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Experimental Bending Performance Characterization of sHAMs Used Underwater Growing Robot

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I. INTRODUCTION

Soft-growing robots represent an emerging field characterized by their ability to extend at the tip while the base remains stationary. These robots offer a unique advantage in navigating through confined spaces inaccessible to humans. Specifically, in underwater exploration tasks, their flexible bodies render them particularly efficient. Moreover, these robots exhibit the capability to steer even while growing. There exist several steering methods including sHAMs (soft Hydraulic Artificial Muscles), sPAMs (soft Pneumatic Artificial Muscles), tendon-driven techniques, and predefined bending mechanisms, applicable both in air and underwater [1],[2].

This paper specifically delves into the study of sHAMs (soft Hydraulic Artificial Muscles) and their inherent characteristics. Various critical factors influence the bending behavior of sHAMs, including pressure, the diameter ratio between the robot body and the sHAM, the length of the robot body, and the number of sHAMs employed. In this study, we concentrate on varying the diameter ratio between the body and sHAM, while keeping other parameters constant. To achieve this, we fabricated robot bodies with varying diameters while maintaining a constant diameter for the sHAM. By systematically analyzing the results obtained from this experimental setup, we aim to provide insights into how the bending angle varies in relation to the diameter ratio.

II. LITERATURE REVIEW

In previous studies, the prevalent approach for altering bend angles involved adjusting internal pressure, applicable both in air and underwater environments [3]. However, this method only allowed for a limited range of achievable angles. Also, head changing is a comparably costly process. And still, there are no concerns about the diameter ratio adjusting for bending angle adjustment. Notably, there exists a gap in research concerning the influence of diameter ratios on bending angles.

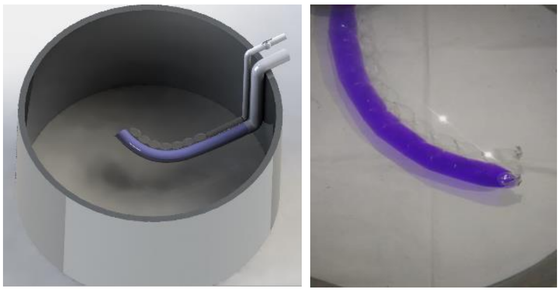
III. MATERIALS AND METHODS

The selected material for constructing the robot body and sHAMs is LDPE (Low-density polyethylene), chosen for its lightweight and flexibility.

A diameter (*d*) of 2.426 cm was chosen for sHAM, while diameters (*D*) of 2.426, 3.234, 4.851, and 6.468 cm were selected for the robot bodies, considering the limitations of the tank size. The length of both the body and sHAM was standardized to 30 cm.

The primary focus of this experiment lies in the analysis of bending characteristics. Initially, the robot body will be grown by providing a constant flow rate of water. Subsequently, the sHAMs will be actuated by supplying water at fixed intervals under a fixed head to maintain consistent internal pressure.

A camera setup will capture a top-down view, enabling measurement of the angles. This experiment will be conducted five times for each body diameter type. The resulting data will be graphed and analyzed to establish a relationship between diameter ratio and angle.



(a) *(b)*

Fig 1. Experiment on sHAMs. (a) Experimental setup, (b) A bent sHAM.

IV. RESULTS AND DISCUSSION

The experiment yielded a dataset comprising observed values of bending angles corresponding to various diameter

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ratios of the robot body and sHAM. These values were meticulously recorded and analyzed for their correlation.

In addition to the dataset, a graphical representation was generated to visually illustrate the relationship between diameter ratio and bending angle. The graph provides a clear visualization of the observed trend.

TABLE I. DIAMETER RATIOS AND BENDING ANGLE

sHAM Diameter (cm)	***Body Diameter (cm)***	***Diameter Ratio d/D***	***Bending Angle (o)***
2.426	2.426	1	121.29
			126.63
			124.11
			134.53
2.426	3.234	0.75	74.43
			83.2
			83.61
			80.28
2.426	4.851	0.5	37.44
			37.51
			40.58
			32.6
2.426	6.468	0.375	13.78
			12.56
			18.71
			20.35

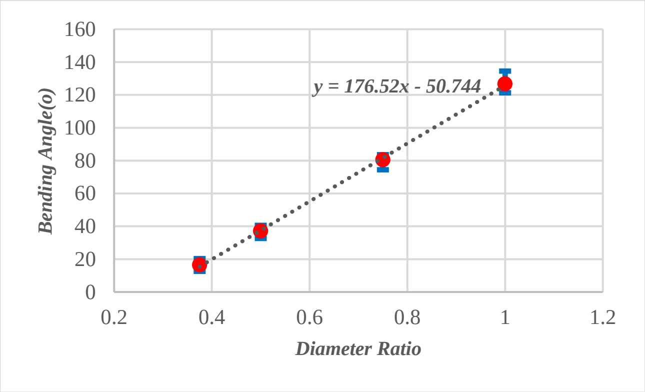

Fig 2. Diameter Ratios vs. Bending Angle

Considering the above graphical representation, it can be said that the bending angle of the robot body and the diameter ratio of the sHAM and robot body have a linear representation. The relationship can be represented by this equation.

$$y = 176.52x - 50.744 \tag{1}$$

This finding highlights the critical role of diameter ratios in achieving controlled bending behavior, a crucial aspect in the design and optimization of soft-growing robots. The observed consistency across multiple trials underscores the reliability of the experimental setup.

V. CONCLUSION

In conclusion, the experimental investigation focused on the relationship between diameter ratio and bending angle in soft Hydraulic Artificial Muscles (sHAMs) has yielded significant insights. The results demonstrate a clear linear correlation between these parameters, indicating that as the diameter ratio increases, so does the bending angle. This finding underscores the importance of considering diameter ratios in designing and developing soft-growing robots, particularly in applications requiring precise control over bending behavior.

The outcomes of this research not only contribute to the understanding of sHAM behavior but also offer practical implications for the design and optimization of soft-growing robots. Engineers and researchers can fine-tune the bending characteristics by strategically manipulating the diameter ratio to suit specific operational requirements.

In future studies, exploring additional factors that may influence bending behavior, such as material properties, pressure variations, and environmental conditions may be beneficial. Additionally, investigating the applicability of these findings in real-world scenarios and further refining the design parameters of soft-growing robots would be valuable avenues for continued research.

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