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THE SMART JOINT: MODEL AND OPTIMIZATION OF A SHAPE MEMORY ALLOY/SHAPE MEMORY POLYMER COMPOSITE ACTUATOR

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ABSTRACT

The Smart Joint, developed at Cornell University, is a composite device which functions as both a structural element and shape changing mechanism. Through resistive heating, the device will provide a tip deflection on the order of 5-20% of its undeflected length, with a high specific work capability. The joint possesses sufficient stiffness to function as a load-carrying element on a structure, inspired by the need to consume minimal energy through passive rigidity. An overview of Smart Joint operation is provided, followed by an improved model encompassing embedded actuators, applicable to many strain actuation systems. Previous work has developed a model that describes the shape change capability of the joint as a function of composition and layering structure, and the revised model is an extension of that work, agreeing well with finite element analysis. Benchmarking is conducted through a heuristic optimization study, providing a framework for selecting joint structure to match desired application by joint composition family. Implementation on a bat-like morphing wing is proposed that uses the Smart Joints as self-actuated hinge structures along the skeleton, capable of providing increased wing camber and tip deflections while in flight.

INTRODUCTION

In order to apply control to the structure, strain actuators are frequently bonded to the surface of a beam (Chaudhry and Rogers, 1994), or motors are inserted at hinge joints of a structure (Love *et al.*, 2004). Some research has gone into the use of embedded actuator structures, and the work of Kota *et al.* (2005) is geared towards developing a 'compliant' element which serves as a hybrid flexure joint and self-actuated system.

This is what is accomplished by the Smart Joint, developed at Cornell University's Laboratory for Intelligent Machine Systems (Manzo and Garcia, 2008a). The Smart Joint is defined as a fusion between structure and actuator, containing embedded strain actuators and elements of variable rigidity to use either along the entire structure of a shape changing mechanism, or as self-actuating flexure joints akin to Kota's ideal compliant joint. The purpose of the joint is to serve as an actively rigid structural element; the stiffness of the joint in its passive state is sufficient to carry 'useful' structural loads (described shortly), and when a change in curvature is desired the system can drastically reduce its stiffness and reorient itself with its embedded strain actuators before returning to its passive, rigid state in the new curved position. The system consumes no energy unless actuation is required, having a distinct advantage over many morphing actuator designs.

In an earlier paper (Manzo and Garcia, 2008b), the joint model was presented with either externally bonded or embedded actuators, and an optimization study was conducted with the proposed model. The model was validated against finite element results for the case of externally bonded actuators to prove that the Euler-Bernoulli assumption was valid. Since then, improvements to the model have provided a solution algorithm which, although and with more degrees of freedom, more accurately reflects the Smart Joint behavior for a variety of layerwise configurations including embedded strain actuation. A new optimization study provides greater capabilities for the joint, with new materials providing even greater enhancements.

1.1 The Smart Joint actuator

The Smart Joint is formed through layering of a strain actuating material, chosen as Dynalloy's Flexinol® shape memory alloy (SMA), and variable rigidity shape memory polymer (SMP) from Cornerstone Research Group to control structural stiffness when in the active phase of operation. Both of these elements are activated by temperature change; the SMA contracts from the elongated detwinned martensite to its contracted austenite when heated resistively, and the SMP experiences a 100-fold decrease in elastic modulus when heated above its glass transition temperature of 60 ^{o}C (Cullen, 2003). In addition, a layer of nichrome at the core of the joint functions as an additional heating source. Figure 1 shows a