, from being a medium, in which information was transmitted and used, into a platform, in which content is created, shared, repurposed, and passed along. Users are no longer merely reading, listening or watching, but having a conversation, not just with words but with images, video, multimedia and any other way. Evolving Web services, described in the subsequent section and used in e-learning are called Web 2.0 services.

As an example we can look more closely to the simple file sharing among users. According to different studies [6] users believe that information (set of documents) is something meant to be shared. This belief is manifested in free and open-source software, Creative Commons licenses for content and open access to academic and other works. Sharing content is not considered unethical; on the contrary, keeping the content is viewed as antisocial. Blogging as another example changed from the static web pages into a service used by many users, supported by easy content creation tools (e.g. Blogger, WordPress) and more importantly, connected to each other through the means of RSS feed, that is, simple XML (Extensible Markup Language) format enabling sending of the content to the readers (subscribers). Creation of online communities using specific tools (e.g. Plone, Drupal), use of online collaboration tools, such as Wiki (<http://wiki.org/wiki.cgi?WhatIsWiki>), audio re-cording tools (e.g. Audacity) and other simple means of content creation fostered user generated and connected content, even more. We can see, that when speaking about Web 2.0 services it is not about technological revolution, but about social revolution. We are also not speaking about net-works in technology terms, but about "Social Net-works" [7].

In the e-learning, social networking is most obvious in building communities. Etienne Wenger [8] promotes "Communities of Practice", which are characterized by "a shared domain of interest" where "members interact and learn together" and "develop a shared repertoire of resources". In e-learning discussions are known for a

longer period of time in the form of structured post-reply format. Internet forums, embedded in the e-learning systems are most commonly used. However, lately, authors of this article noticed that students of the Faculty of Electrical Engineering in Ljubljana, for example discuss a wide range of topics with their peers worldwide instead of using pre-assigned forums and topics with their faculty peers. Additionally, Web 2.0 services, such as blogging are more and more commonly used in education process (e.g. <http://www.ebn.weblogger.com>) for wide variety of purposes, as they tend to be different from traditionally assigned content in the way that they are less formal and written from the personal point of view. It is expected that e-learning software in the future, such as LMS and other systems used are going to become less and less content delivery systems but more and more content authoring tools, where content and learning is going to be created. Systems used in e-learning will represent one of the nodes in the web network of content. These systems will not be applications installed and maintained by a target organization or company exclusively, but will become personal learning environments, a collection of interoperating systems, adapted to the learners' needs and interests.

Knowledge management and e-learning

The knowledge management aims at managing knowledge assets (tacit and explicit) in the target environment so that all the information is available when it is needed and to those who need it [9]. Knowledge management should help those acquiring information to find new creative ways of solving problems in the changing environment. When compared to e-learning as described in the previous chapter, one could assume that knowledge management is only a new name for modern e-learning process. However, there are knowledge management features that are not covered within the core e-learning process. These features concern means of adding new knowledge into target environment knowledge pool [10]:

- externalization of tacit knowledge into explicit knowledge;
- socialization among workers (it increases tacit knowledge);
- "interiorization" of explicit knowledge into tacit knowledge;
- combination of explicit knowledge training processes.

There is an increasing need of managing knowledge in

the target organizations, as they usually represent closed environments and need new knowledge also through external factors. What used to be tacit knowledge held by individuals can be made readily available to others, thus increasing the organization's knowledge base [11]. As an example of usefulness of knowledge management integration into e-learning process are skill or knowledge gaps that target organizations may encounter. These are gaps between what the target organizations need in order to face new challenges and the notions users (students, teachers or employees in corporate environments) can make available to the pursuit of such projects. In order to overcome the skill gap, corporate environments especially, need to map all the skills and competencies that each employee owns. Additionally these skills need to be analyzed in order to prepare the training or e-learning plan for example. Along with the presented problem there are other issues and challenges that make knowledge management and e-learning common introduction in the target environment reasonable. This can be done by adapting the Learning Management System used. Adaptation consists of LMS integration into existing applications of the target environment and additional analysis of the data necessary.

Finally, we can see that the development of up-to-date e-learning application derived from an LMS consists of two contradictory tasks. The first one is integrating an unstructured combination of different applications used in the modern e-learning, presented in the previous chapter of the article and the second one is integrating structured and organized applications in order to support knowledge management processes in the target environment [12]. Both tasks are difficult to achieve. At the Faculty of Electrical Engineering we have developed an LMS that will be presented in the subsequent chapter of the article. Through an iterative process of adapting our LMS we are trying to meet the objectives of the modern e-learning as well as to support the knowledge management in the target environment. However, there is a long way to achieve both tasks and many more implementations will have to be performed in the future in academic as well as corporate target environments.

1 E-CHO learning management system

There were several reasons that led us to develop and implement our own learning management system. Commercially available e-learning systems can be di-

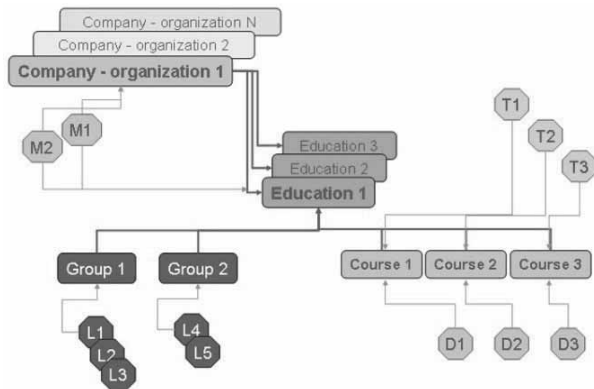


Figure 1. The top view of the model on the surf.

vided into two groups. The first one consists of the systems that support required e-learning prerequisites and can be functionally verified. These systems tend to be too complex to use and too expensive to purchase, especially for the smaller and medium size target environments. The second group consists of mainly open source systems that support e-learning components partially, but are difficult to be adapted to the specific needs of target environments or to be integrated with knowledge management features needed [13]. However, main reasons for the implementation of the e-learning system reside in the constraints and challenges that emerged from our practical implementations of e-learning.

1.1 Basic features of the system

The name, given to the e-learning system, discussed in this article, is E-CHO. System enables multilingual user interfaces, as well as course catalogue creation. Different roles of users were determined in order to define the level of access rights to the system. The authentication and authorization rules disable unauthorized proceeding among different roles within the e-learning system.

The system enables access to course content for the learners, creation of personalized courses. Pedagogical and administrative support during e-learning is also supported.

Tracking learners' progress as well as different statistical reporting is an important feature of the system in order to provide the full learning experience.

Readers who are interested in the real e-learning environment, based on the E-CHO system can log on to the <http://www.e-cho.org/> web page, where the e-learning implementation for the Faculty of Electrical Engineering at the University of Ljubljana, Slovenia can be experienced. The E-CHO e-learning system was implemented at the national fixed telecom operator,

national mobile operator in Slovenia as well as in the biggest Slovenian bank for the internal employee training. Currently, there are more than 20000 users learning via the E-CHO e-learning system.

1.2 Understanding E-CHO

The e-learning system is an internet based application. As such it can be integrated with any other internet or intranet application that would be potentially used for education purpose.

Education and training of employees, customers, students, etc. is often closely related to the business process of the target environment. The e-learning system is designed in a way that simplifies the integration with the existing information system of the target environment. It usually serves as the part of its information system.

Three main guidelines were set up during the functional specification of the e-learning system:

- simplicity of use
- system independent course content creation
- personalization of the learning activities

Main features of the system are Learning Management System (LMS) and Learning Content Management System (LCMS) [14].

1.3 Learning management

The use of the LMS is almost inevitable, as soon as the e-learning consists of different groups of users and different knowledge requirements. For larger corporate or academic environments, flexible and easy to use LMS is necessary [15].

The system enables access to the learning content, joining of users into groups, administrative and pedagogical support of the learning process as well as acquisition and tracking of the learning progress data.

The following main entities of the system were defined:

- *users* can have one or more different roles in the system
- *courses* are complete series of content building blocks, pedagogically and technically suitable for e-learning delivery
- *learners* enable flexibility and simplicity of the learning management process

Figure 1 presents entities of the system. We can presume that the system is installed at the Learning Service Provisioner (LSP) [16]. The top entity is 'Company (Organization)'. Several of them can use the system on

the same server separately. 'Companies (Organizations)' create 'Educations', the core entity of the system. Each 'Education' consists of one or more 'Courses' and one or more 'Groups' of users.

All users access the e-learning system through specific user interfaces over the internet browser. Due to complexity of the e-learning, transparency and adaptation requirements, system distinguishes five types of users: learners (L), tutors (T), developers (D), managers (M) and system administrator.

One can be registered in the system as the member of different types of users at the same time.

Managers' work in the system is related to organization of the e-learning. In classical education or training activities, his work is done by the administrative workers in the student departments of the academic environments or human resources and training departments of the corporate environments.

1.4 Learning content management

Content represents the most important component of e-learning, thus it has to be rich in multimedia, interactive and pedagogically appropriate. These conditions require system or platform independent content development. Content developers should use arbitrary tools for development, according to the needs of the content. They shouldn't be limited with any compulsory content development tools by the e-learning system that is used for content delivery [17].

This approach to content development increases the portability of the content, as long as it is being developed in any of the standardized internet format.

The e-learning system discussed enables importing of any internet based content. The content is usually represented as a series of HTML pages with belonging media building blocks.

The role of LCMS is to develop courses from the imported raw content. First the course building blocks have to be distinguished, sorted into series, then the levels of the building blocks have to be defined. This way the table of contents of the course is created, similarly to the table of contents of the textbook. Subsequently studying tools for the course have to be defined. There are several of them integrated within the system (e.g. user notes, dictionaries, calculator, adding favorite links, etc.), others can be added by integrating any existing internet applications, used for learning.

Course developers can add standardized meta data about the course from which the course catalogue can

be created.

Navigation and personalization of the e-learning is achieved by creating different suggested studying paths, adapted to the specific needs of learners or groups of learners. In this way learners access and navigate only through the course building blocks of their interest. The course content is manageable and personalized from the learners' point of view.

The usage of arbitrary content search mechanism on the server is possible, due to e-learning system independent content development.

Assessments from the external knowledge assessment server (e.g. QuestionMark Perception) can be added to the course, thus enabling pre-tests, self-assessment tests and post-tests.

1.5 System architecture

System is based on the widely used Microsoft technologies. System software consists of: operating system on the server (Microsoft Windows 2003 Professional), database server (Microsoft SQL 2005) and internet server (Microsoft IIS).

Functionality of the system is implemented with three tier object architecture. Business logic layer is made up of two sub layers, therefore the term four tier architecture can be used [18].

Database layer is implemented with the MSSQL Server 2005 database. Stored procedures are used for data retrieval. Format of data retrieved to the business logic layer is XML. Chosen technology enables integration and synchronization of the e-learning system with existing information systems and Lightweight Directory Access Protocol (LDAP) directory services.

Business logic layer consists of Component Object Model (COM+, ActiveX) objects, arranged into classes. Classes are made up of number of methods.

Layer provides for calls of stored procedures, accepts requests from the presentation layer and re-returns corresponding data. It is also used for business logic operations of the system, such as computing statistical data, learners' progress tracking, etc. Layer is divided into two sub layers. The application (APL) sub layer processes requests of the presentation layer and provides data to it. Database (DB) sub layer, on the other hand provides for communication with database layer (collecting and entering of data). DB sub layer simplifies the migration to different databases.

The Business logic layer is implemented as two Dynamic Link Libraries (.dll) files, that have to be in-

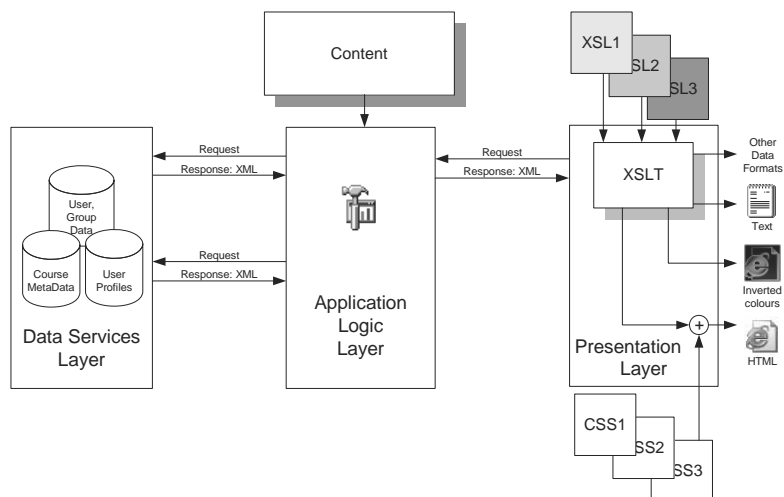


Figure 2. E-CHO system architecture and multi-modal presentation of content

stalled, to the IIS WWW server.

Presentation layer uses XML (Extensible Stylesheet Language - XSL files) and Active Server Pages (ASP) technology that are both embedded in IIS server. ASP files are used for calling corresponding objects of the business logic. XSL files that define appearance of the user interfaces acquire data needed from the objects of the business logic that perform XML transformation. The use of technologies described above enables integration of any internet application (proprietary or non-proprietary) that could be used in the education process. The four tier architecture described in this chapter was used in order to achieve better efficiency and scalability of the system. The verification process of the e-learning system showed that it can process approximately 100 requests per second.

2 E-CHO case studies

E-CHO system is used through several different courses at the Faculty of Electrical Engineering, University of Ljubljana. This target environment is specific as the faculty covers variety of electrical engineering fields, such as electronics, automatics, telecommunication or power engineering. Within different areas, students and teaching staff use different studying tools and didactical approaches that need to be integrated or embedded into an LMS. Therefore also various e-learning implementations for different departments have been prepared [19]. For example, students of the first year of the undergraduate study use E-CHO LMS within “Computer Engineering II” subject. Through the E-CHO system they can learn different programming languages and program

using specially designed emulator. This course was successful, as the first year of undergraduate studies comprises around 300 students and the quality of the lecturing process increased with the introduction of E-CHO as a part of their studying process.

The second subject, where E-CHO became important part of education process, is “Fundamentals of Electrical Engineering I”, where topics, covering electrical and magnetic fields with visual presentations, animations and interactive simulations, are included (see Figure 3). This content is used widely among undergraduate students, assisting them to conclude laboratory work and exercises

compulsory to the subject.

E-CHO was introduced also for two modules (Process automation and Intelligent systems) of the fifth year at the Automatics regarding the subject Multivariable systems. It is used during the time of laboratory exercises, but it also enables testing and experimenting using virtual and remote experiment which mimic complex multivariable process control problem (see Figures 4 and 5) [20]. In Figure 4 the animation of the process is presented together with system responses, which illustrates basic system properties in time domain, while in Figure 5 the remote usage of the pilot plant is presents as can be observed through video stream.

Postgraduate students use E-CHO as the main studying tool within the “Project management and communication in research and development” course. This course consists of different invited lectures from professionals

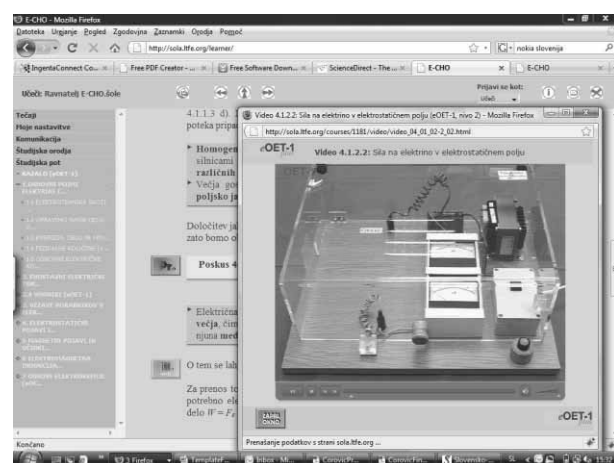


Figure 3. Interactive “Fundamentals of Electrical Engineering I” course in the E-CHO LMS

in the corporate and academic sector from Slovenia and abroad. Some lectures and speakers change on the yearly basis. All previous lectures are available to students with-in the E-CHO system. Each lecture consists of synchronized video lecture with additional slides or other multimedia material used within the lecture. This forms a base of more than 40 different lectures for new students. As each of the students needs to prepare one project as the final result of the subject, communication and collaboration among peers and teachers was performed within the E-CHO system in order to achieve the goal. All projects were submitted through the E-CHO system and graded by the teacher. Each student needed to present the project live in front of an audience. Presentations were also re-corded in the same way as the lectures and inserted into the E-CHO system. This enabled students to see and improve their presentations as well as teacher to thoroughly grade their knowledge.

There were more than 2000 students enrolled in different e-learning implementations until now.

3 Conclusions

There is a rapid change in the concepts of software used for modern e-learning. Unlike the past, this change is not technology driven but by new ways of using modern technology, meaning communicating, collaborating, community building and generating content on behalf of end users. It is expected that e-learning software in the future, such as LMS and other systems used are going to become less and less content delivery systems but more and more content authoring tools, where content and learning is going to be created [21]. Systems used in e-learning will represent one of the nodes in the web network of content. These systems will not be applications installed and maintained by a target organization or company exclusively, but will become personal learning environments, a collection of interoperating systems, adapted to the learners' needs and interests. At the same time need for knowledge management in the corporate and academic environments increases. This calls for integration of additional structured and organized features into e-learning software used. Both tasks are contradictory and difficult to achieve. At the Faculty of Electrical Engineering we have developed an LMS named E-CHO that is used in different corporate and academic organizations. Through an iterative process of adapting our LMS we are trying to meet the objectives of the modern e-learning as well as to support the

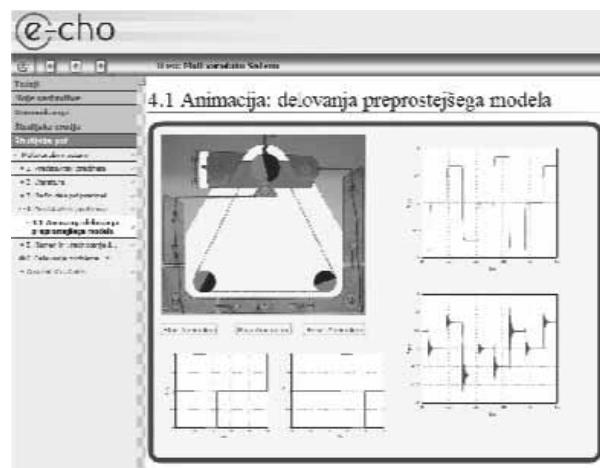


Figure 4. Virtual laboratory – animation of multivariable process



Figure 5. Remote usage of laboratory pilot plant

knowledge management in the target environment. However, there is a long way to achieve both tasks and many more implementations will have to be performed in the future in academic as well as corporate target environments.

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Two Examples of Testing Global Identifiability with the DAISY Software

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Abstract. DAISY (*Differential Algebra for Identifiability of Systems*) is a recently developed computer algebra software tool which can be used to automatically check global identifiability of (linear and) nonlinear dynamic models described by differential equations involving polynomial or rational functions. Global identifiability is a fundamental prerequisite for model identification which is important not only for biological or medical systems but also for many physical and engineering systems derived from first principles. Obviously, once a priori identifiability is assessed, the accuracy of the estimates will eventually depend on other different factors, as for example, noise, the paucity of the available data and/or the complexity of the model with respect to the available data.

The software does not require understanding of the underlying mathematical principles and can be used by researchers in applied fields with a minimum of mathematical background.

We demonstrate the DAISY software by checking the a priori global identifiability of two benchmark nonlinear models taken from the literature. The analysis of these two examples includes comparison with other methods and demonstrates how identifiability analysis is simplified by this tool. It includes discussion of some specific aspects related for example to the role of observability and knowledge of initial conditions in testing identifiability. The main focus of this paper is not on the description of the mathematical background of the algorithm, which has been presented elsewhere, but on illustrating its use and on some of its more interesting features.

DAISY is available on the web site <http://www.dei.unipd.it/~pia/>.

1 Identifiability of a Model for a Batch Reactor

In this section we shall analyze the identifiability of a nonlinear model of microbial growth in a batch reactor in which only the concentration of microorganisms is

measured. This model has been widely employed as a benchmark model for studying global identifiability [2], [3]. The model incorporates Michaelis-Menten-type nonlinearities and is mathematically described by the following rational nonlinear differential equations:

$$\begin{aligned}\dot{x}_1(t) &= p_1 x_1 x_2 / (p_2 + x_2) - p_3 x_1 + p_4 u \\ \dot{x}_2(t) &= -p_1 x_1 x_2 / ((p_2 + x_2) p_5) + p_6 u \\ y(t) &= x_1\end{aligned}\quad (1)$$

where x_1 and x_2 are the concentrations of microorganisms and of growth-limiting substrate respectively, $\mathbf{p} = [p_1, p_2, p_3, p_4, p_5]$ is the unknown parameter vector, u and y are the measured input and output of the model, respectively. The initial concentrations are

$$x_1(0) = x_2(0) = 0$$

The main question to be addressed is whether the unknown parameter vector \mathbf{p} is globally identifiable from the input-output experiment.

