Development of a soft robotic manta ray with various actuation techniques

Kritika Iyer, WPI, Smart Materials and Actuation project report

***Abstract*—Smart materials are those which give a small physical output for a given input. Soft robots need small amounts of actuation which can be given by smart materials and can be used in underwater applications with some waterproofing. Biomimetic motion is fluid and underwater applications do not need big output motion to move, this plays to the advantage of using smart materials for this motion. This paper actuates the motion of a manta ray. There have been many cases where manta rays have been actuated using ionic polymer metal composites (IPMCs). This paper aims at finding other more feasible and cheaper methods of actuation. Mini Manta rays are fabricated using 3D printed molds and actuated using pneumatics and shape memory alloy nitinol wires. The manta rays were successfully actuated using the above two and can be used for further research. The actuation using Shape memory alloys(SMAs) and pneumatic actuation are compared.**

***Keywords*—Manta ray, Smart materials, Actuation**

I. Introduction

Smart materials are those materials which give a certain change in a physical property for a given input stimulus [1]. This property has made them highly popular in the past few years. They are being used in actuators, generators and also sensors for various stimuli [2]. Smart materials like IPMCs, SMAs etc are used to actuate robots [3]. Robots have found various underwater applications for exploration, maintenance, and research of underwater species [4]. For all applications of robots, optimization is the goal and biomimetics is the best way to get an optimized design as there is nothing more optimal than that of nature [5]. For proper biomimetic motion, look and feel, soft robotics is the best to recreate nature [6]. Soft robots are those robots that do not have rigid links and have redundant degrees of freedom [7]. These robots are perfect for underwater applications as they are fluid in motion and can mimic the motion of aquatic life. Some smart materials require water or a liquid medium for actuation and are hence ideal to make underwater soft robots.

In this paper, soft robotic manta rays are cast in 3D printed molds and actuated using SMAs and pneumatics. The actuation in both are compared and results are obtained. This paper discusses the whole process of design and fabrication of the soft manta rays. It gives details about what was good and novel and more importantly what failed and why.

A. Shape Memory Alloy

Shape Memory alloys are those materials which deform under loading and temperature change [3]. This temperature change can be brought about by inducing electricity in the alloy as well. Fig 1 shows the change in structure of SMAs under different conditions. This property of having 2 different states is advantageous for actuation of motion. The SMA can be retrained into any desired shape by heating in the desired shape and quenching immediately after, after which on heating produced the desired shape and goes back to its normal shape once it is cooled down.

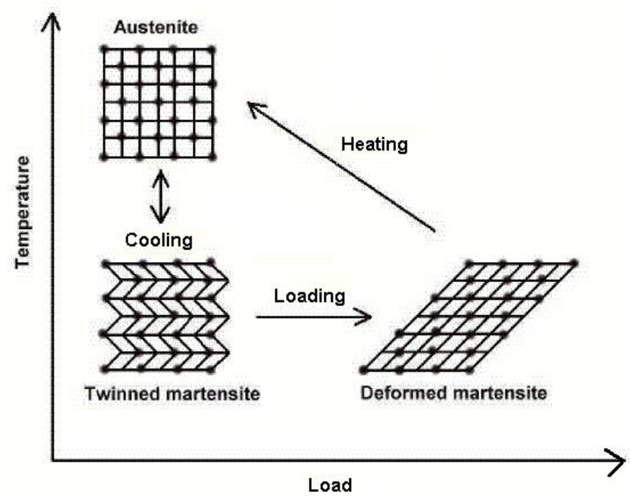


Fig. 1: SMA

B. Pneumatic Actuators

Pneumatic actuators are very simple mechanisms. The consist of a piston and a valve. The piston pushes the air and the valve allows the air to go through the piston retracts and the air retracts as well. In soft robotics, the air deforms the robot's 'skin' and hence causes motion like in Fig 2.

