Enhancing Learning Experience with Dynamic Animation

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Abstract: This paper reports on the use of dynamic animation to enhance learning and interest for a senior level course on system analysis. This course includes analytic methods from both frequency and time domains with emphasis on real world problems. Ansim, the freely available Mathworks animation toolbox, was chosen because it works seamlessly with Matlab/Simulink, a required software for the EE undergraduate curriculum. A series of lab sessions are introduced to the class to complement the lecture materials and to guide the students into the design project. The use of animation provides many advantages: better visual effects, improved communications, and higher interest levels. Student response has been very positive. A number of recommendations are made in this work based on instructor observation and course evaluations.

(I) Introduction

System analysis is a multidisciplinary subject encompassing all fields of engineering applications. However, the traditional treatment (in the sense of teaching pedagogy) of this subject tends to be highly theoretical and mathematical with heavy emphasis on equation derivation and algorithmic development. Such approach is convenient from the instructor's point of view but may not be beneficial to the students who are classified as sensing types (MBTI), or visual (ILS), or concrete experience Kolb's [11] model.

It is observed that about 70% of learners are not analytic learners. Kolb's experiential learning theory advocates a holistic approach to combine experience, perception, cognition and behavior. This curriculum is designed to adopt Kolb's theory and to adapt to students' learning needs. These class activities allow students with various learning styles to move through stages of experiential learning for one would learn best when one uses all four processes: 1) Concrete Experience, 2) Reflective Observation, 3) Abstract Conceptualization and 4) Active Experimentation.

One of the major functions of education is to shape students' attitude toward learning and to develop effective learning skills. The authors hope to accomplish these objectives by using dynamic animation and team project. It is not merely about including practical experiences but utilizing these experiences to induce higher levels of learning. Furthermore, students will be exposed to the importance of team work, working collaboratively through individual differences which is an integral part of real work scenarios.

In the past decade, the availability of student dynamic simulation and analysis software provided the first step towards closing the gap between classroom and "real-world" experience. The term animation covers a broad range of software applications such as kinematics and dynamics. For kinematic animation, use of keyframing and motion capture constitute the primary mean of driving the animation sequence (e.g. Poser, 3D Studio Max, Jack, etc.). Emphasis of kinematic animation falls on "life-like" quality and stunning graphics. It is therefore as much art as science. Dynamic animation is driven by the outputs of a simulation engine to provide a 2D or 3D display of the physical characteristics of the application. The output may contain simplified geometric objects such as line, rectangles, circles, etc. The benefits of dynamic animation include: (1) better interpretation of the results of the simulation so that the students can actually visualize the execution of the system/subsystem, (2) more efficient communication of the results, and most importantly, (3) improving student interest in the subject materials.

A number of researchers have reported their effort in using animation to enhance design and/or education effectiveness. For example [1] described an engineering animation tool that included motion control development. In [2], a real time simulation/animation tool was developed to facilitate the evaluation of active suspension systems. In [3], animation of flexible manufacturing system was carried out in conjunction with modeling and control. Arrival of student versions of graphical simulation software such as Matlab, VisSim, and LabVIEW sparked interests in adding an animation stage to the simulation. Such efforts were described in [4], [5], [6], and [9]. In [8], [10], a Visual C++, Direct-3D based software was generated for interactive modeling, simulation, animation, and control f dynamic systems. In [7], the ubiquitous world wide web was utilized to implement computer animated simulation instruction modules. This paper describes a similar approach to the past effort, i.e. using Matlab/Simulink as the numerical engine. However, the Matlab Animation toolbox, a freely downloadable software that works seamless with Simulink (professional as well as student versions), is used to generate simple dynamic animation for the purpose of enhancing student learning and appreciation of "real-world" dynamic systems. Furthermore, the simulation/animation component is directly integrated into the course so that progressive learning and coordination with the lecture materials can be carried out.

(II) Course Description

Dynamic animation was introduced into the senior level course "EE482 Instrumentation and Control" in the 2000 academic year and has since been an integral part of this required course. The old curriculum focused extensively on classical frequency response methods such as complex variables, frequency response methods (Bode, Nyquist, Nichols), stability assessment techniques (Routh-Hurwitz, root locus), performance criteria (sensitivity, steady accuracy, transient response), and compensation (lag, lead). Although it may be argued that the course contents possess educational values, it is generally agreed that significant revision is necessary to reflect the change in technologies and modern engineering career challenges. In particular, computer-aided analysis, state space methods, and nonlinear systems are introduced into the curriculum, replacing lag, lead compensation, Nichols chart, and parts of the performance criteria. That is, the emphasis of the course is on analysis rather than control design which is relegated to a second course "EE486 Control Systems Electives". An outline of the lecture is shown below:

- Introduction to Systems, Review of LaPlace Transform
- Transfer Functions, Signal Flow Graphs, Stability
- Frequency Response of Linear Systems: Bode and Nyquist
- Identification of Dynamic Systems
- Performance Characteristics and Feedback; Case study: positioners, actuators, and sensors
- Properties and Solution of State-Space Systems
- Modeling of Physical/Biological/Nano Processes, Linearization
- Stability Assessment: Routh-Hurwitz
- Root Locus Method
- The Nyquist Stability Criterion
- Describing Functions and Limit Cycles
- Application of Describing Functions
- Review and Project Presentation