The a priori identifiability of this model has been first analyzed in [2] by using the similarity transformation approach. Note that the state isomorphism test requires a preliminary check of the minimality (controllability and observability) of the system, which may turn out to be quite difficult for nonlinear systems. The method requires an assumption of linearity of the state isomorphism map and some lengthy analysis is needed to check whether this assumption holds. In order to overcome this limitation, a modified method has been applied by [3], still based on the local state space isomorphism theorem. This method is based on the possibility, valid under certain restrictions, to perform a linear/nonlinear splitting of the similarity map.

Our global identifiability test uses a method based on differential algebra. A first advantage with respect to the similarity transformation approach is that it does not require a preliminary check of minimality of the model. The differential algebra test is implemented in the computer algebra tool DAISY. In the following the calcula-

tions performed by DAISY will be illustrated referring to the two specific examples treated in this paper. The input and the output files of the program are reported in the Appendix 6.

The user has to write in the input file the ordered list of the input, output and state variables as indicated in the instructions of the program, the list of the unknown parameters, the number of the state and the output variables respectively, the model equations and the initial conditions. The program can manage (partial or complete) knowledge of the initial conditions of the model and automatically uses this information in the identifiability analysis. This is theoretically justified in [7].

By looking at the input file reported in Appendix 6.1, one may appreciate the advantage of using this computer algebra tool: DAISY does not require expertise on mathematical modelling by the experimenter. For this example, in less than two seconds DAISY provides all the required calculations needed to provide the global identifiability answer.

Specifically, DAISY automatically ranks the input, output, state variables and their derivatives, starts the pseudodivision algorithm and calculates the *characteristic set* of the model (for explanations see [7]). This is a minimal set of differential polynomials which provides an equivalent description of the model (1),

$$\begin{aligned} & \dot{u}yp_1p_2p_4p_5 - \ddot{y}yp_1p_2p_5 - \dot{y}^3 \\ & + \dot{y}^2u(3p_4 + p_5p_6 + \dot{y}^2y(2p_1 - 3p_3) + \dot{y}^2p_1p_2p_5 \\ & + \dot{y}u^2p_4(-3p_4 - 2p_5p_6) + 2\dot{y}uy(-2p_1p_4 \\ & - p_1p_5p_6 + 3p_3p_4 + p_3p_5p_6) - \dot{y}up_1p_2p_4p_5 \\ & + \dot{y}y^2(-p_1^2 + 4p_1p_3 - 3p_3^2) + u^3p_4^2(p_4 + p_5p_6) \\ & + u^2yp_4(2p_1p_4 + 2p_1p_5p_6 - 3p_3p_4 - 2p_3p_5p_6) \quad (2) \\ & + uy^2(p_1^2p_4 + p_1^2p_5p_6 - 4p_1p_3p_4 - 2p_1p_3p_5p_6 \\ & + 3p_3^2p_4 + p_3^2p_5p_6) + y^3p_3(-p_1^2 + 2p_1p_3 - p_3^2); \end{aligned}$$

$$-x_1 + y;$$

$$\dot{y}x_2 + \dot{y}p_2 - ux_2p_4 + x_2y(-p_1 + p_3) + yp_2p_3;$$

The first differential polynomial does not depend on the variable x and provides the so-called *input-output relation* of the model. After a suitable normalization, the input-output polynomial can be rendered monic and its coefficients provide a set of rational functions of the unknown parameter p which form the so-called *exhaustive summary* of the model, see Appendix 6.1. Identifiability is checked by checking injectivity of the exhaustive summary with respect to the parameter p . This is

done by solving for the unknown parameters the algebraic equations obtained by equating these coefficients to a set of pseudo-randomly chosen numerical points in their range set. Solution of these algebraic equations is done by computing a Grobner basis. Solving the system provided by the input-output relation in (2) by the Buchberger algorithm yields the following Gröbner basis:

$$\{p_2p_5 - 90, p_6p_5 - 170, p_3 - 15, p_1 - 15, p_4 - 12\} \quad (3)$$

which shows that only parameters p_1, p_3, p_4 are uniquely identifiable from an input-output experiment as are the combinations p_2p_5 and p_2p_6 . So far this result agrees with what presented in [2] and successively in [3]. Note that the construction of the characteristic set ignores initial conditions and the identifiability result above holds irrespective of which initial conditions the system may have started from. However, Daisy can also manage known initial conditions and check if, based on this extra information, some additional parameter can be globally identified. To this end, after having checked the algebraic observability [7] of the model, Daisy calculates at time zero the polynomials of the characteristic set where the state variables appear. In this example, DAISY calculates at time zero only the third polynomial. Recalling that both initial states are equal to zero, this yields:

$$\dot{y}(0)p_2 - u(0)p_2p_4 + y(0)p_2p_3$$

Equating this polynomial to zero, provides an extra equation to be added to the solution of the exhaustive summary (3). It is easy to see that this new equation, involving only p_3 and p_4 , parameters already globally identifiable without initial conditions, does not modify the previous identifiability results.

2 Identifiability of a Model for in vitro Homoacetogenesis by Human-colon Bacteria

In this section we shall analyze the identifiability of a fifth order model based on *in vitro* experiments to study the kinetics of homoacetogenesis by human-colon bacteria. Due to its complexity it is considered in [8] as a challenging example to analyze. The model is mathematically described by the following rational nonlinear differential equations:

$$\begin{aligned}
\dot{x}_1(t) &= \frac{\mu_{\max} x_1 x_5}{k + x_5} - k_d x_1 \\
\dot{x}_2(t) &= k_d x_1 - k_1 x_2 + k_5 x_2 x_3 + k_5 x_2 x_4 \\
\dot{x}_3(t) &= k_{la} (x_5 - k_{hrt} x_3) V_l / V_g \\
\dot{x}_4(t) &= \frac{1 - y_h}{y_h} \frac{\mu_{\max} x_1 x_5}{k + x_5} - k_5 x_2 \\
\dot{x}_5(t) &= - \frac{\mu_{\max} x_1 x_5 (k + x_5) + k_{la} y_h x_3 (k + x_5)^2}{\mu_{\max} x_1 (k + x_5) - \mu_{\max} x_1 x_5 - k_{la} k_{hrt} y_h (k + x_5)^2} \\
y_1(t) &= \alpha (x_1 + x_2) \\
y_2(t) &= x_3 \\
y_3(t) &= x_4
\end{aligned} \tag{4}$$

where $x_i, i = 1, \dots, 5$ are concentrations, k_{la} , k_{hrt} and α are physical constants known from the literature. Following [8], the ratio V_l/V_g is assumed known and is not included in the list of unknown parameters so that the unknown parameter vector turns out to be $\mathbf{p} = [\mu_{\max}, k, k_d, k_1, y_h]$. The variables y_1 , y_2 and y_3 are the measured outputs of the system. The initial conditions are unknown.

The a priori identifiability of this model has been first analyzed in [8] by using a sufficient condition for global identifiability due to [4]. This condition holds for uncontrolled models started at known initial conditions. To verify this condition (which is only sufficient) several calculations are required.

We test the identifiability of this model by using DAISY. With the standard ranking of the input, output and state variables, i.e. $y < x_1 < x_2 < x_3 < x_4 < x_5$, the program starts all the required calculations. Due to space limitations we do not report here the exhaustive summary of this model which is very long but only its Gröbner basis solution:

$$\{k_3 - 4, k_4 - 13, k_5 - 6, k_6 - 14, k_7 - 9\} \tag{5}$$

which shows that all the parameters k_3, k_4, k_5, k_6 and k_7 are uniquely identifiable from input-output experiments. Note that in this case, the knowledge of the initial conditions would be redundant to identifiability.

Even for this rather complex model, in few minutes DAISY provides all the required calculations to give the global identifiability answer.

3 Conclusions

Our aim in this paper was to show that the software DAISY based on differential algebra, described in detail in [1], is a useful tool for checking a priori identifiability

of nonlinear dynamical systems. We have shown how easily DAISY checks global identifiability of two nonlinear biological models from the literature: a batch reactor model and a model of *in vitro* homoacetogenesis by human-colon bacteria which have taken quite some effort to be analyzed by different identifiability methods from the literature.

We may conclude that, based on our experience, DAISY is the only available software tool which, although being based on a rather sophisticated set of mathematical tools, is very easy to use especially for medical/biological investigations.

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Appendix A: Input file of a non-linear batch reactor model

```

1 WRITE "BATCH REACTOR MODEL"$
  % B_ is the variable vector
2 B_ := {u, y, x1, x2}$
3 FOR EACH EL_ IN B_ DO DEPEND EL_, T$
  % B1_ is the unknown parameter vector
4 B1_ := {p1, p2, p3, p4, p5, p6}$
  % Number of states

```

```

5 NX_:=2$
  % Number of outputs
6 NY_:=1$
  % Model equations
7 C_:= {df (x1,t)=p1*X1*X2/(p2+X2-p3*x1+P4*u,
      df (X2,t)=-p1*X1*X2/(p5*(p2+X2))+p6*u,
      y=x1}$
8 SEED_:=30$
9 DAISY()$
  % Values of initial conditions are given
10 IC_:= {X1=0,X2=0}$
11 CONDINIZ()$

```

Appendix B: Output file of a non-linear batch reactor model

```

1 BATCH REACTOR MODEL$
2 seed_:=30$
3 NUMBER OF EQUATIONS$ n_:=3$
4 VARIABLE VECTOR$
5 b_:= {u,y,x1,x2}$
6 PARAMETER VECTOR$
7 b1_:= {p1,p2,p3,p4,p5,p6}$
8 RANKING AMONG THE VARIABLES$
9 bb_:= {u,y,df (u,t),df (y,t),df (u,t,2),df (y,t,2),
      x1,x2,df (x1,t),df (x2,t)}$
10 NUMBER OF INPUTS$
11 nu_:=1$
12 NUMBER OF OUTPUTS$
13 ny_:=1$
14 MODEL EQUATIONS$
15 c_:= {df (x1,t)=(- (p2+x2)*(p3*x1-p4*u)+p1*x1*x2)
      / (p2+x2),
      df (x2,t)=((p2+x2)*p5*p6*u - p1*x1*x2)
      / (p2*p5+p5*x2), y = x1}
16 CHARACTERISTIC SET$
17 aa_(1):=df (u,t)*y*p1*p2*p4*p5-df (y,t,2)*y*p1
      *p2*p5-df (y,t)**3+df (y,t)**2*u*(3*p4+p5*p6)
      +df (y,t)**2*y*(2*p1-3*p3)+df (y,t)**2*p1*p2*p5
      +df (y,t)*u**2*p4*(-3*p4-2*p5*p6)+2*df (y,t)*u
      *y*(-2*p1*p4-p1*p5*p6+3*p3*p4+p3*p5*p6)
      -df (y,t)*u*p1*p2*p4*p5+df (y,t)*y**2*(-p1**2
      +4*p1*p3 - 3*p3**2)+u**3*p4**2*(p4+p5*p6)
      +u**2*y*p4*(2*p1*p4+2*p1*p5*p6-3*p3*p4-2*p3
      *p5*p6+u**2*y*p4*(2*p1*p4+2*p1*p5*p6-3*p3*p4
      -2*p3*p5*p6)+u*y**2*(p1**2*p4+p1**2*p5*p6
      -4*p1*p3*p4-2*p1*p3*p5*p6+3*p3**2*p4
      +p3**2*p5*p6)+y**3*p3*(-p1**2+2*p1*p3-p3**2)$

```

```

18 aa_(2):=-x1 + y$
19 aa_(3):=df (y,t)*x2 + df (y,t)*p2 - u*x2*p4
      - u*p2*p4 + x2*y*(-p1 + p3) + y*p2*p3$
20 THE SYSTEM IS ALGEBRAICALLY OBSERVABLE$
21 RANDOMLY CHOSEN NUMERICAL PARAMETER VECTOR$
22 b2_:= {p1=15,p2=9,p3=15,p4=12,p5=10,p6=17}$
23 EXHAUSTIVE SUMMARY$
24 flist_:= {p1*p2*p4*p5 - 16200,
      -p1*p2*p5 + 1350,
      p1*p2*p5 -1350,
      -p1*p2*p4*p5 + 16200,
      3*p4 + p5*p6 - 206,
      -3*p4**2 - 2*p4*p5*p6 + 4512,
      2*p1 - 3*p3 + 15,
      -p1**2 + 4*p1*p3 - 3*p3**2,
      p4**3 + p4**2+p5*p6 - 26208,
      -p1**2 + 2*p1*p3 - p3**2,
      2*p1*p4**2 + 2*p1*p4*p5*p6 - 3*p3*p4**2
      - 2*p3*p4*p5*p6 + 2160,
      -2*p1*p4 - p1*p5*p6 + 3*p3*p4 + p3*p5*p6-180,
      p1**2*p4 + p1**2*p5*p6 - 4*p1*p3*p4
      - 2*p1*p3*p5*p6 + 3*p3**2*p4 + p3**2*p5*p6}$
25 MODEL PARAMETER SOLUTION$
26 g_:= {{p2=90/p5,p6=170/p5,p3=15,p1=15,p4=12}}$
27 SYSTEM NONIDENTIFIABLE$
28 BBBB_ INCLUDES THE BB_ ENTRIES CALCULATED T=0$
29 bbbb_:= {df (y,t,2)=y20, df (u,t,2)=u20,
      df (y,t)=y10, df (u,t)=u10,
      y=y0, u=u0, x1=0, x2=0}$
30 EXHAUSTIVE SUMMARY INCLUDING 2 KNOWN INITIAL
      CONDITIONS$
31 flist1_:= {p2=270/p5, p6=250/p5, p1=25, p3=23,
      p4=8, 27*(-8*u0 + 23*y0 + y10)}$
32 MODEL PARAMETER SOLUTION(S)$
33 g_:= {{p2=90/p5,p6=170/p5,p3=15,p1=15,p4=12}}$
34 SYSTEM NONIDENTIFIABLE$

```

Randomisation and Grading of Complex Questions in the E-Learning System Maple T.A.

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Abstract. At Vienna University of Technology the Maple T.A. (abbr. for Testing and Assessment) e-learning system was introduced into mathematical courses. It proved to be a useful e-learning addition to usual teaching methods. Students are able to train their calculation skills and deepen their knowledge in different mathematical disciplines outside of the lectures. Further Maple T.A. is a helpful tool to test and assess the skills of students, since it contains an assignment module and a gradebook module that provide these tasks. During the two years of usage of Maple T.A. at the Vienna University of Technology a large amount of questions and exercises were created for different mathematical topics. But with increasing complexity of the topics the creation of questions became more and more difficult. The main problems were the creation of randomly specified questions and the final grading of these questions. To overcome these challenges two Maple libraries were developed. One of them is responsible for the randomization of more complex objects and the other one aims to simplify the grading process for these more complex objects in Maple directly instead within the web environment.

Introduction

At the Vienna University of Technology the web-based e-learning Maple T.A. is used to assist the assessment of students' mathematical skills. It proved to be a useful addition to the common way of teaching math.

Former studies [1, 2] showed that with the possibility to practice their mathematical skills, students were able to deepen their knowledge in different mathematical disciplines outside of the lectures. Due to the randomization abilities of Maple T.A. students always get randomized specifications of questions and examples, and so they can practice the same tasks over and over again, but with differing parameters. Further the software additionally provides an assignment and a gradebook module which are helpful tools to perform assignments for students' skills.

During the last two years of usage of Maple T.A. at the Vienna University of Technology a large amount of questions and examples were created for different mathematical topics. But with increasing complexity of the topics the creation of questions became more and more difficult. Where for the beginner's lectures the common functions of Maple T.A. satisfied the demands adequately, difficulties arose in continuative lectures. In particular the randomization and grading of more complex mathematical objects (e.g. matrices, vectors, etc.) with special properties were challenges that had to be overcome.

For this purpose two additional Maple libraries were developed and added to the Maple core of the Maple T.A. system. One of them is responsible for the randomization of these mathematical objects and the other one aims to simplify the grading process for them.

1 Randomisation Library

1.1 Function Definitions

Function FromSet. Random elements from a set are selected. The data types of the set elements are not restricted. According to the parameters set the return value of the function is either a vector or a single value.

Parameters:

- *Set* – set with selectable values
- *Count* – number of elements to be selected
- *Distinct* – with or without replacement
- *Sorted* – determines whether the return vector is sorted or not

Function MakeInts/FromInts. For given interval boundaries the function returns a sequence of either a specified number or all integers between these boundaries.

Parameters:

- *Min* – lower boundary of the interval
- *Max* – upper boundary of the interval
- *Count* – number of desired random values

Function MakeRats/FromRats. The function is similar to MakeInts/FromInts. The return values are here rational numbers that are restricted by some additional parameters for the denominators.

Parameters:

- *Min* – lower boundary of the interval
- *Max* – upper boundary of the interval
- *Count* – number of desired random values
- *MinDenom* – smallest possible denominator
- *MaxDenom* – largest possible denominator

Function Vec. For a given dimension this function returns a random vector with user-defined entries.

Parameters:

- *Set* – set of numbers for random vector entries
- *Dim* – desired dimension of the vector
- *Zerocount* – number of zeros in the vector

Function VecInts. A random vector with integer entries is created and returned.

Parameters:

- *Dim* – dimension of the return vector
- *Max* – for each entry k : $k \leq k_{\max}$
- *Zerocount* – number of zeros in the vector

Function Mat. The Mat-function generates random matrices. It is possible to define the matrix dimension as well as a desired shape.

Parameters:

- *Set* – set of numbers for matrix entries
- *rows* – number of matrix rows
- *cols* – number of matrix columns
- *zerocount* – number of entries equal zero
- *shape* – determines the matrix shape (e.g. triangular, symmetric, etc.)

Function MatInts. Just like the vector functions, MatInts creates matrices only with integer entries.

Parameters:

- *Max* – absolute values of entries are $\leq \text{Max}$
- *rank* – desired rank of the matrix
- *rows* – number of matrix rows
- *cols* – number of matrix columns
- *zerocount* – number of matrix entries equal zero

Function MatIntsDef. This function delivers a random symmetric matrix with integer entries and specifies numbers of positive (pos), negative (neg) and eigenvalues equal zero (zero). The dimension of the matrix is

defined by: $\text{dim} = \text{pos} + \text{neg} + \text{zero}$, and the rank equals $\text{pos} + \text{neg}$.

