Curricular Module Development Integrating Hands-on Physical Tests with Model-Based Design: Gear Test Activity for GE 410

PI: Prof. James T. Allison[1,3,4]; Research Assistant: Junwu Zhang[2,3,4]

Department of Industrial & Enterprise System Engineering (ISE)[1], Department of Mechanical Science & Engineering[2], College of Engineering[3], University of Illinois at Urbana-Champaign[4]

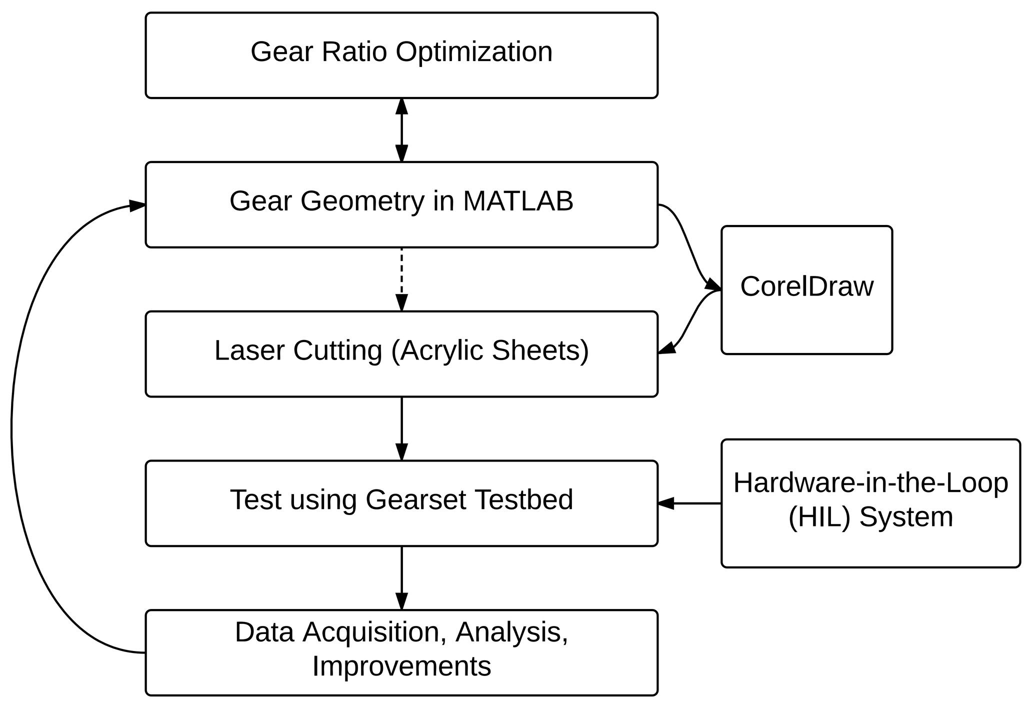
Introduction & Aim

Motivation:
Through our experiences in design courses including GE 410 (Component Design), we found that students often struggle conceptually with the design of gears, due to a lack of first-hand experience using them. We anticipate that students will strongly benefit from a complete design activity where they design a gearset to meet specific requirements, fabricate the gears, and test the physical system to evaluate its performance.

Design Problem Context:

American Solar Challenge	Simulated torque output (HIL)	Find gear ratio that: • Minimize time to travel fixed distance • Stand adequate force & stress

Gear Ratio Design:

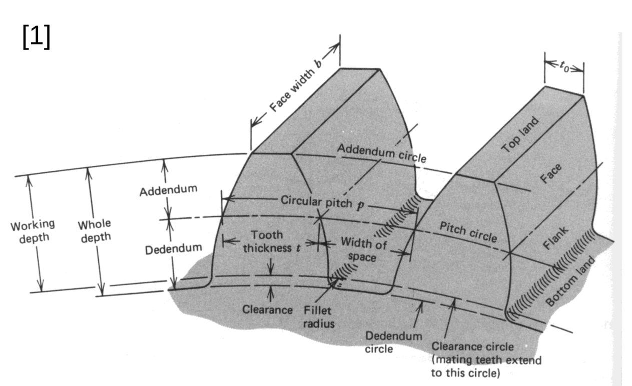


Technical Background

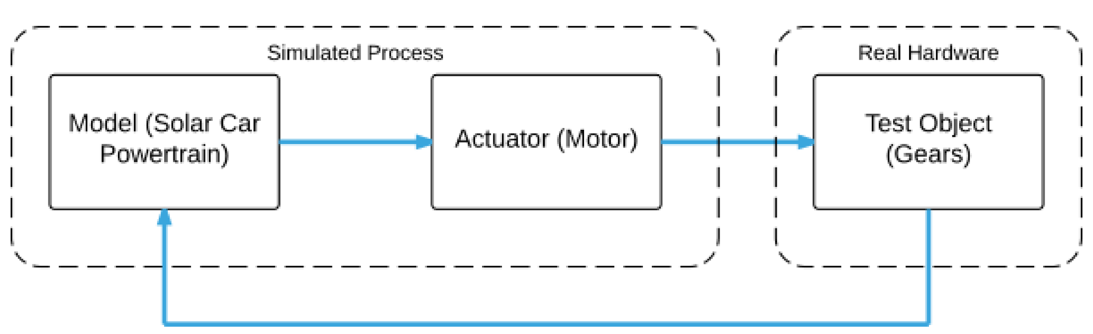
Gear Design:

- Involute profile
- Simplest, commonly used
- Conjugate action
- Force analysis
- Geometry design through MATLAB

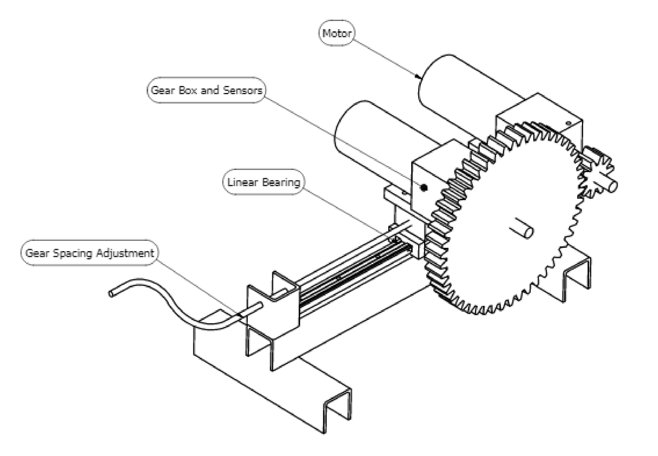
[1]



Hardware-in-the-Loop (HIL) Simulation:



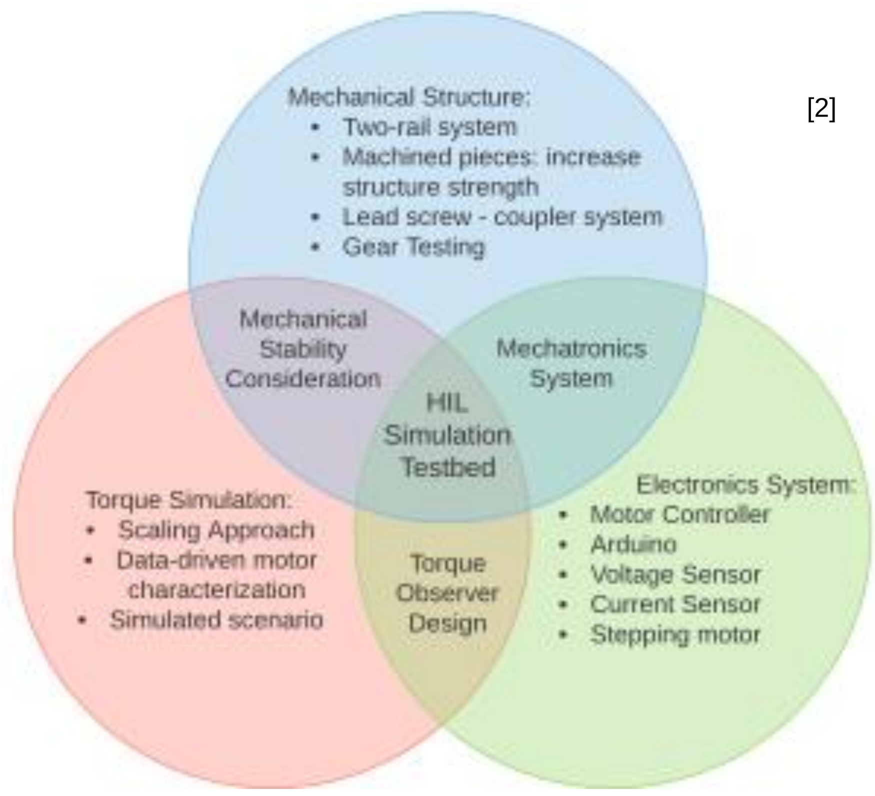
Testbed



Gearset Testbed CAD Model

- 2 x 12V Brushless DC Motors
- CNC Milling machine used for test bed machining
- Motor Controlled Lead Screw (upgrade over initial design)
- Encoder, Current and Voltage sensors attached for torque estimation

[2]



Gear Geometry Through MATLAB

Involute Gear Profile Equations

Basic equations:

$$P = \frac{N}{d} \quad (1)$$

$$p = \frac{\pi d}{N} = \pi m \quad (2)$$

Equation used to generate gear geometry, where:

$$t = 2 \times r \times \left| \frac{t_P}{2 \cdot r_P} + (\tan \varphi_P - \varphi_P) - (\tan \varphi - \varphi) \right| \quad (3)$$

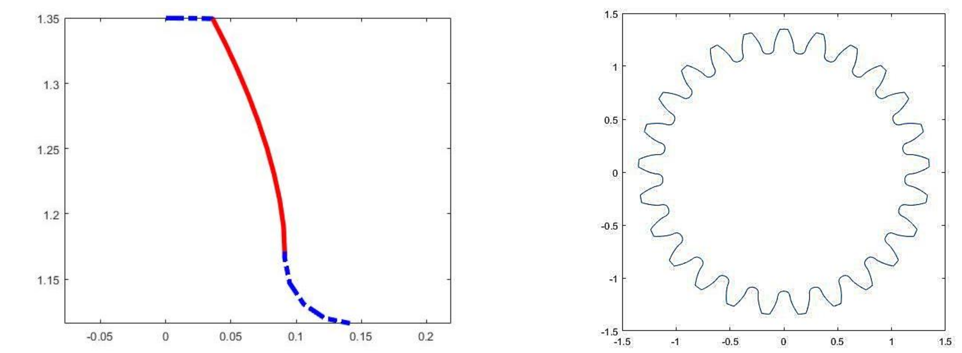
and

$$\varphi = \cos^{-1} \frac{r_b}{r} \quad (4)$$

are t and r at pitch circle, respectively.
D and N represents pitch diameter and number of teeth, respectively.

$$t_P = \frac{\pi \cdot D}{2 \cdot N} \quad (5)$$

$$r_P = \frac{D}{2} \quad (6)$$



Geometry used to Laser Cut Gears

Solar Car Simulation Through MATLAB

Optimization:

$$\min -d(x) \quad (7a)$$

subject to:

