Innovative Fish Robot based on an Asymmetric Flexible Pneumatic Actuator

Aswath S, Chinmaya Krishna Tilak, Kalyani Jayaprakash, Anila G Nair, Arathi S Nair, Aiswarya Mohan, and Ganesha Udupa

***Abstract*—**Design and prototyping method of asymmetric flexible pneumatic actuator (AFPA) and its application for an innovative fish robot is proposed in this paper. The structure and properties of AFPA are described. The AFPA under internal pressure will curve in the direction of the side having greater thickness as the expansion of the thinner side (outside radius) will be more than thicker side (inside radius) due to differential expansion and moment induced due to eccentricity. Experimental results demonstrate that bending based on AFPA can meet the designed requirement of application. The AFPA is used for both the fins of the fish robot. The front fins help in the forward direction. The two other AFPAs are used for making the tail part to have control over the direction. The internal pressure of the AFPA is controlled using a solenoid valve which is interfaced using an Arduino microcontroller for fish like moves. The developed fish robot is made of rubber and polymer materials and it swims in water smoothly similar to a living fish. This type of fish robot has many advantages such as good adaptability, simple structure, small size, high flexibility and less energy loss. The robotic fish can be used to ensure underwater security and for the habitat study of aquatic creatures.

Keywords- Asymmetric Flexible Pneumatic Actuators, Fish Robot, Microcontroller.

I. INTRODUCTION

A fish is an aquatic vertebrate that simply moves its tail and its fins to swim. They move their caudal fins (tail fins) to propel themselves through the water. Their pectoral fins, and for the most part, the rest of the fins, are used to help the fish change direction, along with the pectoral fins helping them to stop. Wagging the body and tail is the main propulsion method of marine swimmers (e.g., billfish and sailfish), allowing them to reach necessary speeds. By replicating nature via robotics, we understand the significance of the number of joints (Dean et al., 2009), the shape of the fin (Curet et al., 2011), and the direction of a tail swish (Long et al., 2006) for controlling movement. Control systems coordinate the multiple fins.

Aswath S, Chinmaya Krishna Tilak, Kalyani Jayaprakash, Anila G Nair, Arathi S Nair, and Aiswarya Mohan are with the Electronics and Communication Engineering Department, Amrita Vishwa Vidyapeetham (University), Kollam, Kerala 690525, INDIA (corresponding author's phone no: +91-9995766565, email: aswathashh10@gmail.com, chinmaya94@ gmail.com, kalyani.jayaprakash@gmail.com, arathinair93@gmail.com, anilanair93@gmail.com and aiswarya1692@ gmail.com)

Ganesha Udupa is with the Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham (University), Kollam, Kerala-690525 INDIA.(e-mail:ganesh@am.amrita.edu)

Sensors integrating different sensory modalities are sought to develop navigation systems that reliably guide the robot to reach its destination. We test out new actuators that accelerate unsteadily to increase thrust.

Pneumatic rubber actuators has a simple structure and are water resistant. The high elastic deformity and high power/weight ratio of these actuators makes them applicable for soft handling robots allowing smooth motion like livings and used for human-support robots, robotic hands for various works in size and shape. The working principle of this actuator is very simple. Flexible pneumatic actuator (FPA) was designed by Joseph L. McKibben in 1950's known as Pneumatic Muscle Actuator. But it was not practically interested until 1990's, when universities and big corporations such as Toshiba, Bridgestonc, Festo, Imagesco, WestGroup from USA, Japan and Germany started researches related to flexible pneumatic actuators. Toshiba Corp. (Japan) developed a three degree-of freedom actuator known as Flexible Micro-actuator (FMA) [1]. Even though the FMAs with two or more chambers with fibre reinforcement provides multiple DOF but requires multiple pressure supplies, valves and sensors as well as complicated manufacturing. Based on study of the flexible pneumatic actuators mentioned above, a flexible pneumatic actuator has been developed [2]. The only difference is that there is a restricting wire along with spring as reinforcement rather than the fibre used in FMA. The two ends of the steel wire is fixed to the end covers on one side by bolts to get the bending motion. In another variation [3], expansion principle of FPA is used to get the bending motion by connecting the FPA to connecting rod and shaft combination and making the structure bulky and complicated.