Parameters:

- *Max* – absolute values of entries are $\leq \text{Max}$
- *pos* – number of positive eigenvalues
- *neg* – number of negative eigenvalues
- *zero* – number of eigenvalues equal zero
- *zerocount* – number of entries equal zero

1.2 Algorithms Example

To demonstrate the functionality of one randomization algorithm, we give a short example for the creation of a random $m \times n$ matrix. Consider the following function call:

`MatInts(Max=4, rows=7, cols=5, rank=3)`

We start with creating a matrix that obviously has the desired rank r . Therefore we choose r random integer values within the given range and write them in the “diagonal” of the first r rows.

$$\begin{pmatrix} -4 & 0 & 0 & 0 & 0 \\ 0 & -4 & 0 & 0 & 0 \\ 0 & 0 & -4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (1)$$

Then we progressively fill the first r rows with random integer entries within the given range. When doing that, we have to make sure that we do not reduce the rank of the matrix. It can be shown, that for each selected entry there is at most one number $\alpha \in \mathbb{Q}$, that makes the matrix rows linear dependent. So if α lies in the given range, we have to select another value.

$$\begin{pmatrix} -4 & -4 & 4 & 1 & -3 \\ 0 & -4 & -2 & 0 & -4 \\ 2 & 4 & -4 & -4 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (2)$$

Now that we have a matrix with random entries and the desired rank we proceed with finding $m - r$ linear dependent vectors with integer entries within the given range and replace the last $m - r$ rows. For this purpose we first transpose the matrix and build a base of the span of the first r columns, which is easier to handle.

$$B = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 3/2 & -7/12 & 7/6 \\ 2 & 1/4 & 3/2 \end{pmatrix} \quad (3)$$

This transformation ensures that each linear combination of the columns with integer linear coefficients $|\alpha_i| \leq \text{Max}$ has correct entries in the first r components. After that we calculate the common denominator (q) of all entries and multiply the last $m - r$ rows with q .

$$q = 12, \quad P = \begin{pmatrix} 18 & -7 & 14 \\ 24 & 3 & 18 \end{pmatrix} \quad (4)$$

We apply Gauss elimination modulo q .

$$Q = \begin{pmatrix} 6 & 5 & 2 \\ 0 & 3 & 6 \end{pmatrix} \quad (5)$$

At last we randomly choose a vector $v \in \{-\text{Max}, \dots, \text{Max}\}^r$ such that $Qv = 0$ and the absolute values of all entries of the vector $w = Bv$ are less or equal Max , for example:

$$v = \begin{pmatrix} 2 \\ -4 \\ -2 \end{pmatrix}, \quad w = \begin{pmatrix} 2 \\ -4 \\ -2 \\ 3 \\ 0 \end{pmatrix} \quad (6)$$

We transpose w and insert it into the matrix

$$\begin{pmatrix} -4 & -4 & 4 & 1 & -3 \\ 0 & -4 & -2 & 0 & -4 \\ 2 & 4 & -4 & -4 & 1 \\ 2 & -4 & -2 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (7)$$

After repeating the last step for the remaining rows and a final permutation of rows and columns we get the resulting matrix of our algorithm:

$$\begin{pmatrix} -2 & -1 & 3 & 2 & 2 \\ -4 & -2 & 3 & 0 & 2 \\ 2 & 1 & -3 & -2 & -2 \\ -4 & -2 & 3 & 0 & 2 \\ -4 & 4 & 1 & -3 & -4 \\ -4 & -2 & 0 & -4 & 0 \\ 4 & -4 & -4 & -1 & -2 \end{pmatrix} \quad (8)$$

This function is also used when generating random definite matrices. Consider the function call `MatIntsDef(M, pos, neg, zero)`. So the aim of the algorithm is to get a matrix with pos positive eigenvalues, neg negative eigenvalues, and eigenvalue zero with multiplicity zero . Therefore we calculate a random

matrix $B \in \mathbb{Z}^{(\text{pos}+\text{neg}) \times (\text{pos}+\text{neg}+\text{zero})}$ with the rank $\text{pos}+\text{neg}$ using the `MatInts` function. Let then the first pos rows of B be B^+ and the last neg rows of B be B^- .

We determine the matrix $A = (B^+)^T B^+ - (B^-)^T B^-$. Regarding to Sylvester's law of inertia [4] A has pos positive, neg negative eigenvalues and eigenvalue zero with multiplicity zero . This algorithm is repeated until the absolute value of all entries of A are less or equal M .

2 Library Grading

Automatic grading of answers is not always an easy task. It is necessary to have well defined rules when evaluating the correctness of entered sets, vectors or matrices. For this purpose Maple T.A. provides the Maple-Graded question type that connects to the Maple engine when grading student's responses. The question designers have to write some Maple code that is responsible for the handling of the answers. According to the complexity of the question this task can be quite tricky and may need long development time. With the additional Maple grading library, that takes care of most of these problems, this time can be reduced. Following functions are supported:

- **Function Expr.** This function is for common mathematical expressions. They are checked for mathematical equivalence to the given correct answer. For this object type no partial grading is possible. So the student's response is either completely correct or wrong.
- **Function ExprDiff.** `ExprDiff` is used when grading anti-derivatives. The response is derivated and then compared to the original specification of the question.
- **Function Set.** For sets partial grading seems reasonable. Students may enter subsets or supersets of the correct ones. To handle this issue a return value is calculated that lies between 0 and 1, depending on how correct the student's answer is.
- **Function Vec.** The Vector grading function returns 0, if the entered vector and the correct one have different lengths. Otherwise the return value is determined by dividing the correct entries by the total number of vector entries.
- **Function Mat.** Evaluating the correctness of matrices follows the same way as for vectors. If the response matrix and the correct matrix have different sizes the entered matrix is graded with 0. In all other cases the return value is again the correct number of entries di-

vided by the total number of entries.

- *Function FundSys*. This function is used for grading real fundamental systems which define the sets of solutions of systems of homogeneous linear differential equations. The order of the differential equation determines the cardinality of the set. So the return value is calculated similar to the one of the set-grading function: The order of the differential equation is equal $|C|$, $|R \setminus C|$ corresponds to the greatest number of linear independent real solutions in the response and $|R \setminus C|$ is equal to the smallest number of functions, that have to be removed from the response set, to get a set of linear independent real solutions.

3 Usage Experience

The usage of the new libraries simplified the creation of Maple T.A. questions significantly. Due to the fact, that most of the algorithms used in questions were assumed by the new libraries and the Maple engine, the exercises became less error-prone and better readable for non-editors. On the other hand the increased use of Maple entailed some other unexpected problems. With many requests at the same time a certain slowdown of the system could be noticed. Also the creation of algorithms within questions has to be done with slight more attention. Infinite loops or other computationally intensive operations can cause very long computing times for the system. To avoid these problems question development within a local Maple installation is advisable.

Nevertheless the Maple T.A. system became more reliable with the use of the new libraries. The needed time for the development of exercises decreased in a noticeable way. So a larger amount of high-quality questions could be placed at disposal for the students.

4 Summary and Outlook

The recent work with the new developed library gained acceptance of the system among both students and question designers. But as everywhere there is still plenty of room for improvement and further development of new algorithms. According to the above mentioned system speed concerns the existing algorithms should also go under closer investigations. Further we are looking forward to future releases of new Maple T.A. versions, since some helpful features for question development have not been integrated into the system yet. Maybe the most wanted one is the conjunction of students' responses. With it the creation of high quality questions would be easier.

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Simulated Race for Exam Grades

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Abstract. The idea on how to motivate students to learn subjects such as Computer Aided Control Systems Design (CACSD) at the Faculty of Electrical Engineering, University of Ljubljana is presented. A simulated race instead of exam is tested, meaning that the students are graded according to the success achieved in the competition. The aim of the competition is set by the professor, and the students have to design a controller to achieve the best possible result they can. The paper concludes with the description of solutions applied by students and the faculty experiences with the course.

Introduction

The standard approach to teaching/examining Computer Aided Control Systems Design is to give lessons on control algorithms and design tools, to give students exercises to be completed in a classroom equipped with computers, to provide similar exercises in the written part of the exam, and to complete the exam with oral questions/answers.

Modern education demands a significantly different approach to classical methods. Students must get new perspectives and learn how to solve practical problems. The mere transmission of facts to them must be replaced by giving them knowledge of how to cope with the challenges of the market economy.

In the paper a new idea in examining Computer Aided Control Systems Design (CACSD) – namely a competition – is presented. It is organized as follows: In Section 2 the idea of the virtual race is presented. The subjects of the virtual race, used in the last four years at the Faculty of Electrical Engineering, University of Ljubljana, are given in Section 3. In Section 4, the solutions, applied by students, and our experience with the virtual race are given, while Section 5 presents the students' view of the examination.

1 The Idea of the Examination by Virtual Race

The main idea for the exam is to be a competition or a race. The student's mark depends on his/her position in the race. The student winning the competition gets the best mark. The distribution of marks equals the distribution of average student marks in the classroom. This measure should prevent the copying of solutions among students. The object of the competition is different every year, thereby preventing copying of the solutions from previous years.

The competition is performed by simulation using Simulink/Matlab. The plant (its structure) is known to the students; however, some parameters remain unknown (only lower and upper bounds are known). The inputs and outputs of the plant are defined as an interface to the controller to be designed by students as a single block. The students are totally free in designing the controller; they should use their knowledge to obtain the best result.

The problems to be optimally solved by students are not classical in nature. For example, the printed information is not always the transfer function and the criterion function. Instead, problems are structured to encourage curiosity, emphasize mathematical describability, be numerically non-demanding and include some complexity.

Mathematical describability is necessary since the problem is only given to the students in the form of equations, not as a simulation model. In our approach, students have to build a model according to the given equations and to design a controller which controls the simulated model optimally according to the specified criterion. Also, the interface between the controller and process is exactly specified.

All the students (regardless of their computers' power) must have equal possibilities; therefore, it is important how numerically (non)demanding a problem is. The complexity of the model enables students to show their creativity.

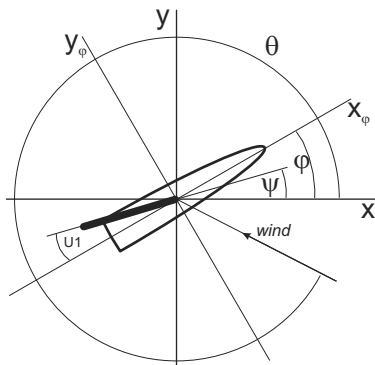


Figure 1. The top view of the model of the surf

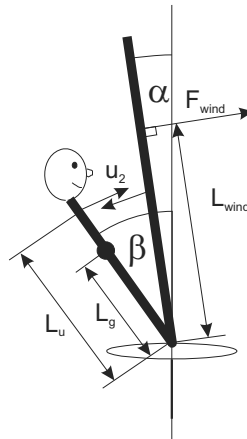


Figure 2. The front view of the model of the surf.

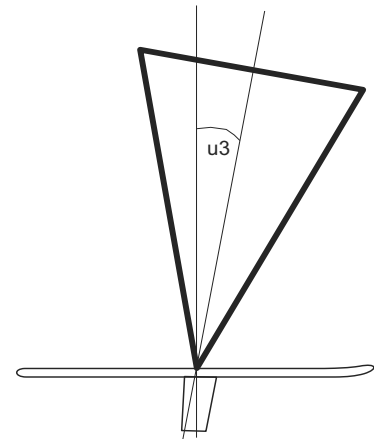


Figure 3. The side view of the model of the surf.

The students have three to five weeks to design the controller. During this time, they can come to the professor for discussions; they can also test their controller on the test model.

Even though students are highly motivated to obtain good marks, there are a few individuals in every classroom who try to minimize their effort and copy the solution. There is an effort to suppress this anomaly in the competition; better results get better marks. In addition, a traditional oral exam concerning the subject of the applied controller, as well as penalties for equal solutions, should prevent copying.

This new approach also tries to break the traditional notion that students are allies against the professor and introduce a new notion with the professor and student being allies and with students competing against each other. This practice was introduced four years ago; and, since every year the practical problem to be solved is different, four problems being solved by students are given in the next section.

2 Subjects of the Virtual Race

Four different competition subjects have so far been used. They are the inverted pendulum, the solar sail race, the giant slalom contest, and the surf regatta. All four objects are non-linear processes. Besides this, the control variable or variables respectively were also saturated. In all four cases, minimal time was the criterion function.

In the first year, the goal was to transfer an inverted pendulum from one point (standing upright) to another point 4.8 meters away and to remain there in an upright position (within $\pm 2.5^\circ$ tolerance) for five seconds. In

the second year, the goal was to transfer a solar sail from a circular 700 km orbit to a geostationary orbit (only to cross it, not to remain in it) as quickly as possible. In the third year, a giant slalom contest was performed. The model of the skier was completely known. However, the course setting was unknown to students; it was given to them five minutes before the start. In these five minutes they could make final adjustments to the controller. The contest consisted of two runs: a simple run and a more sophisticated run. For a positive mark, only the first run had to be completed without any fault (missing gates).

In the fourth year the subject of the competition was a surf regatta. The model of the surf was completely known to the students and so was the course: to encircle in the prescribed direction the two buoys and to return to the starting point (the finish line was ± 50 meters apart from the starting point). Unknown (in advance) were the wind direction and force. The model of the surf is illustrated in Figures 1 to 3. The surf is driven by the wind according to

$$F_{\text{wind}} = p_{\text{wind}} S (v_w - v_{\text{surf}\theta}) \cos \alpha \sin(\theta - \psi) \quad (1)$$

where p_{wind} is the wind pressure, S is the area of the surf sail, v_w the velocity of the wind, $v_{\text{surf}\theta}$ the velocity of the surf in the direction of the wind, θ the wind direction angle, ψ the angle of the sail according to the fixed co-ordinate system, and α the lateral angle of the sail (limited to $\pm \pi/2$) (see Figure 2).

The wind force F_{wind} is decomposed into two forces, into the force $F_{\text{wind}\phi}$ pushing the surf forward and into the force $F_{\text{wind}\theta}$ pushing the surf perpendicular to the direction of the surf

$$F_{\text{wind}\varphi} = F_{\text{wind}} \sin(\phi - \varphi) \cos \alpha \quad (2)$$

$$F_{\text{wind}90} = -F_{\text{wind}} \cos(\psi - \varphi) \cos \alpha \quad (3)$$

where φ is the surf board direction angle. Due to these two forces, the surf is moving into the direction of the surf board (x_φ) and perpendicular to it (y_φ).

$$m\ddot{x}_\varphi = F_{\text{wind}\varphi} - k_2\dot{x}_\varphi \quad (4)$$

$$m\ddot{y}_\varphi = F_{\text{wind}90} - k_3\dot{y}_\varphi \quad (5)$$

where m is the mass of the surf (surfer and board) and k_2, k_3 ($k_2 \ll k_3$ due to the keel) the resistance constants into directions x_φ and y_φ , respectively.

The velocity of the surf into the direction of the wind is given by

$$v_{\text{surf}\theta} = \dot{x}_\varphi \cos(\theta - \varphi) - \dot{y}_\varphi \sin(\theta - \varphi) \quad (6)$$

The movement of the surf in the fixed coordinate system is obtained by the following transformations:

$$\dot{x} = \dot{x}_\varphi \cos \varphi - \dot{y}_\varphi \sin \varphi \quad (7)$$

$$\dot{y} = \dot{x}_\varphi \sin \varphi + \dot{y}_\varphi \cos \varphi \quad (8)$$

The lateral dynamics of the surf (sail and surfer) is the dynamics of two coupled inverted pendulums (see middle part of Figure 1).

$$I_{\text{sail}}\ddot{\alpha} = -F_{\text{wind}}L_{\text{wind}} + u_2L_u \quad (9)$$

$$I_{\text{surfer}}\ddot{\beta} = -u_2L_u + m_{\text{surfer}}g \sin \beta L_g \quad (10)$$

where I_{sail} and I_{surfer} are the momenta of inertia of the sail and surfer respectively (around the horizontal axis), u_2 the force of the surfer to the sail (limited to ± 800 N), L_u , L_{wind} and L_g , the levers of the surfer's force to the sail, wind and gravity respectively, m_{surfer} the mass of the surfer, g the gravity constant, and β the lateral angle of the surfer (limited to $\pm \pi/2$). The gravity force of the sail was neglected.

The angle of the sail relative to the wind is determined by

$$\psi = -u_1 + \varphi \quad (11)$$

where u_1 is the angle of the sail relative to the surf board.

The turning of the surf is obtained by placing the wind force center point forwards and backwards, as illustrated in the right part of Figure 1. The angle of the surf board is determined by

$$I_{\text{surf}_\varphi}\ddot{\varphi} = -k_4\dot{\varphi} + F_{\text{wind}}L_{\text{wind}} \sin u_3 \quad (12)$$

where I_{surf_φ} is the momentum of inertia of the surf board

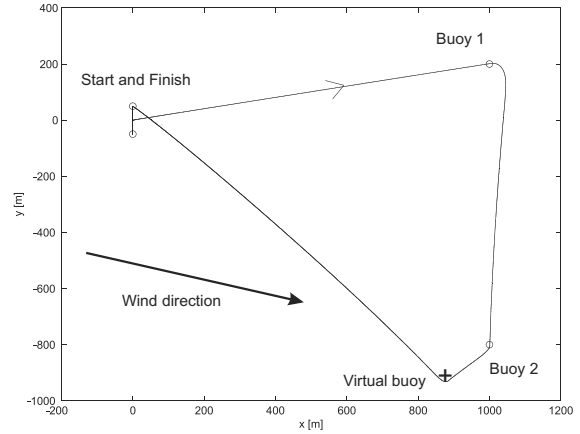


Figure 4. The course of the surf regatta.

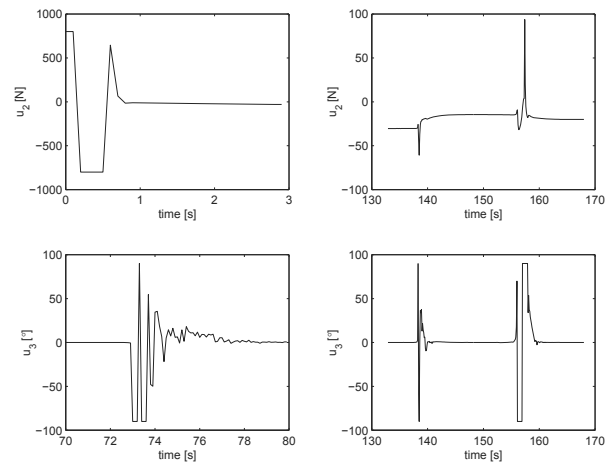


Figure 5. The time history of the control variables: the angle of the sail relative to the surf (uppermost), two details of the force stabilizing the inverted pendulum system surfer – sail (middle), two details of the angle of the mast in the direction forward - backward (lower).

and surfer around the vertical axis, k_4 the coefficient of resistance, and u_3 the angle of the mast in the direction forwards-backwards. The interface between the controlled object (the surfer) and the controller to be designed by students was specified.

3 Solutions and Experiences

According to our observations the great majority of students is very enthusiastic about the competition. The problems and results are discussed among students, but the details and new ideas are not revealed. In the case of the inverted pendulum, solar sail, and giant slalom contest, the most favored approach applied by students was to linearize the models in different operating points, to optimize the controller parameters by optimization pro-

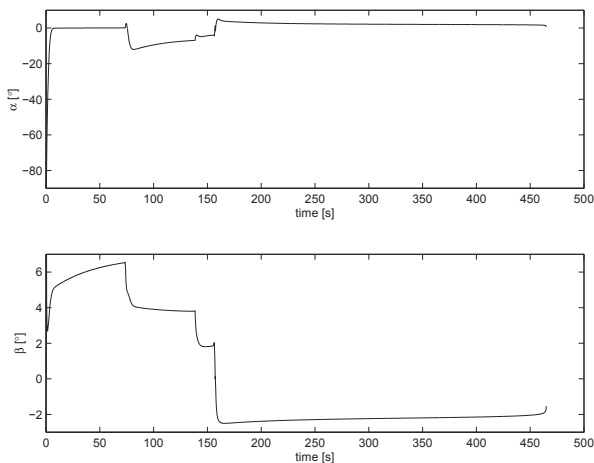


Figure 6. The time course of the lateral angles of the sail and surfer.

cedures, and to schedule the controllers according to the state of the process. In the case of the surf regatta, the tuning of controllers was not very important in comparison to the optimal course setting. This fact was realized by the students quite early; and, in the shortage of time, the concentration was focused on the course setting.

Figures 4, 5, and 6 illustrate the results of a typical solution. In Figure 4, depicting the course, it can be seen that the used course was detoured to sail quicker against the wind. With respect to the control strategy a detour may be obtained by setting an additional (virtual) buoy. In Figure 5 the time history of control variables is shown. In the uppermost part of the figure the angle of the sail relative to the surf direction is depicted. In the middle part of the figure two details of the force stabilizing the inverted pendulum system surfer-sail are shown. The beginning of the race, i.e., lifting the sail from the horizontal position is depicted on the left, while the segment involving the turn around the second buoy and the virtual buoy set to make a detour is shown in the right-hand side of the middle part of the figure. The lower part of the figure contains two details of the third control variable – the angle of the mast in the direction forward and backward. In the left part the time history during the turning around the first buoy and in the right part the turning around the second and the virtual buoys are shown, respectively. It can be seen that the fixed controller was tuned for the turning around the second and the virtual buoys; the control signal during the turning around the first buoy is quite oscillatory.

In Figure 6 the time history of the lateral angles of the sail and surfer are presented. The optimal position of the sail is vertical. However, if the wind is too strong to

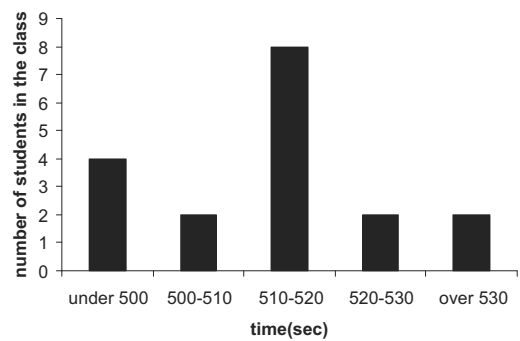


Figure 7. The distribution of scores for the surf regatta.

be compensated by the gravity force of the surfer, the sail must be inclined in order to reduce the wind force. In the actual race the wind was not so strong, so the reference value for the upper part of the figure is zero. It can be seen again that the controller was tuned for the last part of the race; it was too “lazy” in the segment of the race prior to the first buoy.

