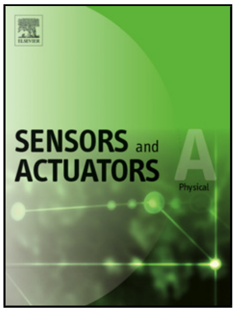

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PII: S0924-4247(16)30566-0
DOI: http://dx.doi.org/doi:10.1016/j.sna.2017.03.033
Reference: SNA 10048

To appear in: *Sensors and Actuators A*

Received date: 6-10-2016
Revised date: 22-3-2017
Accepted date: 24-3-2017

Please cite this article as: Nima Zamani, Mir Behrad Khamesee, Mohammad Ibraheem Khan, Novel Laser Processed Shape Memory Alloy Actuator Design with an Embedded Strain Gauge Sensor using Dual Resistance Measurements. Part I: Fabrication and Model-Based Position Estimation, *<![CDATA[Sensors & Actuators: A. Physical]]>* (2017), http://dx.doi.org/10.1016/j.sna.2017.03.033

Novel Laser Processed Shape Memory Alloy Actuator Design with an Embedded Strain Gauge Sensor using Dual Resistance Measurements. Part I: Fabrication and Model-Based Position Estimation

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Abstract

Shape Memory Alloys have sparked great amount of interest in the field of actuation over the past decades. Until now, sensorless position estimation of SMA actuators under dynamic unknown applied stresses has not been feasible due to the complexity of the system and the number of unknown parameters which the proposed extra information obtained from the embedded sensor solves. In this paper, a novel laser processed NiTi Shape Memory Alloy (SMA) actuator is proposed containing two different material compositions in one monolithic piece of actuator wire. Each of these compositions behaves differently at room temperature, one exhibits a shape memory effect (SME) for actuation, and the other is pseudo-elastic (PE) which is used to enable an embedded sensor. Fabrication of the wire included laser processing, heat-treatment, and cold-working procedures. The actuator wire was subsequently trained to stabilize its properties using iso-stress thermal cycling. Additionally, a novel model-based sensorless position estimation algorithm is presented. Proposed model can estimate the position of the actuator under varying applied stresses with an approximate accuracy of 95% only using dual resistance measurements across the two different material compositions. The proposed actuator has significant application in robotics, wearables, haptics, automotive, and any other application which the mechanical load is not known in advance.

Keywords: shape memory alloys, NiTi, nickel-titanium, SMA, embedded sensor, strain gauge, actuator, laser processed, smart material, novel actuator, self-sensing, dual resistance, sensor-less, position estimation

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1. Introduction

Shape Memory Alloys (SMAs) are an extraordinary class of materials which exhibit unique properties including Shape Memory Effect (SME) and Pseudo-Elasticity (PE). The first observation of SME behavior occurred in 1932 by Arne Olander [1] with Cadmium-Gold alloy. However, it was not until the 1960s which the term Shape Memory Alloys were given to a set of materials which exhibit similar properties. Numerous alloy compositions of shape memory alloys have been identified, including CuAlNi, TiNb and FePt. However the most widely used and commercially available SMA is NiTi, commonly referred to as Nitinol. NiTi poses several advantages over other actuators such as high force to mass ratio, large recoverable strain, super-elasticity, and bio-compatibility.

Over the past decades, there have been significant advances in both understanding the behavior of existing SMA's and discovering new compositions. This has enabled the significant use of these alloys in a variety of applications, such as biomedical vascular stents, automotive, robotics, aviation, and vibration absorption to name a few. However, there still remains two major drawbacks that severely limit the application of SMA's, including the actuation speed and sensor-less controllability under varying loading conditions. There are several ways of dealing with the actuation speed limitation of SMA such as using an active cooling device [2], increasing the surface area to volume ratio using a bundle of wires instead of a single thicker one [3–5], or using high temperature SMAs such as the most common high temperature SMAs NiTiHf & NiTiXr [6, 7]. However, the second limitation is substantially more difficult to overcome using existing methods.

1.1. Motivation

Based on previous literature, position control of SMA actuators dates back decades, and many different control techniques have been implemented using different feedback signals. The most reliable and commonly used feedback signal is a direct position measurement [5, 8–13]. However, position sensors can be expensive and add complexity to the actuator assembly; thus, preventing SMAs to compete with other actuation technologies such as piezoelectric and magnetic actuators. Sensorless methods such as using Electrical Resistance (ER) as a feedback signal has also been used to control the position of the actuator [14–16]. However, in many of the studies, the applied stress is either constant or known in advance and has a monotonic relationship with displacement such as springs [8, 15–20]. One of

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