MESO: Simulated Muscles for a Humanoid Robot

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The Problem: To create a motor control system for the humanoid robot Cog which emulates the biomechanics of muscles and a skeleton.

Motivation: Cog is an anthropomorphic robot: one fundamental principle of its mechanical design is that it should have enough degrees of freedom and articulation to enable it to recognizably emulate human motor behavior. This is a hardware requirement: Cog can't pretend to move an arm it doesn't have. The basic requirements for the control system are not so stringent, though. A very elaborate animatronic motor controller could produce very life-like canned motion, albeit with a very unanthropomorphic control system. The goal of the project is to explore mechanisms for generating and learning social behavior. If Cog emulates the human form at the right level of granularity, these mechanisms should have a very natural form. With that in mind, Cog's actuators should incorporate human-like control as well as kinematics.

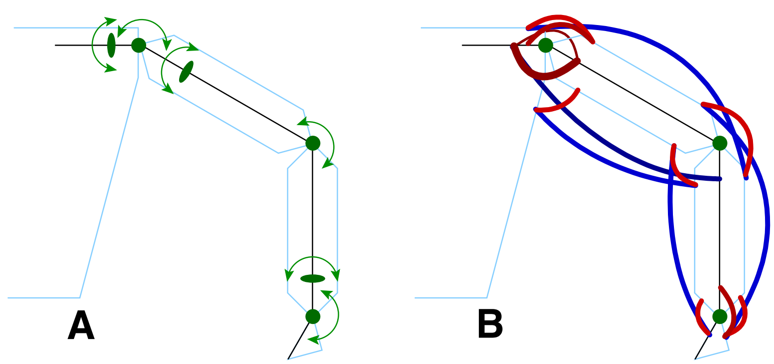

Figure 1: Cog's arms have six single-axis actuators (A); however, they will be controlled as if they were actuated by antagonistic pairs of real muscles (B). On Cog, most muscles are polyarticulate. For example, any muscle spanning a shoulder must actually span three revolute joints.

Approach: Given the mechanics of the existing robot, the best way to do this is to implement the thinnest possible abstraction layer which provides an effective simulation of human musculature. This system is called meso. Cog's actuators are already force-controlled [6], which is muscle-like in itself. meso adds a layer on top of this which simulates "virtual muscles" which approximate the function of muscles in a human body. Approximately 40 such muscles are used to control the 15 joints in Cog's arms and torso. Figure [maddog:arm] illustrates the use of virtual muscles on one arm.

meso incorporates essential features for human-like behavior and response: reflex stiffness, polyarticulate coupling [3] [2, pp.298-303], and fatigue models [5, ch.6]. This allows production of human-like movement which a higher-level control system can tune and optimize via biologically relevant feedback cues.

meso is divided into two layers: a skeletal model which accounts for the kinematics of the robot and the virtual muscles, and a muscular model which calculates the muscle forces and fatigue properties.

The purpose of the skeletal model is to calculate two functions: $\vec{l}(\vec{\theta})$, the vector of lengths of the virtual muscles, and $\vec{\tau}(\vec{\theta}, \vec{F})$, the vector of joint torques. The inputs to the skeletal model are $\vec{\theta}$, the skeletal configuration expressed as a vector of joint angles, and $\vec{F}$, the vector of muscle forces provided by the muscular model. To calculate these two functions, the skeletal model requires a description of the mechanical linkages in the real robot and a list of the insertion points (anchor points) of the virtual muscles.

The role of the muscular model is to compute the force output of the virtual muscles by simulating muscle tissue. The force is basically a spring-like function of the muscle length, which is further modulated by a fatigue model. This means that the robot cannot exert a large continuous force forever; it will appear to tire over time. The muscle fatigue is one component of a fairly sophisticated model of energy metabolism, based on human biochemistry[1].

The skeletal, muscular, and fatigue models, and the joint sensor and motor control, are implemented as individual processes which are linked together via an interprocess communication framework called sok.

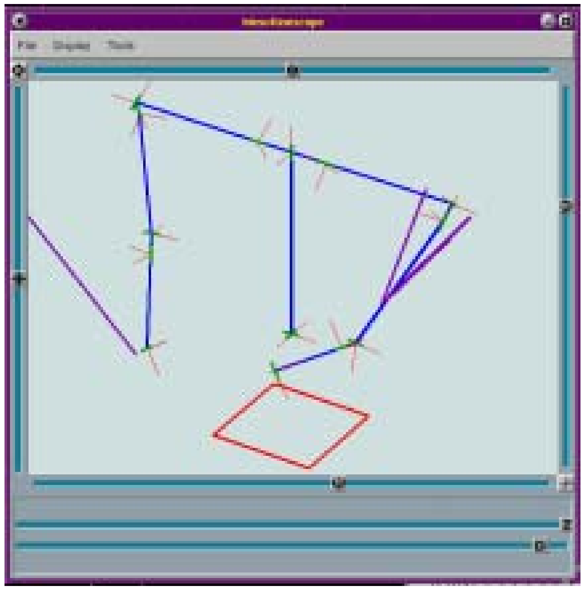

Figure 2: vmeso is the GUI used to create and edit skeletal models, and to view their operation in real-time, since virtual muscles are invisible on the physical robot. Links and joints are shown in blue and green; virtual muscles are depicted in purple.

Impact: meso provides human-like biomechanical constraints to the robot, in the form of a simulation of human musculature. Given an adaptive motor control scheme which is sensitive to these constraints (e.g. minimizes spent biochemical energy and fatigue), Cog should develop human-like motion, without being explicitly hardwired to do so [4].

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