The distribution of scores for the inverted pendulum and solar sail competitions had a normal (Gaussian) character. The distribution for the giant slalom competition had an “inverted” normal distribution. The reasons for this seem to be the non-selective course setting and too much time (5 weeks) elapsing between giving the exercise to the students and the actual competition. Also, the distribution of the surf regatta, shown in Figure 7, does not exhibit Gaussian shape. The reason for this unexpected phenomenon is that the optimal course on the part of the path which was in the direction against the wind was not to go directly to the next buoy but to make a detour. Students using this detoured course gained better results, but not all students realized this strategy. The consequence is a double peak distribution for students’ scores.

4 The Students’ Perspective

The non-standard examination approach was well-accepted by students, and the theory taught in the standard course was recognized only as a necessary but not sufficient tool in solving practical problems. The key point of a good score was innovation. This and new, fresh ideas is what enterprises, competing on the market, expect from an engineer. Innovative thinking cannot

be taught, but modern education should at least stimulate and remunerate this approach by setting priority in scoring to ideas rather than to the ability of memorizing. Another very important point is motivation. According to the assertions of students, even though the amount of time spent on the Virtual race project was greater than the amount of time spent on other projects, students enjoyed studying the course and did not regret have chosen it. A learning-by-game approach seems to be more attractive.

The attractiveness of the race subject seems to be an important point. Regarding this issue the surf regatta was the most exciting. Some of students even started wind-surfing after the course.

5 Conclusions

A new practice in examining the subject of CACSD has been introduced in the last four years. A virtual race – a competition between students – enables them to demonstrate their creativity. Four objects of the competition

are given in the paper: the inverted pendulum, the solar sail race, the giant slalom contest, and the surf regatta. The description of the most favourable controller design solutions, the experiences with the virtual race, and the distributions of results are also given. It is the experience of the authors that students accepted the competition as a form of the written part of exams with enthusiasm. Accordingly, this practice will be continued in the future.

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LABI – *L*aboratory of Mathematical Models

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Abstract. In the educational publications it is often pointed out that modeling is just another word for system understanding. Technically it can be regarded also as a system analysis. During teaching process examples usually play an important role to dynamical system understanding. To improve illustration possibilities, to encourage observation of system properties and to stimulate students' activity LABI (Laboratory of Mathematical Models of SISO and MIMO systems) graphical user interface has been developed in Matlab, through which illustrative examples and important analytical and some design functions can be accessed in a user – friendly way. They are organized in such a manner that they support and complement the lectures, exercises and students' activities which are basically organized through the so called seminars.

Mathematical/simulation models and/or experiments can be divided regarding different criteria. The starting examples are usually very simple (low order, linear, stable, ...), while several of them describe also real processes, some of them are connected with the pilot plants from our laboratories (Laboratory of Modeling, Simulation and Control and Laboratory of Autonomous Mobile Systems, Faculty of Electrical Engineering, University of Ljubljana, Slovenia).

To the set of models analytical toolbox has been added where the properties of the LTI models can be observed in a user friendly manner. These functions can be used for SISO or MIMO processes. Presented environment was well accepted by the students.

Introduction

At the Faculty of Electrical Engineering, University of Ljubljana, Slovenia, students can attend lectures Process Modeling (PM) and Dynamic Systems Simulation (DSS) in the sixth semester if they choose to study Automatics. Teaching activities are for both lectures simultaneous. To improve educational efficacy and to stimulate students' interest and their activity, several steps have been realized in the past few years.

Regarding the organization of the education process,

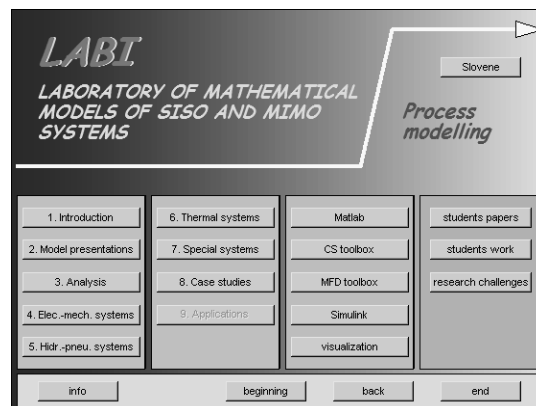


Figure 1. Stating window of LABI toolbox

first both lectures were very carefully synchronized so that the presented knowledge can be shared and combined. As the contents of both lectures are complementary, the proposed approach was of course very well accepted.

Exercises and computer-aided activities are performed by the use of Matlab and its toolboxes [1, 2] (mainly at least) as basics of this software are presented already in the second year of the study. In this way minimum preparation time is needed and students can in a very short time focus on problem solving.

At the beginning both lectures were finished by written and oral exams, which is a rather classical approach at university studies. But later on slow transition to the new form was realized. Now, at the end of the semester, several hours from both lectures (PM and DSS) are devoted also to the seminar work, which has to be prepared by each student. The tasks regarding this obligation are the following:

- problem introduction, suitable for modeling purposes;
- corresponding dynamical model description;
- transformation of mathematical model to simulation scheme;
- visualization and analysis of simulation results.

All prescribed tasks have to be presented in the form of conference paper and accomplished by the set of files, developed through problem solving. These results rep-

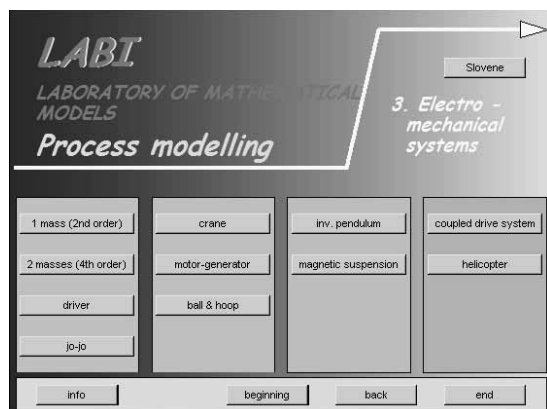


Figure 2. Examples of electro-mechanical group

resent part of exam of both lectures, but they still have to pass the oral part of exam regarding DSS and written part of exam of PM. In addition eight to ten best works are (as a reward) presented also at students' session of Electrotechnical and Computer Science Conference where this group of students can attend also the other sessions and presentations to obtain additional knowledge regarding research possibilities.

1 LABI – Laboratory of Mathematical Models

To support the lectures of Process Modeling and to improve corresponding exercises [3-6], as well as to indicate the links to DSS [7] also the so-called LABI environment was developed. The prepared possibilities can be observed by opening the first window of corresponding graphical user interface, as shown in Figure 1. Information available through LABI can be reached by simply pushing the prepared buttons. The first eight buttons – 1.) Introduction, 2.) Model presentations, 3.) Analysis, 4.) Electro-mechanical systems, 5.) Hydraulic and pneumatic systems, 6.) Thermal systems, 7.) Special systems, 8.) Case studies – also indicate the lecture's content. In the future some of the applications will also be added to illustrate the knowledge transfer to and from industry practice.

The buttons of the third column are connected to the files which offer short description of the main properties and potentially important features of Matlab, Control system toolbox, Multivariable frequency domain toolbox and Simulink in Slovene language. In the last year also a detailed description of visualization possibilities was added. It is also connected (through corresponding buttons) with the examples where visualiza-

tion is used for presentation and illustration purposes of modeling results.

In the last column the buttons

- enable the connection with the corresponding files which illustrate selected students' papers from the previous years (students' papers);
- enable the connection with the GUI where students can add and organize their own results, files and their paper (students work);
- and offer research challenges suitable for students (research challenges); these challenges indicate possibilities for further work which can end in different forms of student's competitions, papers or even diploma thesis.

Let's illustrate some possibilities of the group of electro-mechanical systems. When pushing the corresponding button the window opens, as presented in Figure 2.

This group consists of eleven examples, starting from a very simple one of the second order and finishing with seven examples of pilot plants from our laboratory [8]. First three devices (crane, motor-generator and ball & hoop) are stable SISO – systems, next two are unstable (inverted pendulum and magnetic suspension), while the last two are MIMO processes. Coupled drive system is stable and helicopter unstable one.

For all the examples mathematical models are developed. For the majority of examples they are in non-linear and also in linearized and/or in simplified forms so that also different approximations can be observed and compared. At the beginning testing is usually performed using simulation results which are often also animated.

In the case of ball & hoop process first the problem itself is described and presented schematically (Figure 3 – info button). From this presentation nonlinear mathematical model is developed (modeling button), using Lagrange equations. As for control purposes simple models are of great importance also linearized and simplified solutions are presented (linearization button). Several interesting simulation experiments can be executed using presented models where for better understanding also animation of system response can be observed at the same time (animation button). One of the experiments is illustrated with Figures 4 to 7. In Figure 4 input sinusoidal signal is presented. This is voltage input at servo motor, which is connected with the hoop.

In Figures 5 and 6 hoop and ball – angles are given

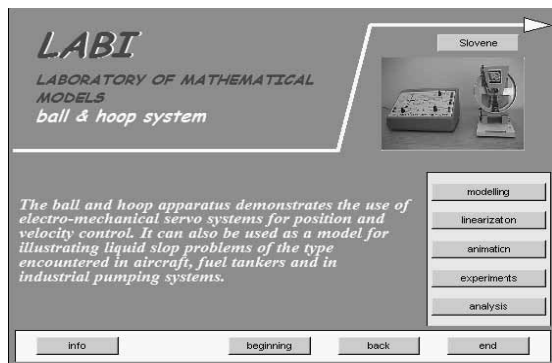


Figure 3. Ball & hoop system (TQ CE9) presentation

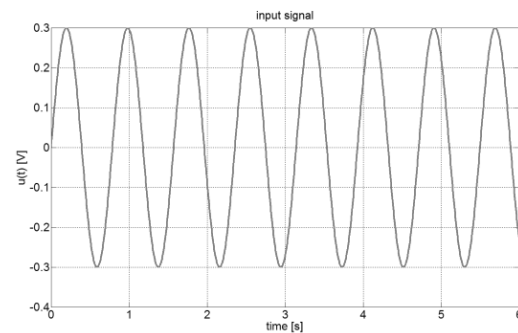


Figure 4. Input voltage signal

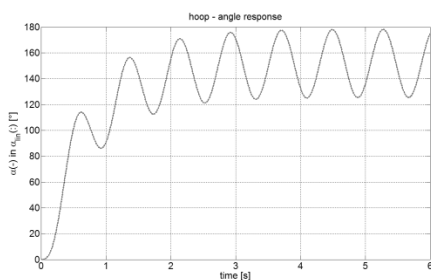


Figure 5. Hoop – angle response

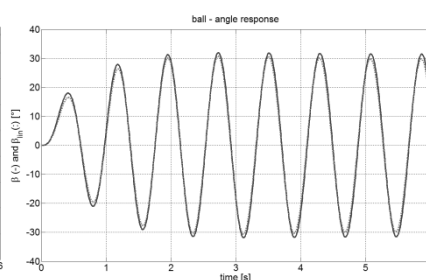


Figure 6. Ball – angle responses

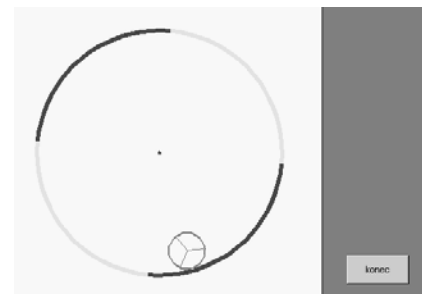


Figure 7. Picture from animation

regarding nonlinear and linearized (dotted lines) model, while in Figure 7 one picture from animation is snapped.

In the case of ball & hoop process (Figure 3) also simulation schemes are prepared (experiments button) which can be started on the computer in the laboratory (otherwise this button is not active) using the same input signals as in prepared simulation results. Mathematical model is in this case replaced with the block, which is communicating with the device in real-time using AD/DA converters. In this way also model validation can be undertaken.

When linearized system model is defined in Matlab also analytical toolbox can be started, as described in the next section.

Experiments from the other groups are organized in similar manner where in some cases also model operation is presented not only in open but also in closed - loop operation [9 – 11].

2 Analysis toolbox

When linear, time – invariant (LTI) mathematical model of observed process is defined in Matlab's working space also the analysis button becomes active and the user can observe system properties in some more details.

The Toolbox for dynamic system analysis [12] consists

of a number of functions which represent an extension and enlargement of the functions available in Matlab, Control System Toolbox, and Multivariable Frequency Domain Toolbox [13]. Several functions have been added, they are organized in graphical windows and can be executed also only by pushing the corresponding button. This is very important, especially when complex systems (like for example MIMO systems usually are) are observed. In such situation the user (especially inexperienced one) can very easily forget to test all important properties.

In all functions explanation and where possible graphical representation of results is added. The amount of additional comments can be controlled by the so called communication vector.

Mentioned functions can be divided regarding different criteria. Some of them can be used with SISO systems, some with MIMO and some are suitable for both groups of processes. Regarding different design situations both groups are organized into four levels.

Open-loop analysis functions use only the information of linear system model. They are grouped into general, time and frequency domain properties as illustrated in Figures 7 to 10. They should give the information of the properties of the process itself and help the user to decide if any improvement is needed, which can be real-

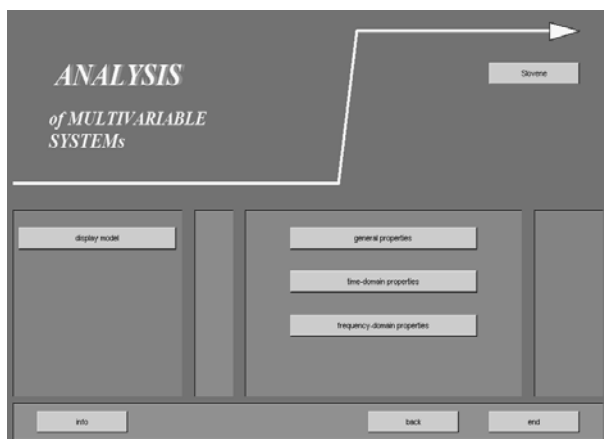


Figure 7. Toolbox for MIMO system analysis



Figure 9. Time – domain properties of MIMO system



Figure 8. General properties of MIMO system

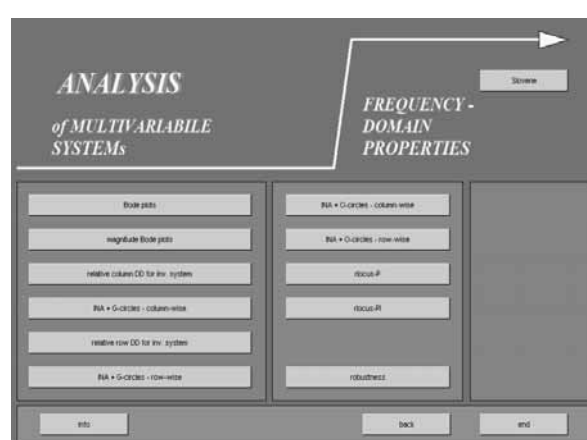


Figure 10. Frequency-domain properties of MIMO system

ized through process reconfiguration or by control design.

Closed-loop analysis functions are organized identically as open-loop ones, however in this case also the information of used controller is needed.

Absolute validation functions are used for evaluation of matching desired design goals, while in comparison with closed-loop analysis here also design goals have to be specified.

Relative validation functions tend to help the user to compare the efficacy of different design solutions and to prepare him/her to the real situation where also different kind of non-linearities have to be expected.

During the lectures of Process modeling only the first two groups are introduced, while absolute and relative validation are more important later, during control-design courses [14].

Important emphasis was devoted also to parallelisms and differences between SISO and MIMO systems.

When LTI - MIMO model is defined in Matlab's

work space, the user can observe the so called general system properties, which are calculated on the basis of system state – space description (Figure 8). Standard operations can define poles, time constants, cyclicity, transfer function matrix, DC-gain matrix, controllability, observability and corresponding indexes, input and output decoupling zeros and transmission zeros.

The last column in Figure 8 is specific for MIMO systems as corresponding functions inspect process interactivity. It is possible to find out if the system is statically, dynamically or integral decoupled. In addition it can be tested if the structure enable static or dynamic decoupling using state or output feedback.

Time – domain analytical functions (Figure 9) observe different systems' time responses, namely initial conditions responses, impulse and step responses, which are also one of the most frequently used testing signals. The second column functions represent direct extensions of usually observed step response properties of SISO systems, defined as delay time, rise time, maxi-

mum overshoot and settling time.

Among frequency – domain functions (Figure 10) it is important to mention Bode plots, direct and inverse Nyquist plots, which are also frequently used to define the so called diagonal dominance, which represents the measure of system cross – coupling.

As a parallelism to SISO root-locus MIMO root-locus was introduced when using a special structure of multivariable P or PI-controller [11, 12].

A group of functions is available also for testing system robustness.

3 Conclusions

In the paper organization of education process is presented for the students of the sixth semester who have chosen to study Automatics at the Faculty of Electrical Engineering, University of Ljubljana, Slovenia. During lectures Process modeling the so called LABI – graphical interface is introduced enabling simplified access to illustrative examples explained through lectures. Graphical result presentations and animations are also extensively explained through info – buttons online help in Slovene language.

When presented software is installed on the laboratory computers which are connected with pilot plants, prepared files can also be used for experimentation with real devices and for mathematical model validation.

As modeling is frequently used as a synonym for system understanding special attention is devoted to process analysis. Presented analytical toolbox can be accessed inside the same environment and enables very efficient work also in the cases of rather complex MIMO processes.

LABI – environment with its modeling examples, visualization and animation illustrations, analysis and sometimes also with closed – loop system operation was well accepted by the students who are now becoming also co-developers of presented toolbox.

In the near future the following improvements are planned:

- additional examples from industry practice, as it is very important for students to understand where the knowledge can be used;
- introduction of video clips illustrating laboratory work; in this way the problems can be made more realistic also in the lecture room;

- model validation on the basis of video clips using pattern recognition approach;
- complete dual representation in Slovene and English language.

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MMT – Mathematics, Modelling and Tools: An E-Learning Environment for Modelling and Simulation

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Abstract. This contribution presents MMT, an e-learning system used in mathematical based courses at Vienna University of Technology. The MMT system makes use of computer numeric systems like MATLAB and R and offers experiments via web server technology. The online tool MMT on the one side enables students to increase their skills in mathematics and modelling, and on the other side to train implementation of models in the computer numeric system used. Developments are planned as well on example libraries as well as functionality.

Introduction

This contribution deals with an e-learning system called MMT- Mathematics, Modelling and Tools. It is constituted to help students of the Vienna University of Technology to increase their abilities on both, basic mathematics on the one hand and modelling and simulation on the other hand.

This e-learning system is based on the MATLAB Web Server Technology. Initially the MATLAB Server of version 2006 was used. As this product has been discontinued MMT has been using a self-made server containing the MATLAB of version 2009a. This fact supports us to update our examples for the students or create examples containing the actual tools of MATLAB, for instance SIMULINK.

Currently there are generated examples which integrate the tools of MATLAB/SIMULINK. These programs are suitable especially for students because it is easy to get the connection to modelling and simulation by watching animated simulations and well-structured program files. They can download these files and edit it by themselves to learn more about MATLAB.

At the moment there is a modification at the system. The improvement of using a Content Management System (CMS) should be realised. This system supports and organizes the shareable creation and adaptation of text-

and multimedia-files. The CMS will provide the means to develop and maintain the MMT examples without the need of HTML knowledge.

1 Use of MMT system

The students of Vienna University of Technology are the main target of the creation of this e-learning system. There are many different courses, which deal with simulation and modelling. It is difficult to teach simulation and modelling without any modern facilities. MMT allows students of different fields like mathematics, geodesy and geomatics engineering, computer science, engineering and electrical engineering to use the provided examples for better understanding of modelling and simulation principles [1].

Beside the modelling and simulation part there are also examples, which help to understand mathematical basics and the influence of parameter variation. By studying the MATLAB file, which is available for each example on the MMT, the student gains insight into MATLAB and its usage. There is the possibility to download these files and edit them. The main part of the visitors of these different lessons, where the Web server application is used, has already attended courses about programming. Therefore they are familiar with reading MATLAB code.

A part of the department of the institute for analysis and scientific computing of Vienna University of Technology works a lot with simulation and modelling. Thus this institute offers many different courses about simulation in addition to the courses for mathematical basics for several studies.

In these lessons the MMT system is used to present different simulation models and explain the main aspects of modelling. This 'learning by doing' process is supported by the availability of these examples via a web interface for advanced learning at home. The rela-

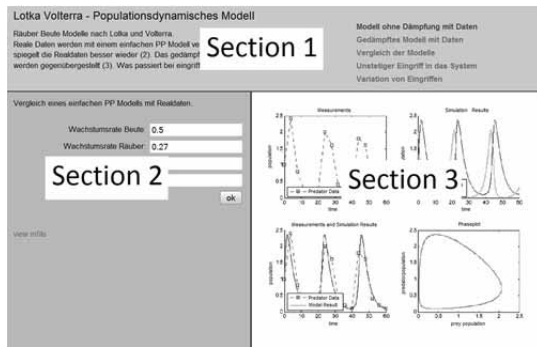


Figure 1. Current layout of the examples.



