Control of a Pneumatic Muscle Powered System

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For a robotic system that shares its workspace with humans and physically interacts with them, safety is of paramount importance. In order to build a safe system, safety has to be considered in both hardware and software (control).

In this presentation, we present the safe control of a 2-DOF planar manipulator (see fig. 1) actuated by Pleated Pneumatic Artificial Muscles (PPAMs, [1]). Due to its low weight and inherent (and variable) compliance, the system hardware has excellent safety characteristics. The length of both links of the manipulator is 30 cm. In order to increase the range of motion, a series arrangement of Pleated Pneumatic Artificial Muscles was used. The compliance of these actuators, combined with the very low total weight of the system (2.6 kg) make the hardware intrinsically much safer than a stiff system would be.

In traditional control methods, safety and good tracking are often impossible to combine. This is different in the case of Proxy-Based Sliding Mode Control (PSMC), a novel control method introduced by Kikuuwe and Fujimoto [2]. The basic idea behind Proxy-Based Sliding Mode Control for robotics is to attach an imaginary, virtual object, called proxy, to the robot's end effector by means of an PID-type virtual coupling. The proxy's trajectory is controlled by a sliding mode controller. The main advantage of the method is the separation of "local" and "global" dynamics. The local dynamics, i.e. the response to small positional errors, is determined by the virtual coupling (parameters PID), while the global dynamics (response to large positional errors) is determined by the sliding mode parameters. It is thus possible to combine responsive and accurate tracking during normal operation with smooth, slow and safe recovery from large position errors that can sometimes occur after abnormal events.

We present both task and joint space (fig. 2 implementations of Proxy-Based Sliding Mode Control applied to the pneumatic manipulator, and compare their performance with PID control. Good tracking results are obtained, especially with the joint-space implementation.

Safety is evaluated by means of the Head Injury Criterium (HIC, [3]) and by the maximum interaction force in case of collision. The HIC values were calculated for two situations: a step response and a discontinuous change in desired trajectory. The HIC values were determined by simulating a collision between the pneumatic manipulator and a human head (using simplified models for both). In both cases, the PID controller responds rather violently, whereas both proxy-based sliding mode controllers show a smoother response. It is found that in spite of the hardware safety features, the system is unsafe when under PID control. In case of a collision, the impact force can be high enough to do serious damage to the human body.

Proxy-Based Sliding Mode control, on the other hand, provides significantly increased safety (see table I) as well as good tracking. More info in [4].

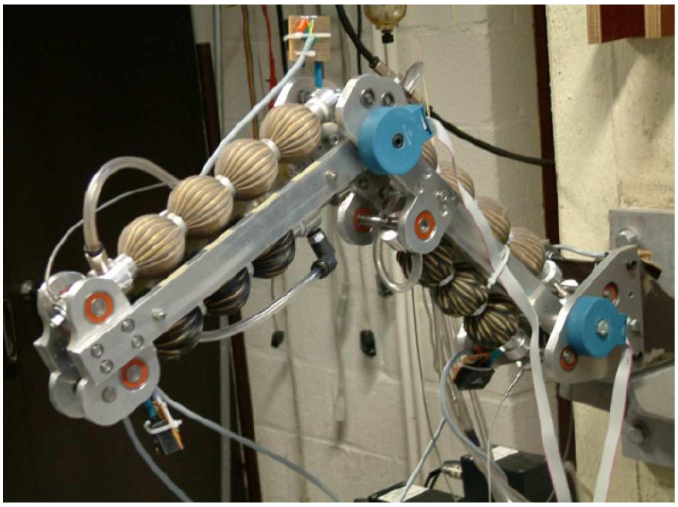

Fig. 1. The 2-DOF manipulator powered by Pleated Pneumatic Artificial Muscles.

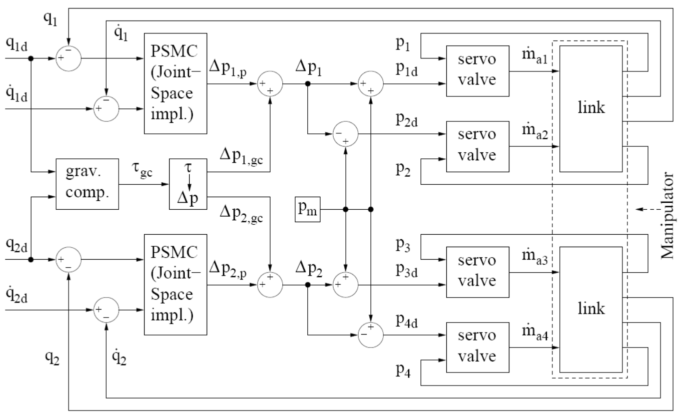

Fig. 2. Schematic representation of the Joint-Space Proxy-Based Sliding Mode controller.

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	Step		Switch between trajectories	
	HIC	$F_{\max}$ $[N]$	HIC	$F_{\max}$ $[N]$
PID	4.81	1524	3.02	1004
PSMC - Joint space - $\lambda = 0.4\,s$, $K_i = 2\,bar/rad \cdot s$	0.23	338	0.10	206
PSMC - Joint space - $\lambda = 0.8\,s$, $K_i = 2\,bar/rad \cdot s$	0.05	167	0.02	100
PSMC - Joint space - $\lambda = 1.5\,s$, $K_i = 2\,bar/rad \cdot s$	0.01	79	0.02	96
PSMC - Joint space - $\lambda = 0.4\,s$, $K_i = 12\,bar/rad \cdot s$	0.48	481	0.14	251
PSMC - Joint space - $\lambda = 0.8\,s$, $K_i = 12\,bar/rad \cdot s$	0.10	233	0.03	132
PSMC - Joint space - $\lambda = 1.5\,s$, $K_i = 12\,bar/rad \cdot s$	0.02	110	0.04	129
PSMC - Task space - $\lambda = 0.4\,s$, $K_i = 2\,bar/rad \cdot s$	0.29	375	0.03	117
PSMC - Task space - $\lambda = 0.8\,s$, $K_i = 2\,bar/rad \cdot s$	0.05	170	0.01	81
PSMC - Task space - $\lambda = 1.5\,s$, $K_i = 2\,bar/rad \cdot s$	0.01	82	0.01	80

TABLE I

VALUES FOR THE HIC AND MAXIMAL INTERACTION FORCE F_{MAX} OBTAINED IN SEVERAL SITUATIONS.

REFERENCES

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