The revised contents can potentially be highly mathematical and run into the same problems of being disconnected from the real world. Therefore, a complementary laboratory session is added to introduce limited hands-on experience for the class. The laboratory engine is based on Mathwork's Matlab/Simulink package and consists of the following topics:

- Introduction to Matlab
- Matlab Differential Equation Solvers
- First and Second Order Linear Systems
- Introduction to Simulink
- Common Nonlinear Systems and Simulation
- Simulating Chaotic systems
- Computer Animation
- Project Development

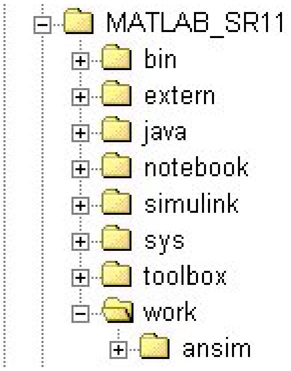
The homework assignments comprise of simpler problems that can be hand calculated so that the students can focus on the concept and mechanics of analysis. More in-depth versions of the problems are assigned in the lab sessions where the students team up and tackle the problems using Matlab and Simulink. The project is introduced at mid-term. It is a realistic, multiple degree-of-freedom type (e.g. two link robot, crane with variable loads) with nonlinear dynamics and were generally difficult to "sense" or "visualize" directly. Dynamic animation provides an extra dimension of learning where the students can develop a deeper sense of understanding of the system characteristics and therefore apply creative solutions to the problem. Finally, a full array of support is available to the students:

- Teaching Assistant
- Peer Facilitator
- Open Lab hours
- Office Hours

- Dedicated website
- Coordinated lectures and lab sessions

(III) Animation and the Matlab Animation Toolbox

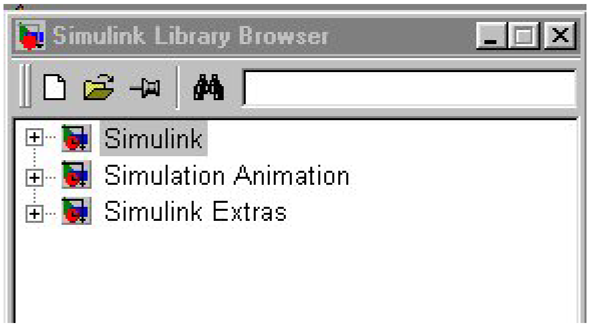
The animation toolbox, Ansim, is freely downloadable from Mathworks. It works with both professional as well as student versions of Matlab/Simulink version 4 and above. Installation of the toolbox is somewhat OS dependent. For the student version (5.3+) running on Windows 98 or 2000 system, the preferred destination of the ansim folder is in the work subdirectory of Matlab as shown in Figure 1 below:



```
MATLAB_SR11
    bin
    extern
    java
    notebook
    simulink
    sys
    toolbox
    work
        ansim
```

Figure 1 Directory Structure of the Ansim Toolbox

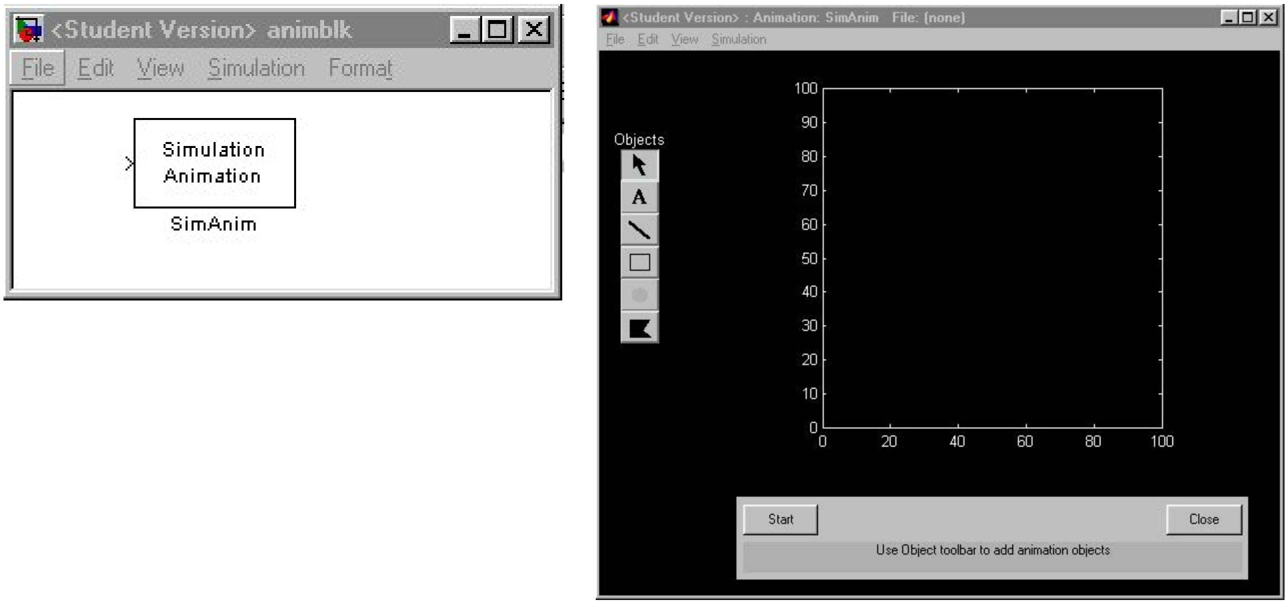
The corresponding Simulink Library Browser window will then correctly reflect the path as shown in Figure 2:



Simulink Library Browser

Simulink
Simulation Animation
Simulink Extras

Figure 2 Simulink Library Browser Window Showing the Animation Toolbox

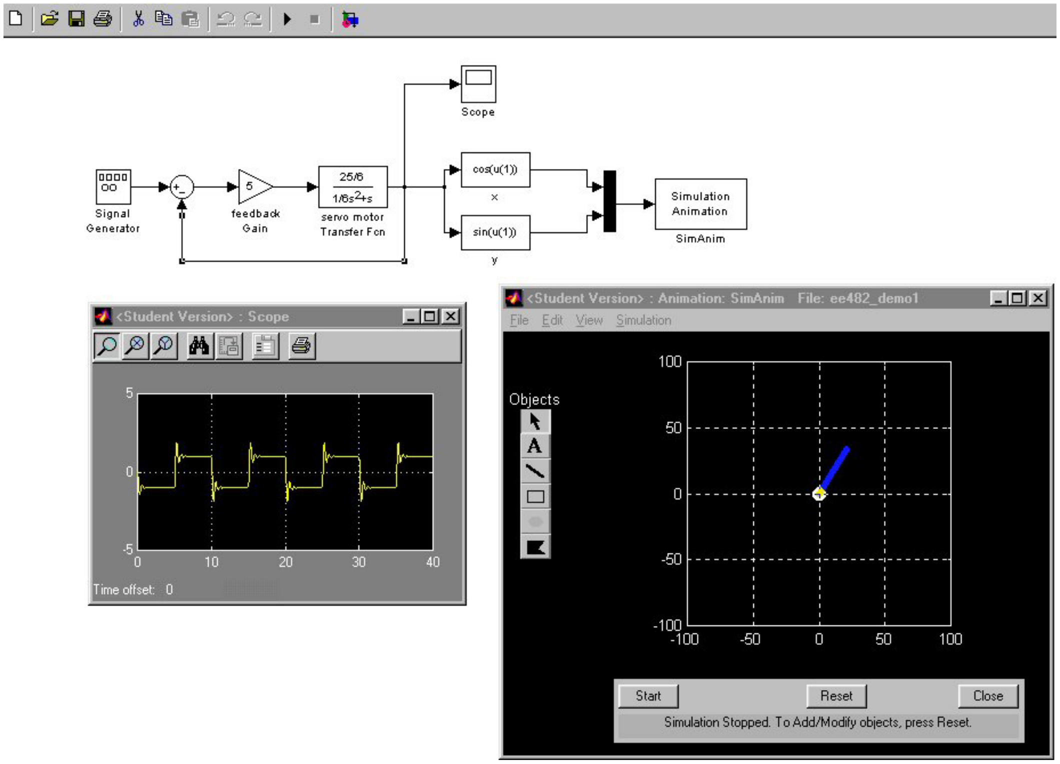


Use Object toolbar to add animation objects

Figure 3 Animblk Block and the Animation Window

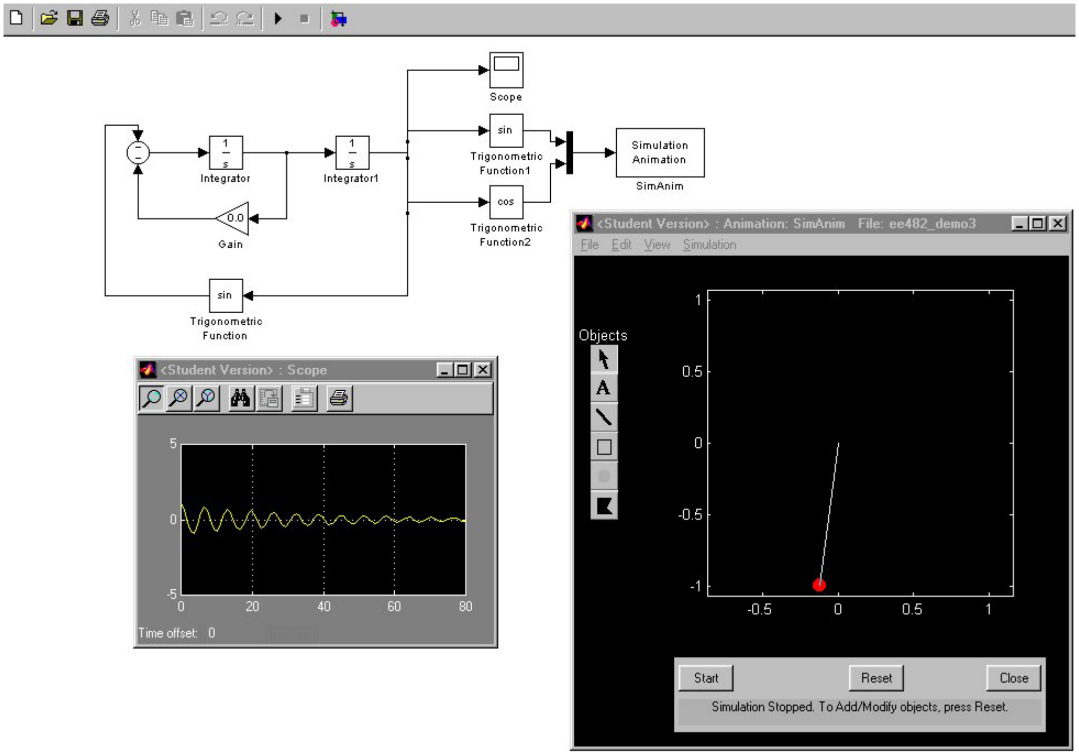
Animblk.mdl in the ansim folder, shown in Figure 3, is a self-contained block that handles 2D object animation based on the Cartesian coordinates generated by Simulink. As shown in Figure 3, there are five basic elements in animblk: text, line, rectangle, dot, and patch. The text element enables the user to move, zoom, color, and rotate a text string. The line element has three vertices defined as (x1, x2, x3) and (y1, y2, y3). These parameters are ported into animblk using a mux element in the Simlink Signals and Systems Library. The line width and color can also be specified by the simulation output. Similarly, the patch object is defined by a series of matching x, y coordinates: (x1, x2, …) and (y1, y2, …). The rectangles, on the other hand, are specified by the lower left x, y coordinates, height, and width. Finally, the dot element can vary in position (as specified by the x, y coordinates), size, and color.

