High speed SMA actuation with sub-micrometer accuracy

R.I. Gaasbeek[1], K. Le Phan [1]

[1] Goodix Technology, MultiMedia Solutions, The Netherlands

RGaasbeek@Goodix.com

Abstract

Shape Memory Alloy (SMA) actuators have significantly higher specific strain and force compared to other active materials (see Figure 1). This makes them an interesting candidate for miniaturized actuator concepts, such as motors that actuate lenses of (smartphone) cameras. In the latter application, the high force of SMA allows the use of heavier lenses, with superior index and transparency (better camera images without increased module size). Application of SMA actuators is still limited, mainly due to their poor accuracy and speed, with a maximum bandwidth of 0.033 – 2 Hz reported in published literature [3].

When a camera lens is moved for Optical Image Stabilization (OIS), the lens is actuated in x, y-plane in order to compensate for hand jitter of the operator, a biological phenomenon occurring at a frequency up to 20Hz [4]. Up to now, SMA actuated OIS motors were unable to compensate adequately for this full frequency range.

In this work, a deeper understanding of the crystallographic changes is utilized to achieve a more predictable and quicker behavior. Sub-micrometer tracking accuracy up to 20 Hz is demonstrated on an actuator used for optical image stabilization.

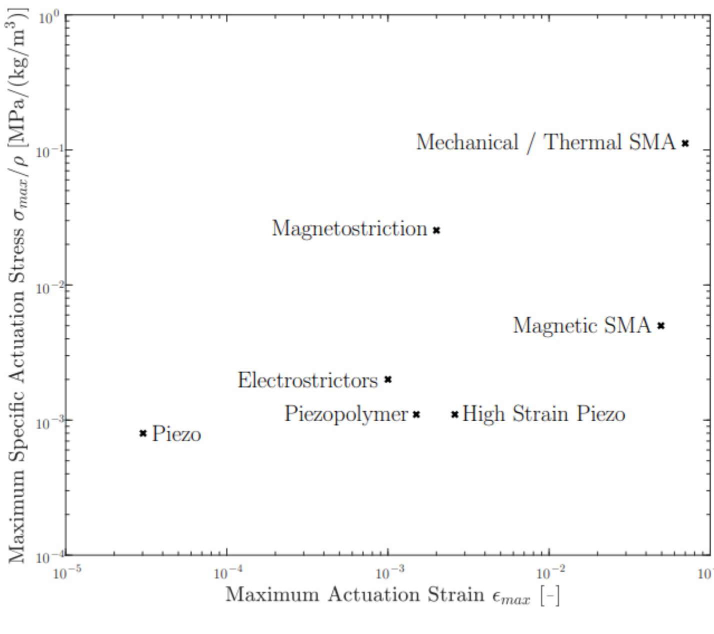

Figure 1: Maximum specific actuation stress vs actuation strain for active materials [1, 2]

In (thermally driven) SMA actuation, one makes use of the fact that the crystallographic structure of SMA material changes based on temperature and stress. Such structure change imposes a large strain effect that is proven to be reproducible for millions of times [5] when the SMA material is in a wire form. Typically, one manipulates the temperature of the wire by applying an electric power to the wire (resistive heating), while heat is removed by natural convection. The latter is a passive process and directly imposes limitations on the speed of the actuator. A method addressing this constraint is to add an active cooling, but this would jeopordize the size the actuator, and hence, is typically not considered for miniaturized mechanisms.

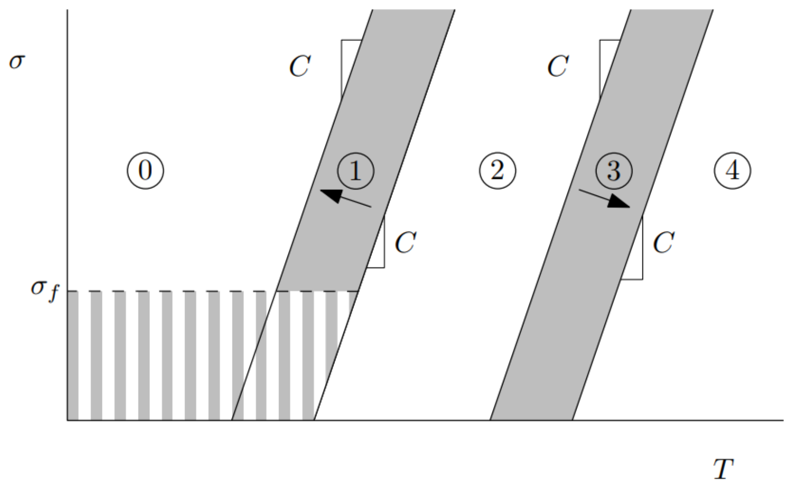

Figure 2: Phase diagram of SMA material (temperature T versus stress σ) [2]

