SciTech 2014 Summer Science Camp

System Identification of a Robotic Leg

Julia Book, Evan Kravitz, Tzvi Merczynski-Hait

Advisor: Israel (Izzy) Schallheim, M. Sc Candidate

Faculty of Mechanical Engineering

TECHNION Israel Institute of Technology

Abstract

This project is part of ongoing research at the Sensory Motor Integration Lab (SMILe) at the Mechanical Engineering Faculty on biologically inspired robots that have natural, energy efficient movements [1]. A leg was constructed by the lab to test those capabilities. At this stage in the leg's development, the theoretical models of the leg must be matched to the physical system by gathering information utilizing system identification methods [2].

Goals and Requirements

The objectives of this experiment are:

- To obtain frequency and time domain response data for the system;
- To use the frequency and time domain response data to extract the dynamic characteristics of the system;
- To derive differential equations that model the leg's movements; and
- To find constants for the modeled equations from the experimental results.

The system identification of the robotic leg requires the design and implementation of a MATLAB — Arduino interface which collects data from two encoders on the leg. The software then interprets the data and uses it to create plots of both the frequency and time domain responses of the system. Mathematical knowledge of Lagrangian equations and Laplace transforms is also required in order to derive the motion equations.

Materials & Methods

The materials in use are a computer, MATLAB software, an Arduino Mega 2560 microcontroller along with the accompanying software, serial cables, motor control equipment, and a robotic leg (Fig.1).