A simple example consisting of a second order system (DC motor) under proportional feedback control is shown in Figure 4. In this example, the students can vary the feedback gain "K" and observe the effects on the output angle which exhibits overdamped, critically damped, and underdamped characteristics as "K" is increased in accordance to the root locus diagram. The conventional output is shown in the scope display. However, the animation screen shows a single rigid link attached to the shaft of the motor so that the link rotates according to the output angle of the motor shaft. The students can now easily visualize the physical characteristics of the motor and draw conclusions that are otherwise less obvious. For example, some students immediately point out that excessive overshoot can be a potential safety problem to both the hardware and people standing near it. It should be noted that the output angle must be converted into the respective Cartesian coordinates for the line element according to (0, L cos ϕ), (0, L sin ϕ) for the x and y vectors. A second example illustrates the motion of a physical pendulum governed by a second order nonlinear differential equation. Both the line element (for the string) and the dot element (for the bob) are used for the animation. Again, the animation output provides a better "feel" for the dynamics of the pendulum (Figure 5).



Simulation Stopped. To Add/Modify objects, press Reset.

Figure 4 Animation of a Second Order Linear Feedback System



Simulation Stopped. To Add/Modify objects, press Reset.

Figure 5 Animation of a Physical Pendulum

(IV) Project Description

The project is an integral part of the course. It accounts for 15% for the total grade and it is assigned at mid-term to the class teams each consisting of 2 students. The project is first broken down into the sub-components for the teams to work on during the lab sessions. That is, simulation block build, debug, and partial animation. The teams are then required to integrate the system together, devise an strategy to coordinate the motion, analyze the results, and produce a parts list and specifications.

Two types of projects have been assigned over the past semesters: a two-link rotary robot and a crane system. Both systems are described by a set of nonlinear differential equations.

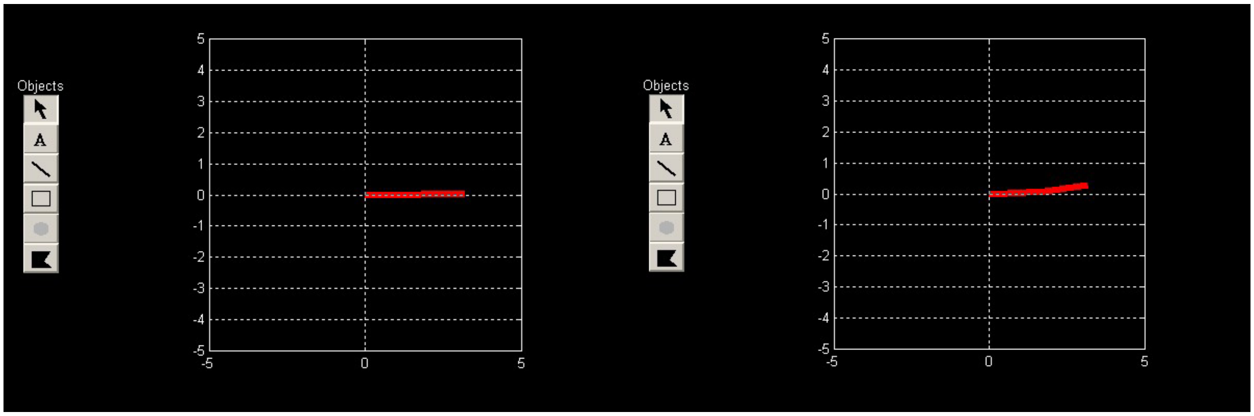
Dynamics of the two-link robot are described by the following equations:

$$
\begin{aligned}
\tau_1 &= m_2 l_2^2(\ddot{\theta}_1 + \ddot{\theta}_2) + m_2 l_1 l_2 c_2 (2\ddot{\theta}_1 + \ddot{\theta}_2) + (m_1 + m_2) l_1^2 \ddot{\theta}_1 - m_2 l_1 l_2 s_2 \dot{\theta}_2^2 - 2 m_2 l_1 l_2 s_2 \dot{\theta}_1 \dot{\theta}_2 \\
\tau_2 &= m_2 l_1 l_2 c_2 \ddot{\theta}_1 + m_2 l_1 l_2 s_2 \dot{\theta}_1^2 + m_2 l_2^2 (\ddot{\theta}_1 + \ddot{\theta}_2) \\
c_i &= \cos\theta_i, i = 1, 2 \\
s_i &= \sin\theta_i, i = 1, 2
\end{aligned}
$$

where

l_1, l_2	lengths of links 1 and 2 in meters
m_1, m_2	mass of motor 1 and 2 in kg
τ_1 τ_2	output torque of the motors 1 and 2 in N-m
θ_1, θ_2	angles of links 1 and 2 with respect to the neutral axis in radians

