Implementation of a Linear Inverted Pendulum System for University Laboratory Instruction and System Identification Research

Adrian Del Grosso (SDSM&T)
Faculty Advisors: Dr. Charles Tolle*, Dr. Alfred Boysen**, Dr. Thomas Montoya*
Department of Electrical and Computer Engineering*
Department of Humanities**

Introduction

Inverted pendulums, such as the one in Figure 1, are one of the classic examples that can be found in almost any control theory textbook. They're easy to take measurements from and well understood. The goals of this project are to implement one of these systems, prove it can be done cheaply using our control board stack and materials for use as a research and education platform, and provide a test bed for changing dynamics.

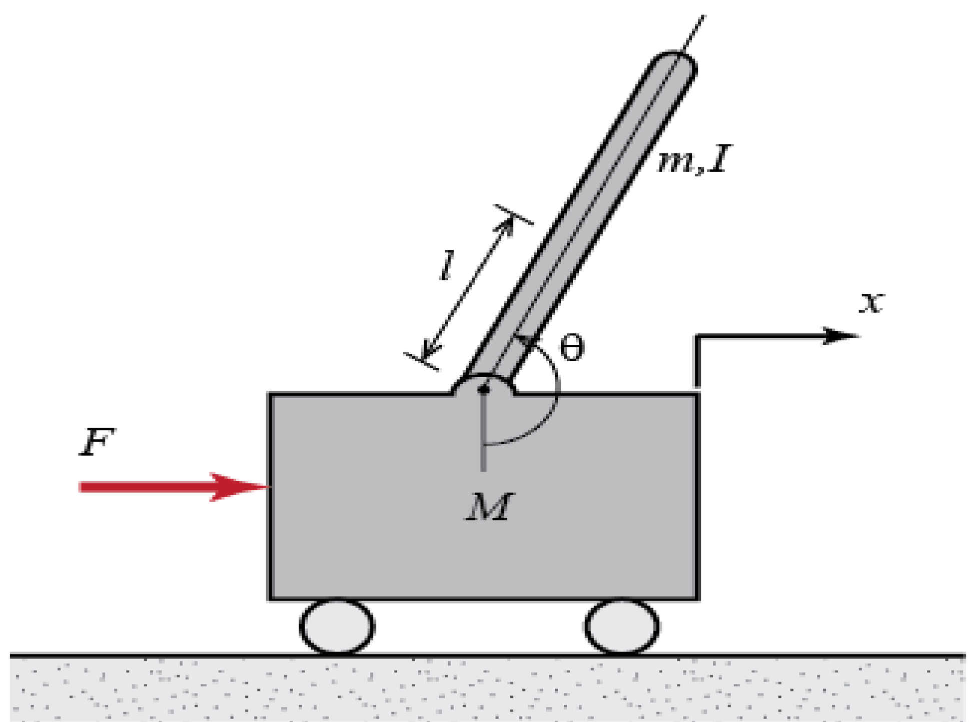


Figure 1. An inverted pendulum example, courtesy of the University of Michigan

Broader Impact

- Research and Educational Platform
- Modeling time-varying complex systems

Procedure

- 1. Develop control board stack software

One of the main goals of the project was to debug this control board stack designed by Dr. Tolle. It includes a motor controller, quadrature decoder, and USB connectivity.

