Achieving High Performance from SMA Actuators

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Abstract

Actuators based on Shape Memory Alloys (SMA) have mechanical properties which, in some respects, resemble biological muscle more closely than they resemble the geared electric motors typically used as robot actuators. For example, (1) they can only pull, (2) they naturally produce large forces at low speeds, (3) they are not very fast, and (4) their effective inertias are very low. Their big disadvantage is, of course, their very low energy efficiency; and this is what limits their commercial use to a few niche applications where their energy efficiency is not an issue. Nevertheless, even in the absence of commercial applications, SMA actuators provide robotics researchers (and others) with an opportunity to study the motion control problem in mechanical systems whose motion dynamics resemble the skeletomuscular system. Such studies can shed new light on how humans and animals move, what control strategies are required, and how to close the performance gap between animals and robots.

In this talk, I will describe the development of a control architecture that implements force control at high speed and unprecedented accuracy on an actuator consisting of an antagonistic pair of SMA wires. This level of performance was achieved not by employing advanced control theory, but by studying the behaviour of the actuator and designing a control architecture that safely pushes it close to its performance limit. Thus, the control architecture is aware that it is controlling two independent (but mechanically coupled) SMA wires that together produce a single output; and it is aware of the thermal and stress limits of each wire, and allows them to get close to these limits without exceeding them. To achieve this result, the architecture employs several feedback loops: one to make the actuator's output track the command signal, and all the rest to safely maximize the actuator's speed and accuracy. The ideas embodied in this architecture could be applied to other actuator technologies.

The idea of motion at the performance envelope is one that deserves further study. Animals routinely exhibit motions that approach the speed and strength limits of their bodies; yet robots typically operate well short of their own performance limits. We, as robot programmers, like the idea of being able to command a specific force or velocity, and have the robot do exactly what we commanded. To bring about this situation, we set upper limits on programmed force and velocity that are so conservative that we can be almost certain that the robot can achieve them in any configuration and under any load condition. Clearly, this is not the right way to close the performance gap between robots and animals.

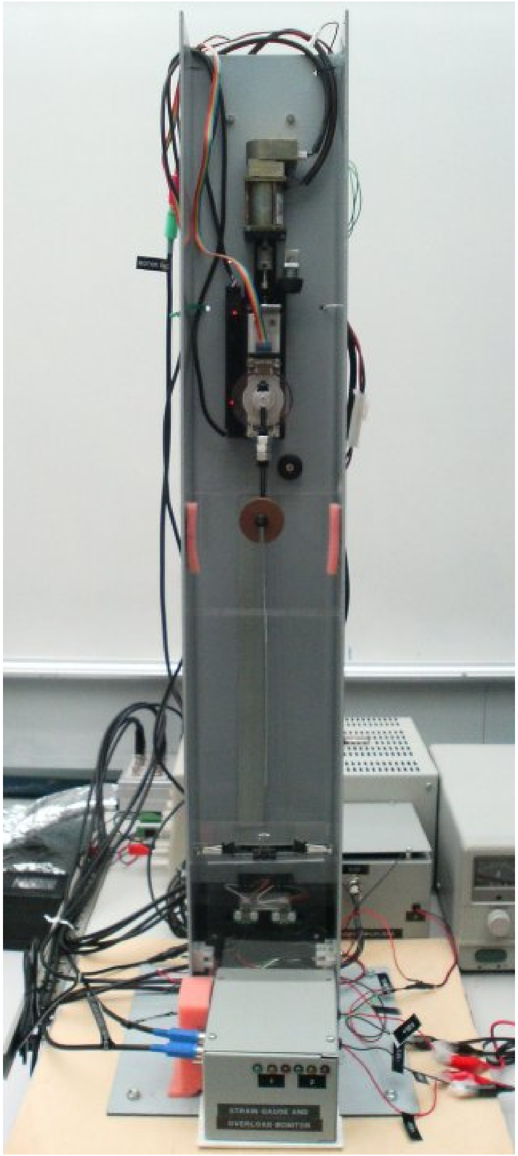

Figure 1: Testbed used to develop the force control architecture. The actuator comprises two parallel SMA wires, which are attached to precision load cells at the bottom and to a pulley at the top. The pulley is instrumented with an optical shaft encoder, and is mounted on a motorized precision linear stage to allow its height to be set or adjusted from the computer. In this picture, the pulley is also connected to a (relatively) heavy pendulum load. See `http://users.cecs.anu.edu.au/~roy/SMA/` for more details.