The objective of the two link robot project is to simulate the system and devise a strategy so that the tip of the robot moves on the circumference for 90 degrees as shown in Figure 6 which is captured from the animation:



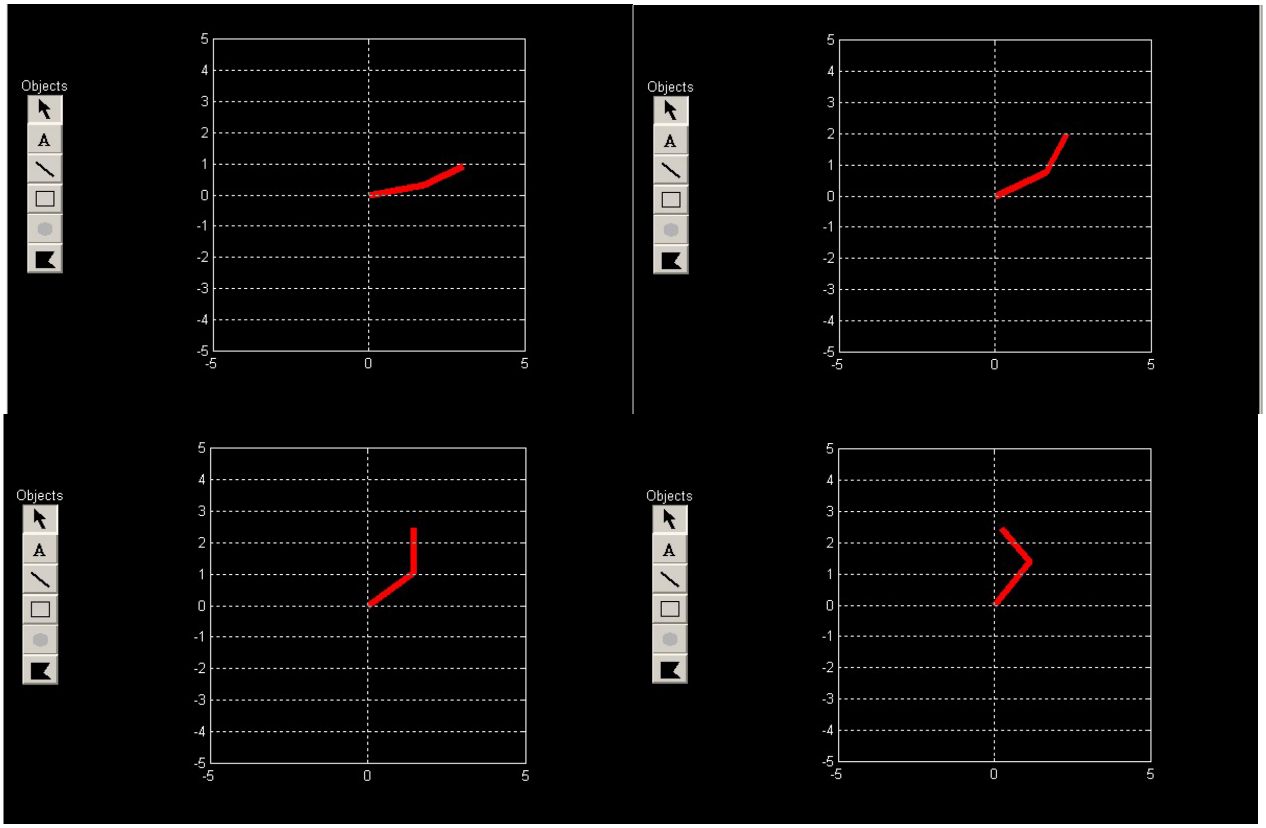


Figure 6 Animated Motion Sequence of the Two Link Robot

A typical Simulink block diagram is shown in Figure 7. Construction of the simulation block diagram requires careful analysis of the equations and coding of the function blocks. This is not a trivial task for undergraduate students that encounter dynamic simulation/animation for the first time. Therefore, three lab sessions were dedicated to the project development. It is especially important that the team members work in a cooperative and proactive manner.