Figure 2. Designed layout in the CMS with the help of another homepage of our workgroup.

tionship between these dynamical models and the reality is also a very important goal of the MMT system [2].

To assure the comprehensibility of the examples and the MATLAB codes, they underlie a certain structure. This well defined structure supports an easy implementation and illustrates special contents of teaching.

Fig.1 shows the current layout of the examples. It is separated in 3 parts. There is the header (section 1) which contains the name of the example the main content the example deals with and on the right there are similar examples. The left block offers the opportunity to choose certain variables which are defined in the text above. There is also a short description of the model. Section 3 is white at the beginning. If the parameters are chosen the student confirms his choice and receives an output-image there. That was the layout used until now.

Figure 2 shows the approximately layout of the MMT e-learning system. In the section 1 the student chooses the right lecture and will get a list of all the examples convenient to this lecture. In section 3 on the right side there will reside the button 'view m-file' and the SIMULINK block model, if the example is implemented in SIMULINK. It is also possible to upload other important files for every example, for instance fitting pdf-documents or pictures. In the middle section number 2 there the description of the example, the input fields and the output window are arranged.

In our case the interface, used for input and output representation, is defined by standard HTML frames. These files interact with MATLAB directly via the web server so the system becomes more stable. After defining the structure once, it is possible to adapt examples and add new ones without any code writing in PHP or HTML.

2 Further Improvements

2.1 CMS – Content Management System

Another development, beside new and revised examples, is the modification of MMT using a Content Management System (CMS). This system supports and organizes the shareable creation and adaptation of text and multimedia-files. The CMS will provide the means to develop and maintain the MMT examples without the need of HTML knowledge. This CMS is already used in combination with another e-learning system. The difference is that, there the CMS is only used for preparation of information and administration.

In this context the CMS is used to integrate the examples directly on the website without a link and the use of a password to open the link. In CMS it is possible to connect to another system, in case of Technical University of Vienna the TUWEL system (TU Vienna e-learning system). If the student attends a certain lecture the system shows automatically all subscribed courses and the adapted examples. So the CMS facilitates the handling of MMT for students as well as for the administrators.

2.2 MATLAB Tools

Currently there are generated examples which integrate MATLAB and the tool of MATLAB/SIMULINK. There are very different MATLAB examples, easier ones for the basic mathematical lectures and other ones for courses about modelling and simulation. The student can study the MATLAB code-file which contains the main instructions for building such models. In addition the student has the opportunity to download the MATLAB file to edit and to test this file and learn more about programming.

SIMULINK In contrast SIMULINK provides a set of blocks presenting data in- and output, mathematical and logical operations. Connectors stand for the flow of data between the separate blocks. In SIMULINK equations can be implemented combining these blocks. To look ahead there will be more examples generated containing SIMULINK models.

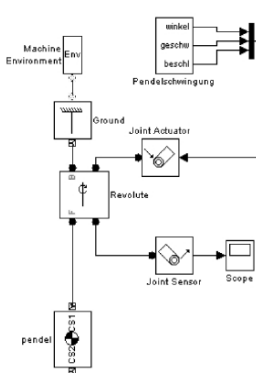


Figure 3. The bar pendulum modelled with SIMSCAPE.

blocks differ from the ones of the SIMULINK library. Below there is shown a model in SIMSCAPE which describes the movement of a pendulum without a free fall. Comparing Fig.3 and Fig.7 the difference between SIMULINK and SIMSCAPE becomes clear. [5]

The model consists of much less blocks and the blocks differ from the SIMULINK ones. There is a ground connected to a revolute-block and the body. The axis of rotation is set within the revolute-block. In the bodyblock the coordinates of the position are set. The, so called, joint actuator block is necessary for the damping, in other words the revolution is influenced by the incoming differential equation of the pendulum. In SIMSCAPE there is also the possibility to take a look at a three-dimensional animation of the model, which is very useful to spark the student's interest in simulation.

3 Examples

In the following paragraph explains some examples contained in the MMT e-learning system, based on MATLAB and the MATLAB-tool SIMULINK. The advantage of SIMULINK is the clear block structure. The program code of these examples consists of many small mathematic blocks which describe every single step of the based equations. It is also possible to take a look at the based MATLAB code.

3.1 Interpolation with Splines

The first example shows an interpolation problem. It is implemented in MATLAB. The topic is the interpolation of a function which describes an increase in trapeze form by using 4 different variants.

As shown in Fig.4 the different coloured lines char-

SIMSCAPE Another innovation will be the embedding of examples working with other MATLAB tools, for instance SIMSCAPE. SIMSCAPE is another block-structured simulation tool of MATLAB. This tool simplifies representing physical structures because it is not necessary to formulate the based mathematical equations. It has also a block library and the examples are developed by combining these blocks. But the

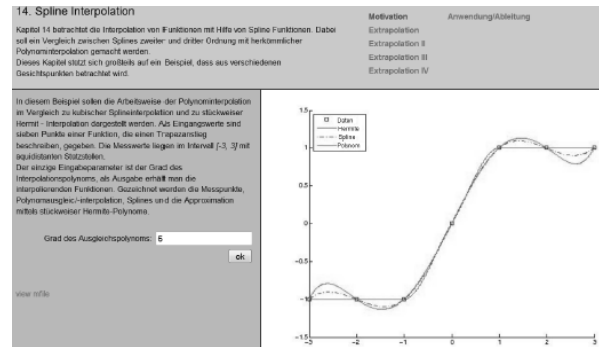


Figure 4. An example of the basic mathematical course-spline-interpolation

acterises the different ways of interpolation. The green line describes the piecewise hermit-interpolation. This interpolation takes care of the derivations of the function which has to be approximated. The dashed red line shows the interpolation with splines. Splines are defined piecewise with the additional condition that the meeting point of two polynomial pieces has to be differentiable.

The used splines in this example are cubical which means that the meeting point has to be two times differentiable. The pink line describes a normal polynomial-interpolation. There is only one selectable parameter which describes the degree of the interpolation-polynomials.

Figure 5 shows the influence of the chosen degree for the interpolation-polynomials.

3.2 Discrete Controller

In this subsection a water level regulator is considered with draft from [4]. In modeling and simulation the control theory is an important field. This theory is easy to learn by typical examples like this water level regulator, so it is reasonable that the MMT e-learning system contains some applications in control theory.

The principle of the water level regulator is shown in Fig. 6. It consists of a water supply, a float lever and a tap. The requirement of the controller is to adjust the water inflow.

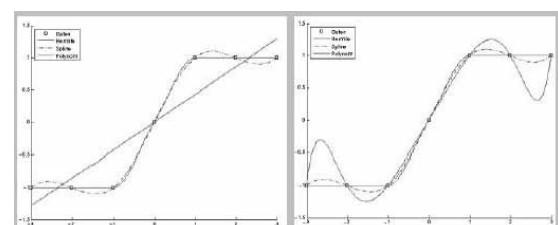


Figure 5. Influence of different chosen degrees of the interpolation polynomial.

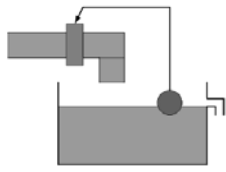


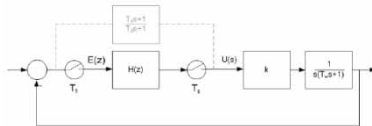
Figure 6. Sketch of a water level regulator.

The adequate continuous controller for this requirement is a PDT1-controller. When $U(s)$ describes the control deviation and $E(s)$ the actuating variable, for given $T_1, T_2 \in \mathbb{R}$ the equation in Laplace-space is given by

$$U(s) = \frac{T_1 s + 1}{T_2 s + 1} \cdot E(s) \quad (1)$$

In Figure 7 the control circuit is figured. The objective is, to design a discrete controller. For this problem the discrete controller is abstract characterized in the z -domain as

$$U(z) = H(z) \cdot E(z) = \frac{a_0 - a_1 z^{-1}}{1 - b_1 z^{-1}} \cdot E(z) \quad (2)$$



with $a_0, a_1, b_1 \in \mathbb{R}$. The discrete controller works with the sampling time T_s and the coefficients calculate to

$$a_0 = \frac{T_1}{T_2} e^{-T_s(\frac{1}{T_2} - \frac{1}{T_1})}, \quad a_1 = \frac{T_1}{T_2} e^{-\frac{T_s}{T_2}}, \quad b_1 = e^{-\frac{T_s}{T_2}} \quad (3)$$

This both control strategies, the continuous and the discrete controller is implemented and compared in SIMULINK, see Fig. 7.

The scopes of the model in Fig.7, allow the students to view the results of the simulation. They can observe the influence of the sampling time T_s on the performance of the discrete controller. Another aspect is the real technical implementation of the discrete controller. In technical systems they are realized via a micro controller and it is possible that a failure occurs. This time lag causes a failure in the behaviour of the controller. For the observation of this influence a MATLAB-function is provided on MMT e-learning system. The system differentiates between a failure, when the micro

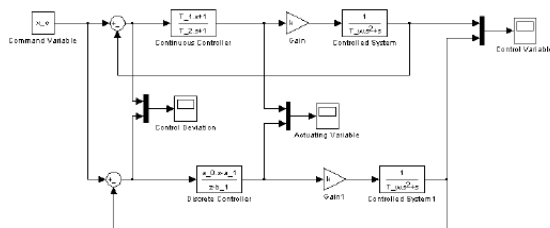


Figure 7. Control circuit with continuous and discrete controller implemented in SIMULINK

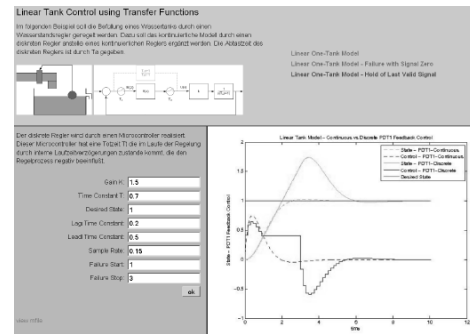


Figure 8. Discrete controller with failure

controller stores the last valid actuating variable longer than scheduled or the micro controller produces a zero signal at the output. In Figure 8 the case of storing the last valid actuating variable is shown.

4 Conclusion

The main aspect of the MMT-system is to give the students the possibility to get a connection to the modelling and simulation. On the one hand there are many examples which help the students to test different parameters and their impact on the other hand there are shown different ways to implement examples of modelling and simulation, like MATLAB and SIMULINK. They get to know a lot of connected fields and applications of modelling like control theory and simulation as shown in the pendulum example. The pendulum especially also shows how to connect to different models, which is also a very important part of simulation.

Additionally there is the background part. The conversion to CMS helps the lecturer and his assistants to coordinate the examples to the right lectures. There is also the permission point which is controlled by the web system as well.

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Modeling Exercising on Wrist Exerciser

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Abstract. Powerball® is commercial name of a gyroscopic device that is marketed as a wrist exercisers. The device has rotor with two unactuated DOFs and can be actuated with suitable motion of additional human or robot wrist axis. After initial rotor's spin, applying the properly torque about wrist axis lead to spin-up of the rotor. Finding this torque intuitively is easy job for most peoples, but not so easy for technical consideration for example in robotics.

The articles main contributions are dynamic models with considered friction effects. Working principles of this device in all three modes: free rotor and both modes of rotor rolling in the housing are described. The work introduces reduction to 1 DOF excitation, considering preliminary research results, which enables laboratory control experiment. Estimation of friction parameters is also discussed. Both, the simulation with animation and experimental results are presented.

Introduction

The wrist exerciser named Powerball® is a gyroscopic device popular in the 90-ties. They are patent pended [1]. Rolling connection of the rotor and the device housing enables the spin-up of the rotor by the appropriate wrist rotations. This movement is accompanied with the torque vector reaction proportional to the square of the rotor spin. The rotor can reach the speeds up to 16000 rpm for the plastic version showed on Figure 1. and an astonishing 20000 rpm for the metal version.

Our scenario includes manipulating robot, which is able to spin-up the Powerball. This gyroscopic device represents a dynamic load to the robot as is discussed in [2] and represents underactuated and nonholonomic load for the manipulator kinematic chain [3]. Spin-up of the wrist exerciser is based on rolling which depends on friction between the rotor shaft and the housing. Friction is neglecting or it became significant. It depends on rotor state and on the wrist rotation reaction normal force on the shaft housing connection. The model is of the ODE type and has uncontinuous right side. Therefore it is a nonholonomic, underactuated, and variable structure type system.

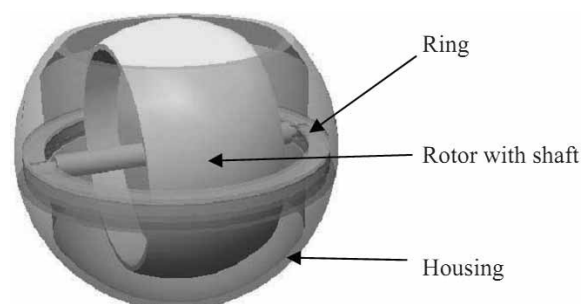


Figure 1. Wrist exerciser components

The main contribution of the paper in comparison to the results in references [4, 5, 6] is the dynamic model, which replicates all there modes of gyroscopic device: the free rotor, the left, and the right mode of rotor rolling in the housing. This model enables insight to dynamics which further serves in development of control experiment. It is of one active degree of freedom and the spin velocity output type. The parameter setting of the model and control are found by estimation and experiments.

The paper is organized as follows. First the modes of operation and appropriate models are discussed. The variable structure model is developed next. Then the robotic activation will be reported, control strategy discussed, and after that the experimental results are shown. On the end of the paper future work will be discussed.

1 Working Principle

A wrist exerciser is essentially a gyroscope with at least three degrees of freedom in rotation. There are spin, precession, and nutation rotation. Powerball is a guided gyroscope in nutation rotation with a special feature of rolling connection in precession and spin degrees of freedom. Nutational rotation causes precession torque reaction which: the first press spinning rotors shaft on a housing to roll in a same direction and the second precession torque acts on the rotor. So the first mode of operation is start-up to the minimal necessary spin. It can be done with a starting rope or some other starting device. The gyroscope after that only spin-off because

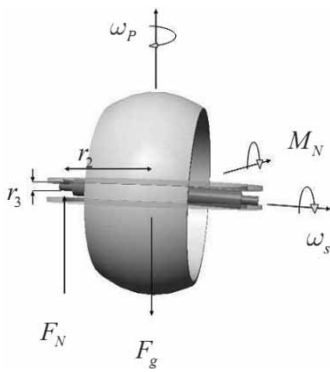


Figure 2. Rotor reaction on torque M_N .

sion ring which enables direct connection between the rotor shaft and the housing of the Powerball.

1.1 Coupling

With this rotor and housing connection the additional friction effect is observed. When the nutation reaction torque M_N is too low, only dissipation of energy is observed. But when the reaction torque causes normal forces on a connection in a degree that the friction is high enough, the rotor shaft begins to roll. The connection with the housing takes place in a gap so two connecting pairs are possible. One is up-down for left precession and another is down-up for opposite precession rotation. The situation for the force pair acting on the shaft is illustrated on Figure 2.

When the rolling is without sliding the precession speed ω_p is proportional to the spin speed ω_s given with equation (1). Direction of the precession depends on amount and direction of torque, which acts against the torque from gravitation on the rotor. In the worst case the rotor axes is horizontal and equation (2) is valid. The ratio in diameters p of the shaft r_3 and the ring r_2 is given with equation (3) and reflects rolling velocities ratio.

$$\omega_p = \begin{cases} -1/p \cdot \omega_s; & M_N \geq \mu \\ 1/p \cdot \omega_s; & M_N \leq -\mu \end{cases} \quad (1)$$

$$\mu \leq \mu_{\max} = |F_g \cdot r_2|, \quad (2)$$

$$p = r_2/r_3 \quad (3)$$

Due to two possible rolling modes transition between them is not trivial. It takes place thru the free rotor mode. This transitions are called reversion and the rotor spin direction is not influenced. In both precession directions the same spin-up is possible.

After rolling takes place the wrist exerciser stays in

there is friction in the bearings. The same is valid for Powerball when the initial spin is not too low and independent from applied or not applied nutation rotation.

When the spin is high enough two additional modes occur. Energy supply to the rotor is possible due to precession

this mode because the precession reacts on the nutation support. On this way the kinematic connection with the rotor takes place. When no work is done to device this state will vanish due to the unavoidable dissipation in the system. But supplying the energy with rotation and the nutation torque thus adds to the rotor kinetic energy and the rotor spin-up. Precession rotor direction changes against nutation rotation, so the nutation should follow the rotor precession rotation.

This can be done by wobbling the two device housing DOF in a human hand or with the robot wrist or only with rotational swing of the one housing DOF. Only the one DOF rotation simplifies the analysis as the experimenting setup so this is done in our work first. This simplified case incorporates singularity which must be avoided at the start-up and the transmitted energy is only one half of the full activated case.

The described principle is quite simplified. The detail discussion is possible only with modeling and the appropriate experiments. This will be done in next sections.

2 Dynamic Model

The masses of housing and the ring are neglected as are the friction in bearings. Only the friction due to normal force F_N acting on the ends of rotor shaft will be explicitly discussed. It conditioned left and right precession rolling and the free rotor spin.

The wrist exerciser has 2 DOF when fixed and additional DOFs then belong to the robot wrist. The torque or impulse applied to rotating body changes its impulse Γ :

$$\mathbf{M} = \frac{d}{dt} \Gamma = \frac{d}{dt} (\mathbf{J} \cdot \boldsymbol{\omega}) \quad (4)$$

where \mathbf{J} is the inertia tensor and $\boldsymbol{\omega}$ is the rotation velocity vector. The equation (4) holds only in the inertial coordinate system (CS). The entries of \mathbf{J} change with the selection of coordinate system. The usual way to start modeling is in the coordinate system of the rotor. In our case the coordinate system of the ring is chosen. Thus the vectors and tensor components are most simplified.

The position of the coordinate system is selected centered for the wrist exerciser which is also the TCP of the robot. The situation is represented on Figure 3. For cos and sin the abbreviations c and s are used. Transformations are given with:

$${}^2T_3(q_3) = \text{Rot}(z, q_3) = \begin{bmatrix} cq_3 & -sq_3 & 0 \\ sq_3 & cq_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad (5)$$

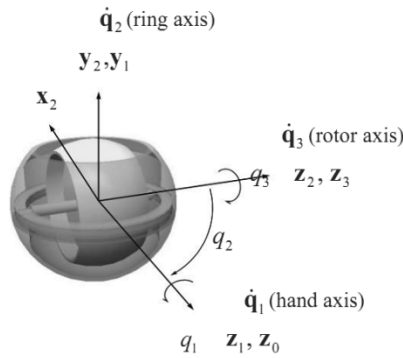


Figure 3. Coordinate systems, axis and rotation velocity vectors

$${}^1T_2(q_2) = \text{Rot}(y, q_2) = \begin{bmatrix} cq_2 & 0 & sq_2 \\ 0 & 1 & 0 \\ -sq_2 & 0 & cq_2 \end{bmatrix}, \quad (6)$$

$${}^0T_1(q_1) = \text{Rot}(z, q_1) = \begin{bmatrix} cq_1 & -sq_1 & 0 \\ sq_1 & cq_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad (7)$$

Let the coordinate system CS 0 be chosen as inertial and the transformation (4) results in

$${}^0M = \frac{d}{dt} {}^0\Gamma = \frac{d}{dt} ({}^0T_2 \cdot {}^2\Gamma) \quad (8)$$

$${}^2M = {}^2T_0 {}^0M = {}^2T_0 \frac{d}{dt} ({}^0T_2) {}^2\Gamma + \frac{d}{dt} {}^2\Gamma \quad (9)$$

where are ${}^0T_2 = {}^0T_1 {}^1T_2$ and ${}^2T_0 = ({}^0T_2)^{-1}$.

Express the transformation derivative with the tensor calculus:

$$\frac{d}{dt} {}^0T_2 = R({}^0\Omega) \cdot {}^0T_2, \quad (10)$$

where ${}^0\Omega$ is a rotation velocity vector of CS 2 in CS 0.

