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Can artificial jellyfish be the next pragmatic autonomous self-deployable actuator?

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Abstract

The advent of soft robotics represents a paradigm shift, incepting an era defined by unparalleled flexibility, adaptability, and a profound embrace of biomimicry. This highlight celebrates one such recent study conducted by Dr. Tadesse and his team, which aims to delve deeper into jellyfish-like self-deployable actuators, thereby bridging the gap between theoretical concepts and pragmatic applications.

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The rise of soft robotics signals a revolutionary transformation in the realm of robotic technology, ushering in an era characterized by unparalleled flexibility, adaptability, and a deep embrace of biomimicry. [1][2] This departure from the conventional paradigm of rigid robotics not only challenges established norms but also opens up a trove of possibilities for groundbreaking applications across a spectrum of industries. In clear contrast to their traditional rigid counterparts, soft robots are meticulously fashioned from materials engineered to mimic the flexibility and elasticity found in natural organisms. [3] This departure from the static and inflexible structures of traditional robots mirrors the principles of nature-inspired engineering. Soft robots, endowed with this biomimetic flexibility, interact with the world in a manner that replicates the versatility observed in living systems. The outcome is a breed of robots capable of bending, stretching, and deforming, seamlessly adapting to dynamic and unpredictable environments. [1]

It is worth noting that while the roots of soft robotics extend back almost half a century, it has only truly emerged as a compelling and widely discussed field within both the scientific community and the general public in the past decade. [4] The gradual recognition of soft robotics within the broader robotic community has sparked a surge of interest and participation from scientists and engineers eager to contribute to this dynamic and evolving discipline. Diving deeper, the significance of underwater robotics (specifically) has grown exponentially, playing a crucial role in both military and industrial applications. The challenges faced by human divers and traditional remotely operated vehicles (ROVs) in harsh underwater environments characterized by extreme temperatures and pressure have underscored the need for innovative solutions. The existing remedies often involve the utilization of expensive and burdensome protective equipment, adding complexity to an already challenging operational environment. [4]

In navigating these inhospitable and largely unexplored aquatic spaces, the key to success lies in adaptability. Recognizing this imperative, researchers have seized the opportunity to explore the potential of soft robotics. A notable example is the deployment of a soft robot in the Mariana Trench, where the underwater depth reaches a staggering 11,034 meters. [5] This pioneering use of soft robotics highlights its potential to revolutionize underwater exploration, providing a nimble and adaptable alternative to conventional technologies.

Another such pragmatic development is the SoFi Fish, an innovative underwater robotic creation, mirrors the movements of a real fish, boasting tetherless and remarkably smooth motion. What immediately sets it apart is its ability to navigate underwater environments without the encumbrance of a tether, allowing for a freedom of movement that closely emulates the fluidity of natural marine life. The researchers behind SoFi Fish have equipped it with a minimalist array of onboard sensors for perception, a servo motor, and a lithium polymer battery commonly found in consumer smartphones, emphasizing efficiency and simplicity in its design. The propulsion mechanism of SoFi Fish centers around a motor in its tail, which orchestrates the movement by pumping water into two balloon-like chambers. As one chamber expands, the tail bends and flexes in one direction, and when the actuators push water to the other chamber, it flexes in the opposite direction. This method of propulsion, mimicking the undulating motion of a fish's tail, grants SoFi Fish its remarkable agility and lifelike movement underwater. [6]

While the foundational principle of linear actuation has proven effective in many soft robots, its limitations become apparent when deployed in the diverse and dynamic environments these robots are expected to navigate. As the field of soft robotics continues to evolve, there is a discernible demand for the development of self-deployable devices capable of tackling complex terrains and responding adeptly to unpredictable scenarios. [7] This necessitates a shift towards a more sophisticated approach, showcasing a multifaceted repertoire of motions. Addressing this imperative, recent research has introduced an innovative solution by integrating nichrome wire with soft polymers. These soft polymer materials, initially configured in a fully twisted state, exhibit a coiling behavior reminiscent of a spring. When subjected to specific stimuli, such as Joule heating or convection heating through fluids with varying temperatures or hot and cold air, these polymers undergo contraction, dependent on their construction. [8]

However, a critical gap in knowledge exists regarding the behavior of these soft polymers, particularly when they undergo a metamorphosis into TCPFL (Twisted and Coiled Polymer Fiber Actuator), especially within an underwater environment. This lack of understanding prompts several important questions:

a. How do stimuli vary underwater, and what impact do these variations have on the response behavior?
b. Is there a delay between the application of stimuli and the response, and if so, how does this delay potentially hinder

the desired actuation?

c. Given that the polymer is inherently hyperelastic, and the polymer actuators exhibit semi-crystalline properties, the resulting coupled system becomes nonlinear. When dynamically activated in water, this complex dynamic system emerges. How does this intricate structure influence the overall actuation process?