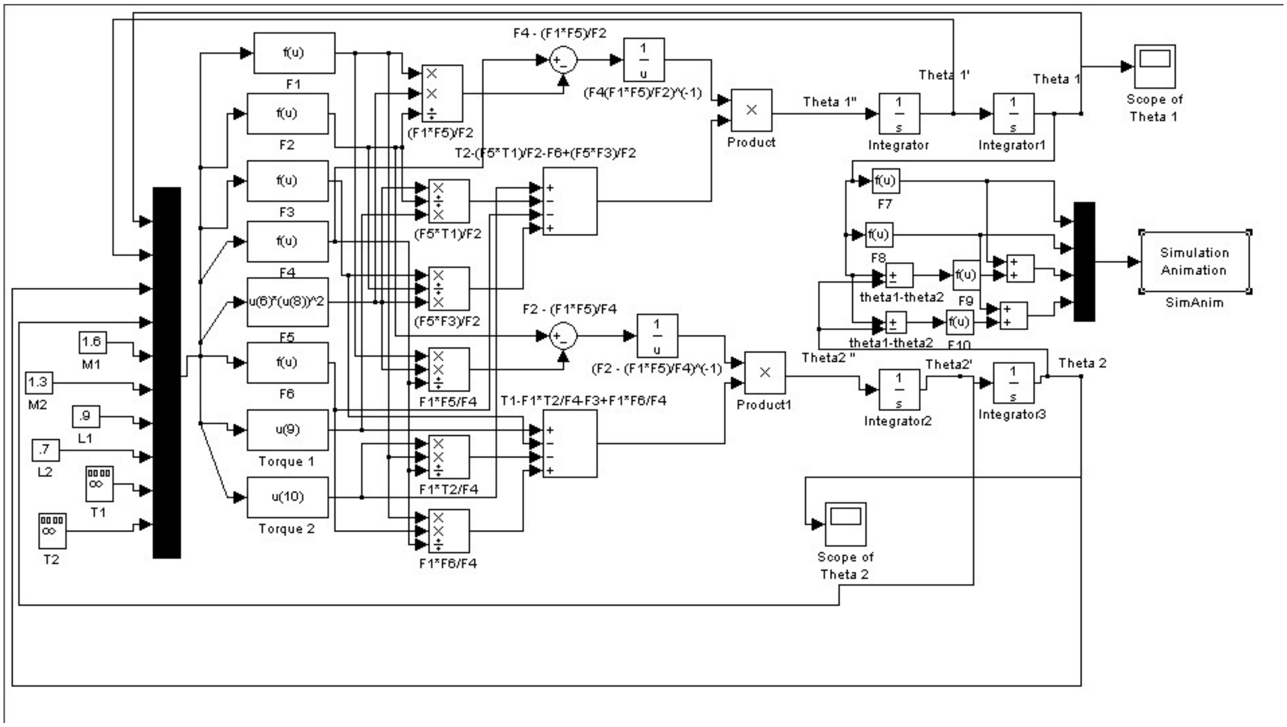


Figure 7 Simulink Block Diagram for the Two Link Robot

Another project (given in the subsequent semester) is a crane system that consists of a crab, a winch, and a cable assembly. The equations of motion are given by:

$$\begin{aligned}
u_1 &= (m_L + m_c)\ddot{x}_1 + x_5\ddot{x}_3 m_L \cos x_3 + \ddot{x}_5 m_L \sin x_3 + b\dot{x}_1 + 2\dot{x}_3\dot{x}_5 m_L \cos x_3 - x_5\dot{x}_3^2 m_L \sin x_3 \\
0 &= \ddot{x}_1 x_5 \cos x_3 + x_5^2\ddot{x}_3 + g x_5 \sin x_3 + 2x_5\dot{x}_5\dot{x}_3 \\
u_2 &= m_L\ddot{x}_1 \sin x_3 + m_L\ddot{x}_5 - m_L g \cos x_3 - m_L\dot{x}_3^2 x_5
\end{aligned}$$

where

m_L	load in kg
m_c	mass of crab in kg
x_1, x_2	crab position, velocity in m and m/s
x_3, x_4	cable angle and angular speed in radians and rad/s
x_5, x_6	cable length and rate of change in m and m/s
u_1, u_2	crab and winch controls
g	$9.8m/s^2$
b	viscous damping

The objective of this project is to simulate the system and devise a strategy to pick up two loads and release them in the final drop zone as shown in Figure 7 for the motion captured animation sequence. In order to do this, the students must coordinate the motion of the crab and winch while avoid hitting the obstacles.