Then from equation (9):

$${}^2M = {}^2T_0 R({}^0\Omega) {}^0T_2 {}^2\Gamma + {}^2\dot{\Gamma} \quad \text{and} \quad (11)$$

$${}^2T_0 R({}^0\Omega) {}^0T_2 = R({}^2\Omega), \quad (12)$$

the torque in the CS of the ring is expressed with:

$${}^2M = R({}^2\Omega) {}^2\Gamma + {}^2\dot{\Gamma} \quad (13)$$

The expression (13) is known as transport theorem:

$${}^2M = {}^2\Omega \times {}^2\Gamma + {}^2\dot{\Gamma} \quad (14)$$

where are quantities valid for CS2 and are defined as:

$${}^2M = [{}^2M_x, {}^2M_y, {}^2M_z]^T \quad (15)$$

$$R({}^2\Omega) = \begin{bmatrix} 0 & -{}^2\Omega_z & {}^2\Omega_y \\ {}^2\Omega_z & 0 & -{}^2\Omega_x \\ -{}^2\Omega_y & {}^2\Omega_x & 0 \end{bmatrix} \quad (16)$$

$${}^2\Omega = [\Omega_x, \Omega_y, \Omega_z]^T = \dot{q}_1 + \dot{q}_2 = \dot{q}_1^2 z_1 + \dot{q}_2^2 y_2 \quad (17)$$

$${}^2\Gamma = {}^2J + {}^2\omega \quad (18)$$

$${}^2J = {}^3J = \begin{bmatrix} J & 0 & 0 \\ 0 & J & 0 \\ 0 & 0 & J_3 \end{bmatrix} \quad (19)$$

The entry J_3 is an principal angular momentum of the rotor spin axes and both J are angular momentums of the perpendicular principal axes to J_3 . Equation (19) is thus valid for the rotor type of the body. The vector of the rotor rotation velocity is given in the component form:

$${}^2\omega = \dot{q}_1 + \dot{q}_2 + \dot{q}_3 = \dot{q}_1^2 z_1 + \dot{q}_2^2 y_2 + \dot{q}_3^2 z_3 \quad (20)$$

When the matrix components are:

$${}^2T_1 = ({}^1T_2)^T = [{}^2x_1, {}^2y_1, {}^2z_1] = \begin{bmatrix} cq_2 & 0 & -sq_2 \\ 0 & 1 & 0 \\ sq_2 & 0 & cq_2 \end{bmatrix}, \quad (21)$$

$${}^2z_1 = \begin{bmatrix} -sq_2 \\ 0 \\ cq_2 \end{bmatrix}, {}^2z_2 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, {}^2y_2 = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \quad (22)$$

then the velocities are given by:

$${}^2\Omega = \begin{bmatrix} -sq_2 \cdot \dot{q}_1 \\ \dot{q}_2 \\ cq_2 \cdot \dot{q}_1 \end{bmatrix} \text{ and } {}^2\omega = \begin{bmatrix} -sq_2 \cdot \dot{q}_1 \\ \dot{q}_2 \\ cq_2 \cdot \dot{q}_1 + \dot{q}_3 \end{bmatrix} \quad (23)$$

When (15 – 23) are inserted in to the equation (13) the dynamical model of the free spinning rotor expressed in the ring CS is:

$$\begin{bmatrix} {}^2M_x \\ {}^2M_y \\ {}^2M_z \end{bmatrix} = \begin{bmatrix} -Js q_2 & 0 & 0 \\ 0 & J & 0 \\ J_3 c q_2 & 0 & J_3 \end{bmatrix} \begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \ddot{q}_3 \end{bmatrix} + \begin{bmatrix} h_x \\ h_y \\ h_z \end{bmatrix} \text{ with } \quad (24)$$

$$\begin{bmatrix} h_x \\ h_y \\ h_z \end{bmatrix} = \begin{bmatrix} -(2J - J_3) c q_2 \cdot \dot{q}_1 \dot{q}_2 + J_3 \cdot \dot{q}_2 \dot{q}_3 \\ (J_3 - J) s q_2 c q_2 \cdot \dot{q}_1^2 + J_3 s q_2 \cdot \dot{q}_1 \dot{q}_3 \\ -J_3 s q_2 \cdot \dot{q}_1 \dot{q}_2 \end{bmatrix}$$

The model (24) is important for expression of the nutation torque in equation (6) because the axis is parallel to x_2 :

$$M_N = -{}^2M_x = Js q_2 \cdot \ddot{q}_1 + (2J - J_3) c q_2 \cdot \dot{q}_1 \dot{q}_2 + J_3 \cdot \dot{q}_2 \dot{q}_3 \quad (25)$$

The axis torques are the projections of the vector (15) on the axes of the system. The projection on z_3 is trivial due to $z_3 = z_2$ and $M_3 = {}^2M_z$. The same is valid for the ring $M_1 = {}^1M_z = ({}^1T_2 {}^2M \cdot {}^1z_1) = -s q_2 {}^2M_x + c q_2 {}^2M_z$ is used, where \cdot here is a dot product.

Torques in the colocated rotations are given with:

$$\begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix} = \begin{bmatrix} H_{11} & 0 & H_{13} \\ 0 & H_{22} & 0 \\ H_{13} & 0 & H_{33} \end{bmatrix} \begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \ddot{q}_3 \end{bmatrix} + \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} \quad (26)$$

where are

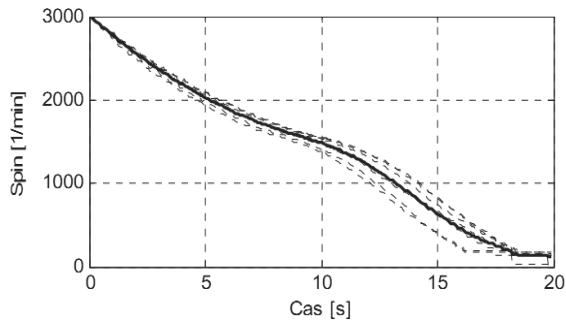


Figure 4. Experiment trace and simulation results of the spin-off.

$$H_{11} = Js^2 q_2 + J_3 c^2 q_2$$

$$H_{13} = J_3 c q_2$$

$$H_{22} = J$$

$$H_{33} = J_3$$

$$h_1 = -2(J_3 - J) s q_2 c q_2 \cdot \dot{q}_1 \dot{q}_2 - J_3 s q_2 \cdot \dot{q}_2 \dot{q}_3$$

$$h_2 = h_y$$

$$h_3 = h_z$$

For Powerball activated only with the one wrist DOF torques M_2 and M_3 are zero. Coupling of the rotor with housing is modeled with the torque vector M_t :

$$\begin{bmatrix} M_{t1} \\ 0 \\ 0 \end{bmatrix} = H \cdot \ddot{q} + h(q, \dot{q}) + \begin{bmatrix} M_{t1} \\ M_{t2} \\ M_{t3} \end{bmatrix}. \quad (27)$$

The first component of this friction vector is again set to zero while this friction belongs to the actuated wrist axis. Remaining components are separated in dissipation and coupling terms:

$$\begin{bmatrix} M_{t1} \\ M_{t2} \\ M_{t3} \end{bmatrix} = \begin{bmatrix} 0 \\ M_{2d} + M_{2s} \\ M_{3d} + M_{3s} \end{bmatrix} \quad (28)$$

First the dissipation effect is modeled. It has viscous (k_v, k_{v3}) and dry part (k_{s3}) dependable from the state indicator ζ :

$$M_{2d} = k_v \cdot \dot{q}_2 \quad (29)$$

$$M_{3d} = \begin{cases} k_{v3} \dot{q}_3 + k_{s3} \cdot \text{sign}(\dot{q}_3); & \zeta = 0 \\ 0; & \zeta \neq 0 \end{cases} \quad (30)$$

Then the coupling friction is modeled, which depends on nutation torque M_N in the direction of x_2 and from slip velocity v . Thru this part of the model the energy flows from the excitation in the rotor and back in direction to the wrist.

$$M_{2s} = -f_t(v, M_N), \quad (31)$$

$$M_{3s} = -\zeta \cdot \frac{1}{p} \cdot f_t(v, M_N) \quad (32)$$

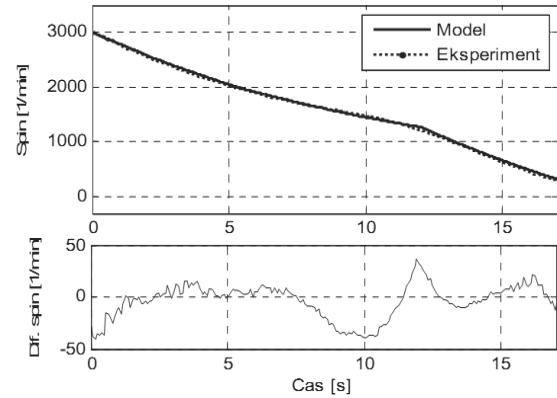


Figure 5. Rolling – sliding experiment and simulation results.

In the equations (31, 32) the function f_t represents dry friction (33) and the constant k_s is the dry friction parameter acting between rotor axle and the groove of Powerball.

$$f_t(v, M_N) = k_s \text{sign}(v) \quad (33)$$

where ζ indicates the mode of the system. At $\zeta = 1$, the negative part of the rotors shaft is elevated and the positive side is down and at $\zeta = -1$ the is situation opposite, and at 0 the rotor floats.

3 Parameter Estimation

Developed Powerball model serves for estimation of parameters k_s, k_v, k_{s3}, k_{v3} and torque μ with spin off experiment and simulation. The experiment trace and simulation results at different parameter sets are depicted on Figure 4 (Time – spin).

By choosing the functional F :

$$F = \sum_{k=1}^n |\dot{q}_3(k)_{(\text{exp.})}^2 - \dot{q}_3(k)_{(\text{sim.})}^2|, \quad (35)$$

which takes in account the only measured quantity \dot{q}_3 the estimated parameter set has optimized entities:

$$k_s = 0.7468, k_v = 0.0068, k_{s3} = 0.0014, \\ k_{v3} = 6.9830 \cdot 10^{-6}, \text{ and } \mu = 0.0148.$$

The parameter set was than tested on the example which contains transition between two states (rolling-sliding) of Powerball (Figure 5).

4 Control Experiment

In the case of rolling the equation (3) enable to compute the excitation wrist torque components: first for coupling compensation, and second for the acceleration.

Torque components and the resulting excitation are

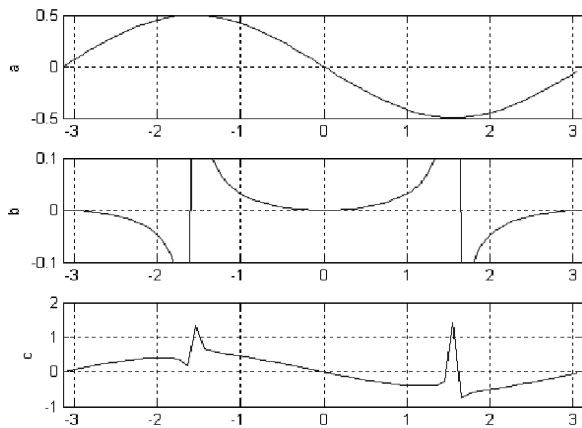


Figure 6. Accelerating in one rolling mode: a) torque for conditional rolling, b) torque component for acceleration, and c) resulting torque M_1 .

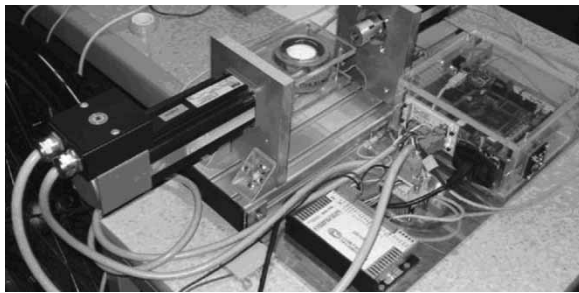


Figure 7. Directly coupled servo-drive and the Powerball.

documented on Figure 6. With acceleration torque it is easy to identify the nature of Powerball coupling. For the one DOF excitation singular positions and the constant acceleration the effort becomes infinite. The developed model serves also for calculating the cinematic variables:

$$\ddot{q}_2 = \frac{1}{J} (T_{2S} - h_2(q, \dot{q}) - T_{2d}), \quad (36)$$

$$\ddot{q}_3 = \frac{1}{J_3} (T_{3S} - h_3(q, \dot{q}) - J_3 \cos(q_2) \ddot{q}_1 - T_{3d})$$

where is \ddot{q}_1 , \dot{q}_1 and q_1 cinematic chain of wrist excitation for the Powerball experiment shown on Figure 7. Experimental set-up is arranged around DSP2 controller and the servo drive Mini AX. Powerball is clamped in an effector capable to measure spin speed only. The cinematic trajectory begins at 200 rad/s, than it is accelerated to 900 rad/s and on the end constant decelerated. The achievement results of spin are on Figure 8.

The rolling mode indicator ζ was either +1 or -1 and was independent from the fact that the model is capable of reproducing rolling, transitions, and slip.

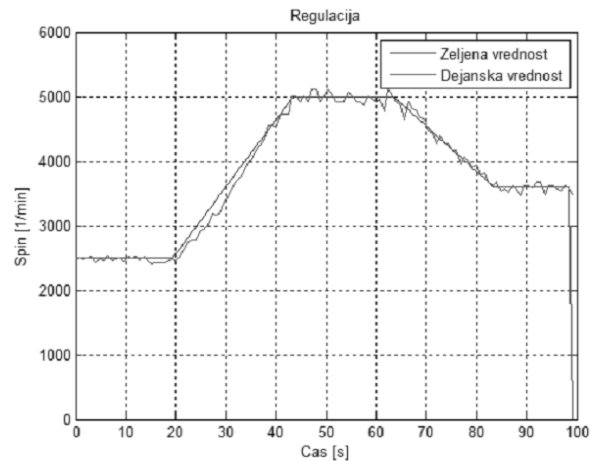


Figure 8. Spin kinematics control experiment.

5 Conclusions

The paper deals about modeling and experimenting with the gyroscopic device. First the model was developed for two DOF excitation and then reduced to one DOF suitable for our experiment setup. Simulation serves in model parameter estimation as well as for cinematic control development. The experiments show that the Powerball can be accelerated and decelerated only with the output variable of rotor spin.

For the precession reversal the implicit torque signal should be considered. The research in this direction was performed with additional passive DOF and partly reported in [14].

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ROBBIT: An Open Source Simulator for Education in Robotics

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Abstract. An open source software, named ROBBIT, aimed at the simulation of multiple mobile robots has been developed at the Università degli Studi di Cassino, Italy together with students coming from the Indian Institute of Technology Kharagpur, India. The main project's objective was to develop a software platform with educational purposes in robotics, computer sciences, non-linear control, behavioral and cognitive sciences. Several potential applications have been identified in order to use this software as a teaching tool for graduate, master thesis and PhD students. ROBBIT is released under the GNU General Public License (GPL).

Introduction

Teaching of control theory and robotics to computer science students can take great advantage in using practical demonstrations, both in laboratory or via numerical simulations [9, 18]. In recent years, both the decrease of the hardware costs and the diffusion of the open source philosophy made accessible to most of the universities the setup of an educational laboratory for robotics applications [14]. Together with the teaching of basic mathematics, physics and systems dynamics, a fundamental role to fully appreciate a robotic class is played by the practical aspects of design, implementing and tuning a controller. A well designed software tool, moreover, may be of crucial importance also in allowing the students to better understand the importance of the modeling and of the identification steps of the design procedure. Software tools may also be used to teach basic feedback control theory to high-level students [12].

Several similar experiences have been proposed in the literature such as [20], based on the LEGO Mindstorm hardware. The work [11] proposes an experience based on the control of a DC motor with the help of the commercial Matlab [15] software, all the design and testing procedure is kept within the same software envi-

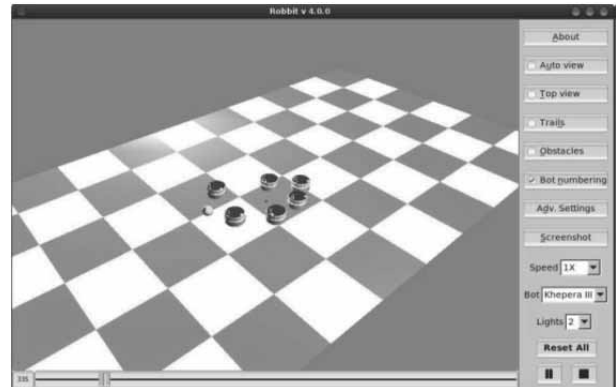


Figure 1. Snapshot of the main ROBBIT's windows simulating 6 mobile robots with a tennis ball as obstacle

ronment thus saving the students time. In [16] the control software for a mobile robot has been explicitly designed to run on PocketPC hardware thus to increase the transportability of the set-up. The work [21] presents the customization of a commercially available mobile robot to be used as test-bed both for education and research within a Matlab environment. An object-based graphical engine is proposed in [19], that provides a graphical user interface and C library to produce graphical simulation of robotic systems under X Windows.

In this paper a new project, named ROBBIT, is presented. ROBBIT is an open-source software, which provides a 3D simulation environment for multiple robot system. In particular, ROBBIT enables the users to write their own controllers, modify the environment and, in future release, use sensors in order to test control algorithm and visualize their effects on different types of robots. It is not designed to provide a real world simulation and it is kept simple, modular and extensible for educational purpose. If needed, the user can easily add obstacles, sensors or define a new robot.

Several educational experiences are possible through the use of ROBBIT. The user can design and implement a customized control algorithm or acquire insights into

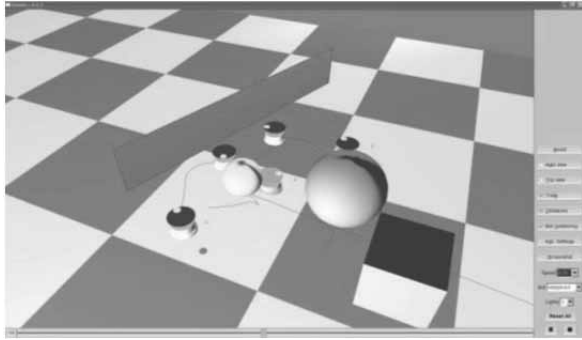


Figure 2. Snapshot of the main ROBBIT's windows simulating 5 mobile robots and several obstacles.

the control design by, e.g., modifying the control gains of existing controllers. An unicycle-like kinematics has been implemented, car-like and Dubin kinematics will follow. Moreover, the software is written for the general case of multiple robots acting on the same environment, thus allowing also its use to more advanced concepts such as coordinated control. At an higher control level, by resorting to the kinematic control implemented [13], it is possible to simulate navigation or exploration algorithms for single or multiple mobile robots. Advanced control strategies strategies, such as, behavioral or cognitive control [10], fuzzy logic, network control or genetic algorithms may be implemented as well. The project's home page is provided in [5], while the SVN server in [4]. ROBBIT is released under the GNU General Public License (GPL). Figures 1 and 2 provide two snapshots of the main window.

Available simulation engines and platforms

Several simulation engines and platforms are currently available, most of them, however, are commercial products and do not satisfy our first requirement (see Section 1); an incomplete list is given in Table 1. In the following, only the free software, or commercial one with free release for academics, will be briefly discussed.

Microsoft recently developed a robotics software platform named Microsoft Robotics Studio [1]. It provides both a simulation environment and a graphical service development toolkit. It implements behavior coordination by resorting to the concept of service arbiters. It is a commercial software available free for academic.

OROCOS [6] is the acronym for Open Robot Control Software project. The project's aim is to develop a general-purpose, free software, and modular framework for robot and machine control. It is not, thus a simulation engine but a platform. It has been designed with a

Name	Type
breve [7]	Open source, free
CLARAty	Open source
Evolution Robotics ERSP	Commercial
iRobot AWARE	Commercial
Microsoft Robotics Studio [1]	Commercial, free
OpenJAUS	Open source
OROCOS [6]	Open source, free
Player, Stage, Gazebo [2]	Open source, free
Simbad [17, 3]	Open source, free
Skiligent	Commercial
URBI	Commercial
Webots	Commercial

Table 1. Some popular platforms and simulation engines.

special care for real-time applications and for Linux O.S. (Operative System) only. It does not have a graphical development neither a simulation environment.

Simbad [17, 3] allows the simulation of single or multiple robots in 3D and it has been developed with education purposes besides the scientific ones. As ROBBIT, it has to be interpreted as an open framework to test new ideas. It is written in Java (requires Java3d library) and runs on Mac OSX, Windows XP and some Linux distributions.

On the same philosophy of open source and free software is also Breve [7], written in Python. The user can develop her/his own controller also using a simple scripting language called *steve*.