Asymmetric flexible pneumatic actuators [AFPA] have been developed for the first time during 1990s using asymmetric polymer/rubber and rubber bellow actuators with proper reinforcement to overcome the disadvantages of FMA and FPAs [4-5]. Recently it has been applied to fabricate a four fingered robot gripper [6] using nitrile rubber actuators. FPA made of three chambers are used to fabricate a manta swimming robot [7]. AFPA were developed as an alternative to other actuation principles of today, such as electro motors, shape memory alloys, McKibben muscles, and flexible fluidic or pneumatic actuators. These actuators have various advantages considering several criteria, including stress improvements, packaging, good power to weight ratio, and high dynamics. This paper proposes an optimal design and prototyping method of single chamber asymmetric flexible pneumatic actuator (AFPA) and its application for an innovative fish robot. The developed fish robot swims very well in water. The cross section of AFPA is asymmetric as compared to symmetric section of FMA or FPA as shown in Fig.1.

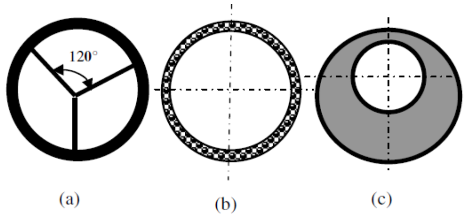


Fig.1. Cross section design of Flexible Pneumatic actuators (a) FMA (b) FPA (c) AFPA

II. Basic Structure and Working Principle

The working principle of the asymmetric tube or bellow actuator is exactly opposite to that of the working of the Bourdon tube. The Bourdon tube initially used has a curved contour with a flat or elliptical cross section. The application of internal pressure will tend the curved tube to open up because under pressure the flat or elliptical section become circular. Contrary to this a straight asymmetric (eccentric) tube or bellow with circular cross section under the application of pressure will become curved and elliptic in cross section.

The tube which is curved initially (due to packing in reels) gets straightened first under the application of the internal pressure and then expands**.** On the other hand if the wall thickness is made asymmetric, the tube under internal pressure will curve in the direction of the side having greater thickness as the expansion of the thinner side (outside radius) will be more than thicker side (inside radius) because of the unequal thickness as shown in Fig.2.

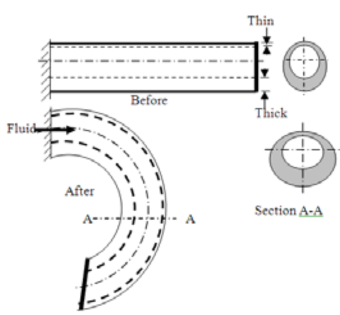


Fig. 2 Bending of asymmetric actuator subjected to fluid pressure.

This effect is due to dual effect of an unequal expansion or in other words differential expansion of the tube at various points and the end moment induced due to asymmetry of cross section.

Bellow actuator with asymmetric cross section will behave similar to the asymmetric actuator but will have higher flexibility and greater rate of expansion and curving under internal pressure. Bellows can be made asymmetric in cross section either with full bellow or half bellow. Figure 3 shows bending of asymmetric flexible bellow actuator subjected to internal pressure.

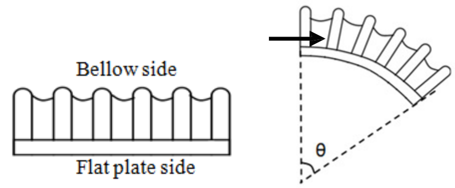


Fig. 3 Bending of asymmetric bellow actuator subjected to internal pressure.

The Bellows can be used as fins of the fish robot. The Bellow allows 1 DOF motion for the fish fin. The two bellows are attached at the front and two at the back to replicate a real fish movement. The front fins help in the forward direction. The two other bellows are used for making the tail part to have control over the direction. The Fig.4 shows the prototype of fish robot.

Fig.4 Prototype of Fish Robot.

III. Manufacturing Of AFPA

AFPA is manufactured using compression molding technique. For the manufacturing purpose, the actuator is divided into two symmetrical equal halves. Then each half is manufactured separately and are bonded to make the complete AFPA. The manufacturing of AFPA metallic mold consists of convex and concave parts. The Silicone rubber paste is used for molding the AFPA. Fig.5 shows the mold manufactured using machining process. Fig.6 shows the manufactured half parts of the AFPA after molding process and the complete actuator is made by bonding the two half parts.

