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Design Process

Starting with the goal of developing a high-performance platform for legged locomotion utilizing laminate construction techniques, a platform suitable for dynamic hopping was developed around a two degree-of-freedom leg concept. The leg is designed to allow energy from hopping to be stored in the elastic deformation of the laminate structure, utilizing laminate materials’ inherent flexibility as a spring. The leg is driven by two motors located at the hip, allowing for controlled vertical and horizontal movement. It consists of four segments, constructed using laminate methods. The lengths of these segments, the cross-sectional geometry of the segments, and the internal gear ratio of the motors were considered as design variables to be explored with this platform.

Model

In order to maximize the leg’s hopping performance, the leg design was optimized for the single highest jump starting from rest. To determine the maximum jump height for a set of design variables, the motors’ ability to apply a vertical force through the leg as the leg extends was analyzed. To do this, the linear torque / angular velocity motor model was used. The torque applied by the motors at the hip joint is applied as a vertical force at the tip of the leg. As the leg extends and the motor velocity increases, the motor’s torque decreases and the gear ratio created by the angles of the leg joints increases to apply more force for a given torque.

Because laminate structures are inherently soft, it is necessary to include a spring in the model to fully capture that effect. The energy stored in the deflection of the leg’s laminate structure is modeled using an angular spring constant to relate the force at the end of a leg segment to the angular deflection of the segment. This allows the force-deflection relationship for a given structure to be determined experimentally by applying several known forces and measuring the resulting deflection.

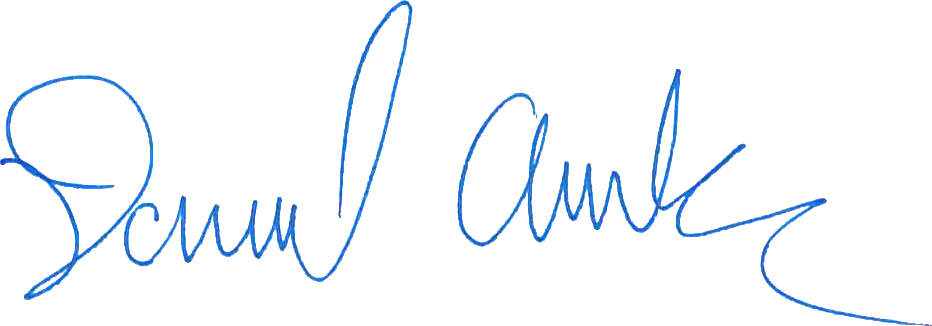
Simulation

Leg design optimization was performed using two simulation methods. The first was a simplified single-mass model, which assumed all the robot’s mass was concentrated in a body at the hip. The force applied to this mass was determined using the linear motor model and current orientation of the theoretical legs. Solving the system for velocity and the angle of the hip joints, allows the force to be calculated incrementally as the motor angular velocity and leg orientation changes as the leg extends. The final velocity resulting from this once the leg is fully extended was then used in an energy projectile model to determine the maximum height of the body.

The second simulation was a more complete dynamic model created using the game engine Unity. It included separate masses for each of the leg segments in addition to the motors and body. To model the deflection of the leg segments, each segment was split into two bodies connected by an angular spring that applies a restorative force proportional to the angular deflection from 180 degrees. This model accounts for the increased inertia of longer and heavier legs and variable stiffness of different leg geometries.

Experiment

An experimental test setup to record the force produced by the leg, the current through the motors, and the position of the leg is being constructed. The platform will perform a single jump starting from rest on a plate mounted to a load cell. As the leg extends, a current sensor and motor encoders will record the state of the motors. The motion of the robot body will be tracked using high speed cameras. The force produced by the legs will also be measured by an embedded force sensor. This test will be performed with several different leg designs chosen utilizing the simulation described above.

Mentor Signature:  Date: 10-4-17