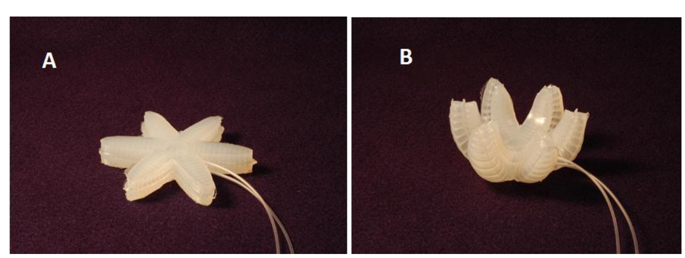


Fig. 2: pneumatic

C. Manta Ray

Manta rays are highly efficient and high speed swimmers with excellent maneuverability [20]. The sin wave type motion of the manta ray's pectoral fin can be seen in Fig 3. This kind of motion is easy to replicate and study and hence manta ray was chosen as the central idea of this paper.

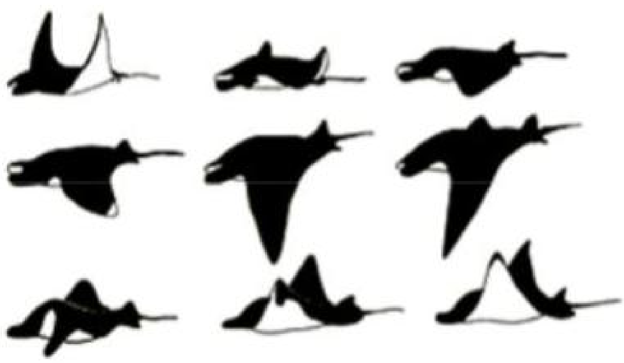


Fig. 3: locomotion

II. Literature Review

There has been a lot of work using smart materials and underwater actuation in soft robotics, especially with manta rays.

A. Manta Rays general actuation

Chunlin Zhou and K. H. Low designed a manta ray made of polypropylene and actuation is done with servo motors. They claim that the model is better than the smart actuated manta rays but have not given sufficient proof to back this statement [9]. Jun Gao et al. used silicone rubber fins attached to a servo motor with carbon fiber tubes to actuate the pectoral fins of a manta ray [10]. Jianhui He and Yonghua Zhang made a motor driven manta ray focusing mainly on the fin's actuation [14]. Festo also created a manta ray using bionic fluid muscles driven by romote control and water hydraulic unit [18]. University of Virginia made Mantabot with wings of silicone [19].

B. Smart material actuation

Zhenlong Wang et al. made a micro manta ray out of PVC and actuated it using SMAs. They achieved forward and turning motion [8]. Zheng Chen et al. made an autonomous manta ray with on board electronics and fins actuated with IPMCs [11], [15]. Yueri Cai et all used artificial muscles and silicone rubber [12]. Andres Punning et al. have created a ray like robot with fins out of IPMCs and latex [13]. Koichi Suzumori et al have made a robotic ray out of silicone and used 4 pneumatic chambers for actuation purposes [16].Kentaro Takagi et al. built a robotic ray using 16 IPMC's and controlled these in a sinusoidal wave [17].

III. Method

The process of carrying out the experiments has been detailed in the following sections. The silicone rubber used for these experiments was dragonskin 10 medium and the SMA used was nitinol wire.

A. Molds

A real size manta ray would be around 250 inches in wingspan. Seeing that as highly unfeasible and too big to be actuated using smart materials the ratios of the manta ray body were obtained [21] from Fig 4 and brought down to scale to a 3 inch wingspan. Using this a mold was created in CAD