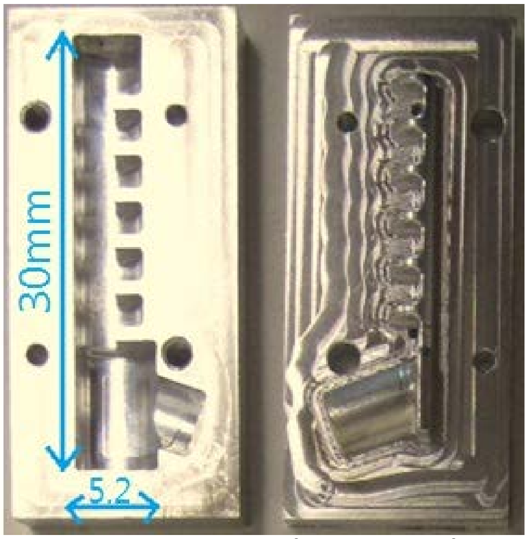
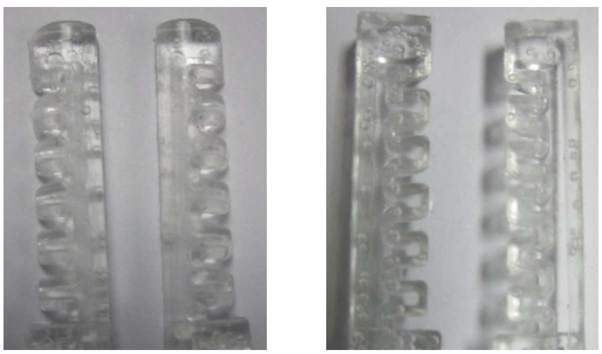


Fig. 5 Convex and Concave molds for AFPA Manufacturing



(a) (b)

Fig. 6 Manufactured half parts of AFPA (a) External (b) Internal half bellow parts.

IV. Circuit Design And Control System

The main fragments of the fish prototype are air compressor, pressure regulator, solenoid valve, AFPA, ULN2003 IC and Arduino microcontroller .The remote control based on pull up configuration is used to steer the movements of the fish. The remote is a three channel remote with three control switches. When a switch in the remote control is pressed, the specific output pin of the channel will be set high else it remains at zero. The output pins of the three channel remote are connected to the digital input pins (4) to pin (6) of the Arduino microcontroller. Arduino is a single-board microcontroller, intended to make the application of interactive objects or environments more accessible. The Arduino ATmega328P pin configuration is shown in Fig.7.

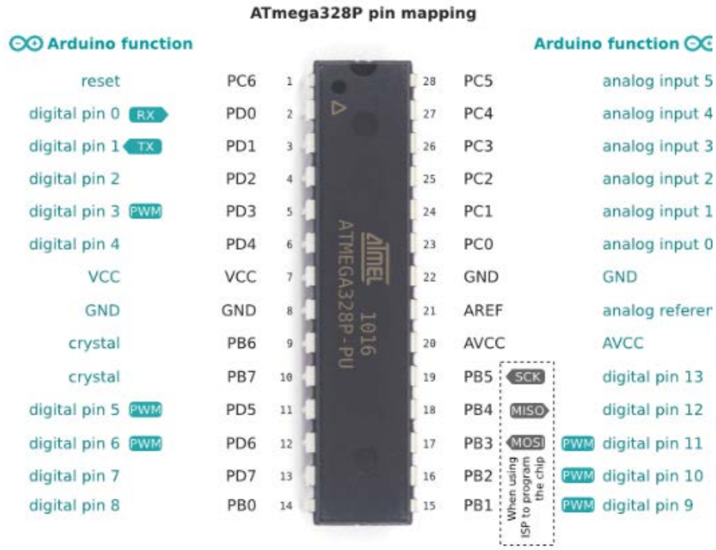


Fig. 7 Arduino ATmega328P pin mapping

The Arduino is programmed to take the inputs and outputs the corresponding decisions to the ULN2003 IC through its output digital pin (8) to pin (10).The Arduino program is based on Pulse Width Modulation(PWM). The output from the Arduino digital pins is fed to input pin (1) to pin (3) of the ULN2003IC. ULN2003 IC is a high voltage, high current Darlington transistor arrays. The Fig.8 shows ULN2003IC pin diagram. The ULN2003 IC is used to drive the 24V relay circuit of the solenoid valve used in the prototype .The output pin(1) to output pin(3) of the ULN2003 are connected to the relay of the solenoid valve.

