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THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF MECHANICAL AND MANUFACTURING ENGINEERING

MTRN3200 - MODELLING AND CONTROL OF MTRN SYS
(course number and course name) [e.g. MECH1300 – Engineering Mechanics 1]

LAB EXPERIMENT 1
(title of document)

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UNIVERSITY OF NEW SOUTH WALES

MTRN3020

Modelling and Control of Mechatronic Systems

Laboratory Experiment 1

Modelling of a Monorail Crane

By Aidan O'Brien

z3324494

1. Introduction

This report will explore the process and results from modelling the monorail crane in the mechatronics lab at UNSW. The process first involved gathering experimental data and from it determining the constants required for an accurate representation of the crane. At which point a derivation of the formula for modelling the relationship between the acceleration of the cart and the angle of the pendulum is conducted. Once the mathematical model is created in MATLAB, then validation of it is conducted on an individually gathered data set. At which point metrics of the accuracy are calculated.

Once the model is shown to be reasonably accurate, a simulation of the crane is used to determine what driving and braking times are required to start the cart and stop it so the pendulum stops swinging at the same moment that the cart stops.

Then the final part of this report discusses the potential sources of errors in the model and how to improve results.

2. Data Collection

The data collection process was performed with a given T1 of 290ms and dynamic braking until stopped. Figure 2.1 shows the velocity plot of the collected dataset.

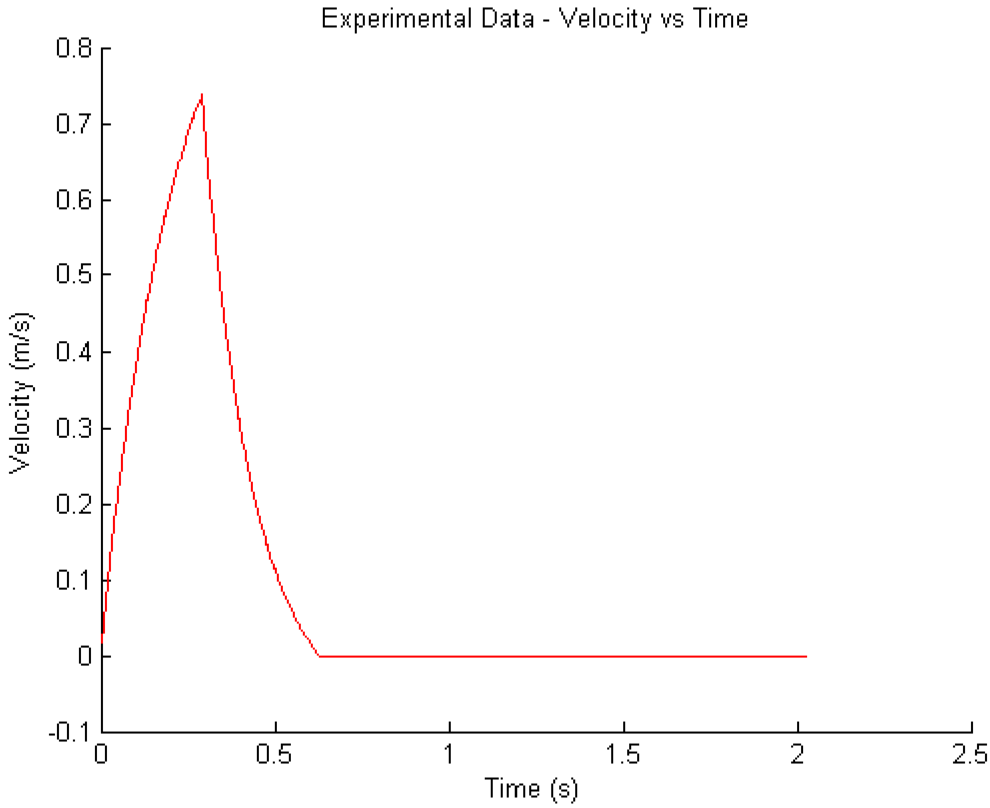

Figure 2.1 Plot of Velocity vs Time collected from experimental data.

3. Determination of Constants

Determination of the constants τd, τb, Ad and Ab was done through using the *cftool* function in MATLAB on the given dataset at 400ms and finding potential starting values. Once given ballpark figures, it was possible to then refine the constants to fit closer using trial and error, resulting in a good match as shown in figure 3.1.