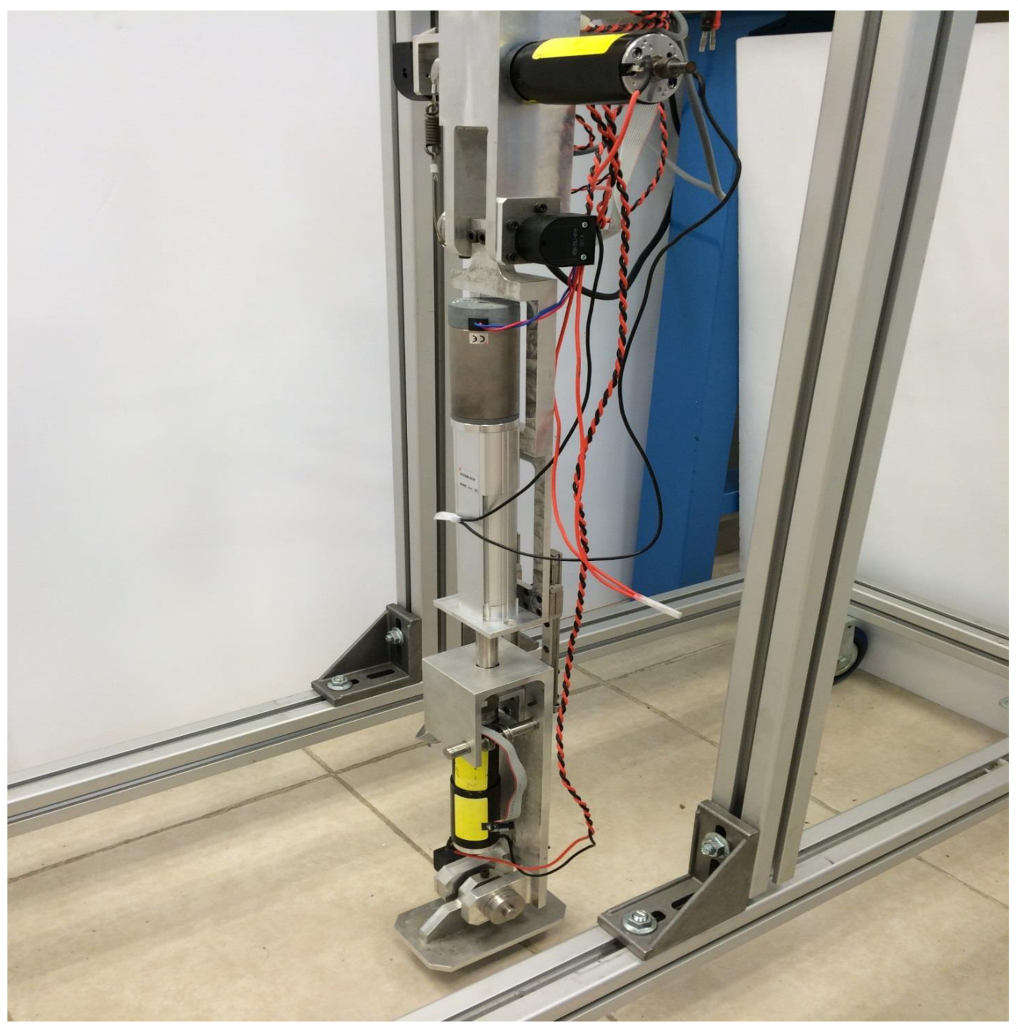

Figure 1: The Robotic Leg

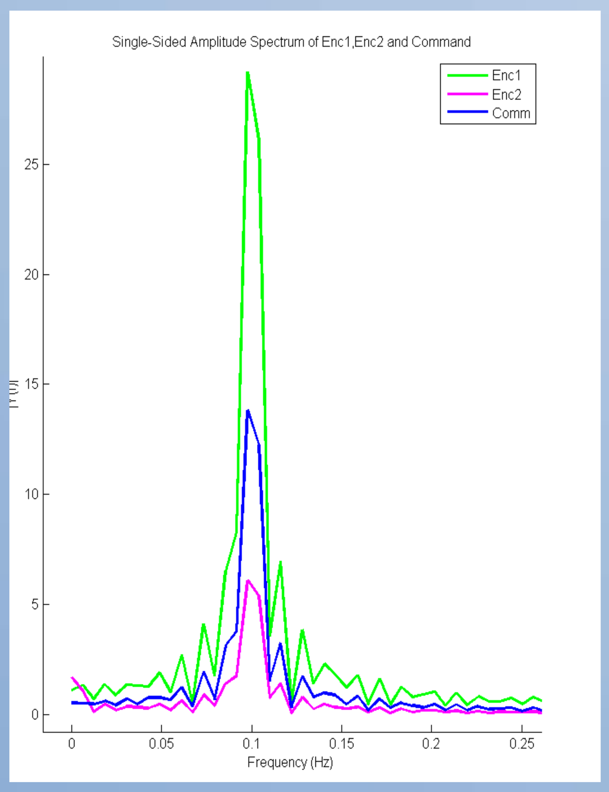

Figure 2.1: Single –sided Amplitude Spectrum for 0.09 Hz

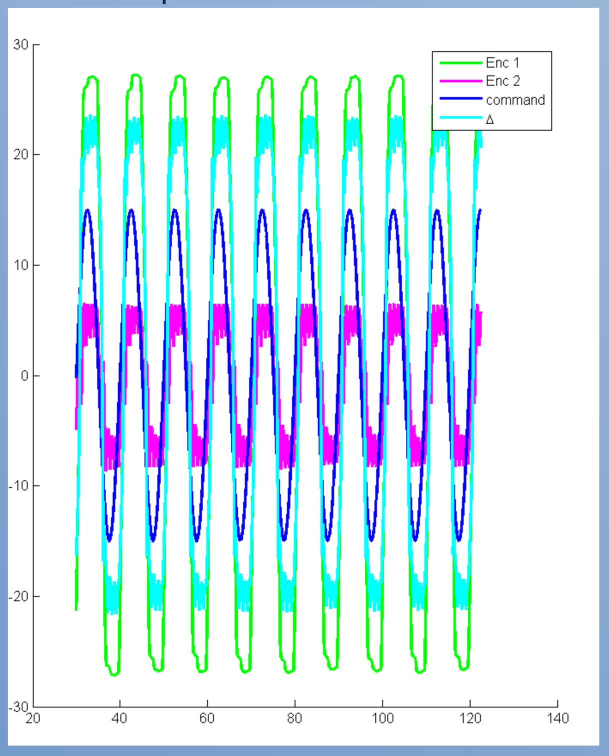

Figure 2.2: Time-domain response for 0.09 Hz

Arduino code is written that gradually increments the frequency of the leg's motion in order to obtain a Bode plot of the leg's frequency response. The leg's response is measured using encoders that read the angle of the leg's motion. The output data for each frequency is then analyzed by MATLAB scripts to obtain a frequency spectrum graph (Fig. 2.1) and time domain response plot (Fig. 2.2). The results from those graphs are then combined to create a Bode plot. The experimental results are then compared to the theoretical data derived from the system's dynamic equations.

In addition to conducting a test to find the Bode plot for the entire system, isolated tests were conducted on the motor with no load. Also tested were the initial conditions response and step response of the leg in order to extract important information about the leg's and motor's dynamics.

