Pendulum Project

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Balancing Robot Project: Introduction

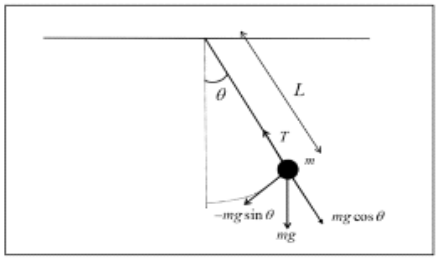
The Objective

We wanted to use the BGSP software to model a bond graph of a real-life system to showcase on the SIMTEC webpage. The BGSP software was made by former students of kyutech so I wanted to use it testrun it with this project. The real-life system was a self balancing robot that was essentially an inverted pendulum system.

Method

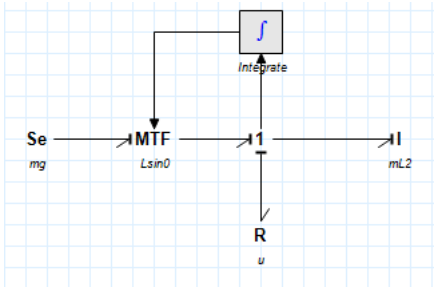
The Assignment

- Physics of a Regular Pendulum
    - In order to fully grasp an inverted pendulum system, I first started with a regular pendulum.



Variable	Bond Graph	Represents
mg	SE	Gravity
-mgLsin(θ)	TF	Torque
mL^2	I	Angular Momentum
μ	R	Friction/Drag

- From the model above, we can deduce four elements necessary for our bond graph.
- Because we have a flow term θ, we need a 1 junction to represent it.
- The resulting bond graph is below.

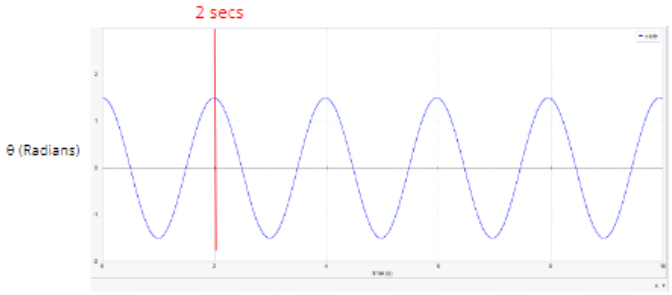


- 20sim Model of Regular Pendulum

    - Using 20sim, another bond graph modeling software, I made the first bond graph using research and papers I found online and the pre-written equations already present in

the 20sim software.

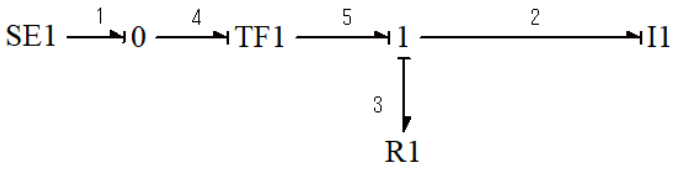
- The integrate function is utilized to generate Theta (θ) as the source for the modulated transformer.
    - Angular velocity (ω) enters the function and Theta (θ) is outputted
- After the 20sim model was complete, I made sure to confirm its accuracy by using the model parameters to calculate the time for one period and comparing it to the software-generated graph of the model.



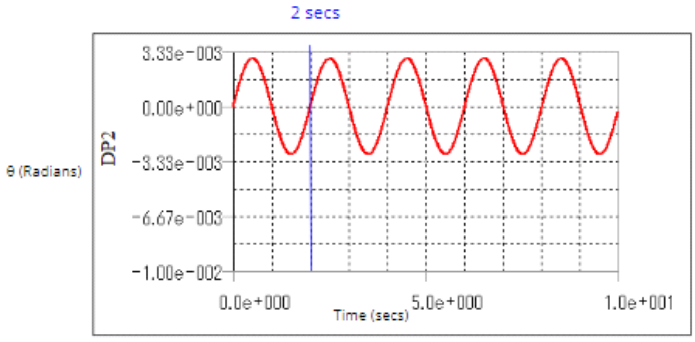
$$T = 2\pi\sqrt{\frac{L}{g}}$$

T=2πsqrt(1/10)
T=2 secs

- BGSP Model of Regular Pendulum
    - After confirming its accuracy, I translated the graph and equations into the BGSP software and got similar results.