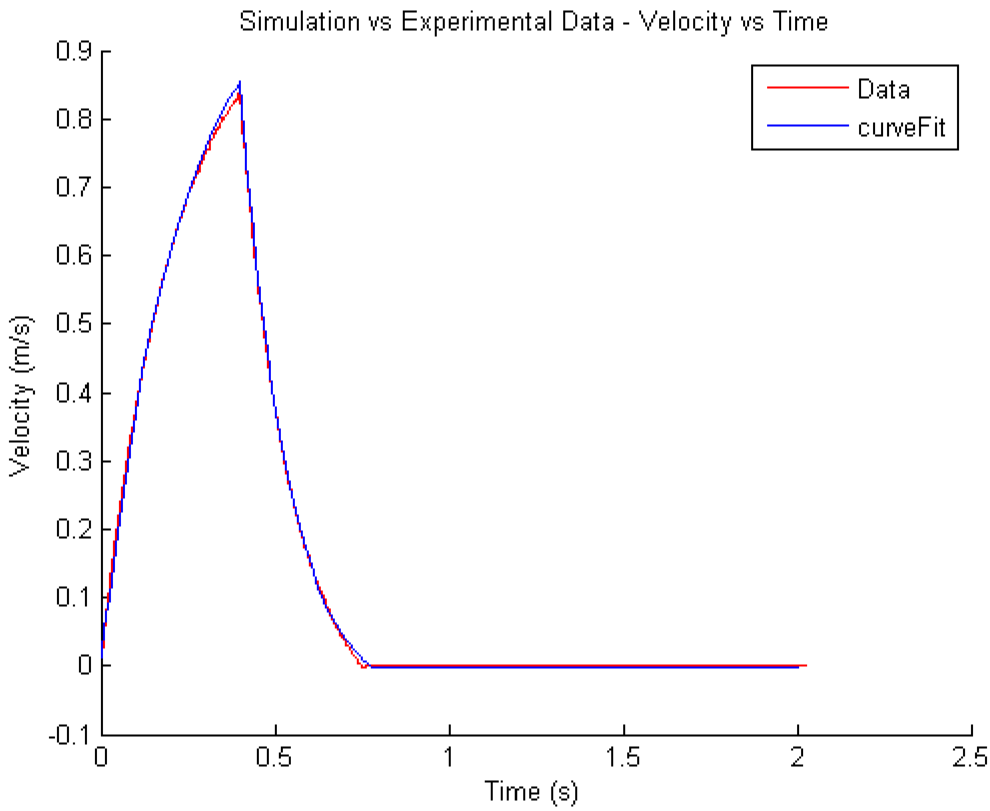

Figure 3.1 Experimental Data vs Simulation showing match for fitting.

The determined constants are shown in Table 3.1.

Table 3.1. Constants determined for Experiment.

	Gain (A)	**Time (τ)**
Driving	0.085	0.220
Breaking	0.059	0.1366

4. Derivation of Equation

The derivation of equation 7 from the report assignment is in the following figure and equations.

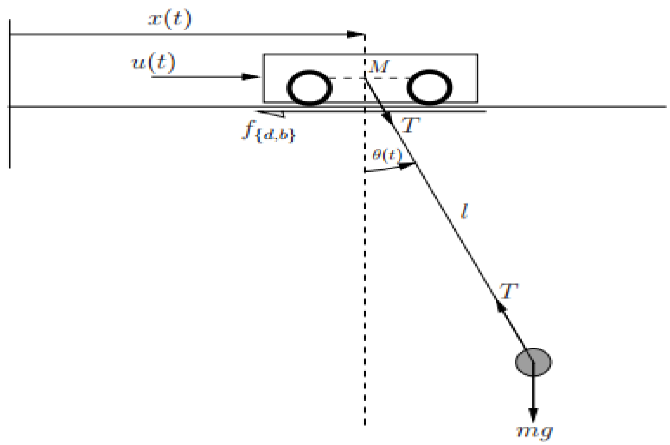

Figure 4.1. Cart and Pendulum layout. From: MTRN3020 assignment specification.