$$\max(v(t)) \le V_{max} \quad (7b)$$

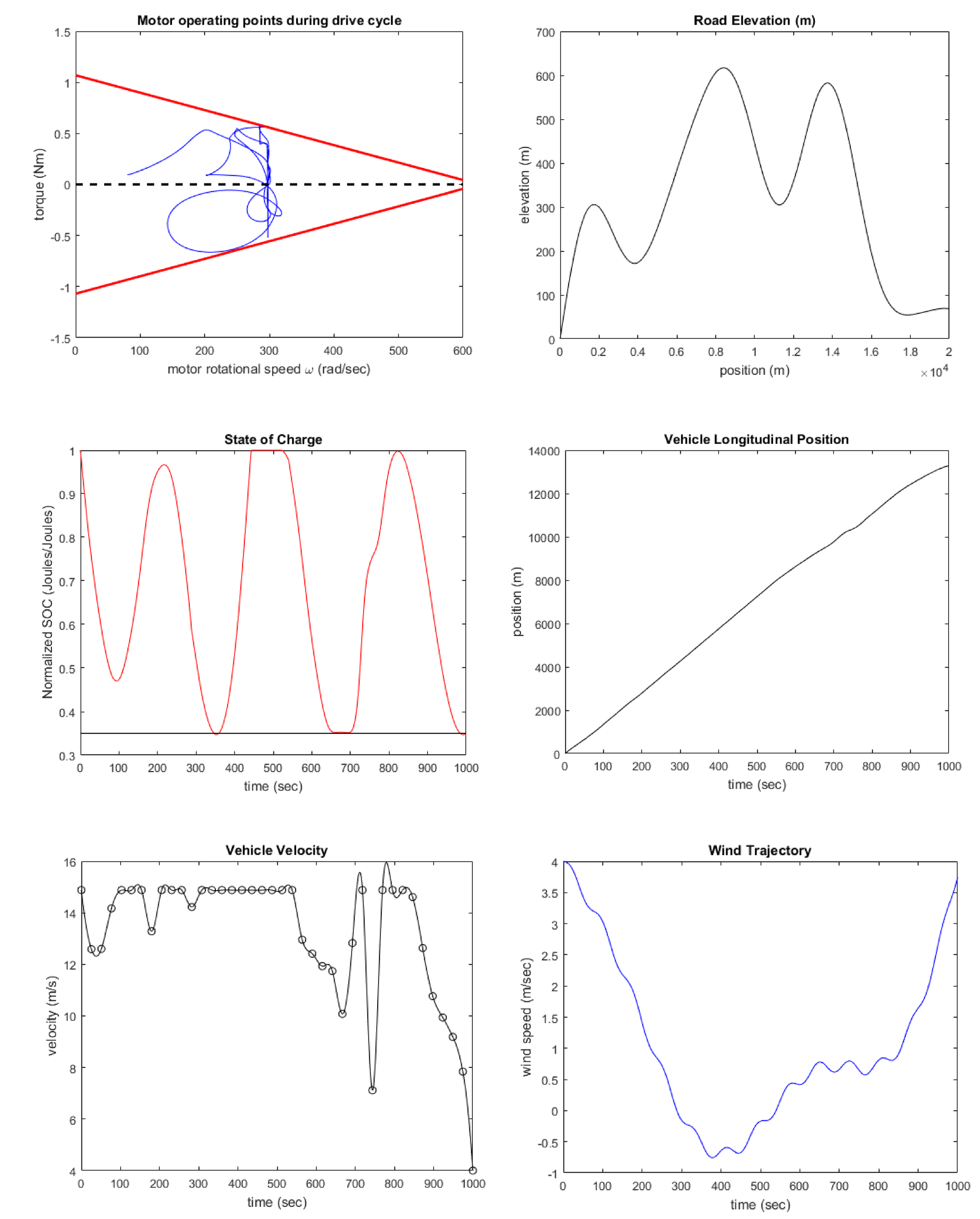
$$\min(v(t)) \ge 0 \quad (7c)$$

$$\min(SOC(t)) \ge SOC_{min} \quad (7d)$$

$$\max(\tau(t) - K_t \omega(t)) \le 0 \quad (7e)$$

Also including vehicle dimensional constraints, road profiles, wind profiles and related constraints.

