DETERMINATION OF ARTIFICIAL MUSCLE PLACEMENT FOR BIOMIMETIC HUMANOID ROBOT LEGS

Ben Bolen and Alexander Hunt

Agile & Adaptive Robotics Lab, Dept. of Mechanical and Materials Engineering, Portland State University, Portland, OR USA

Introduction

Biomimetic robots attempt to replicate the anatomical motions and biological systems of living organisms. Of particular interest to humans are biomimetic bipedal humanoid robots. Bipedal robotic leg kinematics are a key component in designing biomimetic humanoid robots.

This work describes the process of designing artificial muscle attachment locations of the legs of a bipedal robot utilizing pneumatic artificial muscles (PAMs). PAMs offer similar force and activation times to real muscles, while being lightweight and low power. However, maximum strain available is much smaller for PAMs than for actual muscles, therefore muscle attachment locations cannot be exactly the same if reasonable ranges of motion (RoM) and joint torques are to be achieved

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Methods

This work analyzes muscle length, moment arm, and force of muscles over a range of different joint configurations, based on muscle attachment and wrapping points of the Gait2392 model in OpenSim. OpenSim is a freely available, open-source software platform for the biomechanics community that performs musculoskeletal modeling and simulations for in silico investigations [1]. The OpenSim methodology was reproduced in Matlab. Force calculations for human muscles were determined from the work of Millard [2], Thelen [3], and Hoy [4]. These parameters are then used to find joint torques for muscles.

This process is repeated for a model of the robot actuated by PAMs. Force calculations for Festo PAMs were derived from the work of Hunt [5]. Resting Festo PAM length and diameter are also calculated for each of the actuators. Joint torques for individual muscles and groups of muscles are then compared between the models. .

Fig. 1. Skeleton w/ OpenSim muscle paths

Results and Discussion

The bipedal robot design has 27 pneumatic actuators per side to replace the 46 muscles per side found in GaitBody2392. Comparison between the OpenSim model and the Matlab human model shows less than a 2% difference in torque values.

RoM limitations placed on the robot model helped specify acceptable resting lengths for the PAMs. Hip joint angles for flexion/extension were originally set to match the Matlab OpenSim model but after experimentation the limits were set at +110̊ /-15 (respectively). Maximum adduction at max hip flexion is +10 and at max hip extension it is +20. Maximum abduction at max hip flexion is -60 and at max hip extension it is -10.

Many individual PAMs and muscle-actuator groups have torque values that have surface plots with significantly different shapes and torque ranges than the OpenSim model. An improvement in the biceps femoris maximum strain was achieved by changing the muscle origin, insertion, and wrapping points, but there are still joint angles in which the muscle is unable to provide any force. Since this means that the maximum strain is greater than 17.5%, it might be possible that moving the origin point proximally up the sacrum and better modeling of the 3D geometry in Matlab (with wrap points) might further improve the muscle match..