It is possible to find the pendulum's equation of motion by finding the moment at the origin of the pendulum.

$$F_x = ma_x = m\left(\frac{d^2}{dt^2}\left(x + l\cdot\sin(\theta(t))\right)\right) \tag{4.1}$$

$$F_x = m\left(\frac{d}{dt}\left(\dot{x} + \dot{\theta}(t)\cdot l\cdot\cos(\theta(t))\right)\right) \tag{4.1.1}$$

$$F_x = m\left(\ddot{x} + \ddot{\theta}(t)\cdot l\cdot\cos(\theta(t)) - \dot{\theta}^2(t)\cdot l\cdot\cos(\theta(t))\right) \tag{4.1.2}$$

$$F_y = ma_y = m\left(\frac{d^2}{dt^2}\left(l\cdot\cos(\theta(t))\right)\right) \tag{4.2}$$

$$F_y = m\left(\frac{d}{dt}\left(-\dot{\theta}(t)\cdot l\cdot\sin(\theta(t))\right)\right) \tag{4.2.1}$$

$$F_y = -m\left(\ddot{\theta}(t)\cdot l\cdot\sin(\theta(t)) + \dot{\theta}^2(t)\cdot l\cdot\cos(\theta(t))\right) \tag{4.2.2}$$

$$+M_O \rightarrow mgl\cdot\sin(\theta(t)) = F_x\cdot l\cdot\cos(\theta(t)) - F_y\cdot l\cdot\sin(\theta(t)) \tag{4.3}$$

By inserting equations 4.1.2 and 4.2.2 into 4.3, while cancelling the mass and length results in the following equation.

$$g\cdot\sin(\theta(t))=(\ddot{x}+\ddot{\theta}(t)lcos(\theta(t))-\dot{\theta}^2(t)lsin(\theta(t)))\cos(\theta(t))+(\ddot{\theta}(t)lsin(\theta(t))+\dot{\theta}(t)lcos(\theta(t)))\sin(\theta(t)) \tag{4.4}$$

$$gsin(\theta(t))=\ddot{x}\cos(\theta(t))+\ddot{\theta}(t)l(\cos^2(\theta(t))+\sin^2(\theta(t))) \tag{4.4.1}$$

$$0=\ddot{x}\cdot\cos(\theta(t))+\ddot{\theta}(t)\cdot l-g\cdot\sin(\theta(t)) \tag{4.4.2}$$

And so the desired equation is derived.

5. Validation and Simulation Creation

Taking the simulation model that was utilised to find the constants, validation of the data was done by comparing the experimental data taken at T1 and then running the model using T1 and seeing how they fit. Figure 5.1 shows the match for position (x), while figure 5.2 shows the match for the pendulum angle (θ).