To answer these questions and to delve deeper into the phenomenon, Tadesse et al. conducted a study on the Jelly-Z. This study focused on the swimming performance and the analysis of the twisted and coiled polymer (TCP) actuated jellyfish soft robot. The findings of this research form the centerpiece of our discussion, and I believe it represents a captivating stride toward the development of more intricate, autonomous, and self-deployable devices. [9]

Dr. Tadesse's article presents a pioneering biomimetic jellyfish robot, depicted in **Figure 1**, employing TCPFL actuators for underwater propulsion. A notable feature of this work is the unprecedented use and exploration of TCPFL actuators—a technology known for its silent operation and discreet actuation—in a jellyfish-inspired robot, marking a novel contribution to the field. The isotonic testing under 500 g loading conditions for a single TCPFL in an underwater environment is showcased, along with a predictive model based on Joule heating. The model exhibits a commendable fit with experimental measurements, proving its utility in estimating actuation displacement for closed-loop PID control of TCPFL actuators across diverse applications. As shown in the article, the preference for TCPFL actuators over alternatives like SMA wires or 6-ply TCPs lies in their higher actuation stroke per cycle, ease of fabrication, and cost-effectiveness. [10]

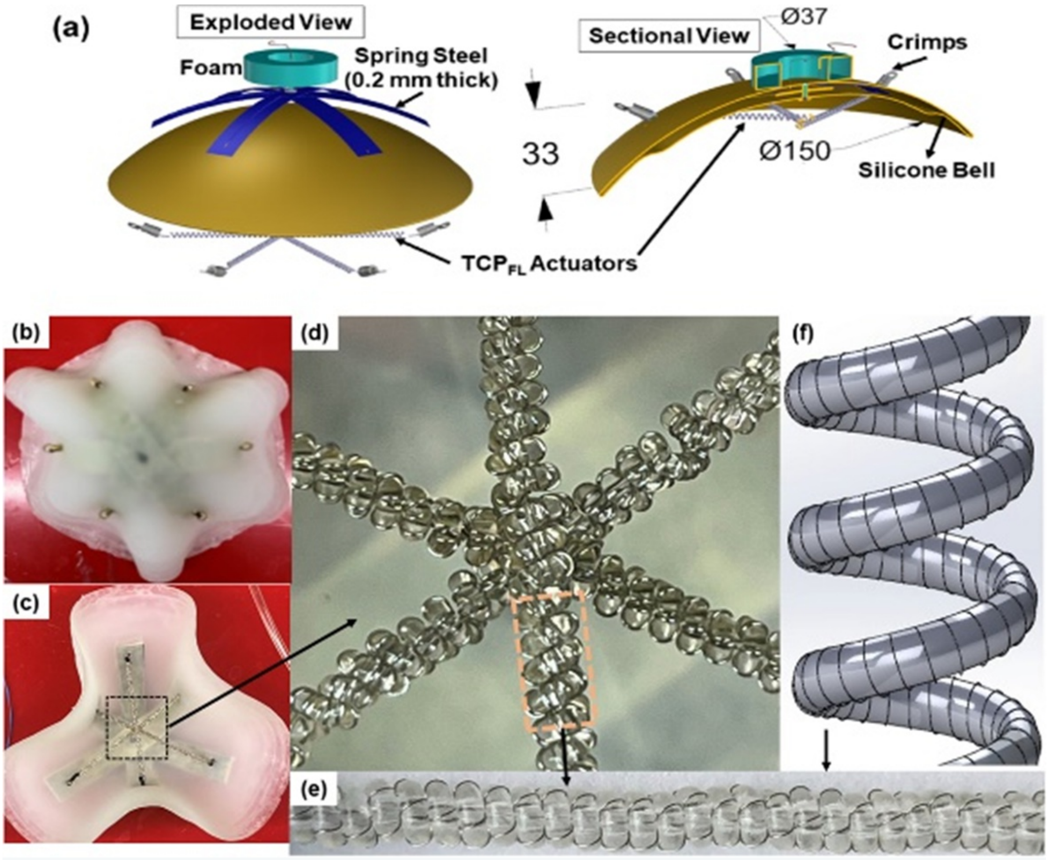

Figure 1. The Jelly-Z prototype is presented with the following elements: (a) a 3D CAD model illustrating both exploded and sectional views of the robot, (b) a top view showcasing the structure of the Jelly-Z robot, (c) a

bottom view providing an alternative perspective of the Jelly-Z robot, (d) an internal assembly depiction of the TCPFL actuators, (e) a magnified view focusing on the details of the actuators, and (f) a CAD model specifically highlighting the structure of the TCPFL actuators, reprinted with permission from [9], copyright reserved Wiley 2023.

Interestingly, the article also features a widely used metric, the cost of transport (COT), that serves as a measure to quantify the efficiency of biological locomotion methods. In the realm of soft robots, both their speed and COT typically fall below those observed in real animals. [11] The COT of Jelly-Z, however, surpasses that of real animals (as depicted in **Figure 2**) primarily due to its high power consumption, low mass, and relatively slow swimming speed.