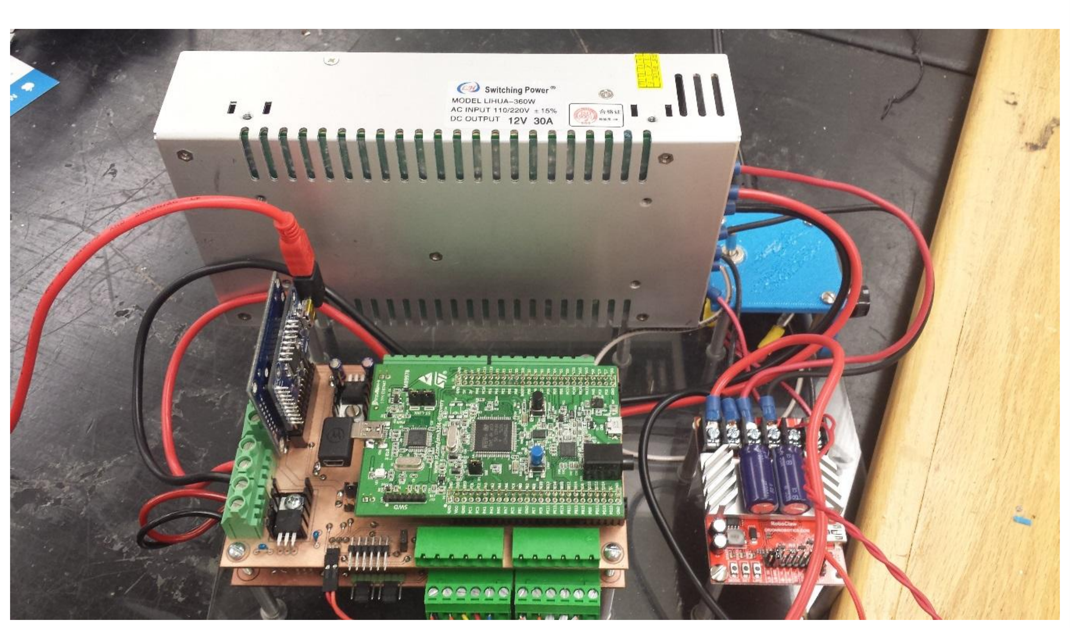


Figure 2. Control board stack

- 2. Embedded Software

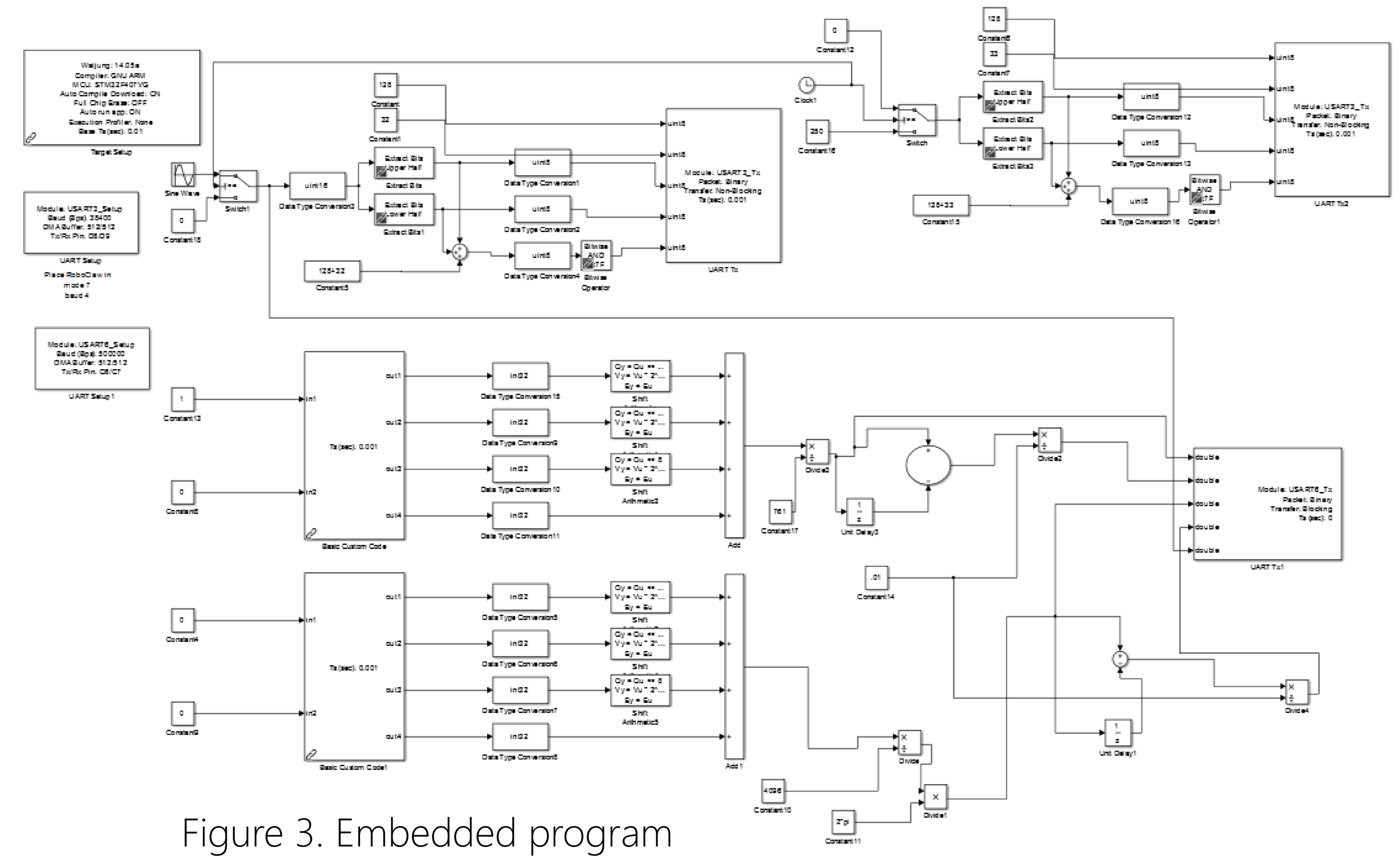


Figure 3. Embedded program

- Simulink and MATLAB – hardware in the loop
  - Compiles to C for ARM M4 CPU
- Custom C code to interface with encoder IC's
- Records pendulum angle and cart position data on a PC

- 3. PC Software