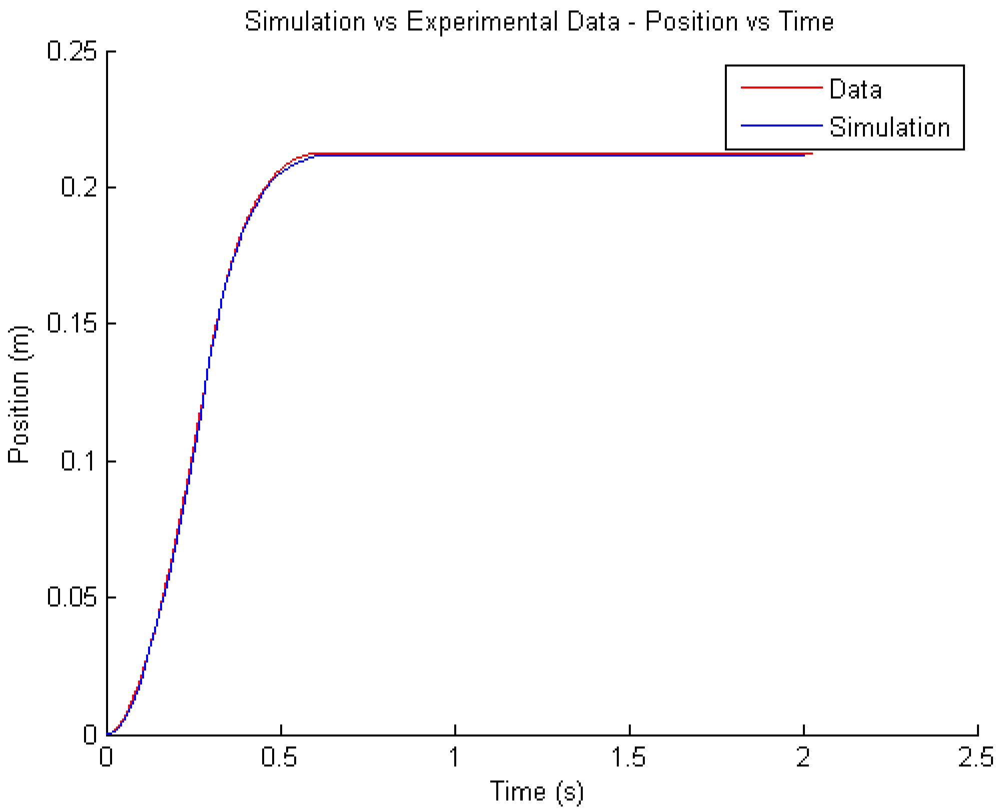

Figure 5.1 Simulation vs Experimental Data – Position.

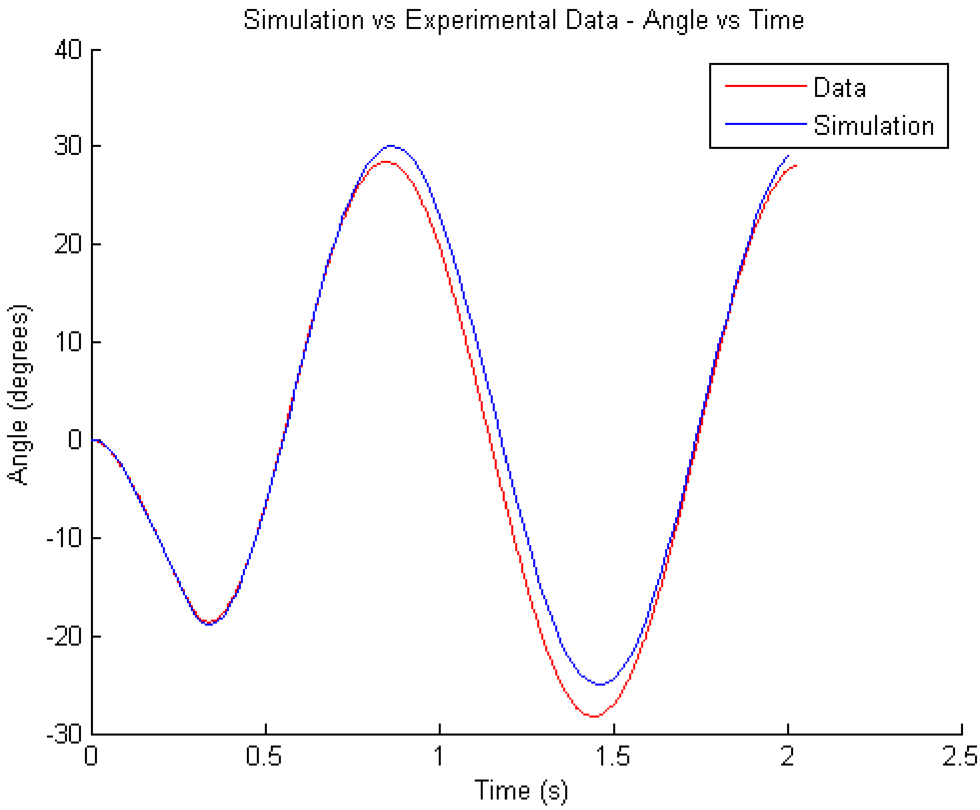

Figure 5.2 Simulation vs Experimental Data - Theta

Utilising the required metrics, Mean Squared Error and Maximum Absolute Error, MATLAB returned the following values.

Table 5.1. Validation Metrics for Simulation Model

	Mean Squared Error	**Maximum Absolute Error**
Position	0.0010	0.0741
Angle	0.1674	0.9429

These values were determined by filtering the number of samples taken to match the number of points generated by the ode45 function at as close a time value as possible. As is possible to see in figure 5.2, the angle has some offset but has similar magnitudes, which could cause a subtle oscillation in the model that wouldn't be possible to exist in the real world.