Results and Discussion

The Bode plots obtained for the entire system show the resonant frequency of the leg at about 0.88 Hz, and show the leg with the motor as a fourth-order system (Fig. 3).

The motor with no load attached does not resonate at the frequencies tested, but does exhibit otherwise typical behavior for a second-order system.

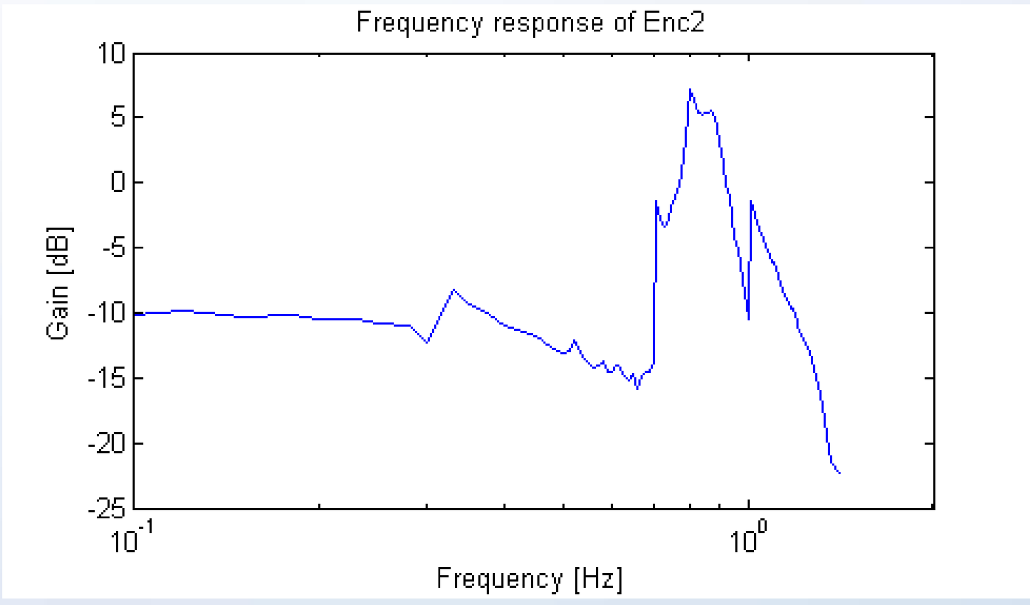

Figure 3: Bode plot for the robotic leg

The initial conditions tests show a damping ratio of about 0.0581 (Fig. 4). The step response test shows the settling time needed for the system to reach equilibrium, and can also be used to extract important properties of the system (Fig. 5).