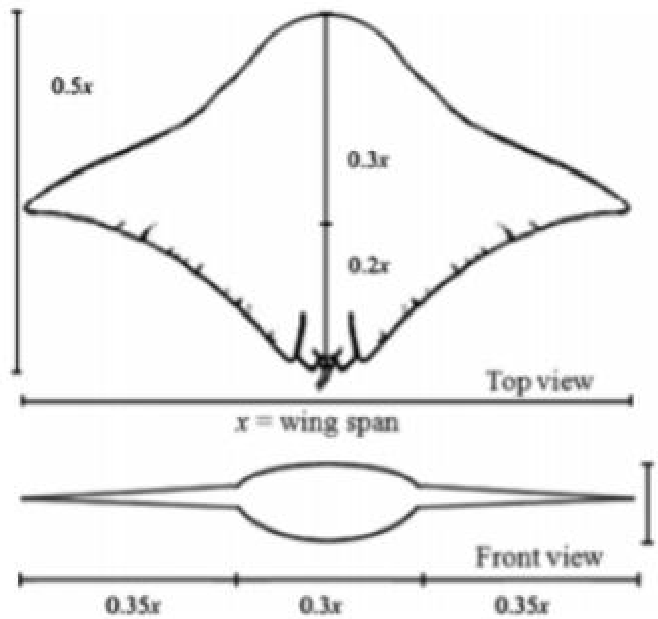


Fig. 4: ratio

and 3D printed. The mold had one hole on top for filling the silicone in and had 2 holes to match the mold halves. The cad drawing of the molds is given in Fig 5.