The software running on a PC will send motor commands back to the board stack based on the data the board stack is sending back. In the future, a full state feedback control system will be implemented.

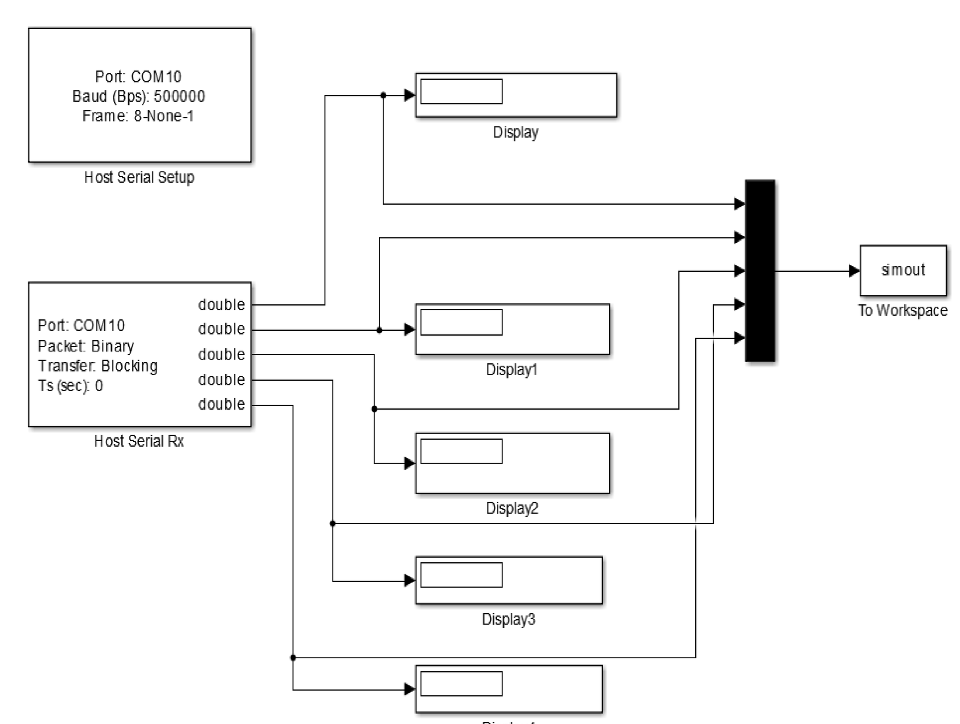


Figure 4. Data logging PC program

- 4. Testing

The system will be tested using a linear approximation of the system's dynamics, which will be determined by using system identification methods.

