Introducing Simulation Tools early in Engineering Course

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Brasil
Summary

• Brief facts about São Paulo, USP, and Escola Politécnica
• Course Structure
• Simulation Classes
• Pros and Contras
• Conclusions
Abstract

Recently the Mechanical Engineering Course of the Escola Politecnica da Universidade de Sao Paulo –Brazil has been updated. The goal was to turn the program more flexible and to introduce engineering lectures earlier in order to make the course more attractive to young students. The updated program is now reaching the final years of the course, and we are getting a first glance of the pros and contras of the new program structure.

Modeling was always a common task in many disciplines in mechanical engineering, e.g., classical mechanics, instrumentation, mechanical vibration, dynamic systems modeling, fluid and thermodynamics, analog and digital control, biomechanics, etc. But, in the old program we have experienced that in all classes that use modeling and simulation, students spend more time trying to get their models running than actually analyzing the phenomena. Therefore we decided to anticipate a class in system modeling to an earlier stage in the mechanical course with the goal of introducing simulation tools as soon as possible. The purpose was to make simulation tools available for the students along the rest of the course. So a new class on simulation was created, where the students are exposed to simulation concepts and have the opportunity to practice with simulations tools.

The scope of this discipline is introducing numerical integration of systems of algebraic and ordinary differential equations, show some representation options, like, algebraic-numerical model, state-space representation, block diagram, equation and component representation.

We present typical simple dynamic problems in many domains as class and homework examples, like simple and double pendulum, spherical pendulum, sphere moving in a fluid with viscose and drag forces, mass-spring-damper system, electrical first and second order systems, hydraulic and thermal systems and the serial and parallel association of them.

In a view to making this tools available for students, at all times, we use only free available computing software like Scilab, Xcos, and OpenModelica. This paper presents the structure of the curricula, strategies, and exercises of the simulation class, and discuss our experience, their pros and contras.
Brief facts about São Paulo

São Paulo is the industrial and financial center of Brazil
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
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<tbody>
<tr>
<td>Economically-active population 15 years of age or over</td>
<td>69.7%</td>
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<tr>
<td>Economically-active women 15 years of age or over</td>
<td>60.03%</td>
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<tr>
<td>GDP per capita</td>
<td>8,528 US$</td>
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<td>Investment in research and development</td>
<td>1.15% of GDP</td>
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<td>Overall GDP</td>
<td>1,772,591 million US$</td>
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<td>Public expenditure on education</td>
<td>5.8% of GDP</td>
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<td>Public expenditure on health services</td>
<td>9.7% of GDP</td>
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<td>Total exports</td>
<td>225,098.41 million US$</td>
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<tr>
<td>Total imports</td>
<td>229,060.06 million US$</td>
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<tr>
<td>Tourist arrivals</td>
<td>6,430,000 tourists</td>
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</table>
Some facts about São Paulo State

<table>
<thead>
<tr>
<th>MHDI 2010</th>
<th>MHDI range</th>
<th>Population (2010 Census)</th>
<th>Area</th>
<th>Demographic density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.783</td>
<td>High</td>
<td>41,262,199</td>
<td>248,222,36 km²</td>
<td>166.23 hab/km²</td>
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<td>(MHDI between 0.700 and 0.799)</td>
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</table>

Population in São Paulo State:
- **Population**: 44,000,000
- **GDP in BRL million**: 1,408,904
- **GDP in USD million**: 721,036
- **Share**: 32.1%

Map showing the demographic density of all Brazilian states.

9th OpenModelica Annual Workshop
City of São Paulo

About US$ 150 billion

~12%
Brazilian population is aging – demographic transition
Brazil

Layer: Municipality

Legend

- 0,800 - 1
- 0,700 - 0,799
- 0,600 - 0,699
- 0,500 - 0,599
- 0,000 - 0,499
- No data

Partners

9th OpenModelica Annual Workshop
University of São Paulo – USP
and
Escola Politécnica

Escola Politécnica is the Engineering School of USP
University of São Paulo

Public university established in 1934
Advanced center for education, research and extension services to the community
• 247 undergraduate courses
• 239 graduate programs
• 5,940 professors
• 58,000 students
Escola Politécnica

Since 1893
Incorporated to University of São Paulo - USP in 1934

Total Area
≈ 152,525 m²

Faculty and Staff
466 lectures and professors (about 20% full professors)
466 staff

Students
4,964 undergraduate students
1,830 graduate students
Master Degree 705
Doctor Degree 694
Special enrollment 431

Departments - 15
- Civil Engineering
- Structures and Geotechnics
- Environment and Hydraulics
- Transportation
- Computation and Digital Systems
- Automation and Energy
- Electronic Systems
- Telecommunication and Control
- Mechanics
- Mechatronics
- Naval and Offshore
- Production
- Chemistry
- Metallurgical and Materials
- Mining, Oil, and Gas

http://www.poli.usp.br/
International Relations

Offers 3 types of student exchange program:

• Open
• Credit transfer
• Double diploma

Polytechnic School has exchange agreements with dozens of education and research institutions abroad, as England, France, Germany, Italy, Korea, Portugal, Spain and USA.
International Agreements and Student Exchange

• 31 agreements for Double Diploma (Germany, Spain, France, Italy, Peru e Portugal)
• 160 agreements for student exchange (credit transfer) with 36 countries from America, Europe, and Asia
• 39 agreement for Double Degree at graduation level
• 02 graduation agreements
• 01 agreement for Technological and Scientific Cooperation

