iMachine: Measuring Manual Wheelchair Mass Properties

Matthew Eicholtz, Stephen Sprigle, PhD, PT, Al Ferri, PhD, Jayme Caspall, MS, Phuc Dao, MS, Stan Wang

Rehabilitation Engineering and Applied Research Laboratory, Georgia Institute of Technology

Introduction

- Mass properties are important parameters in dynamic systems analysis, but may be difficult to estimate for irregularly-shaped objects
- Specifically, the iMachine is designed to analyze manual wheelchairs in an effort to determine the propulsion efficiency using the Anatomical Model Propulsion System (AMPS)

Objectives

- Design a spring-loaded oscillating platform to accurately measure the following parameters:
  - Single-axis moment of inertia
  - Location of the center of mass
  - Total mass
- Analyze the error and reliability of results

Methods

Hardware

- LabJack U6 DAQ device
- Optical Encoder (US Digital, E3 series), 2500 CPR
- Load Cells (Omega, LCGB series), 250 lb capacity

Software

- NI Labview v. 8.5.1
- Pro/Engineer

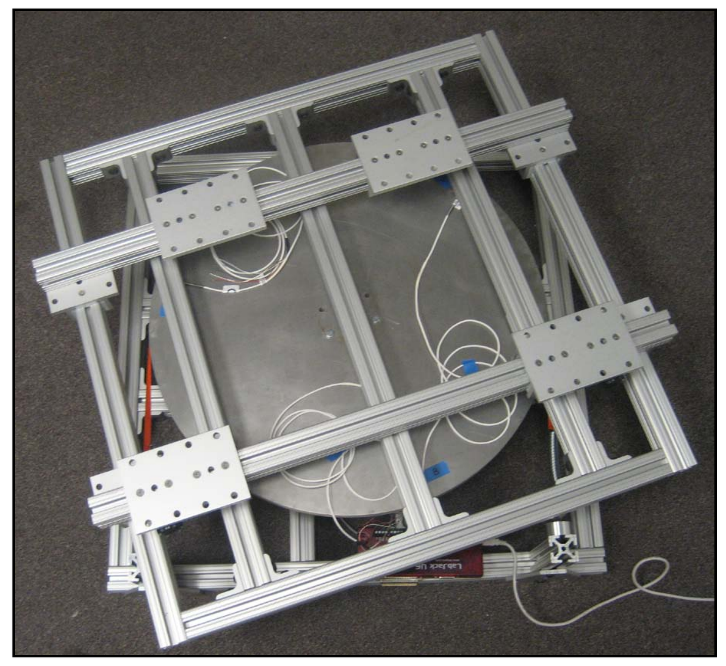
Static Analysis

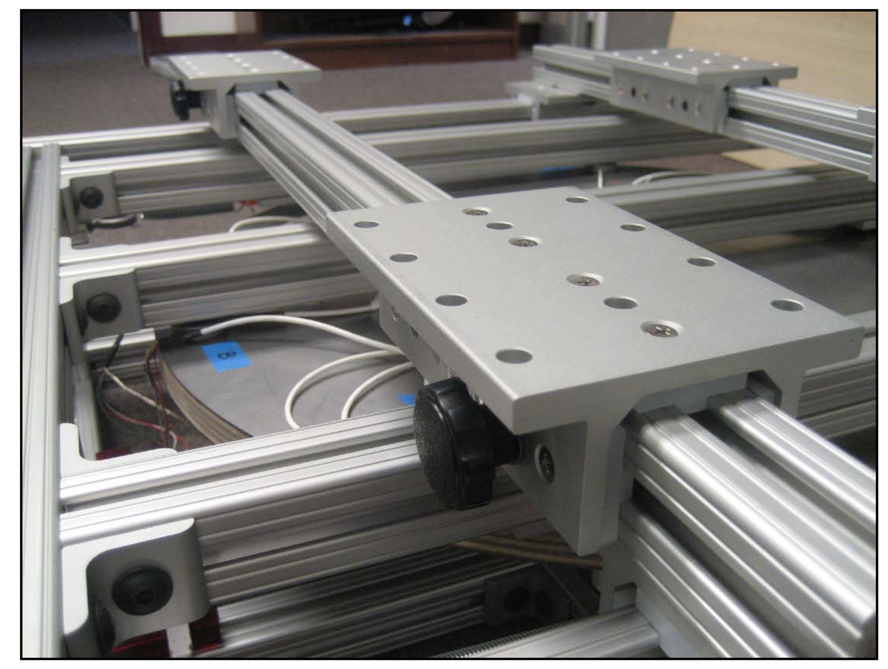
- Record the total system mass using the summation of load cell measurements
- Locate the center of mass and reposition the object until the parallel-axis terms in inertia analysis become negligible