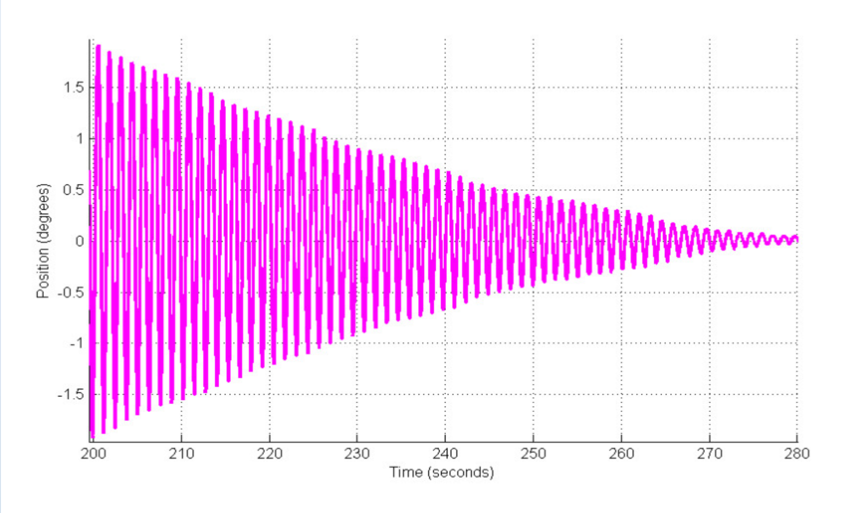

Figure 4: Initial Condition Response for $\theta = 20°$

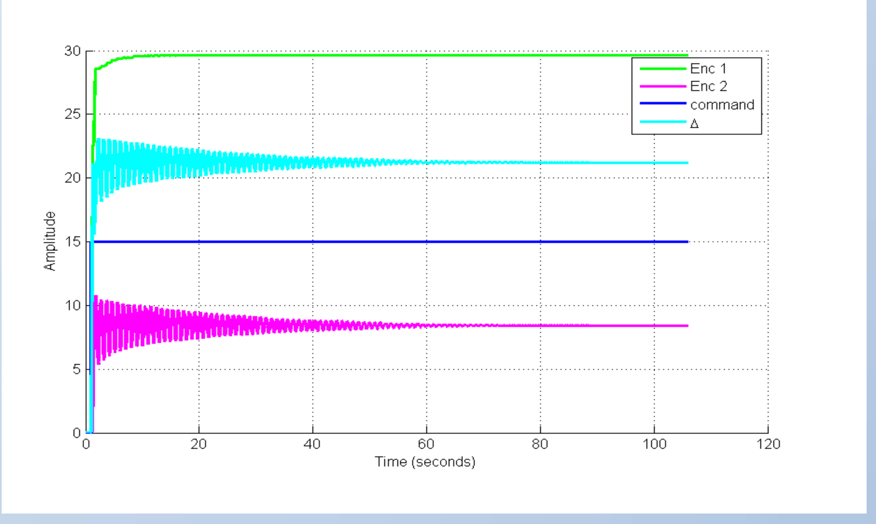

Figure 5: Step Response for an Amplitude of 15 PWM units

The motor's Bode plot was matched with the theoretical model by using different damping coefficient (c_1) and moment of inertia (I_{motor}) values to reduce the difference between the modeled system and the experimental data (Fig. 7). The model had 10.7% error (Fig. 8), mostly due to an aberration at the corner frequency.

The motor's transfer function is:

$$\theta_1 = \frac{K_v}{\frac{I_{motor}R}{k_m N_r}s^2 + \left(k_b N_r + \frac{c_1 R}{k_m N_r}\right)s} v$$

Where:

v - is the voltage applied to the motor.
k_m – is a motor constant connecting the current to torque.
k_b – is a motor constant connecting the voltage to speed.
R – is the total resistance in the motor.
K_v – is the gain of the voltage amplifier.
N_r – is the gear ratio.
c_1 – is the motor's friction constant.
θ_1 – is the angular position of the motor.

