DESIGNING AN ROBOTIC BOXFISH FOR THE MECHATRONICS COURSE

Chandrashekhar Thorbole [1] *and* Behnam Bahr [2]

Abstract-- *This paper discuss about the procedure adapted to mimic the fish tail kinematics to develop a microprocessor controlled biomimetic robot, after review of different Fish swimming modes and understanding the required tail kinematics for different momentum transfer mechanism, we tried to synthesis several compact light weight mechanism which will mimic the Boxfish tail kinematics for the required momentum transfer mechanism. The kinematic analysis of these mechanisms is carried out in Visual Nastran4D for the further selection of the best suited mechanism, after this the body design is highlighted for the stable swimming performance. Tank tests are conducted on the developed fish to investigate the effectiveness of the mechanism selected and to confirm the feasibility of the system and the relation between the speed of the fish and tail beat frequency. The objective of this project is to understand the behavior of rigid body with oscillating tail which is similar to the ostraciiform mode of swimming.*

Index Terms—Biomemitic, Ostraciiform, Propulsor, Visual nastran4D.

INTRODUCTION

Biomemitic robot mimics biological system or utilize the mechanism developed by nature in the process of evolution, recently there is lot of research on biological inspired robots like Robofly, lobster robot and eel robot.

There is lot to learn and adapt from the nature as how fish swims so efficiently in the water without disturbing the water in its vicinity, what makes fish so maneuverable, if we succeeded in applying the principles of fish locomotion to the underwater vehicles and robots then these can be as efficient and maneuverable as the fish. Before developing the fish robot it is important to understand the morphology and different swimming modes of the fish.

Fish exhibits large variety of swimming modes these modes basically depends on the Foraging requirements and predator Avoidance [P.W Webb] [1], on the basis of this there are many morphological adaptations of different fish and this gives diversity in the propulsor and momentum transfer mechanism.

The basic modes of propulsion are classified as BCF mode and MFP mode, in the former mode the thrust is produced by the body and caudal fin of the fish and in the latter mode the median fins are used for the propulsion.

Breeder (1926) designed the classification of the different swimming modes which included three terms namely "anguilliform", "ostraciiform" and "carangiform", Anguilliform mode is purely undulatory mode of swimming in which whole body participates in the thrust production, eels are the best examples of this mode, In carangiform mode the thrust is produced by the oscillating posterior part of the body with stiff tail and in ostraciiform mode the propulsion is achieved by the pendulum like oscillation of the rigid tail, The body of these fish are not flexible and streamlined, this fish is not competent in forward swimming but these are highly maneuverab le.Borelli,In 1960 published the first diagram of fish locomotion, Fish swimming by sweeping it tail side-to-side in an arc. He tried to disprove Aristotle that the paired fins when present are the main locomotion organs. In 1874 Pettigrew challenged Borelli View about forward motion produced the net forward motion; he argued that moving the tail from the mid line to outwards during the "preparatory" Sweep would produce a backwards movement of the fish.

Breder (1926) comments "his logic would seem to be correct, but that he was in error has been positively proved by the construction of a model". What Pettigrew's overlooked that the outward sweep of the tail, on a fish, does not move the whole body backwards; instead, it swings the main body slightly in a sidewise arc opposite to that of the tail. Ostraciiform mode of locomotion is neglected from long time due to its low swimming efficiency but now due to rigid body of ostraciid fish and high maneuverability this mode of swimming is gaining an attention from the researchers of the underwater vehicles as this study will facilitate in developing a Smart autonomous underwater vehicle employing the features of Ostraciid fish. This paper discuss about the approach used to develop the robotic ostraciid fish.

FIGURE. 1
BOXFISH

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After understanding the propulsion of ostraciid fish a mechanism is devised which will imitate the motion of the propulsor similar to the boxfish.

CAD MODEL

To understand the relative motion of the oscillating tail with respect to the body a CAD model is developed using Pro-e, This model is developed with driving mechanism for the tail and using pro-e animation the relative motion between different links can be understood with respect to the body, this approach will facilitate in understanding the feasibility of the mechanism to be used.

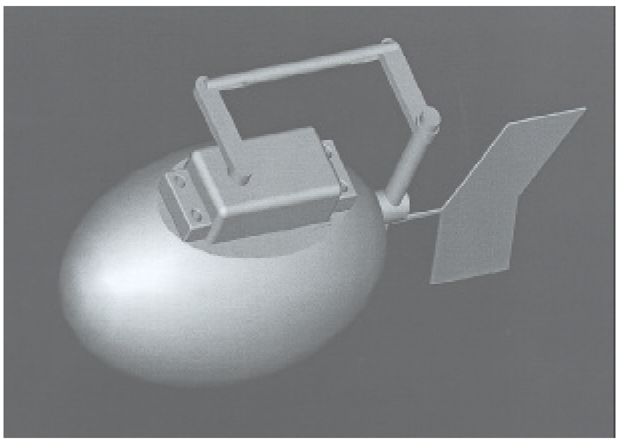


FIGURE. 2
PRO-E MODEL WITH DRIVING MECHANISM.