I believe this is an area that needs more research, and efforts should be directed at reducing the COT. One such pathway is to functionalize the soft polymer, applying a nanomaterial coating or integrating with a suitable phase change material aiming to optimize interfacial thermal contacts, thereby improving the actuator's cooling time (and, subsequently, cycle frequency) while reducing power consumption.

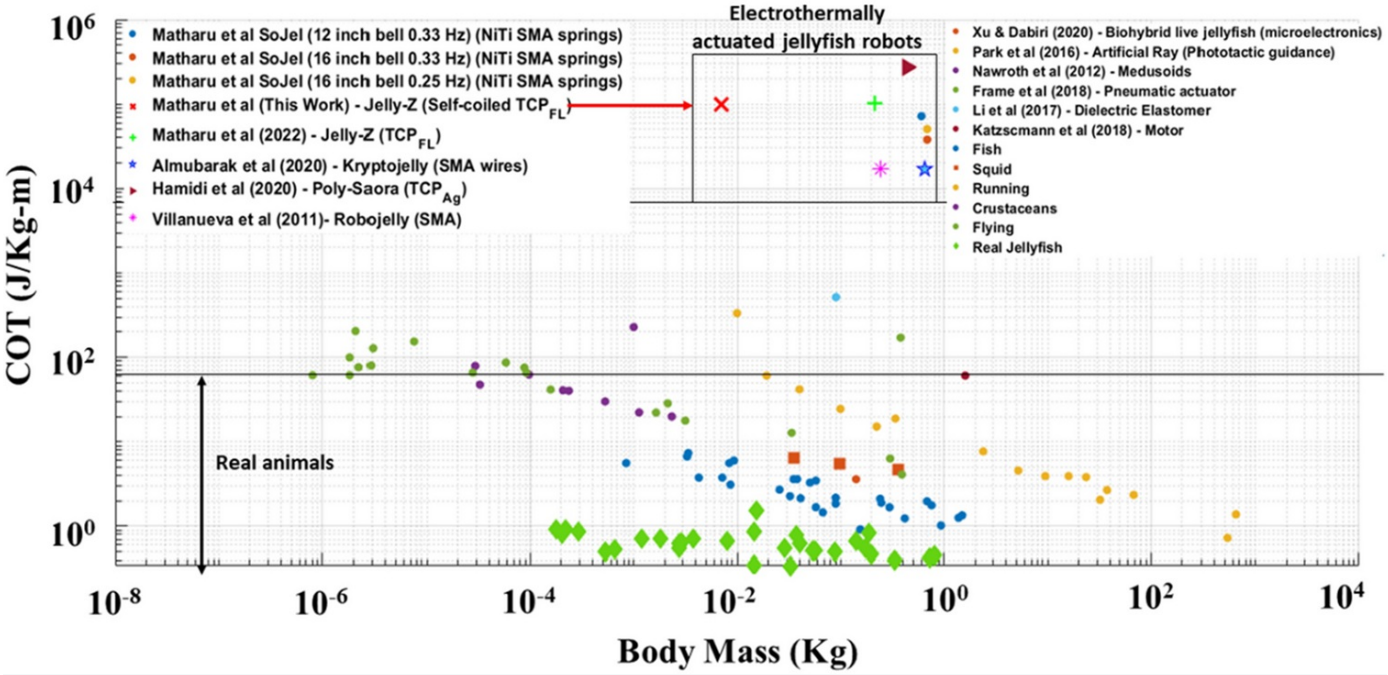

Figure 2. Relative cost of transport concerning body mass is compared for the Jelly-Z prototype developed in this study and other animals engaged in swimming, flying, and running, as well as various underwater robots inspired by different animals and utilizing diverse actuators, reprinted with permission from [9], copyright reserved Wiley 2023.

Although I emphasized a lot on COT, it is to be noted that solely COT does not determine how effective a soft robot is. Most soft robots, when deployed, create noise (actuators driven by servo motors) that sometimes proves detrimental, especially when the actuator is going for any noise-sensitive exploratory programs. [12] However, the current actuator exhibits minimal audio noise, making it better for self-deployable applications.

With a more in-depth study, especially one that considers the nuanced interplay of stimuli and response behavior, the prospects are ascending and promising. Furthermore, the actuators utilized in this research showcase scalability and an uncomplicated in-house manufacturing process. This quality not only opens the door for future advancements in utilizing these actuators but also holds the potential for continued innovation and exploration within this field.

Could we anticipate the emergence of another groundbreaking creation akin to SoFi? Perhaps this time, envision a more intricate design resembling a jellyfish, adding a layer of complexity and sophistication to the field of soft robotics.

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Conflict of interest

Sayan Basak declares that he has no conflict of interest.

Human/animal rights

This article does not contain any studies with human or animal subjects performed by any of the authors.

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