Fig. 2. Skeleton w/ Robot PAM paths

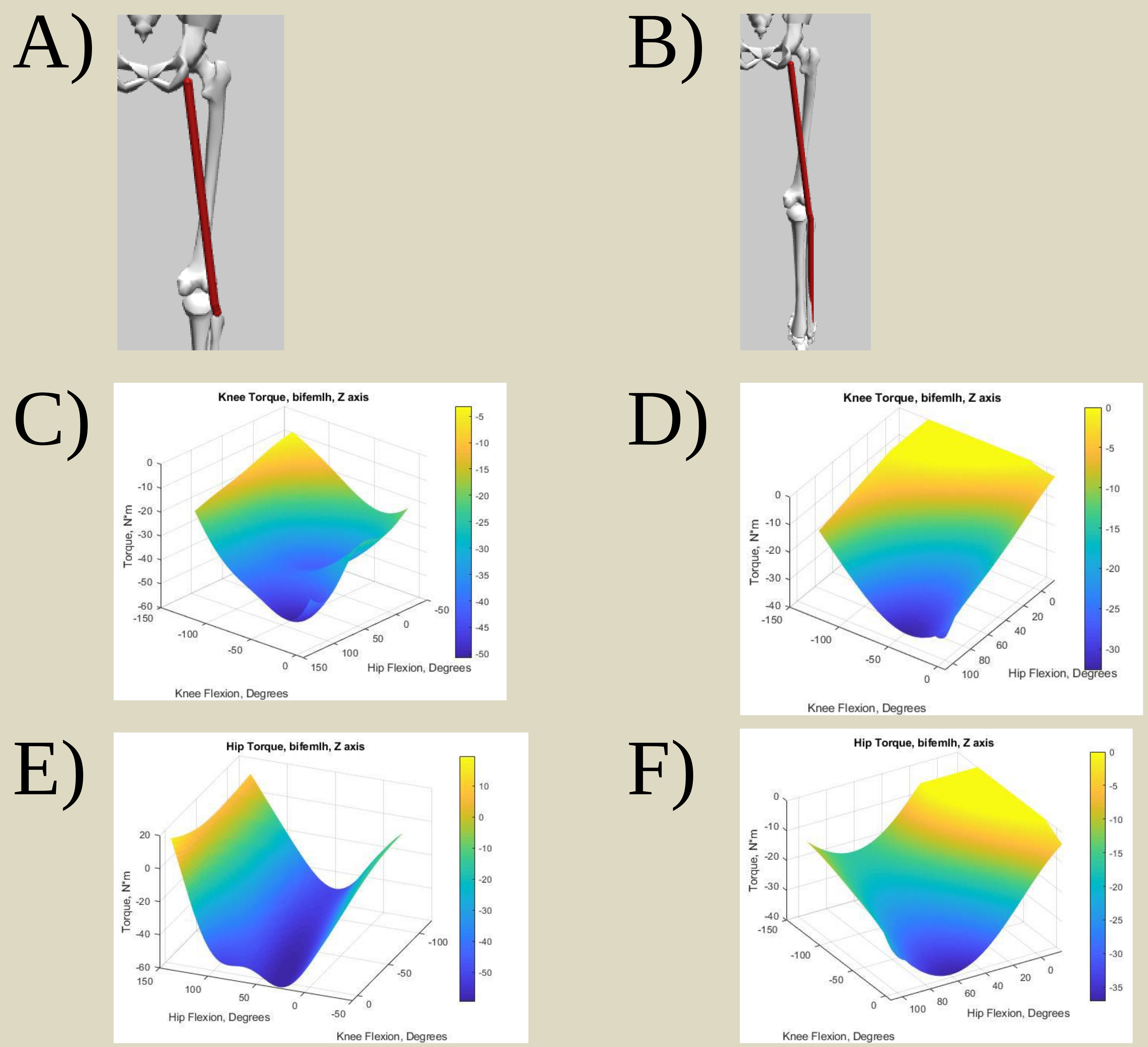

Fig. 3. Biceps Femoris Long Head muscle path (a & b) and torque values (c - f) for OpenSim (a, c, e) and robot model (b, d, f), for knee (c, d) and hip Z-axis (e, f).

References

1. Seth A, et al.. *Procedia Iutam* **2**, 212-232, 2011.

2. Millard M, et al.. *J Biomech* **135**, 021005, 2013.

3. Thelen DG, et al.. *J Biomech* **125**, 70-77, 2003.

4. Hoy MG, et al.. *J Biomech* **23**, 157-169, 1990.

5. Hunt AJ, et al.. *IDETC/CIE*, Cleveland, OH, ASME paper no. V05AT08A008, 2017.

Conclusions

The replication of OpenSim calculations in Matlab was successful. Small variations were observed due to a simplification of force calculations and replacing via points with fixed attachment points. The OpenSim Matlab model takes more time to compute values than OpenSim but has the benefit of being able to do surface plots of calculated values over 2 degrees of freedom (DoFs). This can be expanded to analyzing more than 2 DoFs at once, though visualizing the data might get difficult. The robot Matlab model is a lot faster than the OpenSim model because the force calculations for the Festo muscles are faster.

It is a challenge to achieve maximal joint RoMs and stay within the Festo specified limit of 25% maximum contraction. This difficulty is increased when considering that Hunt [5] reports a maximum strain of 17.5% for long resting lengths of the 10 mm Festo PAM.

Results indicate that several muscles torque profiles in the robot closely match that of the human, however, many muscles fall far short of the human capabilities. Where appropriate, muscle attachment locations on the robot have been modified to better match the torque capabilities demonstrated by the OpenSim model.

Tools have been created in Matlab to calculate and visualize values for length, moment arm, force, and torque for the robot design using PAMs. These values can be compared to existing human models. These tools will be effective for further refinement of the robot design. Additionally, more accurate modeling and refinement can be performed through the solid modeled and the skeletal structure can be 3D-printed - the initial steps towards building and testing a physical biomimetic bipedal humanoid robot.