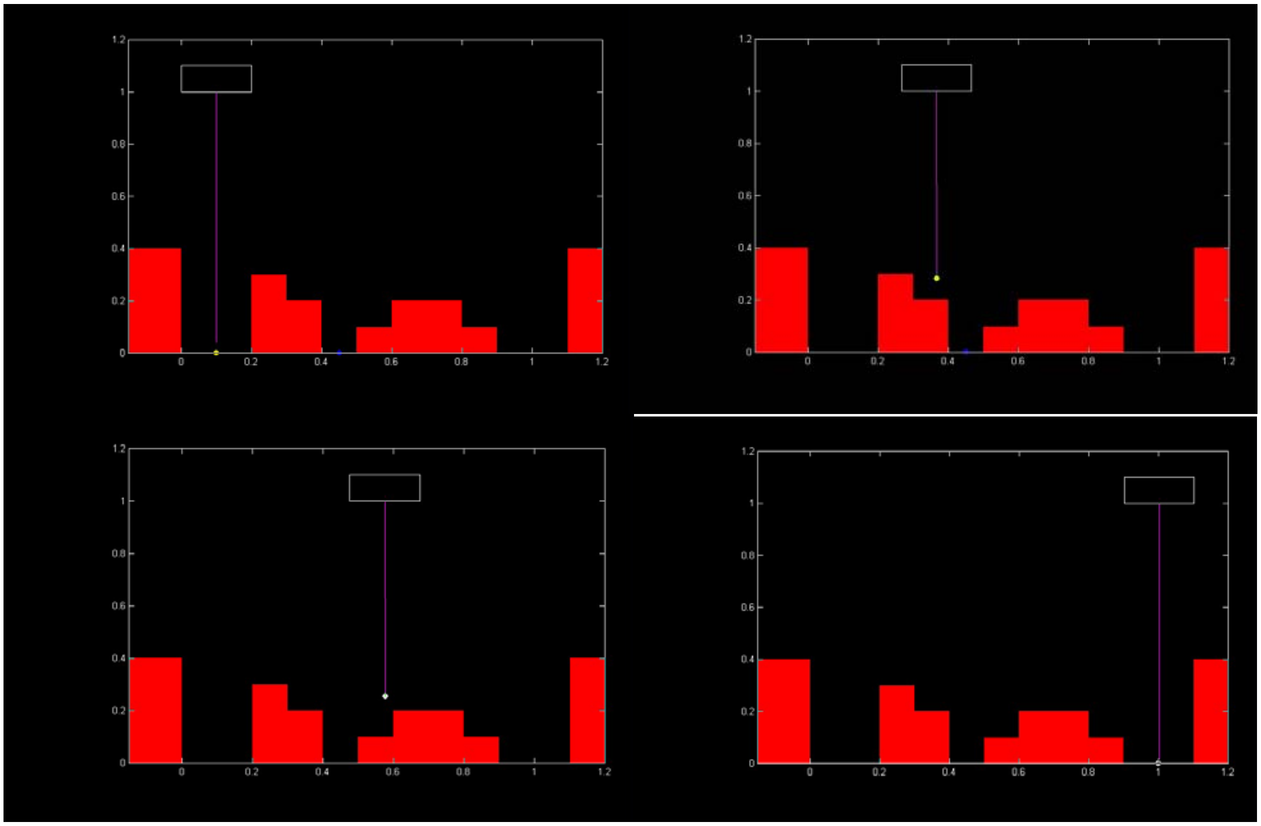


Figure 8 Crane System captured Animated Sequence

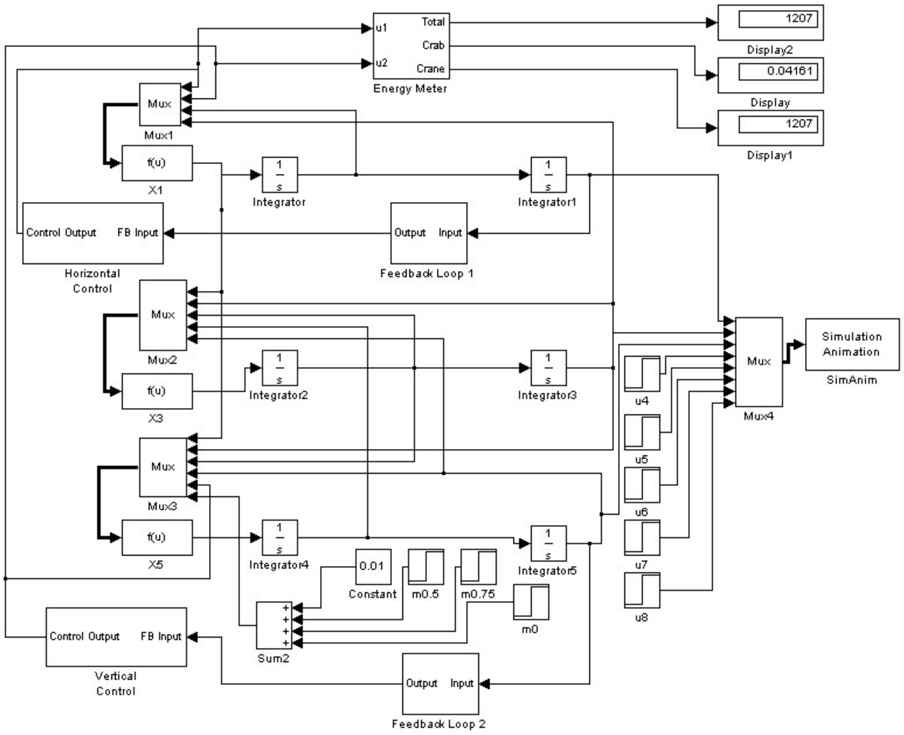


Figure 9 Simulation Block Diagram for the Crane System

A typical simulation block diagram is shown in Figure 9. It is of interest to compare the animation output with the traditional time trajectory plot given in Figure 10. Although the trajectories yield accurate measurement data, the animation produces a much better description of the dynamics of the system and the project results can also be easily communicated to both technical and non-technical audiences.

