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Mechatronics Modelling Project

MXEN2000

Final Model

Due: 10th November 2020

19779797

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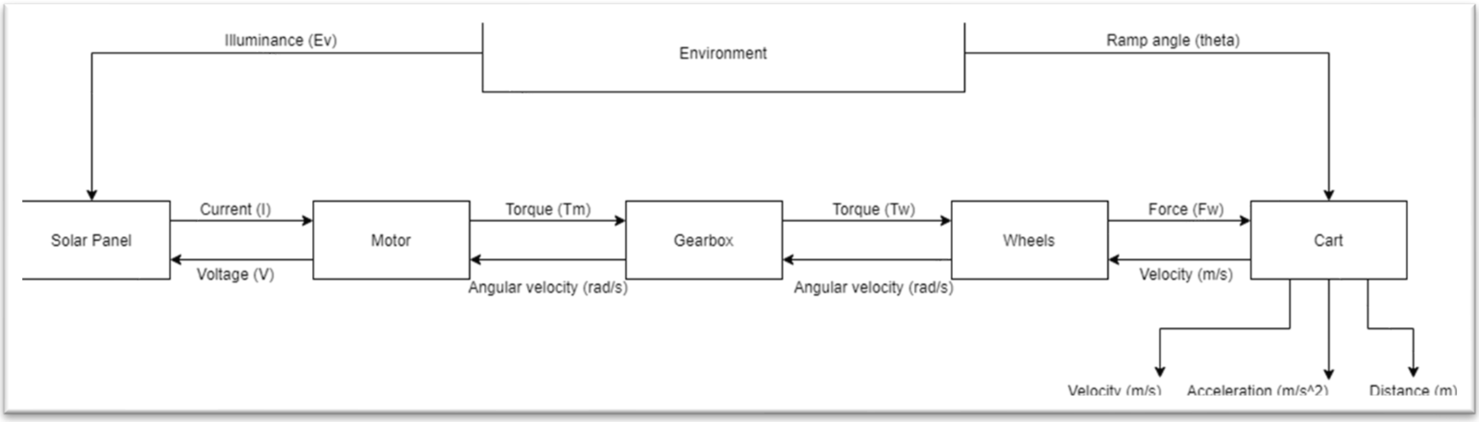
DC motor driven cart: System Model



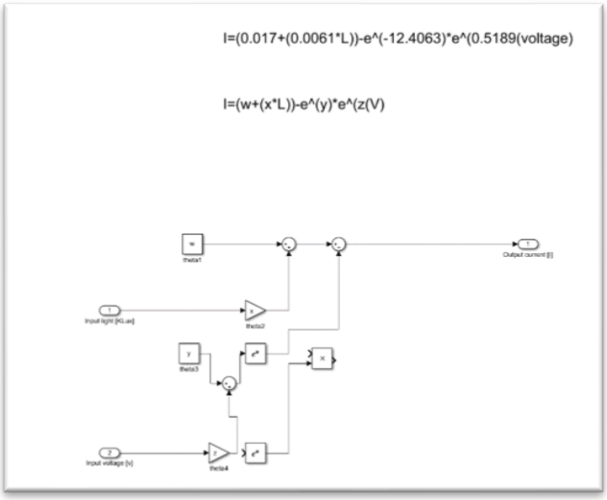
Solar panel

Model used:

$$I(current) = \big(0.017 + (0.0061 * lux)\big) - (e^{-12.4063} * e^{0.5189*V(voltage)})$$

Model derivation:

This model was derived by doing multiple tests in a lab scenario. Tests include measuring how the panel performs at specific light intensity levels (lux) and noting the current and voltage. We could then use MATLAB in order to get a model of the current in terms of the voltage and light intensity level. To derive this equation, we had to assume that we would know the light intensity level (lux) beforehand. We also assumed the series resistance to be 0 and shunt resistance to be infinite, to simplify our equation.