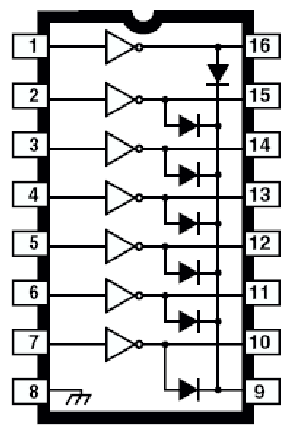


Fig. 8 ULN2003 pin mapping

An air compressor with a max of 10 bar pressure capability is used to supply internal pressure to the AFPA. The compressor is connected to the solenoid valve via a pressure regulator. The pressure regulator is used to limit the pressure to about 3 bar, because enough bending is achieved at this internal pressure by the AFPA for fish like movement. When the ULN2003 IC drives the relay circuit of the solenoid valve, the valve will open and hence the air pressure is supplied to the AFPA of the fish robot that succours for fish like motion.

V. Implementation Of Fish Robot

Fig. 9 shows the experimental setup for implementing the fish robot.

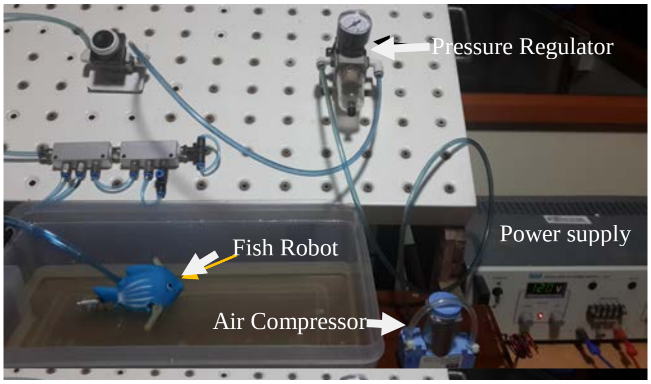


Fig. 9 Experimental set-up

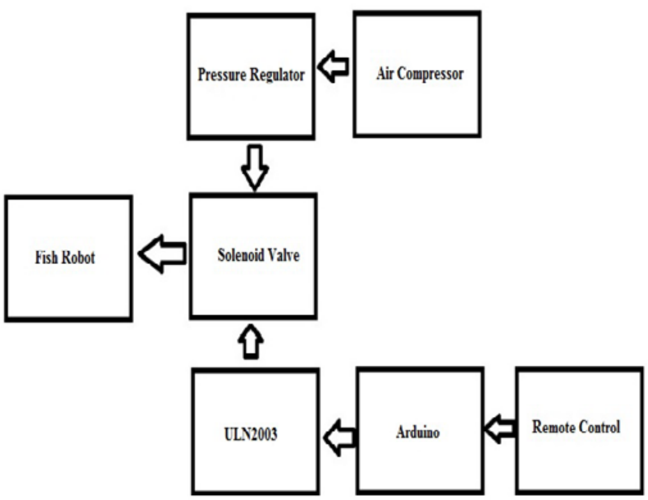


Fig. 10 Block Diagram of the complete control system

Above Figure delineates the complete schematic block diagram of AFPA used in the fish robot. To activate the fish robot, a particular button in the remote control should be pressed. For example when the button '1' in the remote control is pressed the fish starts moving forward. Detailed conditions are shown in the flow chart diagram shown in Fig11.When the button '1' is pressed, the digital logic '1' will be passed to the corresponding digital pin of the Arduino microcontroller. The microcontroller runs the corresponding program based on the input logic received at the input pin and outputs its decision to ULN2003 IC. It controls the 24V relay circuit of the solenoid valve based on the output decision of the Arduino microcontroller.

