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Design and Development of a Robust Controller for SMA Actuators

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Previous participation in RCEU: Yes

Project Summary:

The goal of this project is to design and develop a controller for a lightweight actuation system, which is driven by shape memory alloy (SMA) wires, for a morphing flap capable of sustaining a smooth operation under aerodynamic loads. The chord length of a conventional aircraft wing is altered using leading-/trailing-edge flaps/slats, usually actuated by screw systems. However, the discontinuous contour of such a wing design diminishes the aerodynamic performance of an aircraft. On the other hand, a wing with a continuous contour does not experience extreme flow-stream fluctuations during flight, resulting in improved aerodynamic characteristics.

Many systems depend on actuators as their driving systems and usually those actuators use electric, hydraulic or pneumatic technologies. In aviation, where lightweight and more compact systems are required, piezoelectric or shape memory alloy actuators are considered. SMA actuators are wires made of nickel and titanium alloy that undergoes a change in the inner crystalline structure that allows for the recovery of the material from normally permanent strains, allowing for the creation of a controllable cycle of strain. The result of this cycle is a repeatable and controllable actuation of the wire for a contraction of up to four percent of the length. Although SMA actuators are challenging to control and they have a slow response speed, they have a great potential in niche applications where space, weight, cost and noise are crucial factors.

Control of Shape Memory Alloy (SMA) actuators has been a challenging topic mainly due to their nonlinearities in the governing physical equations and their hysteresis behaviors. These actuators can suffer from fatigue if they are frequently overstressed or overstrained, however commercially available SMA wires, such as Flexinol, are trained to achieve several millions of cycles without losing the shape memory effect and thus are chosen for the purpose of this project. Linear, Pulse Widths Modulation (PWM) and nonlinear controllers are three types used for controlling SMA actuators and all three will be considered in this project. The necessity of a reliable, robust controller capable of transitioning and maintaining the shape of the wing that is best suited to each flight envelope can be seen in the complexity of the nonlinear physical system required to actuate the wires. The fast response rate, and accuracy of the controller will be the critical features in its design consideration. The design of a controller that balances the features of reliability with those of speed and robustness is critical for the incorporation of such a morphing wing design into practice. The goals of this project is to use a model and create a controller capable of precisely and accurately controlling the wing and obtaining data about the performance of each flight configuration. In order to achieve these goals an understanding of the concepts of control theory and shape memory alloy materials will be combined both in theory and practice. This will serve as a continuation of an ongoing project of the mentor.

The RCEU student's tasks in the project include:
i.) Design a controller for SMA wires
ii.) Use optimization tools and algorithms to improve the controller (details)
iii.) Develop the controller and test the performance of both the system (wing and controller)

Student Prerequisites:
The student will be required to have the following skills: i) Good knowledge of Simulink, MATLAB, and LaTeX; ii) Knowledge of fundamental of aerodynamics and material properties; iii) Hands on experience; iv) Experience with writing technical reports; v) A minimum GPA of 3.6 is required.

Student Duties & Deliverable:
The project will require an extensive laboratory effort but also the archiving of results in a formal manner. During these experiments the student will require to use analytical and observational skills. The experimental results must be routinely logged (e.g., log-book) and quality controlled. Repetition is critical to not only ensure repeatability but also ensure the accuracy of the experimentally derived data and determine the inaccuracies of the model. The student will present current results and report progress on a weekly basis. A final report will be submitted during the ~12th week and evaluated by the mentor. The student can also have the opportunity to present the findings in UAH seminars for undergraduate research or national symposiums/conferences. A tentative timeline for 12 weeks is as follows:
Week 1: Introduction to SMA actuators, controller design, and the system to be controlled.
Weeks 2-3: Review literature on SMA control and present an initial controller design and alternative.
Weeks 4-5: Finalize controller design.
Weeks 6-7: Develop, test, and tune the controller.
Weeks 8-10: Integrate and test the morphing wing technology in a wind tunnel.
Weeks 11-12: Data analysis and creation of poster.

Mentor Supervision and Interaction:
During the summer semester, the mentor will spend the majority of his time working in the lab and assist students during experiments. Thus, the mentor will have regular interactions with the RCEU student. The student will also have daily interactions with the graduate students who work and conduct research in the lab. Direct supervision, mentoring, and evaluation of the project by both mentors will occur weekly at regularly scheduled project meetings. In the weekly meetings the current status of the project, recent results, and difficulties encountered, next steps, and address any other issues that may come up will be discussed.