Sabertooth Robotics: A High Mobility Quadrupedal Robot Platform

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Abstract

Sabertooth Robotics is aimed at designing and realizing an innovative high mobility, quadrupedal robot platform capable of delivering a payload over terrain otherwise impassable by wheeled vehicles at a speed of 5 feet per second. Being able to navigate terrain formerly thought to be impossible will serve to be invaluable for navigating and exploring terrain previously thought to be impossible. Specifically, the robot will also ascend and descend straight stairs with a predetermined gait. The robot uses a spring system in each of its legs for energy efficient locomotion. The 4'x4'x3' freestanding four legged robot weighs approximately 275 pounds with an additional payload capacity of 30 pounds. An important feature of the robot is the passive, two degree of freedom body joint which allows flexibility in terms of robot motions for going around tight corners and ascending stairs. The sensor system integrates a LIDAR, an IMU and a camera for staircase recognition, obstacle avoidance, stability control, and environment mapping. A distributed control and software architecture is used for world mapping, path planning and motion control.

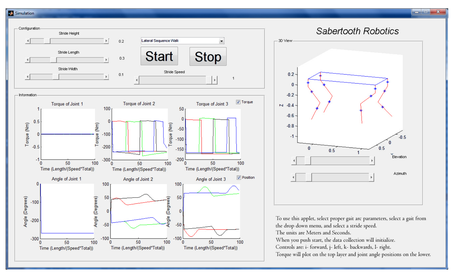
Project Goals

The final first generation prototype must:

- achieve a statically stable 5ft/sec walking gait
- be capable of recovering and monitoring energy lost with each step
- demonstrate ability to develop 3D point clouds of surrounding environment
- demonstrate employment of A* search algorithm for path planning
- have mechanically capability to achieve running, trotting, and walking gaits

Modeling and Simulation

- Developed a dynamic model for the legs using the recursive Newton-Euler formulation
- Implemented 6 gaits in simulation to generate the desired leg trajectory
- Dynamically determines robot stability going through a gait
- Gaits dependent on Denavit-Hartenberg parameters
- Adaptable for different speeds
- Gaits can be changed based on stride height, length and width



Denavit-Hartenberg Parameters (in meters and degrees)

a	α	d	θ
.15	90	0.064	$\Theta_1(t)$
0.381	0	0	$\Theta_2(t)$
0.381	0	0	$\Theta_3(t)$

Duty: Time the foot is allotted contact with the ground.

Offset: The time instance at which the foot first comes into contact with the ground preceding time in the air.

Width, Height, Length: The preset parameters of the arc.

Total : Duty added to the last *Offset* in the gait

i : The value in the domain from 0 to *Total* that represents the location of the gait.

$F_x(X_0,X_1),F_y(Y_0,Y_1)$: Functions that define unit vectors in the directions of input coordinates

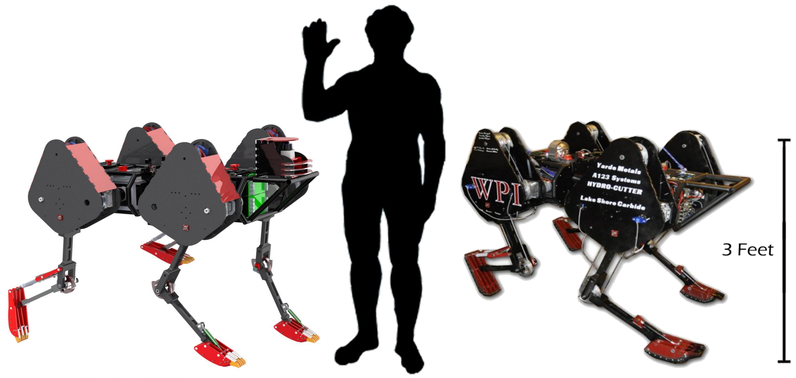
$$x(i) := \begin{bmatrix} i\cdot\left(\frac{F_x(X_0 - X_1)\cdot width}{duty}\right), if(offset < i) \wedge (i < offset + duty) \\ -i\cdot\left(\frac{F_x(X_0 - X_1)\cdot width}{duty}\right), if(offset > i) \vee (i > offset + duty) \end{bmatrix}$$