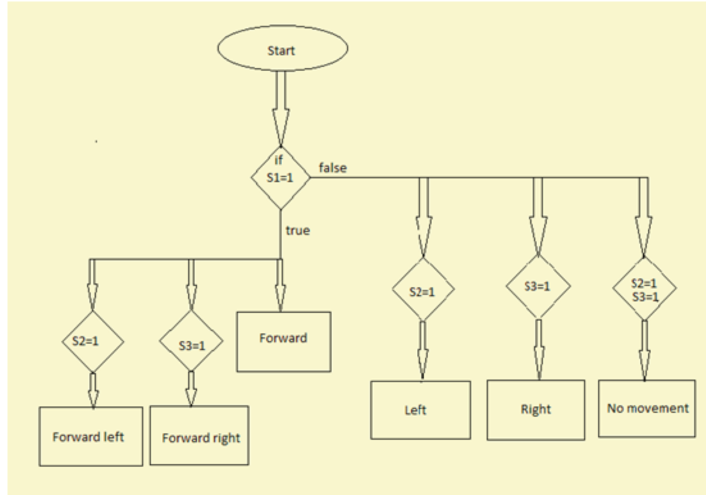


Fig. 11 Flow chart of the commands to Fish Robot

Air compressor used endows a maximum of 10 bar pressure to the pressure regulator. The pressure regulator controls the air pressure in the solenoid valve. In this paper, the pressure required by the AFPA for fish like movement is about 3 bar. So the pressure regulator is used to restrict the air pressure to 3 bar. This pressure is then fed to the AFPA via solenoid valve based on the output of the ULN2003 IC. With this prototype the fish is able to move swiftly in the water.

VI. Results And Discussion

A. Deflection of AFPA

Fig.12 shows the experimental result of bending of AFPA at different pressure. An experimental results show satisfactory bending of the AFPA, The air is supplied to the actuator at a pressure 1.8 bar through a solenoid valve to get sufficient bending for forward motion of the fish robot.

B. The deformed shape of AFPA

In order to verify the principle of bending, the deformed shape of the asymmetric actuator is analyzed in Algor software by cutting a section of the actuator subjected to internal air pressure as shown in Fig.13 (a). It is observed that the cross section of the actuator is deformed to elliptical shape from its original circular shape throughout the length of the actuator. The nodal points of the deformed shape is plotted as shown in Fig.13 (b).

The distortion of the cross section is expressed by the radial displacement u (positive outward) and is given by [8]

$$u = -u_0 \cos 2\beta$$

where, u_0 is the amount of flattening and β is the angle of rotation. This is a reasonable flattened ellipse like curve. Increase in curvature due to flattening = $-3u_0 \cos 2\beta / r_0^2$ where r_0 is outside radius of the actuator. This shows that the flattening effect also influences the elongation of the actuator along with the bending effect.

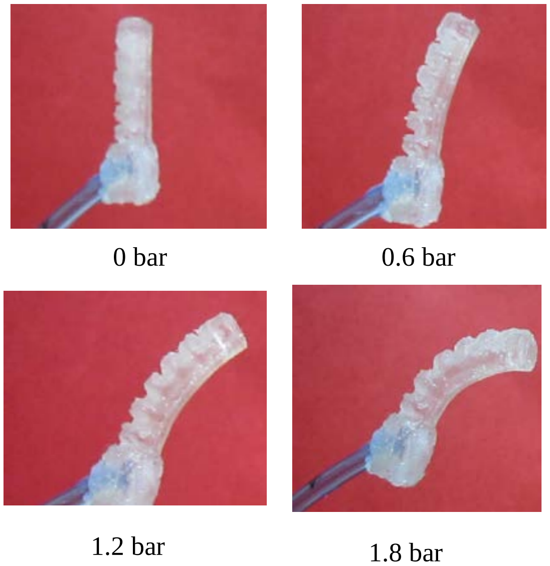
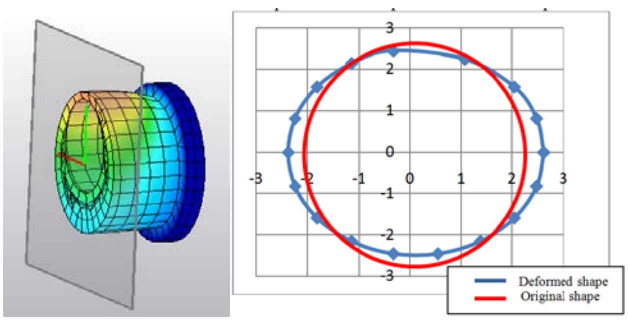


Fig. 12 Deflection of AFPA at different pressures



(a) (b)

Fig. 13(a) Sectional view of the asymmetric actuator (b) Deformed shape of the asymmetric actuator

C. Angular deflection of Asymmetric actuator

Fig. 14 shows the comparison of analytical and experimental data of angular deflection for an asymmetric nitrile rubber actuator subjected to varying pressure. As the pressure increases, the angular deflection of the actuator increases. However the radius of curvature decreases.

