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Two Configurations of Series Elastic Actuators for Linearly Actuated Humanoid Robots with Large Range of Motion

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Abstract— **We have developed two different configurations of series elastic actuators to be used in the lower body of THOR, a full scale humanoid developed for the DARPA Robotics Challenge. Both designs utilize a ball screw transmission but use different output mechanisms. The THOR-Linear actuator uses a simple lever output while the THOR-Hoekens actuator uses a novel inversion of a Hoekens Linkage. The simpler design of the THOR-Linear actuator makes it well suited for parallel actuation applications while the THOR-Hoekens actuator features a larger range of motion and nearly constant mechanical advantage. In this video, we show early tests of the two actuator designs used in the THOR lower body. The video shows the two actuator designs, their range of motion on THOR, and a series of performance tests.**

I. Summary

Series elastic actuators (SEAs) have many benefits for force controlled robotic applications, which has led to their increased use in force controlled humanoids [1] [2] [3]. THOR, the Tactical Hazardous Operations Robot, is a state of the art, compliant, force controlled, 34 DOF humanoid platform. It features a large range of motion approaching, and in some cases exceeding, that of a human. Linear series elastic actuators (SEAs) are used in all 12 DOF of the lower body, with a hybrid parallel/series arrangement in which the knee pitch and hip pitch are serially actuated while the ankle (roll and pitch) and hip (roll and yaw) are parallelly actuated.

The lower body uses two different implementations of linear SEAs; the THOR-Linear and THOR-Hoekens [4] [5] [6]. The THOR-Linear actuator uses a simple lever output while the THOR-Hoekens actuator uses a novel inversion of a Hoekens Linkage. Each design has benefits which make it well suited for a given joint. The THOR-Linear actuator has a simplified design and tighter packaging which makes it well-suited for parallel actuation applications, while the THOR-Hoekens actuator is more complex but enables a larger range of motion at nearly constant mechanical advantage. Table I lists the range of motion of each DOF.

TABLE I. RANGE OF MOTION FOR EACH DOF

DOF	Range of Motion (deg)		
	Hip	***Knee***	***Ankle***
Roll	75	---	60
Pitch	150	135	100
Yaw	65	---	---

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Many robotic joints powered by linear actuators suffer from a loss of torque towards the ends of the range of motion. The THOR-Hoekens actuator uses a novel inversion of a Hoeken's four-bar linkage, using the ball screw as a linear input to actuate the rotary output. The link lengths were chosen to optimize constant angular velocity, resulting in a nearly constant mechanical advantage and torque of 105 [Nm] throughout the entire 150 [deg] range of motion. Fig. 1 shows the range of motion of the two actuator designs.

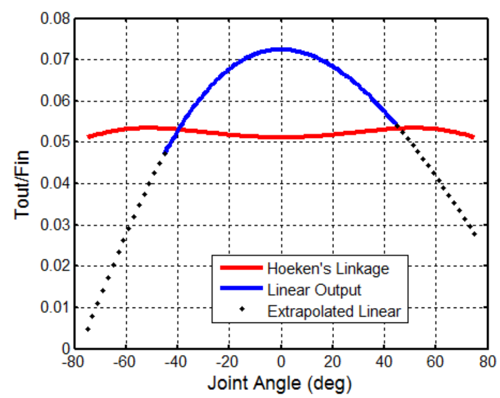

Figure 1. Mechanical Advantage vs. Joint Angle of the two SEA implimentations used in the THOR lower body.

The end result of using the Hoekens output is the flattening of the mechanical advantage curve and the extension of the usable range of motion.

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