Dynamic Measurement and Control of Fiber Reinforced Elastomeric Enclosures

Ryan Bailis '21
BUID: 11936047
Computer Engineering and Management
rb066@bucknell.edu
(610)-573-1805

Professor Keith Buffinton
Mechanical Engineering
keith.buffinton@bucknell.edu

Ryan Bailis

Keith Buffinton

THE RESEARCH QUESTION

In recent years, industrial organizations have developed and implemented computer controlled robotic systems that automate and streamline manufacturing processes. These robots have dramatically improved production quality, protected human life, and increased the efficiency of assembly lines. But, as the market demands increased automation and personal-care in residential spaces, rigid robots are unable to safely serve humans and adapt to more delicate environments.

The field of 'soft-robotics' is making inroads into these challenges by building flexible and adaptable robots from highly compliant materials. One type of soft actuators, Fiber Reinforced Elastomeric Enclosures (FREEs), is reducing the difficulties typically associated with rigid robots in the home. This subset of pneumatically controlled devices can deform in specific ways, most notably elongation and rotation. Depending on material properties (like the winding angle of the fiber established during the manufacturing process), specific motions can be accentuated or minimized. In the lab, the pressure within the enclosures can be controlled by a pressure regulator, which affects the motion of the FREEs in 3-dimensional space.

While the static behavior of the FREEs has been studied extensively through simulations and experiments, there has been little research into the dynamic response of FREEs. The proposed research, which aims to build a comprehensive understanding of the resonant frequencies of the FREEs under sinusoidally varying pressure, will lead to a better model of physical properties and pressure relationships as they change with respect to time. One possible implication for this research is the elimination of extraneous vibrations caused by the change in pressure. If a comprehensive understanding of resonance behavior is achieved, there is potential for control and systematic elimination of undesired vibrations. This can lead to improved tracking performance and noise reduction from sensor data as the motion of the FREEs is measured.

PROJECT DESCRIPTION

Methods

The overall laboratory procedure associated with the proposed research includes the fabrication of the FREEs, testing them utilizing the existing experimental setup (*Figure 1*), developing a suitable LabVIEW system to control the pneumatic valves, and collecting Inertial Measurement Unit (IMU) sensor data regarding the motion of the FREE being tested.

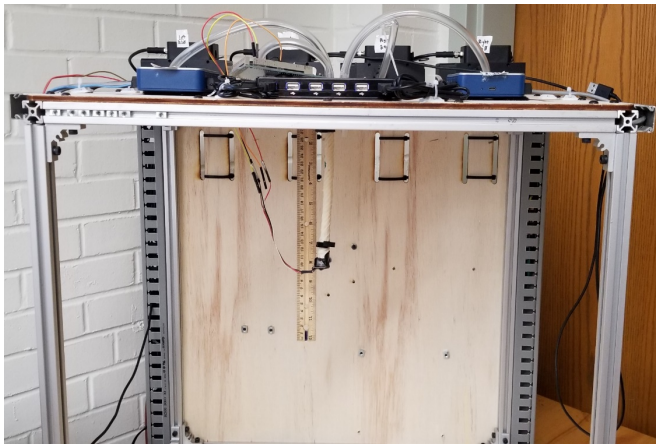

Figure 1 – Experimental setup showing a FREE, pneumatic valves, and the IMU sensor.

Before tests can be run on the FREEs, the characteristic properties (specifically stiffness) must be measured. Taking a simplified view, FREEs can be represented by a liner spring when measuring elongation and a torsional spring when measuring rotation (Figure 2). Understanding the physical and mathematical principles

governing their motion will allow for simplified experimental measurements and eliminate a 'trial and error' methodology.

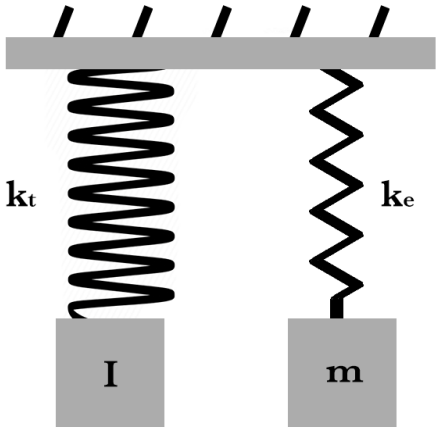

Figure 2 – FREE mechanical model abstractions. The rotational characteristics of the FREEs can be modeled as a torsional spring and the elongation characteristics can be modeled as a linear spring.