6. Time Value Simulation

The simulation for the different time values utilised the same mathematical model as the validation process, except that it included if statements to process when the values between driving and braking should occur. Figure 6.1 shows the plot of Velocity, Angle and Position against one another. It demonstrates the simultaneous cessation of movement of the cart and pendulum.

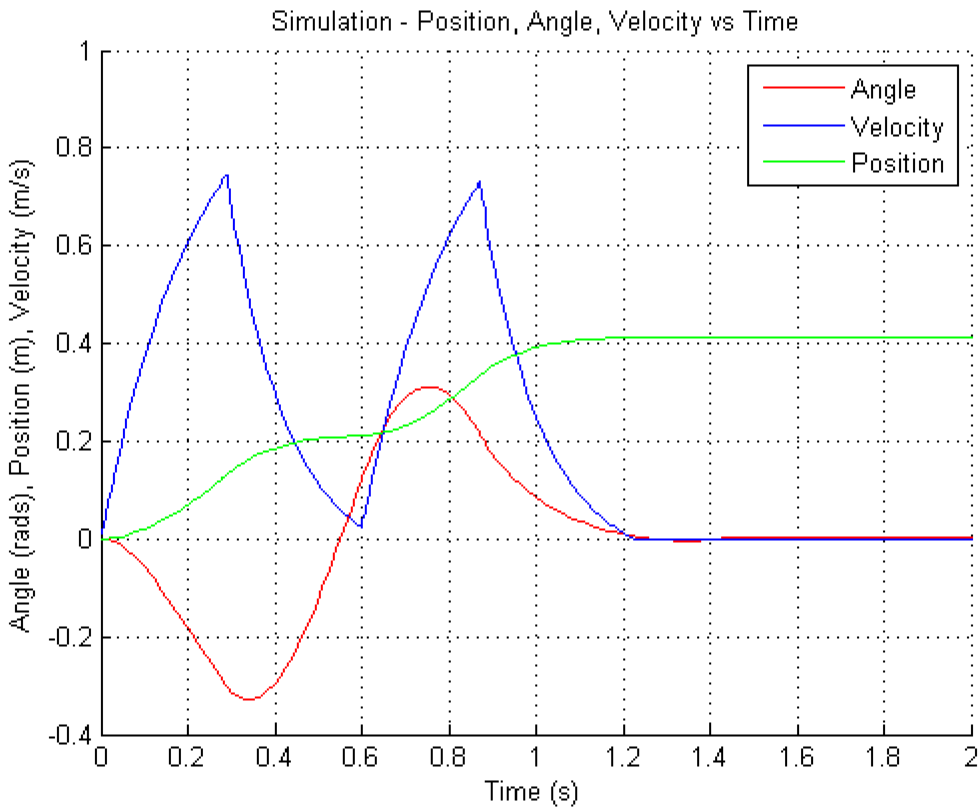

Figure 6.1. Comparison of Simulated Velocity, Position and Angle vs Time.

The values for T2 and T3 were found through trial and error based upon the required T1 of 290ms. Hence the final values found are:

T1 = 290ms

T2 = 310ms

T3 = 272ms

7. Discussion

There were a substantial number of approximations and assumptions made in the modelling of the dynamic equations for this experiment. The first was that the pendulum rod was massless. As it is a real object, to properly account for it, the equation for solving the moment of the rod would need to be included. In addition to the massless rod, there was assumed to be no friction in either the bearings or the air around the cart and pendulum. These provide small but still existent forces that would be required to improve accuracy.

Further assumptions made involved the zeroing of the cart. The pendulum was steadied by hand in the experiment, which has guarantee of being perfectly still. The position and velocity of the pendulum also couldn't be perfectly assured. The location of the cart can also be slightly off from the starting position, although within tolerable limits.

Additionally, due to the discrete measurement of the positions of the encoders, they are not continuous and are subject to inaccuracies and jumps in between data points, which can also be further influenced by vibrations present in the environment. This can make the fitting of data slightly inaccurate at points where sudden changes occur. On this, the sampling time and times given to the machine would not be 100% accurate, providing small inaccuracies.

In the methodology, methods such as trial and error, as well as comparing the graphical output on a plot aren't the most precise method of finding the constants or times, a better method for finding the solution would provide greater accuracy in the making of the model.