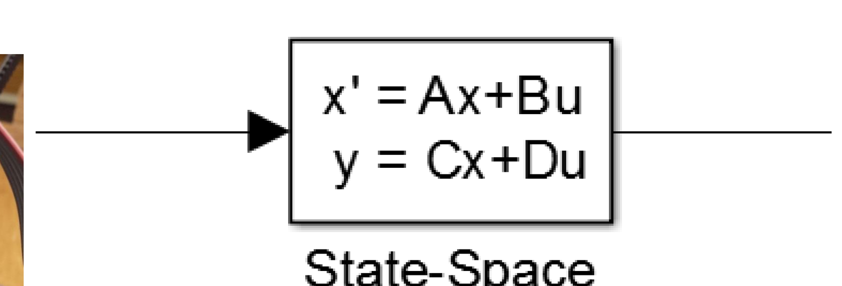
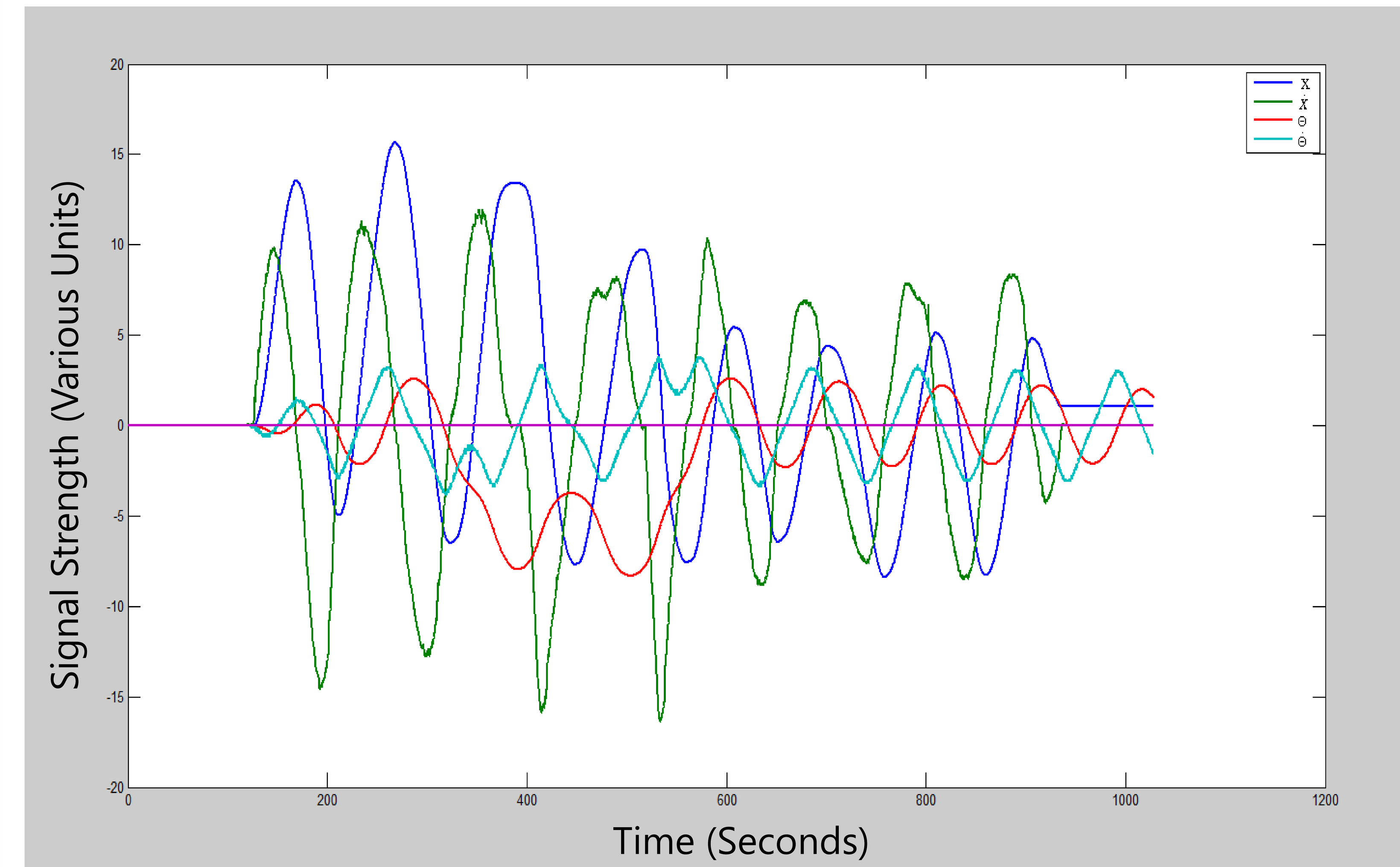


Figure 5 (left) Actual pendulum cart
Figure 6 (top) MATLAB state-space simulation

Results



- System records data on a PC via USB feedback connection
- Pendulum system will allow motor commands based on full state feedback

- Additional Expected Results

- Linear/nonlinear approximation of the system's dynamics
- Pendulum control example

- Conclusion
- Linear inverted pendulum systems that normally cost between $5k and $15k from distributors can be implemented for less than $2k using this set of boards and materials.
- Board stack is viable for additional projects
- System is ready for lab use and research

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