In Figure 2, a schematic phase diagram is depicted. This diagram shows the phases where the crystallographic transformation happens. If stresses are above a critical stress level $\sigma \geq \sigma_f$, dominant changes only occur in region (1) and (3). As an example, if the material is at a high temperature state and the temperature reduces to the left boundary of region (1), the wire is almost completely tranformed to the low temperature crystallographic state. By increasing the stress on the wire, one can see that this tranformation is finished at a higher temperature. As the convection speed depends on the difference between the temperature of the wire and the environment temperature, manipulating at higher wire temperatures corresponds to faster cooling (and thus faster actuation).
Furthermore, for stresses below the crictical stress level $\sigma < \sigma_f$, several unwanted crystallographic structure changes may occur. Although, to some extent, the actuator will still be functional, the stroke may be reduced and the reproducibility is jeopardized.

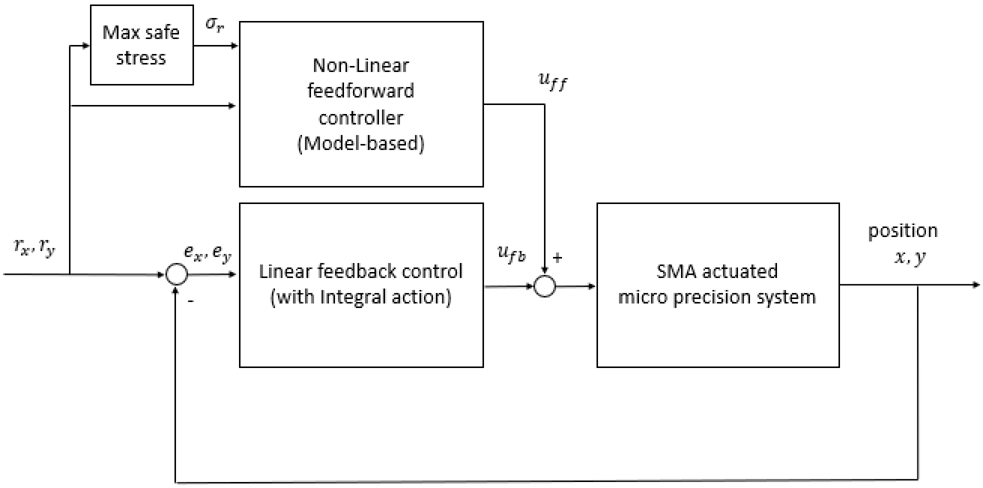

Figure 3: Schematic illustration of the control scheme

By working with an over-actuated system (more actuators than degrees of freedom), a novel feedforward mechanism is employed to regulate the stress level of the system. Stress targets are updated to ensure fast actuation while not endangering the lifetime of the used material.

A classical feedback controller is added to further reduce tracking errors. The control scheme is schematically depicted in Figure 1.

To demonstrate the effectivity of the proposed control approach, this method is applied on a 2-axis motor used for Optical Image Stabilization (OIS). In OIS the lens of a camera module is actuated in x, y-plane to compensate for any unwanted vibrations (e.g. hand tremor of the operator). The 2-axis motor is depicted in Figure 4 and consists of 4 SMA wires (marked as thick black lines on the left hand side diagram (a)).