The most interesting project, from the educational point of view, is given by the triad Player, Stage and Gazebo [2]. They are independent projects that are coordinated in order to be used jointly. Player is an open source TCP/IPbased hardware abstraction layer for several robotics hardware platforms. Stage and Gazebo implements accompanying simulation environments, they use ODE (Open Dynamic Engine - a rigid body dynamics simulator) to compute physical interaction with the environment. These projects are both Open Source and Free, they are probably among the most popular simulation engines in the research laboratories worldwide. They can be used on the following O.S.: Linux, Solaris, *BSD and Mac OSX but not Windows. They represent a powerful tool that needs some time to be learned.

1 ROBBIT Overview

The choice to develop an open source software was natural after a long list of requirements:

- Free. The first requirement is probably the most serious: ROBBIT needs to be free (as in free beer). One of the aims is that students can use ROBBIT using their home computers, moreover, low-budget academic groups should be able to use ROBBIT at no cost as well. It is well known that, for a private, the decision to use proprietary code versus open source code is given by the balance of the economical aspect versus the supposed larger time needed to work with open source SW. In this case, however, practicing with the code is one of the purposes of the project and thus the balance is polarized towards the open source choice;
- Portable. Open source code is usually more portable than closed one. There is no need to install hardware keys or install proprietary software in all the machines where the code needs to run. ROBBIT has been written in share mainly by the Authors of this article relying only to popular libraries;
- Platform independent. ROBBIT is available both for Windows and Linux. Most of the proprietary libraries are developed for Windows only;
- Possibility to switch versus hardware-in-the-loop tests. For this project, the hard real-time issue has not been considered. Using (also) Linux, however, makes it easier to upgrade to a real-time Linux kernel and thus to the possibility to use ROBBIT for hardware-in-the-loop tests;
- Free (as in free speech). Our educational role should be also to promote the wider diffusion of the expertise we learned trying, whenever possible, to avoid artificial threshold. Notice that the slogan was thought for the Free Software and some differences arise with respect to the Open Source philosophy.

Finally, it is necessary to take into account that several, independent, researches demonstrated that Open Source software and Operative Systems are more reliable and performing than the closed counterparts. Moreover, the open-source-community is generally more motivated.

Several other requirements, independent from the Open Source choice, have been imposed to ROBBIT such as the modularity and the simplicity of use.

2 Usage

ROBBIT is released under the GNU General Public License (GPL) and it is available both for Windows and Linux platform. It can be downloaded at the webpage in

OS version	Linux (kernel 2.6.24), Windows XP
Compiler	C,C++ (with Standard Template Library)
OpenGL	openGL Utility Toolkit 3.7.6 (Windows) Freeglut 2.4.0 (Linux)
GUI toolkit	FLTK with FLUID 1.1.9
Images	libpng 1.2.31

Table 2. Main software requirements to run ROBBIT.

[4]. Before the installation it is requested to install the list of free packages given in Table 2.

When running, ROBBIT looks like a graphical interface that allows the user to select different options. At first, the user has to select the source of simulation data to visualize. The user can chose a sample log file from the archive or he can chose his self-developed log file. Then, ROBBIT reads the data from the cho-sen file and shows the motion simulation in the graphical window.

From the interface the user can choose the visualization parameters like camera position or light sources. Moreover he can chose to take some snapshots during the simulation run.

The user have to select the kind of robots used for the simulation. At the actual stage model for both Khepera II and Khepera III robots (manufactured by K-Team) are available. However, the user can define its own robot models.

The interface allows the user to visualize or not the obstacles in the environment, whose position is read from a text file. On the basis of the chosen robots and on their size, ROBBIT recognize the occurrence of collisions with obstacles (if selected) or among the robots. The collisions are evidenced by a temporary change of the robots' color.

The user can chose to visualize some variable useful to understand the behavior of their controller, e.g. paths of the robot, path of the robots' centroid, safety region for obstacle avoidance.

ROBBIT can be easily interfaced with the program containing the control law through text files that contain information about position and orientation of the robots.

3 Case Study

As a case study on the use of ROBBIT, the research results presented in [8] are briefly summarized. In this paper a coordinate control strategy for multiple robot escorting an autonomous target is presented. After the theoretical development of the approach, the first simulations were run under the ROBBIT environment.

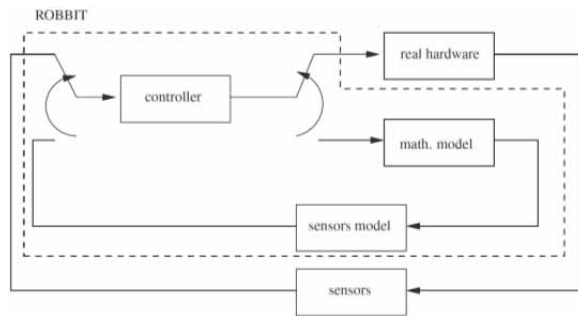


Figure 3. Sketch of ROBBIT as used in an experimental setup

ROBBIT allowed to debug the control code, test the validity of the control law and tune the control gains before doing the experiments. In particular, ROBBIT was used to simulate the motion of a team of khepera II mobile robots; at this purpose a realistic kinematic model of the khepera II robots was used to test the developed control law for non-holonomic vehicle with unicycle-like kinematics. Finally, the same code used for the simulation under ROBBIT was used to perform the experiments with a team of 7 khepera II. The use of ROBBIT gave a reasonable guarantee that the code was debugged and properly working; then, a fine tuning of the control gains was done on the basis of the real dynamics of the system. Figure 3 shows the software architecture.

Figure 4 reports a sketch of the Laboratorio di Automazione Industriale at the University of Cassino where ROBBIT is used as a tool for education and research and where the results presented in [8] have been run. The video of those experiences can be found at <http://webuser.unicas.it/lai/robotica/video>.

4 Future Developments

ROBBIT is seen as an open project, where the user can develop her/his own modules depending on the necessity. Some scheduled developments concern:

- Decentralization of the control software for multiple robots. The control code currently runs on a single machine and the decentralization of the controllers is obtained by software filtering of the available information. It is of interest to actually decentralize the controllers by running separate asynchronous threads.
- The current version of ROBBIT only allows to define simple objects to be used as obstacles during the simulations. It is of interest to easily import and modify office or maze-like environments;

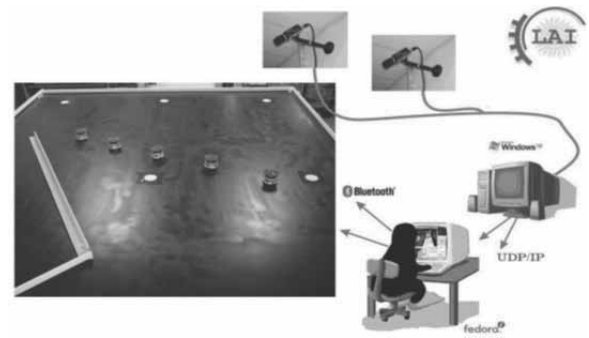


Figure 4. Sketch of the mobile robots experimental facility available at Laboratorio di Automazione Industriale at the University of Cassino where ROBBIT is used as a tool for education and research.

- A library of exteroceptive sensors needs to be developed such as sonar, laser and a simulated vision system;
- The communication among the robots is currently modelled as a simple time delay, better mathematical model may improve this aspect;
- Currently, only the kinematics of unicycle-like or point mobile robots is implemented, it is of interest both to extend the library to additional kinematics as well as to include the dynamics into the simulation engine;
- It is of interest to integrate the software with existing engines of numerical computation to make it easy to, e.g., plot the graphics of a simulation/experiment. Several free softwares might be of interest such as Octave and Scilab.

5 Conclusions

An open source software, named ROBBIT, aimed at the simulation of multiple mobile robots has been jointly developed by the Università degli Studi di Cassino, Italy and students coming from the Indian Institute of Technology Kharagpur, India. The main project's objective was the development of a software platform with educational purposes in robotics, computer sciences, non-linear control, behavioral and cognitive sciences. Several potential applications have been identified in order to use this software as a teaching tool for graduate, master thesis and PhD students. ROBBIT is released under the GNU General Public License (GPL).

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Simple Models for Process Control

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Abstract. A second-order plus dead-time model is derived from the data used for the characterization of a self-regulating process with a view to its PID control. This modeling approach provides guidelines for the design of the controller and tuning relations are proposed which provide flexibility in the choice of the control system responses and guarantee of stability and robustness. These features are illustrated by simulation results.

Introduction

Most industrial processes are stable, hence self-regulating, and they can be controlled by PI or PID controllers combining proportional, integral and derivative control terms. From the pioneering paper [9] by Ziegler and Nichols in the forties hundreds of design relations, tuning rules, and other methods for tuning PID controllers have been proposed in the literature; tens of them are compiled in [5], and the most popular ones can be found in many textbooks on process control; see e.g. [1, 6, 7]. Tuning rules proposed by Ziegler-Nichols in the forties, Cohen-Coon and Chien-Hrones-Reswick in the fifties, and by Astrom-Hagglund in the nineties are based on a three-parameter characterization of the controlled system, that is the process itself and the various components in the measurement and control lines; see [1, 2, 3, 9]. Such a three-parameter characterization of the controlled system is consistent with the use of a PID controller since tuning the latter involves also three parameters, the controller gain and the integral and derivative time constants. The three parameters of the process characterization are the process *static gain* and two parameters in the time domain. The latter may be an *apparent time constant* which provides a rough global representation of all the elementary storage processes in the controlled system and an *apparent dead time* which aims to some approximation of the unknown dynamics related to the interactions between all these individual processes. However a better characterization of the system dynamics is given by the *average residence time* which is the sum of the apparent time constant and dead

time, so determining the time scale of the system dynamics, and by the *normalized dead time*, that is the ratio of the apparent dead time to the average residence time, which is a dimensionless parameter whose value in the range (0, 1) indicates the difficulty of controlling the process. The values of the three parameters can be easily determined by graphical methods from the process reaction curve (step response) or by a method of moments applied to the reaction curve or to the step response of a stable PI control loop.

However, the first-order plus dead-time (FOPDT) model which can be constructed from this three parameter characterization is not a realistic model neither for simulation nor even for controller design if the normalized dead time is small (below 0.5). In any control loop indeed, there are more than one single time constant, there may be additional time constants in the process itself and there are others in the various components of the control loop, especially in the actuator. Consequently, in the time domain the step response of the controlled system exhibits a smooth start-up whereas that of the FOPDT model shows an abrupt take-off. In the frequency domain the gain diagram of the FOPDT model has a slope of -20 dB/decade at frequencies beyond the inverse of the apparent time constant whereas the additional time constants hidden in the control loop result into a steeper descent of the gain diagram at high frequencies. These discrepancies between the true transfer function of the controlled system and its FOPDT model are minor for processes where the apparent dead time is relatively long ($\tau > 2/3$), they may be significant in other cases. Then, a second-order plus dead time (SOPDT) model would be more appropriate for designing a controller. Such a model can be obtained by various identification methods; in the sixties already van der Grinten had proposed formulas determining the model parameters from the process reaction curve and graphical methods [8]. Here it is proposed to construct a SOPDT model with only three independent parameters closely related to that of the usual FOPDT model; the values of these parameters can be determined from the

same two moments used for determining the parameters of the FOPDT model, or directly from the latter or from any transfer function representing the process to be controlled.

1 Model building via the method of moments

Denoting by s the variable in the Laplace domain the transfer functions of FOPDT and SOPDT models of a selfregulating process can be written as

$$M_1(s) = K \frac{1}{1+T_a s} e^{-D_a s} \quad (1)$$

$$M_2(s) = K \frac{1}{(1+T_1 s)(1+T_2 s)} e^{-D_2 s} \quad (2)$$

where K is the static gain, and T_a and D_a are the apparent time constant and dead time for a FOPDT model while T_1, T_2, D_2 are the two time constants and the dead time of a SOPDT model. Such models can be used for designing a PID controller or any three-term feedback controller if the first terms of the Taylor-McLaurin expansion of the model are equal to that of the process. The transfer function of the latter can be expanded as

$$\begin{aligned} P(s) &= P(0) + P'(0)s + P''(0)s^2/2 = \\ &= K(1 + p_1 s + p_2 s^2) \end{aligned} \quad (3)$$

where $P'(s), P''(s), \dots$ are the derivatives of $P(s)$ with respect to the complex variable s and $K = P(0)$, $p_1 = P'(0)/P(0)$, $p_2 = P''(0)/2P(0)$, ... The process gain can be determined from the final value in the process step response; from well-known properties of the Laplace transform the coefficients p_1, p_2, \dots are given by the “moments”, that is integrals, of the weighted complementary function of the normalized response. As for the Taylor-McLaurin expansion of the model transfer function it can be obtained by successive differentiations as in (3) or better by applying the algorithm in Appendix A. Then, comparing the coefficients in the expansions of the process and the model transfer functions yields the following relations:

$$K = r(\infty)/\Delta \quad (4)$$

$$\begin{aligned} T_{ar} &= T_a + D_a = T_1 + T_2 + D_2 = \\ &= \int_0^\infty \left[1 - \frac{r(t)}{r(\infty)} \right] dt \end{aligned} \quad (5)$$

$$\begin{aligned} \frac{1}{2}(T_{ar}^2 + T_a^2) &= \frac{1}{2}(T_{ar}^2 + T_1^2 + T_2^2) = \\ &= \int_0^\infty t \left[1 - \frac{r(t)}{r(\infty)} \right] dt \end{aligned} \quad (6)$$

These relations provide values of the three parameters in the FOPDT model (1), hence the value of the normalized dead time

$$\tau = 1 - T_a/T_{ar} \quad (7)$$

For determining the parameters of a SOPDT model additional relation or constraint is necessary; here, it is proposed to set

$$\begin{aligned} T_1 &= T_{ar}(1 - \theta), \quad T_2 = T_{ar}\theta(1 - \theta), \\ D_2 &= T_{ar}\theta^2 \end{aligned} \quad (8)$$

where θ is dimensionless parameter with values in the interval $(0, 1)$, close to that of the normalized dead time τ . From the equality in (6) straightforward calculations indeed result into the following relationship between the two dimensionless parameters τ and θ :

$$1 - \tau = (1 - \theta)\sqrt{1 + \theta^2} \quad (9)$$

starting from the initial approximation $\theta = \tau$; less than 5 iterations provide the value of θ with 4 exact decimals, which is largely beyond the accuracy required for controller tuning.

It should be noted that this SOPDT model is based on three parameters, the static gain of the process, the average residence time, that is the time scale, of the latter, and a dimensionless parameter θ indicating the difficulty of controlling the system. This is exactly the same simplicity as with the usual FOPDT model, and the tools used for parameter estimation are the same, with no more data being required. These data can be obtained from the process reaction curve or from the step response of any stable control system including the process to be controlled and a proper PI controller, as it is shown in Appendix B. Actually, the SOPDT model can be viewed as being derived from the FOPDT model but it is more realistic, both in the frequency domain and in the time domain. This SOPDT model indeed contains a main time constant $T_1 = (1 - \theta)T_{ar} = T_{ar}/\sqrt{1 + \theta^2}$, which is close (slightly lower) to the apparent time constant $T_a = (1 - \tau)T_{ar}$ of the FOPDT model, but the additional uncertain dynamics of the process is now modeled at the first order (in θ) by an additional time constant $T_2 = \theta(1 - \theta)T_{ar}$ and at the second order by a dead time $D_2 = \theta^2 T_{ar}$ whereas it was modeled at the first-order by the apparent dead time $D_a = \tau T_{ar}$ in the FOPDT model. Last but not least, this SOPDT model provides guidelines for the design of a PID controller.

2 Design of a PID controller

In 1965 A. Haalman proposed to tune PID controllers via the representation of the process to be controlled by

μ	1.3	1.5	2	3
Gain margin	2	2.4	3.1	4.7
Phase margin	46°	52°	61°	71°

Table 1. Robustness with proposed controller settings.

a SOPDT model and the cancellation of the two process time constants by means of the two controller time constants [4]. This method is resumed here with the SOPDT model (2) but a design parameter μ is included in the controller gain, then allowing some adaptation of the control loop damping by a modification of the controller gain only. Setting

$$K_i = 1/(\mu KD_2) \rightarrow K_p = T_i/(\mu KD_2) \quad (11)$$

where K_i and $K_p = K_i T_i$ are, respectively, the integral and proportional gains of the controller, the open-loop transfer function then becomes

$$P(s)C(s) = KK_i \frac{1}{s} e^{-D_2 s} = \frac{1}{\mu D_2 s} e^{-D_2 s} \quad (12)$$

In the Nyquist plane the plot of the open-loop transfer function (12) is a spiral which is starting along a vertical with abscissa $-1/\mu$, asymptotically from the zero frequency, and which is getting wound around the origin for increasing frequencies; at all frequencies, the Nyquist plot is standing at the right-hand side of this vertical $-1/\mu$. Straightforward calculations then yield the ultimate frequency ω_u and the ultimate value μ_u bringing the closed-loop system to the stability limit

$$\begin{aligned} D_2 \omega_u &= \pi/2 \rightarrow \omega_u = \pi/2 D_2 \text{ and} \\ \mu_u D_2 \omega_u &= 1 \rightarrow \mu_u = 2/\pi \end{aligned} \quad (13)$$

Therefore, with a selected value of μ , the designer of the control system can determine the gain margin μ/μ_u , as also the cut-off frequency and the phase margin of the control loop

$$\begin{aligned} D_2 \omega_{co} &= 1 \rightarrow \omega_{co} = 1/\mu D_2 \text{ and} \\ \Phi_M &= \frac{\pi}{2} - D_2 \omega_{co} = \frac{\pi}{2} - \frac{1}{\mu} \text{ rad} \end{aligned} \quad (13)$$

as shown by Table 1.

Since there is a close relationship between the damping and the phase margin of the closed-loop system, selecting values of μ between 1.3 and 3 allows the designer to choose the types of closed-loop responses, from fast responses with a high overshoot ($1.3 < \mu < 2$) to over-damped slow responses ($2 < \mu < 3$). This choice can be achieved by varying the parameter μ , that is the controller gain only, without changing the controller time constants; by the way, this is the natural reaction of control engineers and plant operators when they want to change on-line the behavior of the control system.

Process	FOPDT parameters			SOPDT parameters			
	T_a	D_a	τ	θ	T_1	T_2	D_2
$P_1(s)$	0.67	0.33	0.33	0.37	0.63	0.23	0.14
$P_2(s)$	0.32	0.68	0.68	0.75	0.25	0.19	0.56

Table 2. Parameter values of the FOPDT and SOPDT for the processes (14, 15).

In [1], Åström and Hägglund have proposed a collection of transfer functions representative of typical industrial processes. Many simulation runs have been performed with various transfer functions of this collection. For all of them the shape of the open-loop Nyquist plot was similar to the spiral shape of the nominal transfer function (12), with the plot standing at the right-hand side of the vertical $-1/\mu$ or at least close to it at all frequencies. Therefore, the minimum distance from the actual Nyquist plot to the critical point $(-1,0)$ is greater than $1 - 1/\mu$, and the gain margin and the phase margin are greater than, respectively, μ and $\arccos 1/\mu$. Therefore, the proposed tuning method is not only simple and intuitive, but it also provides some flexibility in the choice of the closed-loop responses together with some guarantee on the control system robustness. This is illustrated by the simulation results presented in the next section.

3 Simulation results

Simulation tests have been performed with the two following typical transfer functions:

$$P_1(s) = \frac{1}{(1+Ts)(1+\alpha Ts)(1+\alpha^2 Ts)(1+\alpha^3 Ts)}, \alpha = 0.4 \quad (15)$$

$$P_2(s) = 1/(1+Ts)^n, n = 10 \quad (16)$$

with the same average residence time $T_{ar} = 1$ for the two transfer functions. Table 2 below shows the parameter values of the FOPDT and SOPDT models for the two processes, and the responses of each process and its FODPT and SOPDT models are shown in Figure 1.

