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Experimental evaluation of a shape memory alloy wire actuator with a modulated adaptive controller for position control

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Abstract
This paper presents an experimental investigation of position control of a shape memory alloy (SMA) wire actuator with adaptive and modulated adaptive controllers. The transfer function model of the SMA wire actuator is determined from the experimental open loop response. Adaptive controllers, namely LMS–GSPI, RLS–GSPI and Kalman–GSPI, and modulated adaptive controllers using pulse width modulation (PWM) are designed. The performances of these controllers are experimentally investigated for the position control of an SMA wire actuator with and without thermal disturbance. Experimental results demonstrate that the modulated adaptive controllers outperform adaptive controllers.

(Some figures may appear in colour only in the online journal)

1. Introduction

Shape memory alloys (SMAs) are metals which undergo a transformation from a parent or austenite phase to a martensite phase. The transformation can be induced by a change in alloy temperature, with the martensite phase being present at lower temperatures than the parent phase [1]. There has been a lot of interest in the past in developing SMA based applications because of their ability in producing large deformation, high power to weight ratio, clean and silent actuation. However, the control of SMA is difficult due to its inherent properties such as nonlinearity, hysteresis and low energy efficiency. Hence developing an accurate, adaptive and robust controller for SMA actuators is very important.

The mathematical modeling of SMA actuators is invaluable to develop its control system for them. Even though new applications for SMA actuators have abounded over the years, their mathematical modeling is still an open research problem. An improved analytical model of an SMA actuator based on a simple energy balance with varying temperature during phase transformation is developed and applied to linear actuators [2, 3]. A complete mathematical model of a spring biased SMA wire actuator driven by an electric current and a feedback control scheme with inverse compensation based on the inverse SMA model to achieve higher tracking accuracy can be seen in [4]. Time domain open loop experiments were proposed for the coarse modeling of the SMA actuator and they show a linear relation between heating time and per cent strain [5]. A mathematical model of the SMA heating cycle useful for designing actuator control can be seen in [6–8].

The position and tracking control of SMA wire actuators with proportional-integral (PI), proportional-derivative (PD), proportional-integral-derivative (PID), sliding mode and sliding mode with PID have been applied experimentally and evaluated for their performance in [9–15, 20]. A modulated controller attracts attention to reduce the energy consumption while maintaining the same control accuracy as demonstrated in [16, 17]. In this paper, a model of the heating cycle of an SMA wire actuator is experimentally determined and, adaptive and pulse width (PW) modulated adaptive controllers

