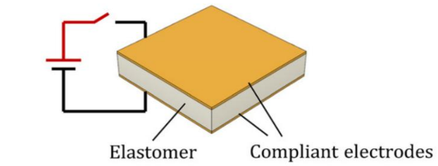
Liquid Dielectric Elastomer Actuator Motor for Underwater Propulsion

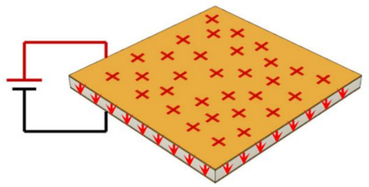
J. Kagle, K. Lobas, J. Lau, Y. Jin, C. Cao

Department of Mechanical & Aerospace Engineering, Case Western Reserve University, Cleveland, OH 44106

Introduction & Motivation

Hard actuation of aquatic robotics operate poorly under deep water pressure, is energy inefficient, and can be bulky. A way around this is the use of soft actuators. One form of soft actuation for aquatic robots is dielectric elastomer actuators (DEAs). While these alleviate the problems associated with hard actuation, traditional DEAs have a very high resistance and thus require a high amount of voltage to operate.





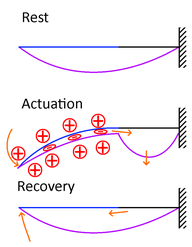
E. Hajiesmaili et al., ***Dielectric elastomer actuators***, 2021

Dielectric elastomers (DEs) are a type of soft active material, a type of material that deforms in response to some stimulus. Voltage charges of opposite signs applied to either side of the material is the typical method that causes deformation. Traditional DEAs are essentially a thin membrane between two electrodes that will deform when a voltage is applied and use that to create motion. Liquid DEAs use the same idea of deformation from stimulus, however, these materials create high displacement with low force while traditional DEAs have high force with relatively low displacement.

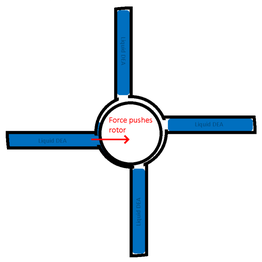
Here we propose an investigation of the effectiveness of liquid dielectric elastomer actuators as a method of propulsion. In the future, liquid DEAs could be utilized for small biomimetic aquatic robots or to mimic muscle like sarcomeres. We demonstrate a proof of concept of a deformable rotary motor controlled via liquid DEAs.

Design Methodology

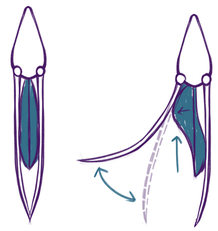
Before our final design, multiple previous designs were considered. These designs were derived from previous studies, and many of them were biomimetic. Three of these designs are shown below. Weighted trade studies were then used to determine the best possible design combinations.



Bioinspired Flapping Propulsion



Liquid DEA Rotor



Liquid-Solid DEA Hybrid

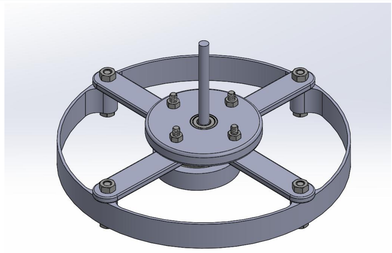
Soft-Actuation Methods			Motors		Hydraulics		DEAs		Liquid DEAs	
Criteria	Specifics	Weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Energy Efficiency	W	0.3	3	0.9	2	0.6	4	1.2	4	1.2
Force Output	N	0.2	3	0.6	3	0.6	3	0.6	2	0.4
Displacement	cm	0.2	3	0.6	3	0.6	1	0.2	3	0.6
Simplicity	# of parts	0.1	3	0.3	1	0.1	3	0.3	3	0.3
Cost	$	0.05	3	0.15	1	0.05	4	0.2	4	0.2
Biomimicry	Sim. to SCM	0.05	1	0.05	1	0.05	4	0.2	4	0.2
Stiffness	N/m	0.1	1	0.1	2	0.2	3	0.3	4	0.4
TOTAL		1	17	2.6	13	2	22	2.7	24	2.9

Weighted trade study on soft actuation methods

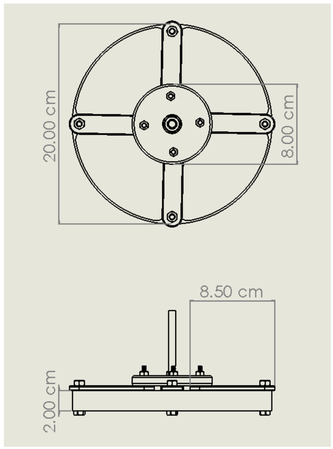
Movement Methods			Flapping		Rotary		Jetting	
Criteria	Specifics	Weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Energy Efficiency	W	0.3	2	0.6	4	1.2	2	0.6
Force Output	N	0.2	4	0.8	3	0.6	2	0.4
Displacement	cm	0.2	2	0.4	4	0.8	3	0.6
Simplicity	# of parts	0.1	3	0.3	3	0.3	3	0.3
Cost	$	0.05	3	0.15	3	0.15	2	0.1
Biomimicry	Sim. to Animals	0.05	4	0.2	1	0.05	4	0.2
Stiffness	N/m	0.1	3	0.3	2	0.2	1	0.1
TOTAL		1	21	2.45	20	3.1	17	2.2