    - Due to the BGSP program not having integrate functions or initial values, we had some difficulty translating the graph.
        - Using internal feedback loops within the elements and adding initial values into the equations of the elements, we were able to mimic the integral function and initial value setup of the 20sim model.
    - After the BGSP model was complete, I made sure to confirm its accuracy once again by using the model parameters to calculate the time for one period and comparing it to the software-generated graph of the model.



$$T = 2\pi\sqrt{\frac{L}{g}}$$

T=2πsqrt(1/10)
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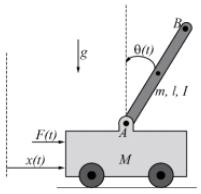
- Physics of an Inverted Pendulum
  - The inverted pendulum, while having similarities, has many stark differences from its regular counterpart.



  - The mobile pivot point of an inverted pendulum creates an unstable system that incorporates forces in both the X and Y direction. This unstable movement also meant that a PID control was necessary to keep it upright.

- 20sim Model of Inverted Pendulum
  - Despite these challenges, I was able to find a paper online modeling the bond graph of an inverted pendulum.

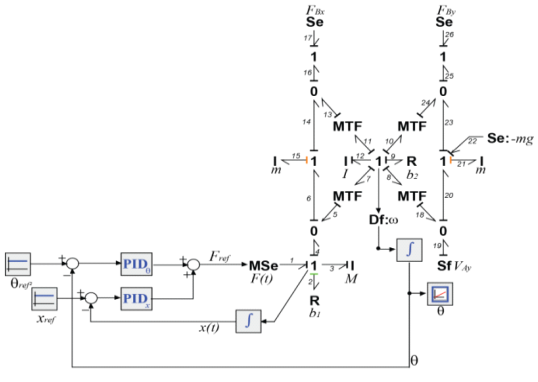
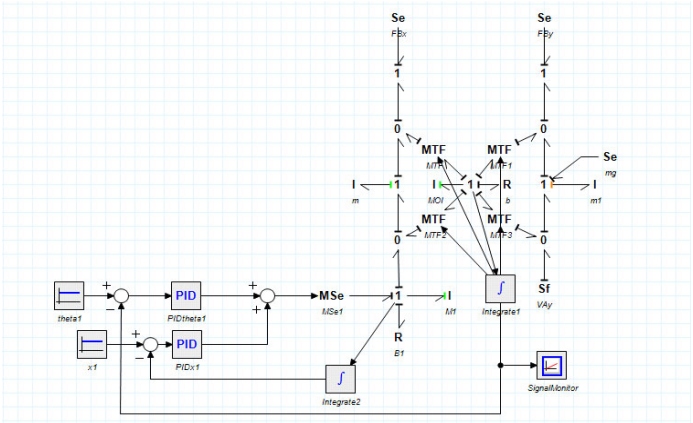


Fig.4 Control structure of PID.

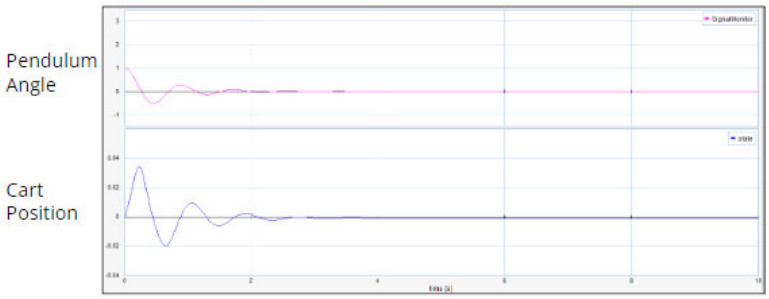
  - The model includes the mass of both the cart and the pendulum, the X and Y forces generated by the falling pendulum and how that affects the cart, gravity, and a PID

controller to control the horizontal force on the cart to keep the pendulum upright.