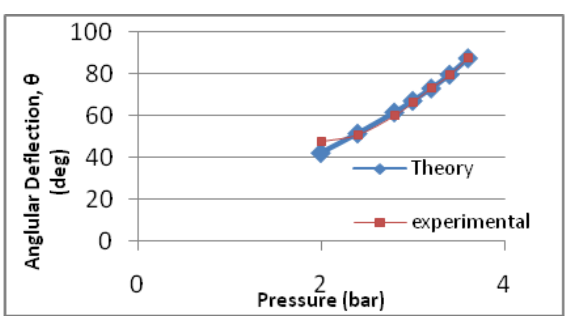


Fig. 14 Angular deflection for asymmetric actuator subjected to internal pressure

Figure 15 shows the deflection of asymmetric nitrile rubber actuator subjected to varying pneumatic pressure. As seen that the deflection of the actuator increases with increase in pressure and it bends more than 80º at a pressure of about 3.5 bar. Similar behavior is observed in asymmetric bellow rubber actuator. Fig. 16 shows the deflection of asymmetric bellow actuator subjected to varying internal pressure. It is observed that the deflection in the case of bellow actuator is more than that of the actuator keeping length same for both the actuators.

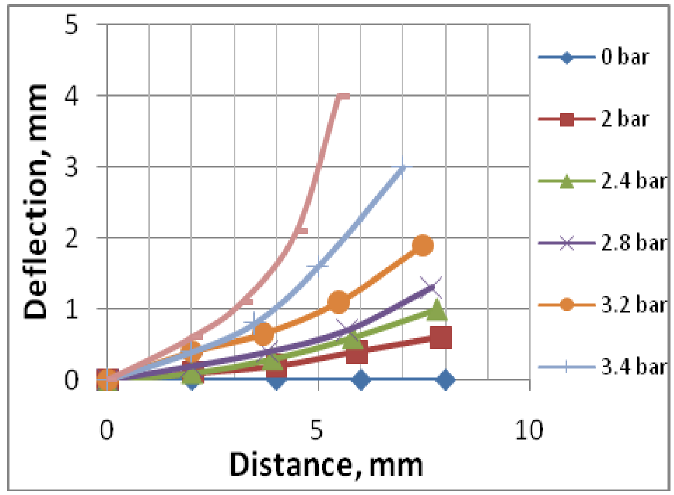


Fig. 15 Deflection of asymmetric nitrile rubber actuator subjected to varying pneumatic pressure

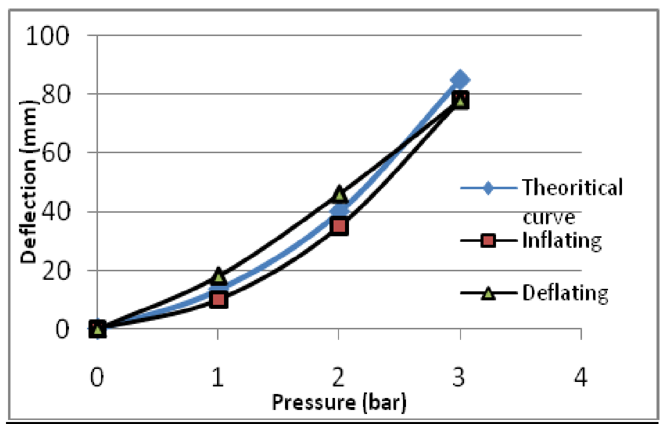


Fig. 16 Deflection of the asymmetric bellow actuator subjected varying pressure.

The three cases indicating different actions of the fish robot is achieved as given below.

CASE (1) Pressing key-1 on the remote control moved the fish robot forward.

CASE (2) Pressing key-2 on the remote control made the fish robot to turn right.

CASE (3) Pressing key-3 on the remote control made the fish robot to turn left.

Case 1: Moving Forward

Case 2: Turning Right

Case 3: Turning Left

Fig. 17 Experimental results of fish robot swimming motions

It is observed that the developed fish robot swims in water smoothly similar to a living fish and the performance is satisfactory. The Fig.17 shows the experimental results of swimming motion of fish robot.