Motor

Model used:

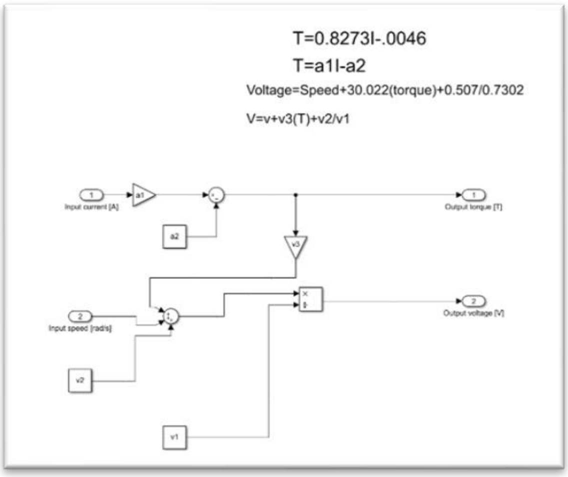
$$speed(v) = 0.7302 * V(voltage) - 0.507 - 30.022 * T(torque)$$

Rearranged:

$$V(voltage) = \frac{v(speed)+30.022*T(torque)+0.507}{0.7302}$$

Model derivation:

In order to get this model, we thoroughly tested the motor, in order to find out a relationship between the torque, speed and voltage. This required us to find the stall torque of the motor, compared to voltage, the no load speed, and speed vs torque relationship for the motor, and finally we could put all these tests together to find the final model. The model can be derived starting from the formula $T(torque) = k_1V + k_3 - k_2\omega$. Using $T(torque) = ki_a$ with this equation, we can gain a relationship between torque, speed, and voltage. This assumes that the conductor has multiple loops.



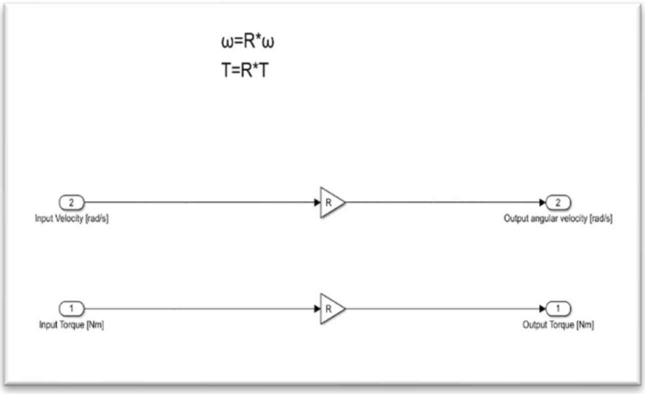
Gearbox

Model used:

$$\omega_M = R * \omega_W$$
$$T_W = R * T_M$$

Model derivation:

This simple model was derived by using the knowledge of gear ratios. Our chosen gear ratio (theoretical) was 2:1, meaning for every 2 turns of the motor, the rear axle turns once. We tested our actual gear ratio by connecting the Arduino decoder, to the wheelless rear axle, and ran the motor to gain the average actual gear ratio. We had to assume that the cart would have the same gear ratio with one wheel missing as it does with it present.



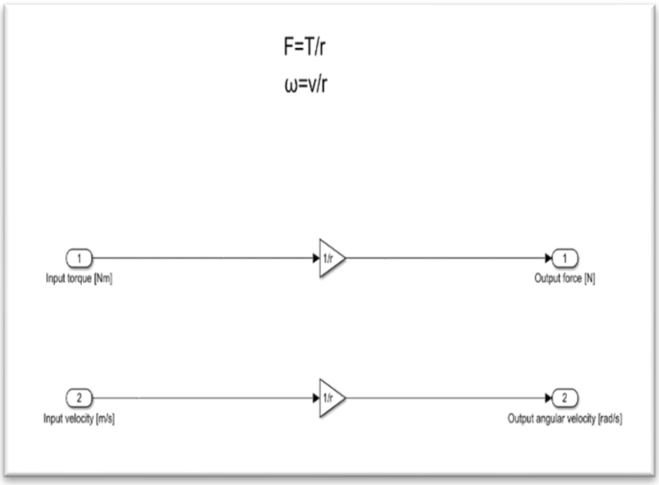
Wheels

Model used:

$$F_W = \frac{T_W}{r}$$
$$\omega_W = \frac{v}{r}$$

Model derivation:

We have decided to exclude friction/grip from the wheel's subsystem/model, due to tests and calculations confirming that it will not play a part in the most extreme of tests that we may face (500g and 15° incline). This model therefore only focusses on finding the force and velocity at the wheels for the cart. This can be done by using the radius of the wheels used. We had to assume for this that all wheels are exactly the same size in diameter, and the force is equal amongst all wheels.