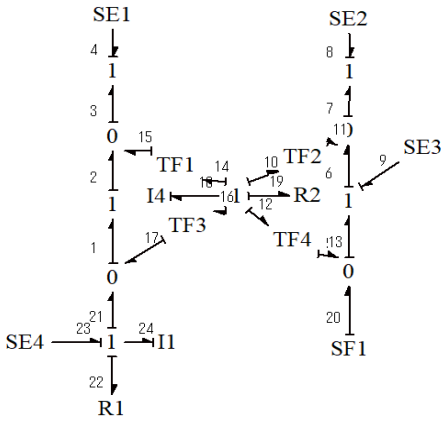
- 20sim Model of Inverted Pendulum
    - Using that as inspiration, I once again started with 20sim, using their pre-written equations to create a foundation for the model.



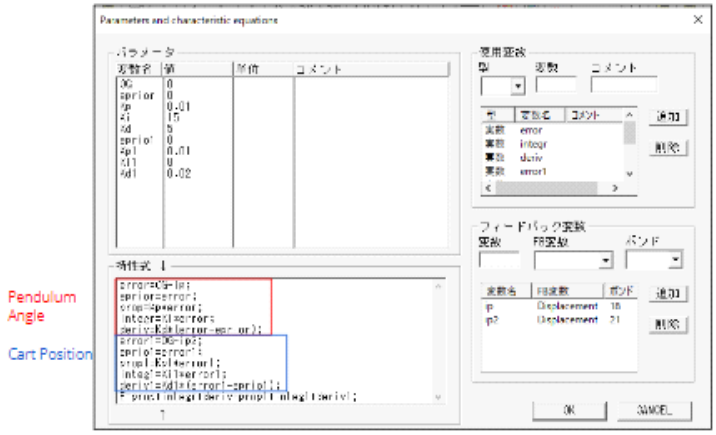
    - Using the same feedback loops and initial values as in the regular pendulum, the inverted pendulum bond graph model was complete.
    - The PID control proved to be difficult to translate as the original PD used in 20sim used an integral in its equations which doesn't exist within the code of BGSP. To combat this I found new PID equations that didn't use an integral to keep the pendulum upright. After the PID was complete, I validated the model by graphing it to ensure both the angle of the pendulum and the horizontal distance covered by the cart would both go to zero as the PID intended.



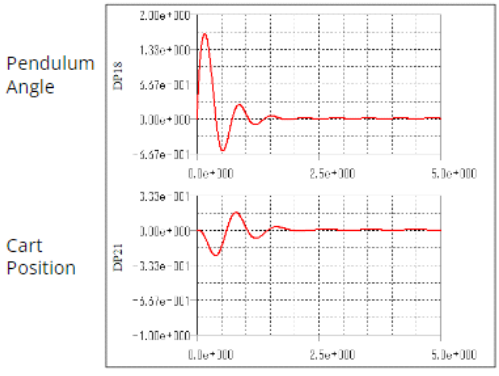
- BGSP Model of Inverted Pendulum



- Similar to the BGSP bond grah of the regular pendulum, the internal feedback loops and initial values within the equations had to be used again.
- The PID also proved to be difficult as the original PID equations included an integral function whic doesn't exist within the realm of the BGSP software.



- Although the new PID equations don't include the integral function, the simulation still had similar results.



Results

The Final Result

After finalizing my graphs, I compiled all of the bond graphs, code, and graphs into a slideshow to present at one of the weekly seminars the department holds. I made sure to contextualize the assignment by first explaining how the robot works before discussing the 20sim and BGSP models. With the slideshow, I was able to use, testrun, and critique the BGSP software and create an effective demonstration of the software to be posted to the Simtec webpage.