The pneumatic Manta ray consists of 8 channels, 4 on top and

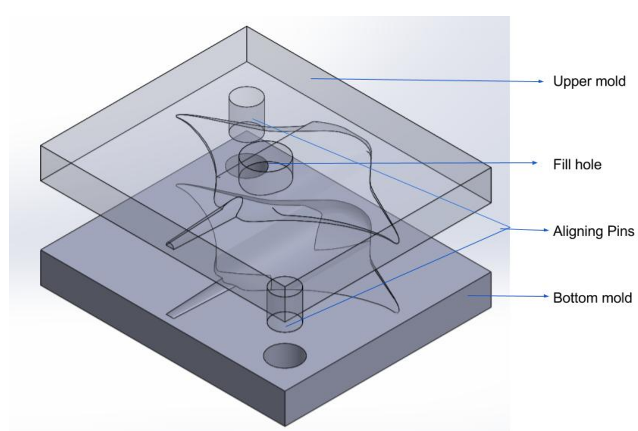


Fig. 5: SMA Mold

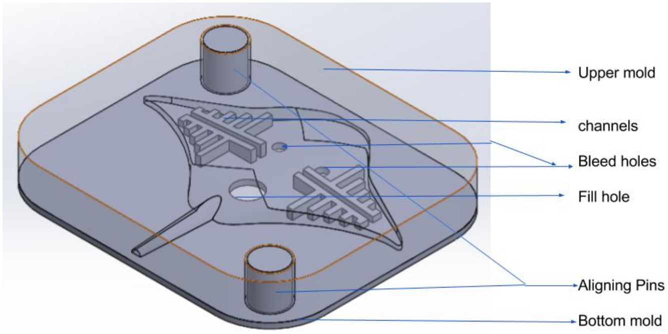


Fig. 6: pneumatic Mold

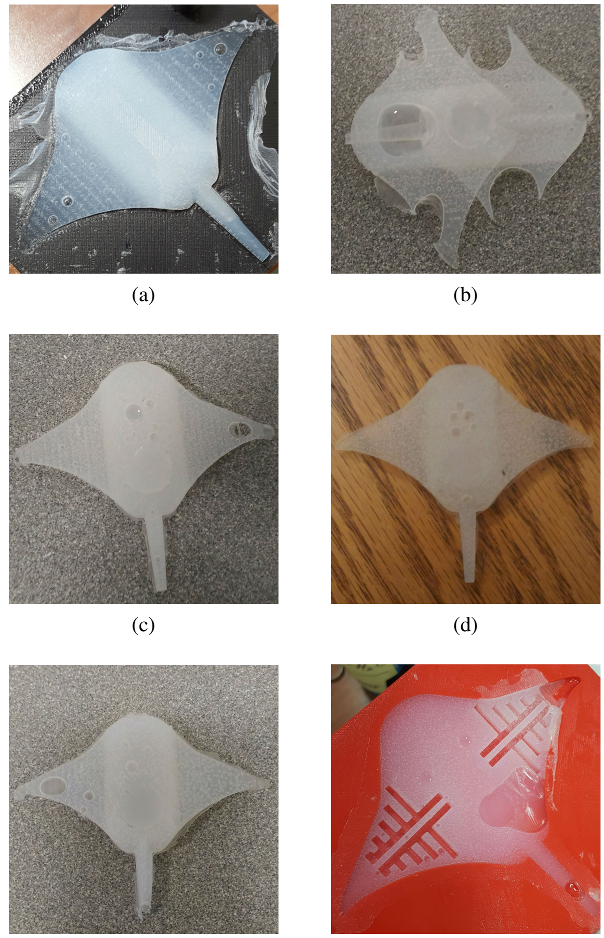
4 on the bottom. This had to be molded in a separate mold Fig 6. One mold consists of one half of the manta ray. Extra bleed holes are to let more air escape and have a denser mold.

B. casting mistakes

This section gives details about the castings that went wrong and preventions. Fig 7a shows the first casting done. The cast was very bubbly and hard to take out of the mold. This can be fixed by degassing and applying mold release to the whole mold. Fig 7b shows the second casting done. It is clearly not usable as the halves of the molds were upside down. This can be fixed by preparing a foolproof mold such that there is no mismatching. The third casting shown in Fig 7c has a hole in the wing formed by bubbles. This may be fixed by pouring the wings first and then keeping the mold on top and pouring the rest of the silicone. The casting in Fig 7d has a cluster of holes at the top this was due to the rising of bubbles due to a vacuum pump above the mold. The bubbles clustered but could not escape. The manta ray showed in Fig 7e has a hole in the wing and the tail is also not cast properly. This is because it was cast in the mold inside a vacuum bag. The degassing caused a lot of silicone to exit the mold and hence not form properly. The pneumatic casting in Fig 7f had many holes and did not cast properly. This was due to the expulsion of silicone into the mold leading to many air bubbles. These air bubbles were filled up with more silicone.

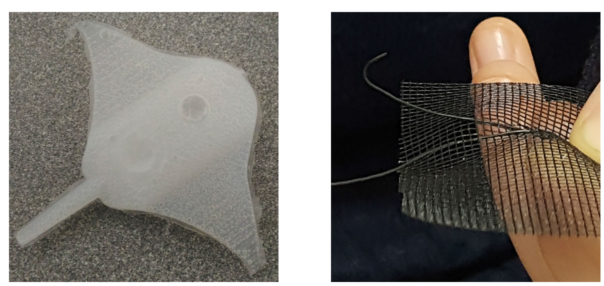
C. Preparation for Actuation

The Fig 8a shows one casting used to perform the actuation motion. The hole in the center is from degassing using a vacuum pump and letting it cast in open air. This hole was actually beneficial to thread the SMA wire in. SMA wires were coiled and cut in semi circles to get an arc shape while heated. The opposing arc shapes were put into the mold one behind the other and electricity was applied. Another casting of the mini manta ray was done and dyed blue. This manta ray had the SMA wires molded into the body. This was done by weaving it into a mesh as shown in Fig 8b. The mesh was placed over the half of the mold and the silicone was poured. The actuation of the non-dye casting was good for a while until the wires started rotating in their place and cutting through the silicone due to this motion. The dyed casting also



(a) (b) (c) (d) (e) (f)