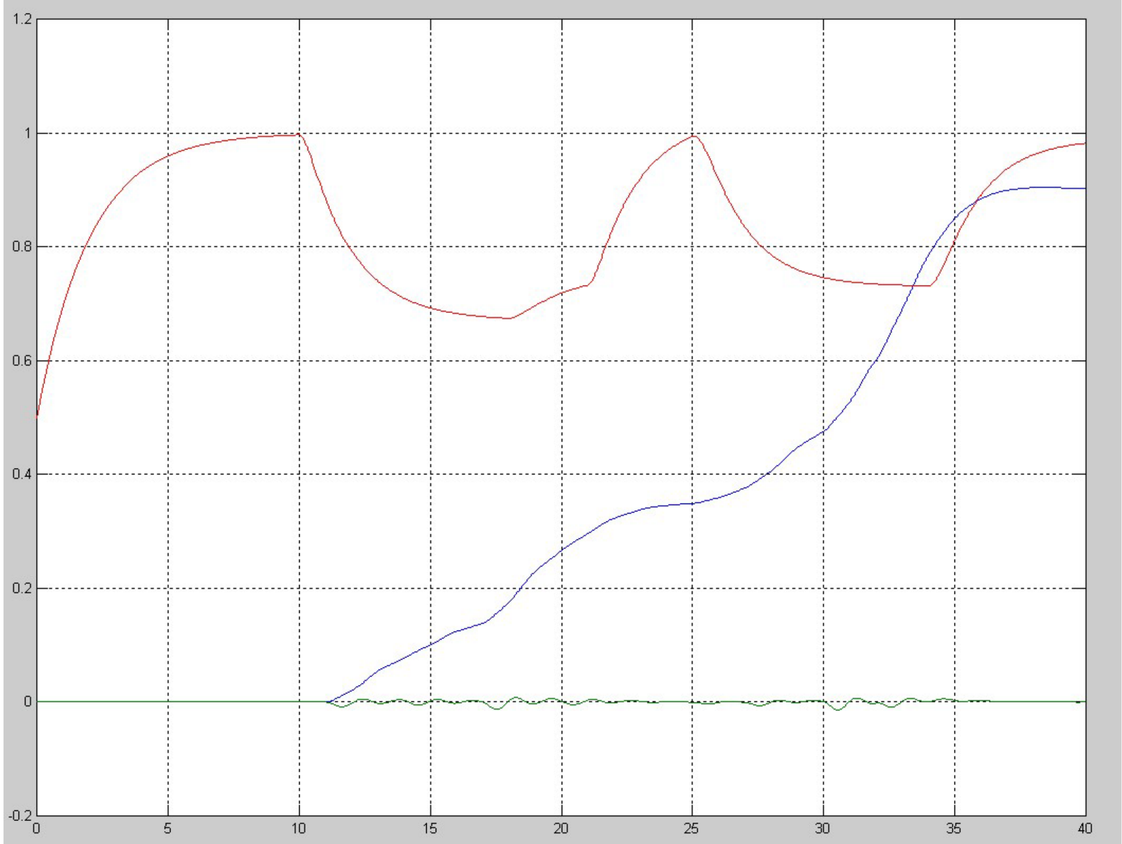


Figure 10 Traditional Trajectory Plots of the Crane System Depicting variables x1 (middle),x3 (bottom), and x5 (top)

(V) Student Experience

Having piloted this new course format for four semesters, student experience can be described as "apprehensive at the beginning" and "exhilarative at the end". Although many students are naturally concerned with the difficulties and workload of the revised course, this concern gradually subsides and a marked increase in interest level is observed. From the course evaluation, students are particularly positive about the following:

1. Introduction of new software technology such as the animation toolbox.
2. Relevance of course contents to "real-life" experience.
3. Challenge and reward of the project.

Although the statistical base is still too limited to draw any definitive conclusions at this point, it is nevertheless observed that:

1. Success rate of the project does correlate strongly with the rest of the lecture grades and work pattern. Students submitting their class works on a timely basis and scoring above average grades in the tests have the least difficulties in completing the project. Therefore, a highly structure project schedule is recommended.
2. Most students prefer feedback approach than open loop strategies. This is because the plants (robot or crane) are marginally stable and adding a bit of proportional feedback does simplify the design. The use of feedback in this project, however, will cause some loss of physical insight into the problem and some open loop strategies should be mandatory.
3. General computer skills (e.g. web surfing, games, etc.) do not necessarily translate into project success. This is because the project is more than just programming: knowledge of analysis and characteristics of the plant are equally important. Coordination of lecture and lab sessions is vital.
4. Team spirit is critical. There are quite a few cases of break down in cooperation between members. Nevertheless, the team approach has its merits and will be continued. It may be necessary to apply additional partnership criteria e.g. Myers-Briggs Type Indicator to improve teaming arrangements.

(VI) Conclusions

In this paper, the use of dynamic animation to enhance learning and interest for a senior level course on system analysis is reported. Ansim, the freely available Mathworks animation toolbox, was chosen because it works seamlessly with Matlab/Simulink, a required software for the EE undergraduate curriculum. A series of lab sessions are introduced to complement the lecture series with the review of Matlab, introduction of Simulink, Ansim, and culminating in the project design. The project is a real-life system with high degree of freedoms and nonlinearities. The use of animation added an extra dimension of visual communication that brought the students closer to the physics (rather than just the mathematics) of the problem. Student response has been very positive despite the extra work and, at times, the difficulties in maintaining coherent team spirit. Interest level in the course has also been increased, as evident in the course evaluations. The Kolb's experiential learning cycle encourages students to observe, think, analyze, synthesize, and apply what they have learnt. The authors are pleased to report the course revision has moved toward the direction of shaping students' learning attitude and developing effective learning skills.

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