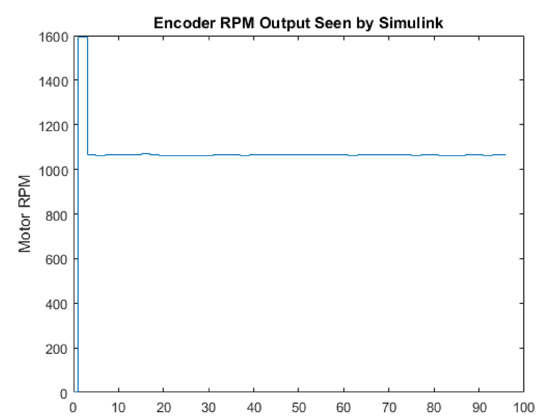
Simulation Results[3]

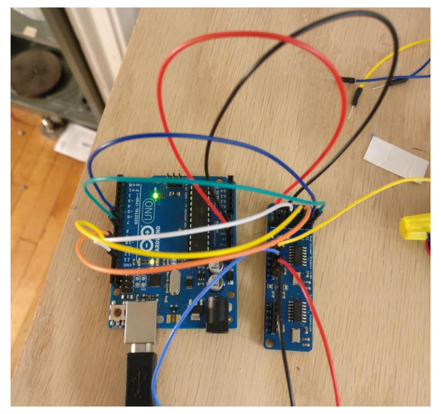


Sensing and Hardware Setup

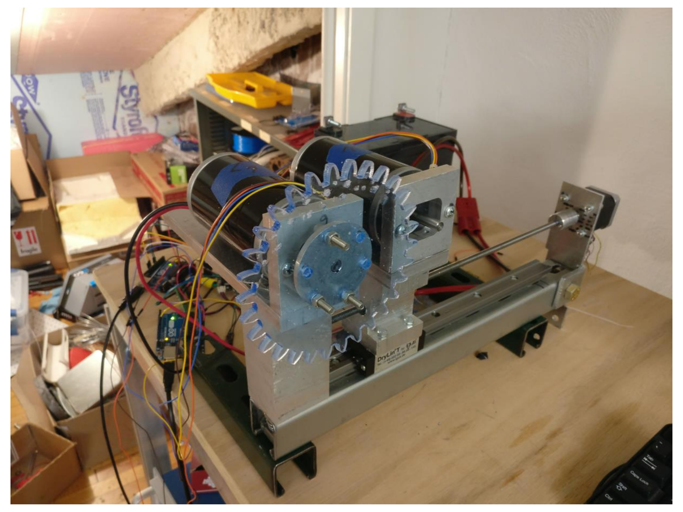
Encoder RPM Sensing

Was a big problem during previous development. Successfully obtained steady and accurate readings by using two LS7366r encoder counter buffers.

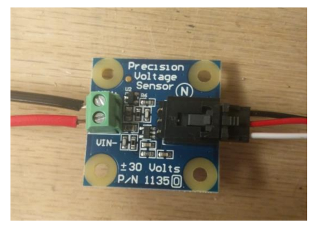




Arduino and Encoder Buffer



Current Testbed Setup



Voltage Sensor

Encoder

Conclusions & Future Plans

Speed and Torque Motor Control:
With current, voltage and encoder sensors in place and working, PID control of either speed or torque can be achieved. Our plan is to realize speed control on traction motor and torque control on load motor. By having these two controls, students can see directly how their gear designs are affecting the smoothness and efficiency of gear transmission

Torque Estimation:
Through data-driven motor modelling techniques, obtain motor torque data and map them accurately with current and voltage. With good torque estimation we can make HIL simulation closer to real-life and more robust.

Acknowledgments

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Reference

[1]coewww.rutgers.edu/classes/mae/mae488/hw/lectures/gear/nomenclature.png
[2] www.lucidchart.com
[3] Co-developed with Prof. James Allison