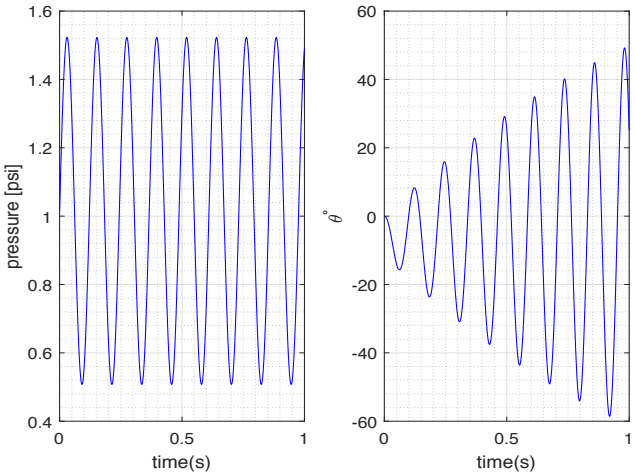

Figure 3 - Simulation of FREEs in MatLab. A low frequency sinusoidally varying pressure can be input into the enclosure, and the resultant rotation indicates resonant behavior.

Anticipated Outcomes

Using low frequency pressure inputs, the FREEs are expected to exhibit resonance behavior. Utilizing previously researched properties, a simulation was run to study how sinusoidally varying pressure alters the amplitude of rotation over time. Simulations indicate that FREEs exhibit resonance behavior, as is evident in the increase in rotational amplitude over the duration of the simulation (Figure 3). However, experimental data is needed to corroborate simulated results.

Another method of studying FREE behavior that has been explored by researchers is the use of Finite Element Analysis (FEA) to mathematically model them without the need for an experimental setup. There has been no FEA research on resonate behavior or dynamic motion done to date, but an adaptation to an existing FEA model can be developed to further explore resonant behavior.

RESEARCH VALUE

The applications of soft robotics have excited people both within and outside of research institutions. In the paper, "What Is the Path Ahead for Soft Robotics?", authors Schultz, Menguc, Tolley, and Vanderborght (2016) describe the incredible potential in the near future.

"*As soft robotics matures as a field, it will continue to draw on the ingenuity of the maker movement, novel materials, and observations from nature, but it will gain a principled methodology common to the wider robotics field, increased integration of structure, actuation, and sensing, moving from proof of concept to integrated systems, and more widespread adoption and commercialization in the next 5–10 years, with the learning and challenges that*

go along with it. The path ahead is bright, for the hobbyist, the scientist, the engineer, and the entrepreneur. ”

As such, the value of this proposed research project is twofold and can be broken down into a technical and non-technical understanding of soft-robotics.

Technical
Understanding of the interaction between the environment and the FREEs is vital to developing a better mathematical model (and vice versa). This proposal describes a question within the field that is largely unexplored. What is the relationship between varying pressure, the material properties of FREEs, and the forces associated with both predictable and unpredictable motion? What can be done to understand the aforementioned unpredictable motions and natural resonances of FREEs?

Non-technical
Research into soft-robots will spark imagination and foster creativity into novel robotic concepts in the future and inspire the development of robots that are marketable outside of the lab. Realizing how this technology will play a part of our future lives is crucial to the development of the field's long-term impact. Bringing new and innovative technologies to market and teaching the public about the value of new ventures is a challenge beyond simply engineering principles.

SHARING THE RESULTS
In addition to the Kalman Research Symposium, the results of this research with will be shared will collaborators at the University of Michigan and at conferences. Regular video conferences will be held with Brent Gillespie, Professor of Mechanical Engineering at the University of Michigan, in which results can be shared among students and faculty. There is also the potential to participate in the *ICRA 2020 Conference*, an International Conference on Robotics and Automation hosted by the Institute of Electrical and Electronics Engineers (IEEE). The deadline for paper submission is September 15, 2019, which fits well into the timeline of research conducted over the summer.

THE FACULTY MENTORING RELATIONSHIP
Professor Keith Buffinton in the Department of Mechanical Engineering will be the faculty advisor and mentor guiding the research described in this proposal. Professor Buffinton and I have been in communication about the project since the fall of 2017 and have discussed, at length, my involvement on this project. During the summer, face-to-face meetings will be held on a daily basis and updates will be documented in writing as the project progresses. In addition to Professor Buffinton, Soheil Habibian a Mechanical Engineering master's student, will be available in the lab to assist with the inevitable challenges that arise.

REFERENCES
Schultz, J., Menguc, Y., Tolley, M., Vanderborght, B., 2016, "What Is the Path Ahead for Soft Robotics?," *Soft Robotics*, 3(4).