Cart

Model used:

$$N(normal\ force) = m(mass) * g * \cos(\theta)$$

$$F_f(friction\ force) = 0.07455 * N(normal\ force)$$

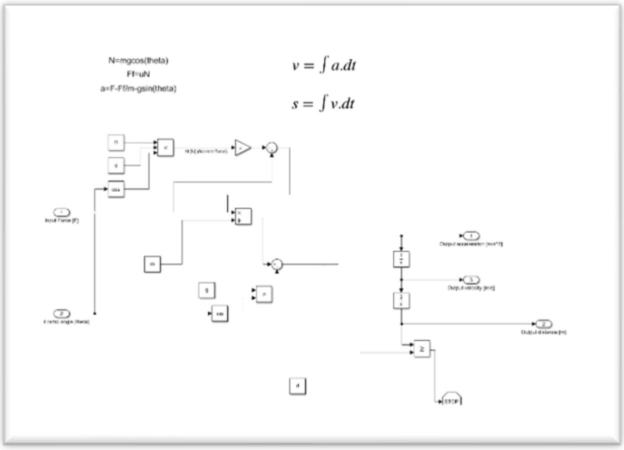
$$a(acceleration) = \frac{F(force) - F_f(friction\ force)}{m(mass)} - g * \sin(\theta)$$

$$v = \int a.dt$$

$$s = \int v.dt$$

Model derivation:

The formula for acceleration was derived by drawing a free body diagram of the cart on the ramp. We then summed all the forces in the x axis (parallel to ramp), and by adding the forces going up the ramp, and subtracting those going down, we get to the acceleration equation (including friction). This friction was calculated by rolling the cart down the ramp whilst timing it. From this we were able to calculate the coefficient of friction for the cart. This is multiplied by the normal force of the cart, to get the total friction force acting on the cart, which is then subtracted from the total force pushing the cart up the hill.



Obtaining model predictions

Scenario 1:

For scenario 1, the parameters to be used were a light intensity of approximately 15000, ramp angle and length of 8 degrees and 1 metre, and an additional load of 250g making the cart total weight 1.628kg. Upon running the generated Simulink model, we get a prediction for scenario 1, with a time of 5.566 seconds to reach the top of the ramp. The total work done in this scenario is 20.292 Joules. This was calculated in Simulink by taking the integral of the force and finding the maximum value. The steady state power, calculated by total work done divided by time, is 3.6457 Watts.

Scenario 2:

Scenario 2 featured an unknown light intensity level, which was measured to be approximately 27000. The mass of the cart, with an extra 500g was 1.878kg and the angle and length of the ramp was 7 degrees and 1 metre. The time estimated for this scenario was 5.2319 seconds, with total work done of 19.2406 Joules and a steady-state power of 3.6775 Watts.

Cart gear ratio:

Doubling the gear ratio of the cart results in a time that is 1.8 times greater than our initial predicted results, in any given scenario. The work done is also 1.78 times greater with double the gear ratio installed in the cart.

Cart mass:

The cart with 0 added mass, with a weight of 1.378kg, is predicted to climb the ramp in 4.9401 seconds (scenario 2), and with an added 500g mass, cart total weight of 1.878kg, the time is 5.2319. This means that 500g of mass made the cart take 5.74% longer to reach the top of the ramp. The work done without the added mass is 13.36 joules, while adding the 500g extra mass uses a lot more energy to get up the ramp, at 23.36 joules.

Ramp inclination angle:

By doubling the ramp angle from 7 to 14 degrees, the time it takes for the cart to reach the top goes from 4.9401 to 5.4387, in a given scenario. This is an increase in time of only 0.5 seconds, being nearly 10% different.