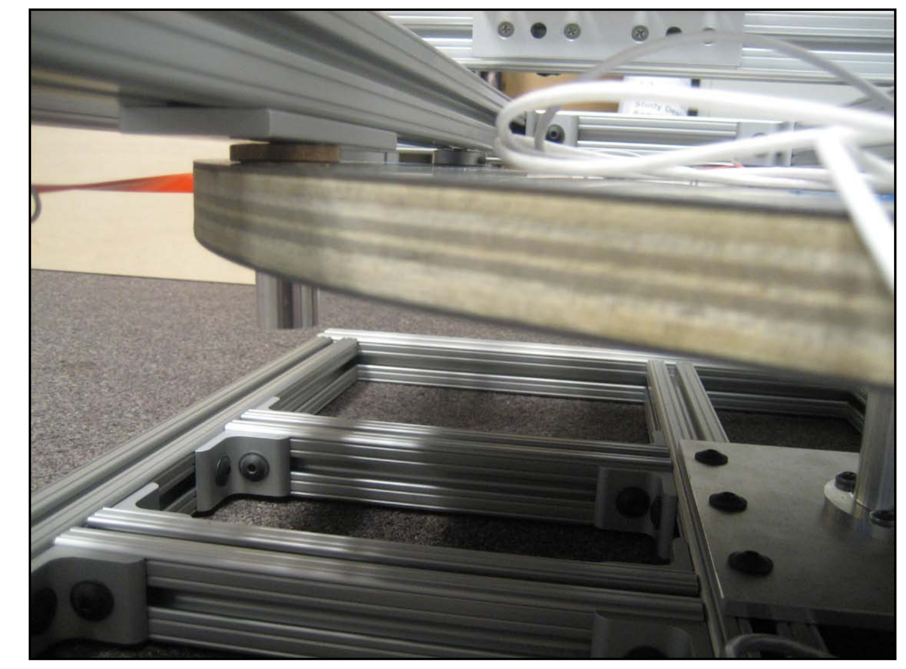
Dynamic Analysis

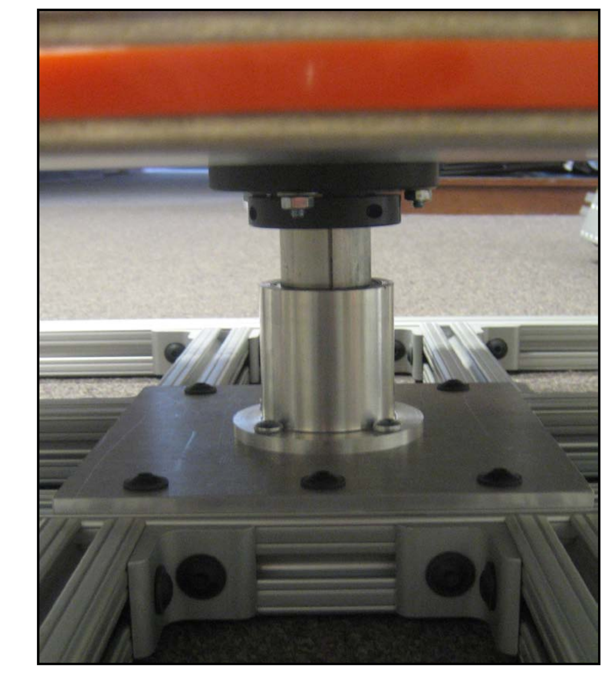
- Release the platform from rest at an initial angular displacement
- Record and monitor the angular position as a function of time
- Determine the average period of oscillation
- Calculate the moment of inertia about the vertical axis using system dynamics

Design and Analysis



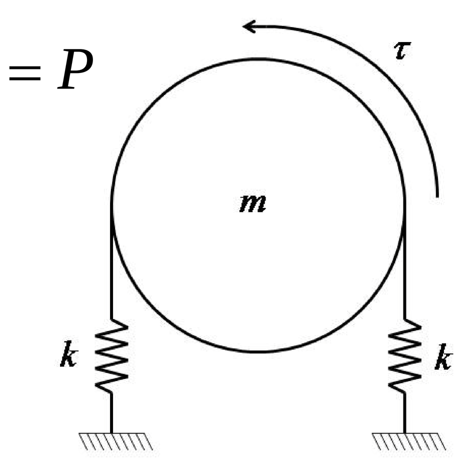






System Dynamics

- Equation of motion: $I\ddot{\theta} + k_{\text{eff}} R\theta = \tau$
- General form of the equation: $\ddot{\theta} + \omega_n^2 \theta = P$
- Natural frequency: $\omega_n = \sqrt{\dfrac{k_{\text{eff}} R}{I}}$
- Oscillation period: $T = \dfrac{2\pi}{\omega_n}$