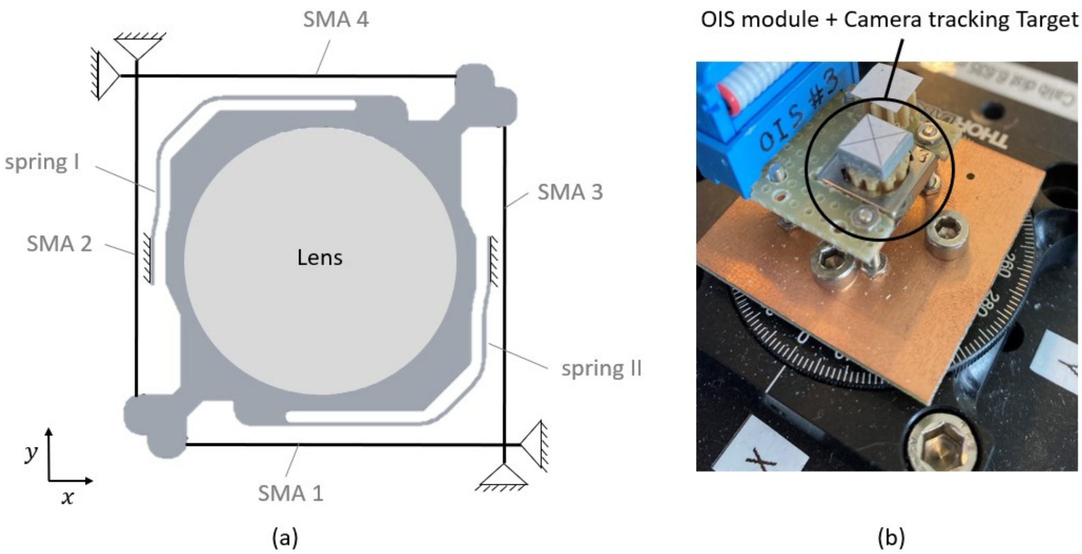

Figure 4: Schematic illustration (a) and picture (b) of the 2-axis OIS motor

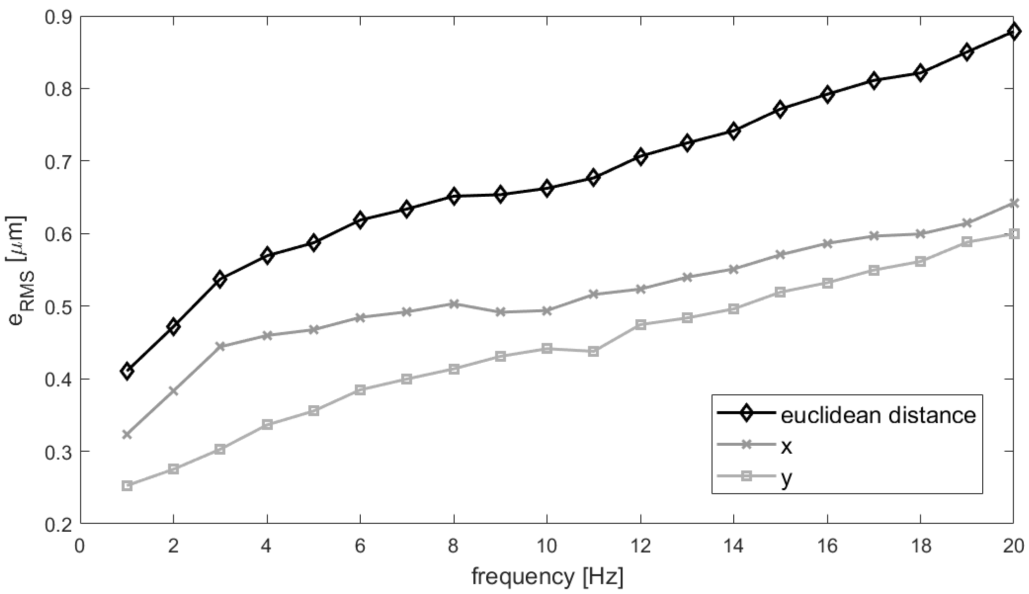

Figure 5: RMS errors at various actuation speeds

References of circular movements were used, varying from 1 Hz (1 second per circle) up to 20 Hz (0.05 second per circle). Resulting RMS errors are depicted in Figure 5. Each circular motion pattern has a diameter of $200\ \mu m$ and RMS positioning errors are confirmed to be well below 1 μm for all references.

[1] S. Lederlé, "Issues in the design of shape memory alloy actuators," Massachusetts Institute of Technology, Massachusetts, Tech. Rep., 2002.

[2] R. Gaasbeek, "Model-based control for SMA actuators : to advance minimal invasive surgery," Ph.D. dissertation, University of Technology Eindhoven, 2018.

[3] S. Nakshatharan, K. Dhanalakshmi, and D. Selvarani Ruth, "Effect of stress on bandwidth of antagonistic shape memory alloy actuator," Journal of Intelligent Material Systems and Structures, 2014.

[4] Y. Teh, "Fast, Accurate Force and Position Control of Shape Memory Alloy Actuators," Ph.D. dissertation, Australian National University, 2008.

[5] F. La Rosa, M. Virzì, F. Bonaccorso, M. Branciforte, "Optical Image Stabilization (OIS)," STMicroelectronics, 2014.