• 915 Total of students abroad
  • 513 at study exchange
  • 402 at study exchange for Double Diploma
• 192 Total of foreigners students
  • 157 foreigners students at the exchange program
  • 45 foreigners students for double diploma
Department of Mechanical Engineering

• 51 professors
• 350 undergraduate students
• 223 graduate students
• 2,000 students from others courses at Poli

http://www.poli.usp.br/
# Course Structure

## Simulation

<table>
<thead>
<tr>
<th>Semester</th>
<th>1</th>
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<td>Calculus 1</td>
<td>Linear Algebra 1</td>
<td>Descriptive Geometry</td>
<td>Experimental Physics</td>
<td>Chemistry</td>
<td>Computation</td>
<td>Introduction to Engineering</td>
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<td>2</td>
<td>Calculus 2</td>
<td>Physics 1</td>
<td>Linear Algebra 2</td>
<td>Classical Mechanics</td>
<td>Mechanical Design</td>
<td>Workshop</td>
<td>Environment</td>
<td>Economy &amp; Administration</td>
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<td>Calculus 3</td>
<td>Physics 2</td>
<td>Physics Lab 1</td>
<td>Analytic Mechanics</td>
<td>Solid Mechanics 1</td>
<td>Manufacturing Lab</td>
<td>Probability</td>
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<td>4</td>
<td>Calculus 4</td>
<td>Physics 3</td>
<td>Physics Lab 2</td>
<td>Fluid Dynamics 1</td>
<td>Solid Mechanics 2</td>
<td>Simulation Lab</td>
<td>Statistics</td>
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<td>Electricity</td>
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<td>Machine Design 1</td>
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<td>Hydraulic Machines</td>
<td>Vibrations</td>
<td>Control</td>
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<td>Engines</td>
<td>Thermal Machines</td>
<td>Instrumentation</td>
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<td>Discrete Control</td>
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260 class credits
Simulation Classes

PME 3201
Lab class offered in the 4th semester
of the 10 semester mechanical engineering course
Simulation Lab

• 24 hours of lab activity
• 6 classes of 4 hours + examination
• 24 students per class
• hands-on class activity and home assignments
• Three main blocks:
  • Numerical Integration – command line programing in Scilab
  • Modeling and Analysis of mechanical systems – direct programing in Scilab
  • Modeling techniques with MODELICA – modeling in OpenModelica
Numerical Integration

• implicit and explicit Euler, Runge-Kutta, Adams
• Integration and interpretation of differential equations and system of differential equations
• State space formulation
• Programming of numerical integration algorithm in Scilab
Modeling of Mechanical Systems

• Application to Mechanical Systems
• Write the differential equations by hand
• Integration of differential equations with Scilab functions
• Solution of linear and non-linear dynamics
• Emphasis on interpretation of the solution and on model verification
• Block diagram representation
\[
\begin{align*}
\frac{\partial L}{\partial \phi} &= (m_1 + m_2) l_1 \dot{\phi}^2 + m_2 l_1 l_2 \cos(\varphi - \theta) \ddot{\theta} \\
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\phi}} \right) &= (m_1 + m_2) l_1 \dot{\phi}^2 + m_2 l_1 l_2 \cos(\varphi - \theta) \ddot{\theta} - m_2 l_1 l_2 \sin(\varphi - \theta) (\dot{\phi} \dot{\theta}) \\
\frac{\partial L}{\partial \theta} &= -m_2 l_1 l_2 \sin(\varphi - \theta) \dot{\phi} \dot{\theta} - (m_1 + m_2) g l_1 \sin \varphi \\
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\theta}} \right) - \frac{\partial L}{\partial \theta} &= 0 \\
\Rightarrow (m_1 + m_2) l_1 \ddot{\phi} + m_2 l_2 \cos(\varphi - \theta) \ddot{\theta} + m_2 l_2 \sin(\varphi - \theta) \dot{\theta}^2 + (m_1 + m_2) g \sin \varphi &= 0
\end{align*}
\]
Introduction to MODELICA

• Solution of simple first and second order dynamic systems
• Mechanical, electrical, thermal and fluid examples
• Modeling with OpenModelica
• Solution with:
  • Graphical approach
  • Flat text solution – acausal equation approach
  • Construction of component library
  • Connecting of physical components
  • Hierarchical class structure
• Exploring of modeling and simulation resources of OpenModelica
• Numeric experiments to explore the response of dynamic systems
Example of problems

- simple and double pendulum;
- spherical pendulum;
- sphere moving in a fluid with viscose and drag forces;
- mass-spring-damper system;
- electrical first and second order systems;
- hydraulic and thermal systems;
- serial and parallel association;
- Non-linear and linearized solution;
- Forced and autonomous solution.
Pros and Contras

• Pros
  • Solution of engineering applications and hand-on approach stimulates student interest
  • Permits “what's if” exploration of system dynamics
  • Acquired Simulation skills make upcoming modeling classes more productive

• Contras
  • Lack of basic knowledge in modeling and have little proficiency in analytical solution of differential equations
  • Short and intense course is not easy for some students
  • Not all Students are mature to understand dynamic solutions
Conclusions

• Earlier contact to numerical simulations motivates students and prepare for modeling classes
• Free software is a very important education resource that can be used in class and at home
• OpenModelica is very appreciate by the students and is an important tool for teaching modelling and system dynamics
• Further analysis must be done to evaluate the performance of students in modeling classes after attending simulation lab
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