- Moment of inertia can be calculated from

$$\therefore \quad I = \frac{k_{\text{eff}} R T^2}{4\pi^2}$$

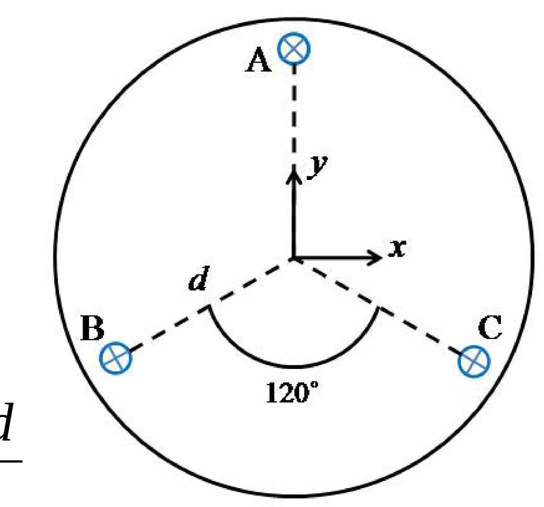
Structural Design

- Frames made from extruded aluminum (80/20 Inc.) for ease of design and assembly
- Linear bearings allow x-y positioning for axial alignment of the shaft with the center of mass
- Spring-loaded disk made from thin steel plates glued to either side of sanded plywood
- Two bearings mounted inside the bottom shaft collar to minimize deflection and withstand 300 lb eccentric load applied at the end of the platform

Load Cell Analysis

- *N*+1 load cells required to specify location in *N* dimensions

$$\Sigma M_x : -F_A d + F_B d \sin 30 + F_C d \sin 30 = mgY$$
$$\Sigma M_y : -F_B d \cos 30 + F_C d \cos 30 = mgX$$
$$\Sigma F_z : F_A + F_B + F_C = mg$$



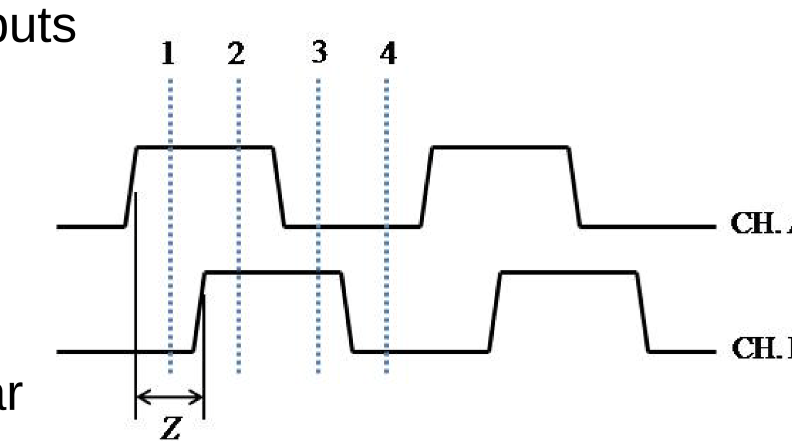
$$\therefore \quad X = \frac{(F_C - F_B) d \cos 30}{F_A + F_B + F_C}; \qquad Y = \frac{[F_A - (F_B + F_C)\sin 30] d}{F_A + F_B + F_C}$$

Encoder Analysis

- 2 channel quadrature TTL squarewave outputs
- Resolution:

$$Z = 90^{\circ}\text{e} \left[\frac{1\,\text{cycle}}{360^{\circ}\text{e}}\right]\left[\frac{1\,\text{rev}}{2500\,\text{cycles}}\right]\left[\frac{360^{\circ}}{1\,\text{rev}}\right] = 0.036^{\circ}$$

- Use 4X quadrature counting to track angular position as a function of time



Future Work

- Finish iMachine assembly
- Conduct validation tests for objects with known mass properties
- Begin testing manual wheelchairs for AMPS project
- Identify potential sources of error and develop a thorough error propagation analysis

Acknowledgements

- This research was conducted as part of the RERC on Wheeled Mobility, which is supported by Grant H133E080003 from the National Institute on Disability and Rehabilitation Research of the U.S. Department of Education.
- I would like to thank the entire AMPS team for their support and Louis Boulanger in the ME Machine Shop for his work on the laminated disk.

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