Dynamics and Control of a Planar Soft Robot: A Nonlinear Oscillator Network Model

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Abstract. Dynamical and material response characteristics necessitate a nonlinear approach to Dynamics and Control in *Soft Robotics*. Reported studies are mostly computational and new mathematical approaches are needed. Here we propose a nonlinear oscillator network model for a soft manipulator and focus on control of the end effector in the two-element case. Finding this system to be controllable, we study the end effector dynamics using two PID control inputs. For a range of coupling intensities between the translational and rotational DOF, the end effector can accurately trace a defined circular path. The model and the results are also significant for *morphological computation* using soft robots.

Introduction

Soft Robotics envisions precise control of soft (intricate) movement of robotic manipulators made from soft materials [1]. Signature dynamical characteristics such as large deformations, curvature and soft actuation underscore the need for nonlinear analyses. Research is fast emerging in this area but reported models are mostly computational. As a step in a new direction, we propose a nonlinear oscillator network model for a soft manipulator with a large workspace and present control results. An individual element of this network is the 2 DOF system comprising a spring-mass-damper (representing X, the translational DOF) coupled to a bob (representing θ, the rotational DOF). We extend this model, adapted from [2], to the *2 and 3 element cases*. The nondimensionalized equations of motion (EOM) for a *single* element system are:

$$\begin{aligned} \ddot{X} + 2\zeta_1 \dot{X} + X - \frac{6R}{5\epsilon}\left[\dot{\theta}^2 cos\left(\theta\right) + \ddot{\theta} sin\left(\theta\right)\right] &= f\left(t\right) \\ \ddot{\theta} + 2\zeta_2 r\dot{\theta} + r^2\theta - \frac{5\epsilon}{6}\ddot{X} sin\left(\theta\right) &= \tau\left(t\right) \end{aligned} \tag{1}$$

where ζ_1 is the damping ratio for the main mass, ζ_2 is the damping ratio for the bob, R is the mass ratio, r is the ratio of the undamped natural frequencies between the bob and the main mass, ϵ is a parameter that couples the EOM/DOF, while $f(t)$ and $\tau(t)$ are the external force and external torque applied, respectively.

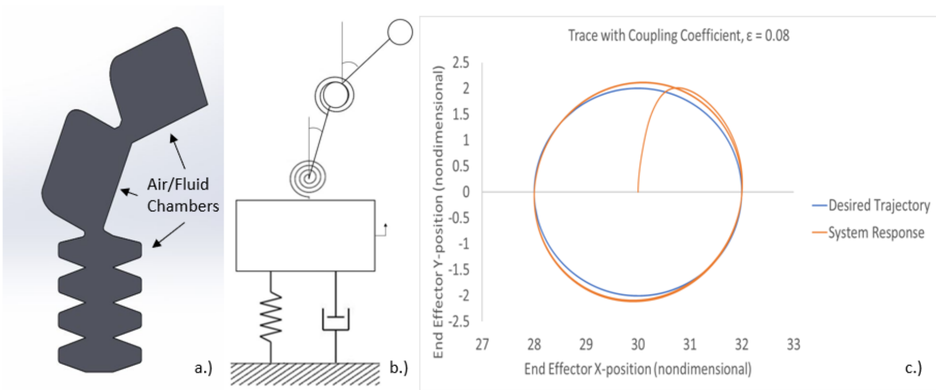

Figure 1: Figure 1: a.) Physical System, b.) Dynamic Schematic, c.) Circular Trajectory

Results and Discussion

Controllability results were obtained for the single and double element models. It was determined that the double element model (3DOF) is controllable via two control inputs - external force and torque applied to the main mass and first bob, respectively. Hence, using a similar approach in [3], a designed feedback control loop using two individually tuned PID controllers achieves a controlled circular trajectory with the end effector of the linearized double element system. Control performance was evaluated for a range of coupling values, given by ϵ. The result in Fig.1 for moderately strong coupling of ϵ = 0.08 indicates the efficacy of the model and the approach. In another Abstract for this conference, we present morphological computation results using this model. Future work includes: analysis of higher number of elements, excitation profiles for novel soft actuators, averaging and bifurcation analyses.

References

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[3] Elkhateeb N.A., Badr R.I. (2017) Novel PID Tracking Controller for 2DOF Robotic Manipulator System Based on Artificial Bee Colony Algorithm. *Electrical, Control and Communication Engineering* **13**:55-62.