Weighted trade study on movement methods

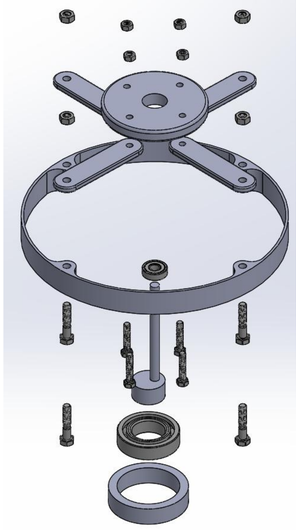
Final Motor Design



Full CAD Assembly



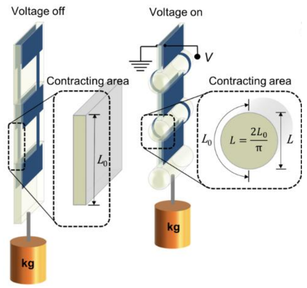
Dimensions of Assembly



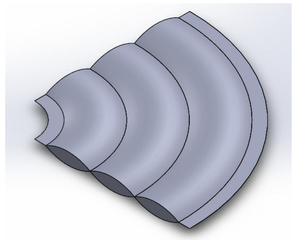
Exploded View

The final design was similar to the DEA Pushing design but using pulling to achieve motion. This design used four liquid DEAs pulling in sequence on a central rotor attached to a shaft. The model was 3D printed and assembled using bolts, along with two ball bearings. The assembly is 20 cm in diameter.

Final DEA Design



Peano-HASEL Actuator Design[A]



Quarter-Circle Actuator Design

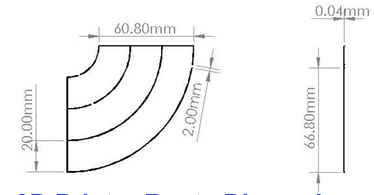


Electrode Layout

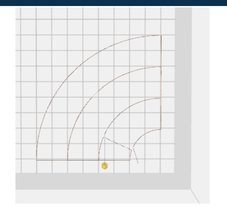
From our weighted trade studies we determined that a liquid DEA would be best for our design. From this we needed to create a design that would fit a quarter circle shape. We settled on 3 pouches to ensure simplicity while reducing edge effects of a larger pouch. Tabs on either end were kept to allow attachment to the motor unit using epoxy. We also chose painted on carbon electrodes as this allowed easy customization of our electrode layout and had a low cost. The DEA is made up of 1 layer of Kapton film, 2 layers of BOPP film and finally 2 layers of carbon electrodes.

[A]**Kellaris** et al**., Sci. Robot.** 3, eaar3276 (2018)

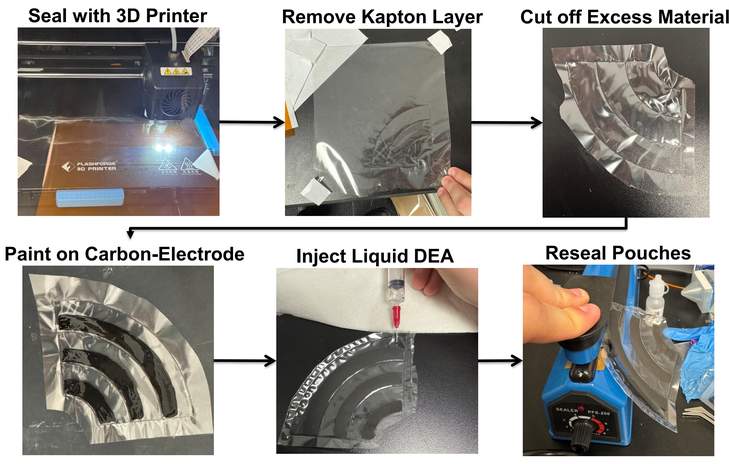
Liquid-DEA Manufacturing Process



3D Printer Route Dimensions



3D Printer Pathing



Step-by-Step Process

Results

Our design iterations found multiple ways of solving the problem of creating a soft-actuator motor underwater and these design choices were weeded out using weighted trade studies. However, due to the opinionated nature of these studies and our target goals other researchers may find different designs beneficial. Most issues were found in the manufacturing process as various hiccups in the process caused delays in production that could easily be avoided if known beforehand. This includes having thicker seal lines on the 3D printer pathing to avoid leaks of the DEA, optimizing injection points, and limiting the amount of air bubbles in pouches.

Due to time constraints testing of our device was limited to ensuring its functionality and the advantages and flaws of our design choices. Future studies should focus on testing our devices against similar papers to ensure that the presented benefits fully overcome the boundaries outlined. This could include testing that the quarter-circle liquid DEA does not limit the liquid DE's movement and that its shape maximized efficiency and space. Further implementation after optimization testing should include future robot design that would implement this motor with a full robot to test its usefulness in various scenarios. Additionally, multiple Peano-Hasel actuators can be stacked to summate multiple actuator's power and output an overall larger force to increase the possible speed of the motor.

Acknowledgements and Citations

Dr. Erkki Somersalo – Actuator Modeling Advisement
Dr. Daniela Calvetti – Actuator Modeling Advisement
Dr. David Kazdan – Circuits Advisement
Mr. John Gibbons – Circuits Advisement
Case Western Reserve University - Funding

QR Code to Citations

RESEARCH POSTER PRESENTATION DESIGN © 2017
www.PosterPresentations.com