$$y(i) := \begin{bmatrix} i\cdot\left(\frac{F_y(Y_0 - Y_1)\cdot length}{duty}\right), if(offset < i) \wedge (i < offset + duty) \\ -i\cdot\left(\frac{F_y(Y_0 - Y_1)\cdot length}{duty}\right), if(offset > i) \vee (i > offset + duty) \end{bmatrix}$$

$$z(i) := \begin{bmatrix} \frac{\sin[(i - offset)\cdot 2\pi]}{duty}\cdot 2\cdot\frac{height}{duty}, if(offset < i) \wedge (i < offset + duty) \\ 0, if(offset > i) \vee (i > offset + duty) \end{bmatrix}$$

Final Mechanical Design

- Passive front and back ankles designed to mimic animal behaviors
- Three degrees of freedom per leg
- Two degree of freedom passive body joint with bias towards center
- Cable system implemented to reduce weight of legs
- Springs in series with motors to recover power lost with each step

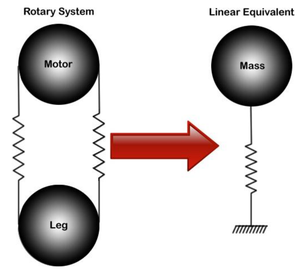


Final Robot CAD Model

Final Robot

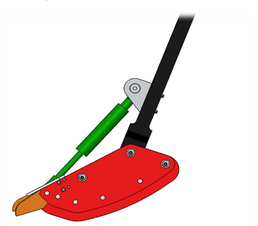
Spring & Cable System

- Springs selected to be optimized for a 5ft/sec trotting gait
- Springs designed to allow for a spring loaded inverted pendulum model (SLIP)
- High order of mechanical compliance due to spring and cable system
- Cable driven from an Ampflow A28-150 Motor with a 28:1 planetary gearbox



Compliance Aspect

- Passive front and back ankles designed to mimic animal behaviors
- Back legs implemented as "power legs" of the system
- Foot pads covered with rubber tires to allow for better grip

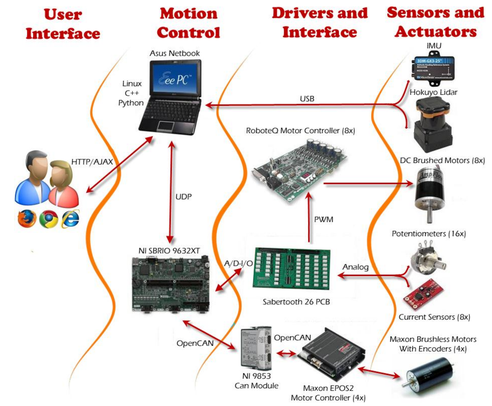


Front Ankle System

Back Ankle System

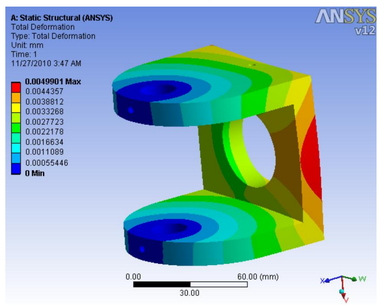
Control System

- NI SBRIO FPGA for sensor input and motor control loops
- Custom PCB breakout board to interface with all sensors
- ASUS netbook for gait algorithms, path planning and error checking
- LIDAR and IMU data to determine dynamic stability and path planning
- PID loop with velocity control implemented on all 12 motors

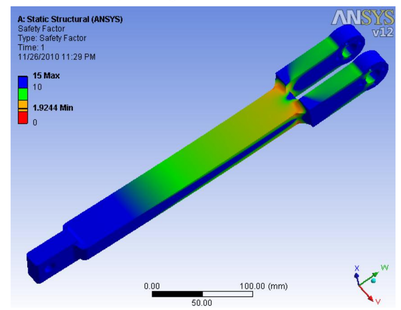


Finite Element Analysis

- Critical components modeled using worst case scenario forces
- Static structural analyses conducted using ANSYS Workbench
- Components redesigned to reduce weight while holding necessary strength



Bushing block deformation analysis



Safety Factor of First Lower Leg Design

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