Clearly, the response of the process is better represented by the SOPDT model than by the FOPDT model, especially for the first process whose normalized dead time is low ($\tau = 0.33$ for $P_1(s)$ versus 0.68 for $P_2(s)$). Obviously, the first process is also easier to control than the other one thanks to its low normalized dead time. The responses to a unit-step change of the process load (disturbance at the process input) are shown in Figure 2 for these two processes and PID controllers tuned according as proposed here or with the well-known Ziegler-Nichols settings or with the Åström-Hägglund settings, the one for slow responses without overshoot, the other

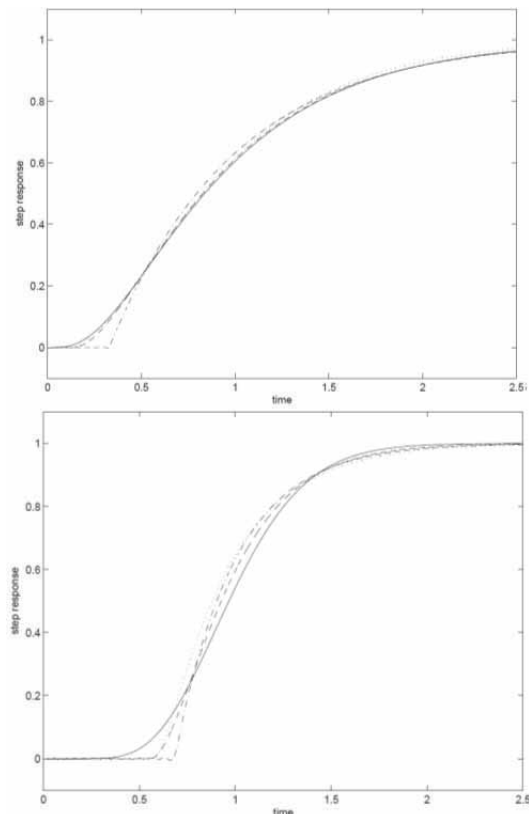


Figure 1. Step responses of the process and its models. Top: $P_1(s)$, bottom: $P_2(s)$; process (full lines), proposed SOPDT model (broken lines), FOPDT model (dash-dotted lines), van der Grinten SOPDT model (dotted lines).

for faster responses with some overshoot. It turns out that the controller tuning based on the SOPDT model proposed here provides better responses with a wide flexibility in the choice of the response damping; thanks to a proper choice of the design parameter, that is of the controller gain, it is possible to cover continuously the whole range between a slow over-damped response and a fast under-damped response, without changing the controller time constants unlike the Åström-Hägglund settings.

4 Conclusions

With a view to the design and tuning of controllers a SOPDT model has been derived from the usual FOPDT characterization most often used for PID control of self-regulating processes. This modeling approach allows the use of tuning methods based on SOPDT models; this provides some flexibility in the choice of the control loop behavior together with some guarantee on the stability and robustness of the latter. These features are

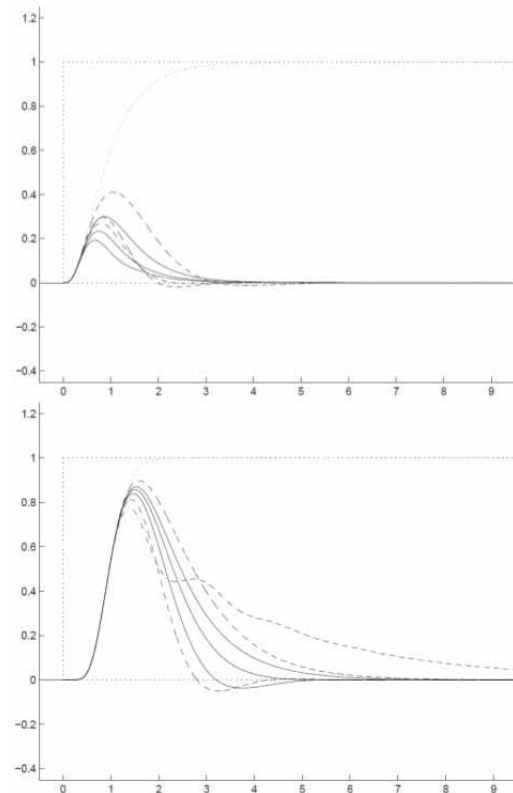


Figure 2. PID control. Responses to a load unit-step change. Top: $P_1(s)$, bottom: $P_2(s)$; Proposed controller settings (full lines), Åström-Hägglund settings (broken lines), Ziegler-Nichols settings (dash-dotted lines), process reaction curve (dotted lines).

proven by simple calculations and they are illustrated by simulation results. Actually, modeling is used here not for simulation purposes but in order to provide some guidelines for the design of controllers.

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Appendix A

Given a transfer function

$$G(s) = K \frac{1+n_1s+n_2s^2+\dots}{1+d_1s+d_2s^2+\dots}$$

the coefficients of its Taylor–McLaurin expansion

$$G(s) = K(1 + g_1s + g_2s^2 + \dots)$$

can be determined without any derivative calculation, just by multiplying the above expansion of $G(s)/K$ by the denominator of the rational fraction and identifying the coefficients of the same degree terms in this product and in the numerator of the latter. This provides the following set of linear equations:

$$n_1 = g_1 + d_1$$

$$n_2 = g_2 + d_1g_1 + d_2$$

allowing a sequential determination of the coefficients g_1, g_2, \dots . If the process transfer function includes non-rational factors, for example the exponential factor associated to a dead time, one has simply to include the Taylor–McLaurin expansions of these factors into the numerator or into the denominator of the rational fraction as appropriate. In particular, the transfer function

$$G(s) = K \frac{(1-T_0s)}{(1+T_1s)(1+T_2s)\dots(1+T_ns)} e^{-Ds}$$

can be written down in the form

$$G(s) = K \frac{(1-T_0D)s+D^2s^2/2+\dots}{1+(T_1+T_2+\dots+T_n)s+(T_1T_2+T_2T_3+\dots+T_nT_1)s^2+\dots}$$

Then, straight-forward calculations yield

$$-g_1 = D + T_0 + T_1 + T_2 + \dots + T_n = T_{ar}$$

$$g_2 = \frac{1}{2}T_{ar}^2 + \frac{1}{2}(T_1^2 + T_2^2 + \dots + T_n^2 - T_0^2)$$

Appendix B

Thanks to the algorithm proposed in Appendix A it is possible to obtain the required characteristics of the process to be controlled from the step response of any stable control loop including this process and a PI controller with known parameters. Denoting by $P(s)$ and $C(s)$ the transfer functions of the process and of the PI controller, and by $G(s)$ and $Q(s)$ the closed-loop transfer functions relating, respectively, the process output variable y and the controller output variable u to the controller reference signal w , and using the following Taylor–McLaurin expansions of these transfer functions:

$$P(s) = K(1 + p_1s + p_2s^2 + \dots)$$

$$C(s) = K_p \frac{1+T_is}{T_is}$$

$$G(s) = \frac{P(s)C(s)}{1+P(s)C(s)} = 1 + g_1s + g_2s^2 + \dots$$

$$Q(s) = \frac{1}{K} \frac{C(s)}{1+P(s)C(s)} = \frac{1}{K}(1 + q_1s + q_2s^2 + \dots),$$

straightforward calculations yield the following relations for the process characteristics:

$$K = \frac{y(\infty)}{u(\infty)} = \frac{w(\infty)}{u(\infty)} = \frac{T_i}{-g_1K_p}$$

$$T_{ar} = -p_1 = q_1 - g_1$$

$$T_a = \sqrt{2(g_2 - q_2) + T_{ar}(T_{ar} + 2g_1)}$$

where

$$g_1 = \int_0^\infty \left[1 - \frac{y(t)}{y(\infty)}\right] dt, \quad g_2 = \int_0^\infty t \left[1 - \frac{y(t)}{y(\infty)}\right] dt$$

$$q_1 = \int_0^\infty \left[1 - \frac{u(t)}{u(\infty)}\right] dt, \quad q_2 = \int_0^\infty t \left[1 - \frac{u(t)}{u(\infty)}\right] dt$$

where $y(t)$ and $u(t)$ are, respectively, the process and controller responses to a step of magnitude $w(\infty)$ in the controller reference variable.

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8th EUROSIM Congress on Modelling and Simulation

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CROSSIM	Croatian Society for Simulation Modeling <i>Croatia</i>
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DBSS	Dutch Benelux Simulation Society <i>Belgium, Netherlands</i>
FRANCOSIM	Société Francophone de Simulation <i>Belgium, France</i>
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SloSIM	Slovenian Simulation Society <i>Slovenia</i>
UKSIM	United Kingdom Simulation Society <i>UK, Ireland</i>
ROMSIM	Romanian Society for Modelling and Simulation, <i>Romania, Observer Member</i>

Contact addresses, weblinks and officers of the societies may be found in the information part of the societies.

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ASIM German Simulation Society Arbeitsgemeinschaft Simulation

ASIM (Arbeitsgemeinschaft Simulation) is the association for simulation in the German speaking area, servicing mainly Germany, Switzerland and Austria. ASIM was founded in 1981 and has now about 700 individual members, and 30 institutional or industrial members. Furthermore, ASIM counts about 300 affiliated members.

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CROSSIM-Croatian Society for Simulation Modelling was founded in 1992 as a non-profit society with the goal to promote knowledge and use of simulation methods and techniques and development of education. CROSSIM is a full member of EUROSIM since 1997.

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CSSS -The *Czech and Slovak Simulation Society* has about 150 members working in Czech and Slovak national scientific and technical societies (*Czech Society for Applied Cybernetics and Informatics*, *Slovak Society for Applied Cybernetics and Informatics*). The main objectives of the society are: development of education and training in the field of modelling and simulation, organising professional workshops and conferences, disseminating information about modelling and simulation activities in Europe. Since 1992, CSSS is full member of EUROSIM.

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The Dutch Benelux Simulation Society (DBSS) was founded in July 1986 in order to create an organisation of simulation professionals within the Dutch language area. DBSS has actively promoted creation of similar organisations in other language areas. DBSS is a member of EUROSIM and works in close cooperation with its members and with affiliated societies.

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HSS – Hungarian Simulation Society

The Hungarian Member Society of EUROSIM was established in 1981 as an association promoting the exchange of information within the community of people involved in research, development, application and education of simulation in Hungary and also contributing to the enhancement of exchanging information between the Hungarian simulation community and the simulation communities abroad. HSS deals with the organization of lectures, exhibitions, demonstrations, and conferences.

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PSCS – Polish Society for Computer Simulation - update

PSCS was founded in 1993 in Warsaw. PSCS is a scientific, non-profit association of members from universities, research institutes and industry in Poland with common interests in variety of methods of computer simulations and its applications. At present PSCS counts 257 members.

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ISCS – Italian Society for Computer Simulation

The Italian Society for Computer Simulation (ISCS) is a scientific non-profit association of members from industry, university, education and several public and research institutions with common interest in all fields of computer simulation.

→ www.eurosim.info

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Last data update April 2005

SIMS – Scandinavian Simulation Society

SIMS is the *Scandinavian Simulation Society* with members from the four Nordic countries Denmark, Finland, Norway and Sweden. The SIMS history goes back to 1959. SIMS practical matters are taken care of by the SIMS board consisting of two representatives from each Nordic country. Iceland will be represented by one board member.

SIMS Structure. SIMS is organised as federation of regional societies. There are FinSim (Finnish Simulation Forum), DKSIM (Dansk Simuleringsforening) and NFA (Norsk Forening for Automatisering).

→ www.scansims.org

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Last data update December March 2011

SLOSIM – Slovenian Society for Simulation and Modelling

SLOSIM - Slovenian Society for Simulation and Modelling was established in 1994 and became the full member of EUROSIM in 1996. Currently it has 69



members from both slovenian universities, institutes, and industry. It promotes modelling and simulation approaches to problem solving in industrial as well as in academic environments by establishing communication and cooperation among corresponding teams.

→ www.slosim.si

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Last data update March 2011

UKSIM – United Kingdom Simulation Society

UKSIM has more than 100 members throughout the UK from universities and industry. It is active in all areas of simulation and it holds a biennial conference as well as regular meetings and workshops.

→ www.uksim.org.uk

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Last data update March 2009 (partially)

CEA-SMSG – Spanish Modelling and Simulation Group

CEA is the Spanish Society on Automation and Control. In order to improve the efficiency and to deep into the different fields of automation, the association is divided into thematic groups, one of them is named 'Modelling and Simulation', constituting the group.

→ www.cea-ifac.es/wwwgrupos/simulacion

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Last data update March 2009

LSS – Latvian Simulation Society

The Latvian Simulation Society (LSS) has been founded in 1990 as the first professional simulation organisation in the field of Modelling and simulation in the post-Soviet area. Its members represent the main simulation centres in Latvia, including both academic and industrial sectors.

→ briedis.itl.rtu.lv/imb/

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Last data update December 2008

ROMSIM – Romanian Modelling and Simulation Society

ROMSIM has been founded in 1990 as a non-profit society, devoted to both theoretical and applied aspects of modelling and simulation of systems. ROMSIM currently has about 100 members from both Romania and Republic of Moldavia.

→ www.ici.ro/romsim/

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✉ ROMSIM / Florin Stanciulescu,
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Last data update March 2009

EUROSIM Societies – Conferences

MATHMOD Vienna Conference Series – Eurosim Events

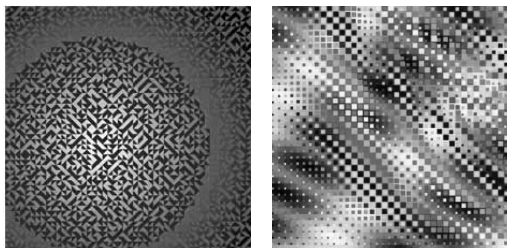
At MATHMOD Vienna – *Vienna International Conference on Mathematical Modelling* scientists and engineers using or developing models or interested in the development or application of various modelling tools are offered an opportunity to present ideas, methods and results and discuss their experiences with experts of various areas of specialization. The scope of the *MATHMOD* covers theoretic and applied aspects of all types of mathematical modelling.



MATHMOD 2012. The conference series *MATHMOD Vienna* was started in February 1994

with the 1st MATHMOD Vienna, followed by MATHMOD conferences in February 1997, 2000, 2003, 2006, and 2009. Since 2009 MATHMOD Conferences organised under the flagship of *EUROSIM Events*. At present MATHMOD 2012 is prepared, to be held February 15 – 17, 2012, at Vienna University of Technology.

MATHMOD 2012 continues with organization of minisymposia, where EUROSIM societies are engaged: SLOSIM (Medicine and Pharmacy – M. Maja Atanasijev-Kunc), SIMS (Water Treatment / Sustainable Energy, Esko Juuso), ASIM (Vibrations in Engineering Systems, H. Ecker; Education, A. Körner; Biotechnology, K. Noeh, Health Technology, N. Popper; Classical and Quantum Circuits, W. Mathis).



Furthermore, since 2009, Vlatko Ceric, past president of CROSSIM, is providing his algorithm art as design for MATHMOD. For MATHMOD 2009, Vlatko Ceric's algorithmic art series *Nexus* (at left) was basis for layouts and for the general MATHMOD logo, and for MATHMOD 2012 the series *Composition and Ocean* (at right).

→ www.mathmod.at

Liophant Simulation – I3M Conferences

Liophant is a non-profit association born in order to be a trait-d'union among simulation developers and users; Liophant is devoted to promote and diffuse the simulation techniques and methodologies; the Association promotes exchange of students, sabbatical years, organization of International Conferences, organization of courses and stages in companies to apply the simulation to real problems.

The society's name underlines the importance of modeling and simulation: the *Liophant* is a mythological being that only simulation can bring back to life !

Liophant Simulation is organizing the Conference Series I3M - International Multidisciplinary Modelling & Simulation Multiconference The M&S multiconference moving around the World and along the years attended by top experts from Mediterranean, Latin & North Americas, Europe, Asia, Africa and Australia.



I3M2012 Vienna. Next I3M, the *9th International Multidisciplinary Modelling & Simulation Multiconference* is scheduled for September 19 – 21, 2012, Vienna. I32012 will combine the following conferences and workshops:

- EMSS2012 - 24th European Simulation Symposium and Exhibition - Simulation in Industry
- HMS2012 - 14th International Conference on Harbour, Maritime & Multimodal Logistics Modelling and Simulation
- MAS2012 - 11th International Conference in Modeling & Applied Simulation
- IMAACA2012 - 6th International Conference on Integrated Modeling and Analysis in Applied Control and Automation
- DHSS2012 - International Defense and Homeland Security Simulation Workshop
- IWISH2012 - International Workshop on Innovative Simulation for Health Care

Info: → www.liophant.org/conferences/2012/

Liophant Simulation has applied for membership in EUROSIM, so that I3M will become a *EUROSIM Event*

Info: → www.liophant.org

**ASIM****ASIM****ASIM**

ASIM - Buchreihen / ASIM Book Series

Fortschritte in der Simulationstechnik / Frontiers in Simulation Monographs - Conference Proceedings

Simulation und Optimierung in Produktion und Logistik.

L. März, W. Krug, O. Rose, G. Weigert, G. (eds.), ISBN 978-3-642-14535-3, Springer, 2011

Integrationsaspekte der Simulation: Technik, Organisation und Personal.

Zülch, G., Stock, P. (eds.), ISBN 978-3-86644-558-1, KIT Scientific Publishing, Karlsruhe, 2010

**Verifikation und Validierung für die Simulation in Produktion und Logistik,
Vorgehensmodelle und Techniken.**

M. Rabe, S. Spieckermann, S. Wenzel (eds.); ISBN: 978-3-540-35281-5, Springer, Berlin, 2008

Advances in Simulation for Production and Logistics Applications.

M. Rabe (ed.), ISBN 978-3-8167-7798-4, Fraunhofer IRB-Verlag, Stuttgart, 2008

Modellierung, Regelung und Simulation in Automotive und Prozessautomation

- Proceedings 5. ASIM-Workshop Wismar 2011. –

C. Deatcu, P. Dünow, T. Pawletta, S. Pawletta (eds.), ISBN 978-3-901608-36-0,
ASIM/ARGESIM, Wien, 2011.

Reihe Fortschrittsberichte Simulation / Series Advances in Simulation

Ch. Steinbrecher: **Ein Beitrag zur prädiktiven Regelung verbrennungsmotorischer Prozesse**

FBS 18, ASIM/ARGESIM Vienna, 2010; ISBN 978-3-901608-68-1, ARGESIM Report 68

O. Hagendorf: **Simulation-based Parameter and Structure Optimisation of Discrete Event Systems**

FBS 17, ASIM/ARGESIM Vienna, 2010; ISBN 978-3-901608-67-4, ARGESIM Report 67

D. Leitner: **Simulation of Arterial Blood Flow with the Lattice Boltzmann Method**

FBS 16, ASIM/ARGESIM Vienna, 2009; ISBN 978-3-901608-66-7, ARGESIM Report 16

Th. Löscher: **Optimisation of Scheduling Problems Based on Timed Petri Nets.**

FBS 15, ASIM/ARGESIM Vienna, 2009; ISBN 978-3-901608-65-0, ARGESIM Report 15

J. Wöckl: **Hybrider Modellbildungszugang für biologische Abwasserreinigungsprozesse.**

FBS 14, ASIM/ARGESIM Vienna, ISBN 3-901608-64-8, 2006, ARGESIM Report 14,

M. Gyimesi: **Simulation Service Providing als Webservice zur Simulation Diskreter Prozesse.**

FBS 13, ASIM/ARGESIM Vienna, ISBN 3-901-608-63-X, 2006, ARGESIM Report 13

R. Fink: **Untersuchungen zur Parallelverarbeitung mit wissenschaftlich-technischen
Berechnungsumgebungen.**

FBS 12, ASIM/ARGESIM Vienna, 2008; ISBN 978-3-901608-62-9, ARGESIM Report 12

H. Ecker: **Suppression of Self-excited Vibrations in Mechanical Systems by Parametric
Stiffness Excitation.**

FBS 11, ASIM/ARGESIM Vienna, ISBN 3-901-608-61-3, 2006, ARGESIM Report 11

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ASIM/ARGESIM Geschäftsstelle Österreich, c/o DWH, Neustiftgasse 57, 1040 Vienna, Austria

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Info: www.asim-gi.org, info@asim-gi.org

**REPORTS****REPORTS**



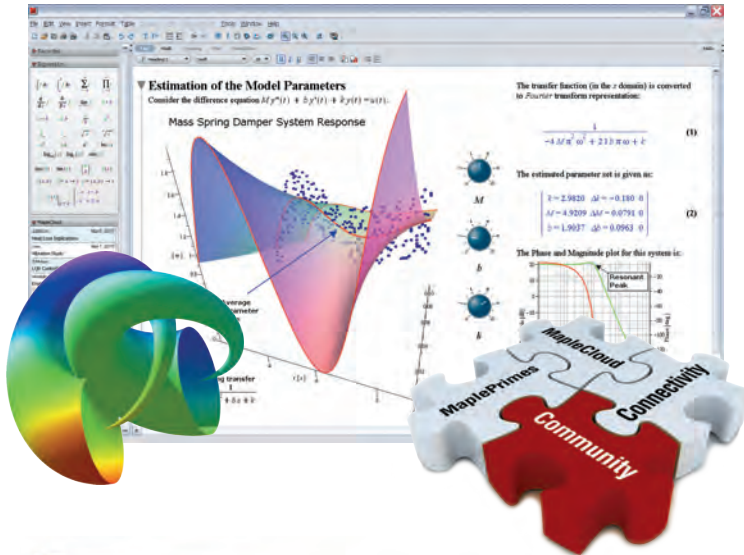
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