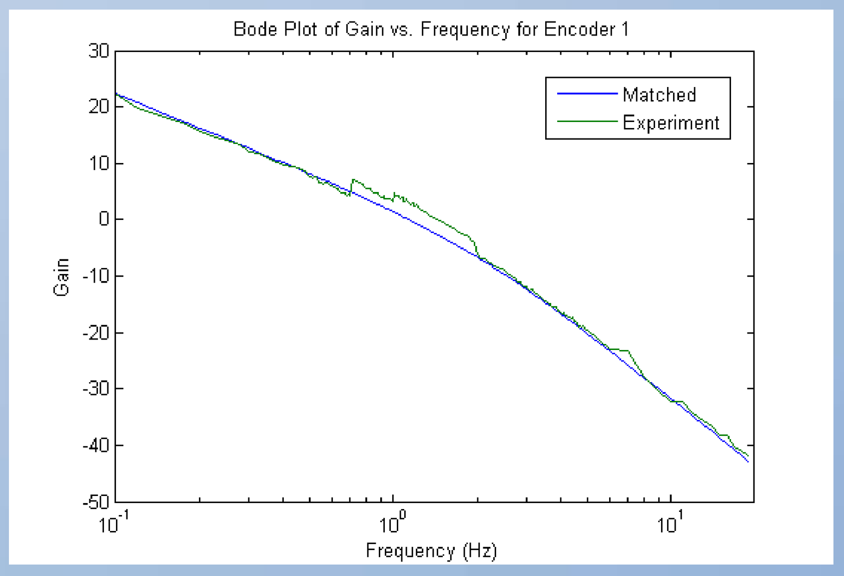

Figure 7: Bode plot for the motor with no load and the modeled equation

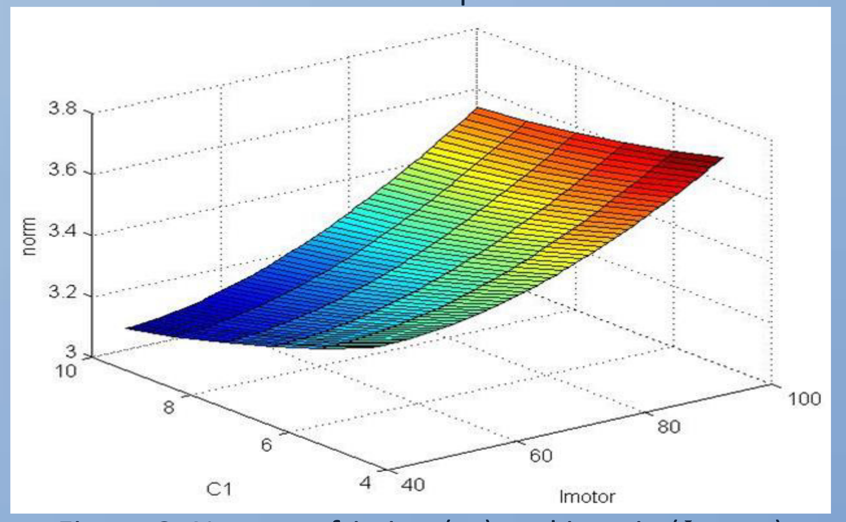

Figure 8: Norm vs. friction (c_1) and inertia (I_{motor})

The initial conditions response for 15 degrees was also matched with mathematic models for the leg only to find the moment of inertia and coefficient of friction for the leg.

The equation of motion for the leg is:

$$I_{leg}\ddot{\theta}_2 + c_2\dot{\theta}_2 + mgl\theta_2 = 0$$

Where:

I_{leg} – is the moment of inertia of leg.
g – is the acceleration due to gravity.
m – is the mass of the leg.
l – is the length of the leg.
c_2 – is the friction of the leg's pivot.
θ_2 – is the angular position of the leg.

The matched equation had only 6.5% error when compared to the experimental results.

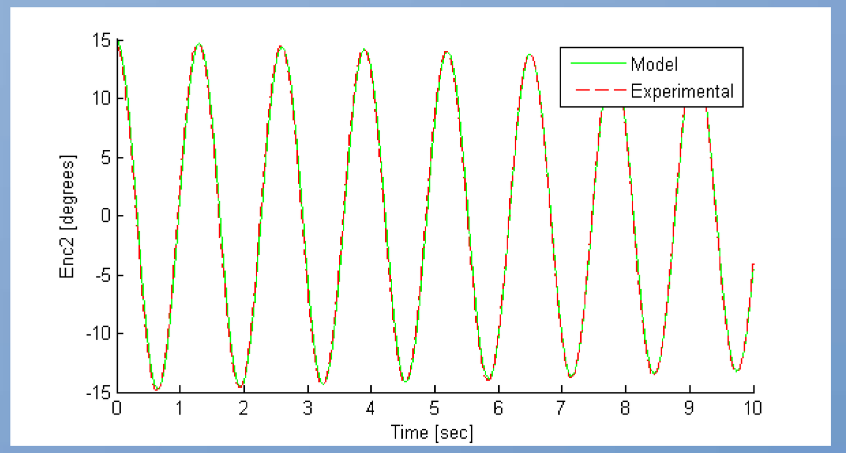

Figure 9: Initial Conditions Response and the modeled equation

Conclusions

The leg's resonance was characteristic of a fourth order system, which confirmed the theoretical model. The linearization of the equations had minimal effect on the validity of the motor's equations.

Further data analysis will match the model of the entire system to the experimental results for the system. This will enable design of an effective controller for the leg by refining the commands sent to the controller. Information from the other tests conducted also aids in perfecting the equations modeling the system.

Bibliography

[1] J. Spitz, Y. Or and M. Zacksenhouse, "Towards a Biologically Inspired Open Loop Controller for Dynamic Biped Locomotion," IEEE International Conference on Robotics and Biomimetics, vol. 1000.

[2] E. Sauther, "Sine Sweep Vibration Testing for Modal Response Primer," Department of Optical Sciences, University of Arizona Opto-Mechanical Engineering; , Tucson, Arizona, 2013.

Acknowledgements

We would like to thank Israel (Izzy) Schallheim for his unparalleled guidance, wisdom, and support as well as Professor Miriam Zacksenhouse for allowing us take part in her project. We would also like to thank the Technion Faculty of Mechanical Engineering for allowing us to use its resources, and specifically Professor Reuven Katz for allowing us to use his laboratory as a workspace. Further thanks to the Maddras Foundation and Mr. Russell N. Stern for their generous support of the SciTech Program.