A Reference Governor for Constrained Control of a Multi Degree of Freedom Metamaterial

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Abstract. A reference governor approach is proposed to control a multi degree of freedom metamaterial subject to constraints. The metamaterial consists of an arbitrary number of bistable "segments" which are attached to each other in a serial manner to generate a "distributed" bistable structure. It is shown that each bistable segment may be controlled using its own reference governor in addition to a nominal controller. Effects from attached segments are modelled as disturbances which must be rejected by the control scheme.

Introduction

Morphing structures have become a popular area of research as they show promise for use in aircraft [1] and morphing vehicles [2]. Employing bistable structures in morphing technology is advantageous as they are capable of adopting two stable shapes which do not require energy to be maintained. This work proposes a reference governor control scheme for the constrained control of a metamaterial concept which consists of multiple bistable elements [3]. With single bistable structures commonly being modelled using the Duffing-Holmes oscillator [4, 5], the equation of motion for the n^{th} bistable element in the metamaterial is given by:

$$m_n\ddot{x}_n = F_n - c_n(\dot{x}_n - \dot{x}_{n-1}) + k_n(x_n - x_{n-1}) - k_n^p(x_n - x_{n-1})^3 + c_{n+1}(\dot{x}_{n+1} - \dot{x}_n) - k_{n+1}(x_{n+1} - x_n) + k_{n+1}^p(x_{n+1} - x_n)^3 \quad (1)$$

where x_n is the displacement of the n^{th} structure, F_n is the force from the controlling actuator, m_n is the mass, c_n is the friction coefficient from the mechanical model, k_n is the destabilizing linear spring stiffness, k_n^p is the restorative nonlinear spring stiffness. The proposed work will offer two contributions: a method for controlling the shape change of the metamaterial where the effects of neighboring bistable structures are modelled as disturbances and a demonstration of the efficacy of a reference governor scheme which can address polynomial constraints and disturbances.

Results and discussion

Figure 1 illustrates the efficacy of the reference governor approach to three connected elements of the metamaterial where the constraining bounds are pictured with red dashed lines. Successful shape change of three

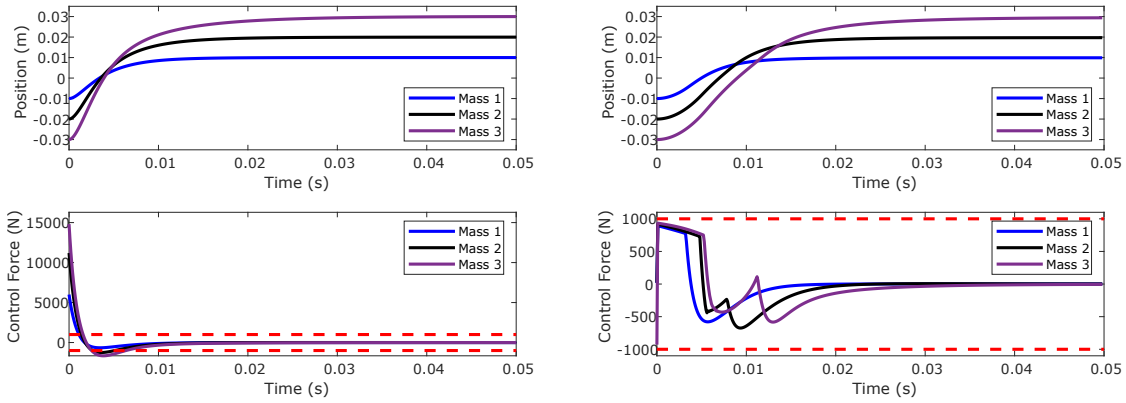

Figure 1: Nominal system response (left) and response with reference governor (right).

series-connected metamaterial elements each initially at a relative displacement of -10 mm and ending at a relative displacement of 10 mm is achieved while satisfying constraints on the control effort which are polynomial in nature.

References

[1] Barbarino S., Bilgen O., Ajaj R., Friswell M., Inman D. (2011) A review of morphing aircraft. *J. Intell. Mater. Syst. Struct.* **22**:823–877.
[2] Valasek J. (2012) Morphing Aerospace Vehicles and Structures. John Wiley & Sons Ltd, Chichester, United Kingdom.
[3] Simsek M.R., Schieni R., Burlion L., Bilgen O. (2022) A Hybrid Position Feedback Controlled Bistable Metamaterial Concept. Presented at ENOC 2022 - 10th European Nonlinear Dynamics Conference, Lyon, France, 2022-07-17, 2022.
[4] Zarepoor M., Bilgen O. (2016) Constrained-energy cross-well actuation of bistable structures. *AIAA J.* **54**:2905–2908.
[5] Simsek M.R., Bilgen O. (2020) The Duffing-Holmes Oscillator Under Hybrid Position Feedback Controller. *J. Struct. Stab.* **20(09)**:2050101.
[6] Burlion L., Schieni R., Kolmanovsky I. (2022) A Reference Governor for linear systems with polynomial constraints. *Automatica* 110313.