Fig. 7: Casting Flaws

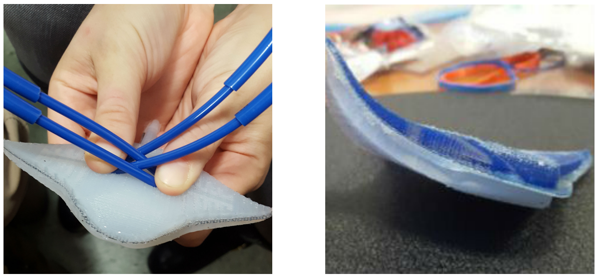


(a) (b)

Fig. 8: SMA wires in both molds

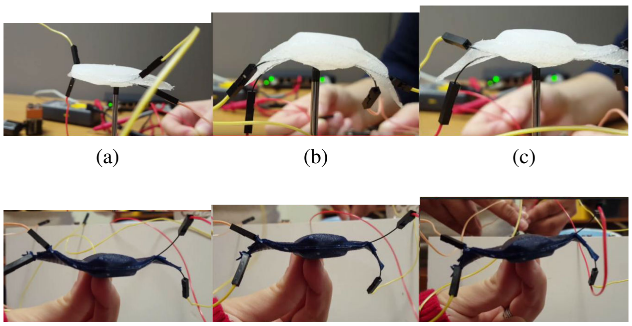
saw the wire try to get out of the wings but the wire did not move and actuated well.

Two pneumatic molds were made, one where the tubes were inserted after casting and actuated. This mold, shown in Fig 9a has some flaws as the mesh used to keep the expansion curved and not linear stuck to the parchment paper more than the mesh. This was fixed in the second mold shown in Fig 9b where the parchment paper and mesh were both kept between two molds and actuation was done directly from the syringe.



(a) (b)

Fig. 9: SMA wires in both molds



(a) (b) (c)

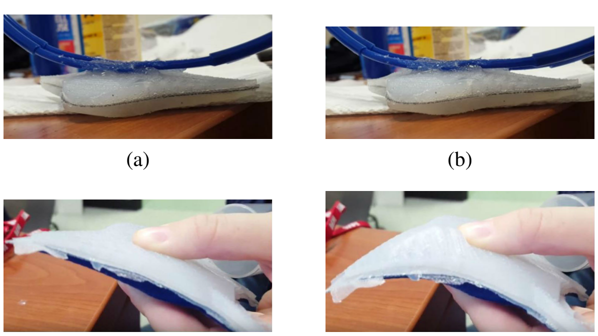
(d) (e) (f)

Fig. 10: SMA ray actuation

IV. Results

The results of the actuation using SMA wires in both cast manta rays are shown below. Fig 10a and Fig 10d show upward stroke, Fig 10b and Fig 10e show downward stroke, and Fig 10c and Fig 10f show the rotation of the wire. Though the rotation is much less in Fig 10f there is still some pulling.

For pneumatic rays only one set of channels have been actuated. Fig 11a and Fig 11c show the rays in a stationary position. Fig 11b and Fig 11d show the rays in an inflated position. The ray doesn't look inflated as there are a lot of gaps in the sealing and hence air escapes. The ray in Fig 11d is inflated well.



(a) (b)

(c) (d)

Fig. 11: Pneumatic actuation

V. Conclusion

This paper is a resourceful paper for beginners in the field of smart materials. During the course of experimentation, a lot was learned about the properties of silicone, SMAs and Pneumatics.The actuation was done successfully and had a good resemblance to the locomotion of a manta ray.

In the future, more SMA wires can be placed over the longest wingspan. The thickness of the pectoral fins can also be increased to reduce tearing and holes. For the pneumatic ray the tubes can be placed inside the mold while casting to maintain a seal-proof insertion. IPMCs can also be tested and the results can be compared. It would be beneficial to compare different permutations & combinations of smart materials in one ray.

VI. Acknowledgment

The author would like to thank the teammates, Gabby and Adela for their total involvement and input in the project. Further thanks goes to Mrs Winola Rasmussen for providing a good work environment and all the tools to do this project successfully.

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