VII. Applications

Fish Robot will help the researchers to have a more complete picture of what is happening under the water, such as climatic changes and other outside forces that disrupt the freshwater ecosystems. Robotic fish could give researchers far more precise data on aquatic conditions, deepening the knowledge of critical water supplies and habitats. Patrolling fish will be able to collect information at an unprecedentedly high spatial and temporal resolution. Robotic Fish will carry sensors recording things such as temperature, dissolved oxygen, pollutants and toxic algal blooms. Since the fish is designed at a low cost, it can be used in various applications like sampling lakes, monitoring aqua farms and safeguarding water reservoirs. The fish robot is considered as the scientists' latest weapon in the war against pollution to improve the performance of underwater autonomous vehicles by using new forms of propulsion. The propulsion by undulation is more effective than the usual propulsion by propeller. Some electronic devices that can navigate and communicate in their watery environment can be inserted. Infrared sensors can also be used for eyes to avoid obstacles. Other applications include military activities, pipeline leakage detection and laying of communication cables. Moreover it can also be used in oceanographically observation, search for mines and underwater archaeological exploration.

VIII. Conclusion And Future Discussion

To imitate the behaviours of the real fish with robotized systems is a real challenge and requires to better known biomechanics of the stroke and hydrodynamic characteristics of the fish. This paper investigates the design and prototype of an innovative robotic fish based on Asymmetric Flexible Pneumatic Actuator (AFPA). The structure and working principle of fish robot is simple, resilient and is cost effective. An experimental result shows satisfactory bending of the bellow if the pressure in the solenoid valve is about 1.8 bar. Visible bending is initiated when a pressure of 0.6 bar is fed to the solenoid valve.

The developed fish robot is made of rubber and polymer materials and it swims in water smoothly similar to a living fish. The main application of the robotic fish is to detect water pollution, ensure underwater security and to monitor the aquatic habitat. The fish robot will carry sensors and its robust structure serves its purpose of detecting climate changes under the surface recording temperature and presence of harmful algae etc.

IX. Acknowledgements

The authors would like to thank Mechatronics and Intelligence Systems Research Lab, Department of Mechanical Engineering, Amrita University, Amritapurit campus for providing support to carry out the research and experiments.

References

[1] K. Suzumori, S. Iikura and H. Tanaka, Flexible microactuato for miniature robots, Proc. IEEE Micro Electro Mechanical Systems Conf., Nora, Japan, 1991, pp.204-209. http://dx.doi.org/10.1109/MEMSYS.1991.114797

[2] Yang Qinghua, Zhang Libin, Bao Guanjun, Ruan Jian, Research on Novel Flexible Pneumatic Actuator FPA [A], IEEE Conference on Robotics, Automation and Mechatronics, Singapore, 2004, pp 385-389,.

[3] Libin Zhang, Zhiheng Wang, Qinghua Yang, Guanjun Baa and Shaoming Qian, "Development and Simulation of ZJUT Hand Based onFlexible Pneumatic Actuator FPA", Proceedings of the IEEE International Conference on Mechatronics and Automation Changchun, China. 2009.

[4] Ganesha Udupa., "Study and Development of an unconventional device for industrial applications including robots and instrumentation," M.Tech. Thesis, Govt. B.D.T. College of Engineering, Davangere, India, 1992.

[5] Ganesha Udupa and R. Krishna Murthy., "A new Flexing Technique for Soft Gripper Design," Proc. 16th All India Manufacturing Technology Design and Research Conference, Bangalore, 1994, pp.353-358.

[6] Ganesha Udupa, Pramod Sreedharan, Aditya K, "Robotic Gripper Driven by Flexible Microactuator Based on an Innovative Technique", Presented at 6th IEEE Workshop on Advanced Robotics and Its Social Impacts, Korean Institute of Science and Technology, Seoul, Korea, 2010.,pp1-6

[7] Koichi suzumori, New pneumatic actuators producing breakthrough in mechatronics, Proceedings of the 7th JFPS International Symposium on Fluid Power, TOYAMA 2008, 2008 pp 197-202.

[8] J.P. Den Hartog.," Advanced strength of materials," McGraw – Hill, 1952.