Illuminance:

By doubling the illuminance from 15 to 30 in a given scenario, the time for the cart to reach the top of the ramp decreases from 5.6128 seconds to 4.9239. the total work done also goes down from 16.5 to 14.5 joules.

Comparing predictions with experimental results.

Scenario Number	SIMULINK Prediction (seconds)	Test run #1 (seconds)	Test run #2 (seconds)	Accuracy
1	5.5660	6.23	6.59	86.83%
2	5.2319	6.16	6.06	85.63%

Comparing Simulink model data to actual experimental data, we can see an accuracy of about 86% for both scenarios. These results show a high precision, but low accuracy, as the accuracy is not great, while both accuracies are about the same. This means that our model is good, yet something is slightly off with it. The reason for this is likely due to an incorrect gear ratio used. This is because when testing the gearing of the cart, we tested it with no load speeds, resulting in very high accuracy, compared to the theoretical gear ratio. If tested while applying load, we would see an increase in the gear ratio, causing the modelled results to be significantly higher, and closer to experimental results.

With constant (except when that parameter is being tested) parameters of illuminance of 30k lux, ramp angle of 15 degrees and weight of 1.378kg, we can alter one to find the limits of our cart. The limit for the maximum angle the cart can climb is 43.7 degrees, consuming 714 joules to do so. A gear ratio that will ensure the quickest ascent time for the given parameters, while still being able to climb the ramp is a gear ratio of 0.9. This will need to be significantly higher of the light intensity is below 30k lux. For these parameters, the minimum light intensity required to move the cart is 12.3k lux. This value would be lower for a ramp of less angle. The maximum mass that the cart can carry up the ramp given this gear ratio and light intensity is 3.1kg (inclusive of the initial cart). This means for any given gear ratio, light intensity, and ramp angle we can calculate the maximum mass that can travel up the ramp.

Conclusion

Model Accuracy & Performance

The overall accuracy of the model, when tested against real life performance is 86.23%. This can be seen as a high accuracy, yet can be increased simply, now that it is known what is causing this underestimate of the time. With these small changes implemented, this model could be used to generate reliable results. These changes will be outlined later under possible improvements. The model ran well on an average laptop, meaning there was no need to alter it in any way, in order to make it perform better. This resulted in being able to generate results quickly, when needing to change the parameters to suit the changing conditions. During the process of making the model, testing was done on each part of the cart separately, resulting in smaller subsystems of the whole cart to be created along the way. The solar panel model featured an accuracy (r^2 value) of 90% and the motor model had an accuracy of 93%. Comparing this with our resulting model accuracy compared to real life performance, we can see a disparity of 7% in regard to accuracy. This could be the cause of the low overall accuracy, however as the accuracy is lower in the final model, it is clear that some more discrepancies come in to play.

Challenges Faced

There were multiple challenged that had to be overcome while testing the different elements of the cart. The first challenge faced was to do with inaccurate data relating the voltage and current of the solar panel. This was noticed when compiling graphs for the panel and resulted in having to retake all of the solar panel data. Another problem that had to be overcome was when testing the motor, the values obtained for the stall torque, had lower torque than some values when testing torque vs speed. This meant testing the stall torque again, to ensure accurate results. Modelling the motor was tough, as it relied on having enough data points to ensure accuracy. The model, at first had an r^2 value of 87%, which resulted in needing to take more data. The model also had to be rearranged multiple times for it to fit in the Simulink properly, allowing to solve for different variables.

Possible Improvements

In order to have a more accurate final model of the solar powered cart, more testing of the gearbox could have taken place, as well as a more in-depth characterisation and model of the solar panel. Testing of the gearbox was only done at no load speeds, resulting in what we believe was an inaccurate gear ratio, that was used in the final model. In order to fix this, we could improve the final model as well as the gearbox model by taking data for speed vs voltage for the gearbox under load, to find its actual performance, as in practice it will be under load and very rarely under no load. With an accuracy of 90%, there is clear room for improvement in the solar panel model. In order to achieve this, more data points for each of the voltages that the panel was measured at should be taken, mainly around the area of the graph where the gradient is changing, to correctly and more accurately characterise this part of the cart.