This model developed is similar to ostaciiform mode of locomotion in which the tail will oscillate like pendulum about one fixed point .In the model the body of the fish is streamlined which is not the actual case as the shape of ostraciid fish is not streamline but it is more like box as it is clear from the fig1.

Servo motor is used for the actuation of the mechanism which in turn will oscillate the tail for the momentum transfer. The momentum transfer is due to acceleration reaction of the fluid which can be enhanced by increasing the velocity of tail sweep from the start to the mid point of the oscillation but for the servomotor it is difficult to vary the speed from start to the mid point so this can be achieved by varying the lengths of mechanism links.

MECHANISM

Mechanism design totally depends on the momentum transfer mechanism used by the Boxfish for the forward swimming [1] boxfish uses their pectoral fins in association with the caudal fin for the forward motion , these fishes uses acceleration reaction momentum transfer mechanism for the forward swimming.

This robotic fish is associated only with the caudal fin for the propulsion, for this reason the study of tail kinematics for efficient propulsion is important as this will help in developing the required mechanism.

Light weight, simple in construction and compactness are some important considerations for the mechanism design.

REQUIRED TAIL KINEMATICS

The curves are plotted for transverse velocity of the trailing edge against distance from the midline or mean position, this curve will facilitate to understand the requirements of the mechanism to develop such movement of the caudal fin.

FIGURE. 3
DIAGRAMMATIC REPRESENTATIONOF LATERAL VELOCITY ABOUT THE MID-LINE.

The plot of transverse velocity against the distance from the mid line exhibits the asymmetrical curve; this curve can be the best required kinematics for acceleration reaction mechanism as compared to the symmetrical curve about the mid-line.

Mechanism should be compact, light and it must follow the above curve with all these requirements several mechanisms were designed and tested for their kinematics using Visual Nastran 4D.The basic idea is to achieve the asymmetrical curve of lateral velocity about the mean position or to achieve the accelerating Fin movements.

MECHANISM DEVISED

Mechanism is modeled in Pro-e and then this is transferred to Visual Nastran4D for the kinematics analysis ,several mechanism are modeled and transferred to Nastran for the kinematics study and based on this analysis an appropriate mechanism is selected which will satisfy the required Tail kinematics.

QUICK RETURN MECHANISM

Pro-e2001 is used to model the mechanism and this is transfered to visual nastran as step . File,this mechanism can be used for the accleration reaction type momentum transfer mechanism in the water.

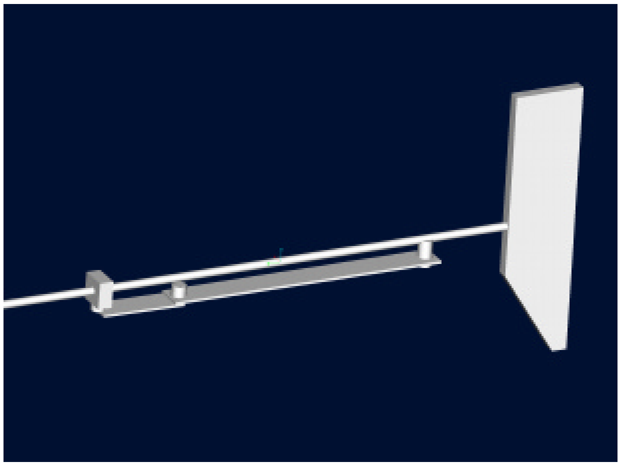


FIGURE. 4
QUICK RETURN MECHANISM MODELED IN PRO-E

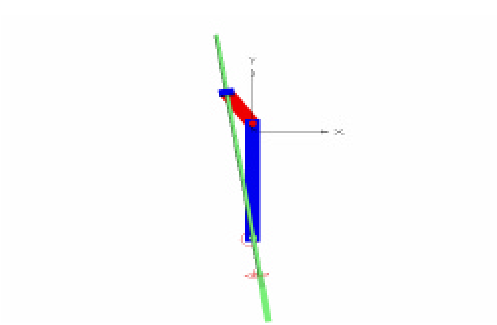
VISUAL NASTRAN 4D ANALYSIS

Kinematic analysis of the mechanism is done using Visual Nastran 4D and due to the nature of quick return mechanism the propulsor accelerates in half of the cycle and this characteristics is useful for the acceleration reaction type of momentum transfer in the water, the speed of the motor can be varied by the gear box and the amplitude of the tail beat can be varied by changing the length of the crank.

As it can be observed from the figure4 that this mechanism is compact and can be easily used for compact fish robot as the base of the mechanism can be directly mounted on the fish.

It is observed that by using the quick return mechanism for the propulsion of the fish the speed of the fish is not uniform but it is oscillating which means that water is accelerated more in one half of the cycle compared to the other half, the yaw of the nose is also more towards one side compared to the other side.

In Visual Nastran 4D the required kinematic of the point of interest can be metered by attaching the coordinate system to the point on the propulsor and then metering the kinematic of that coordinate system, if the particular body is selected than the center of gravity of that particular body is selected by default, in this case the coordinate system is attached to the end of the propulsor.



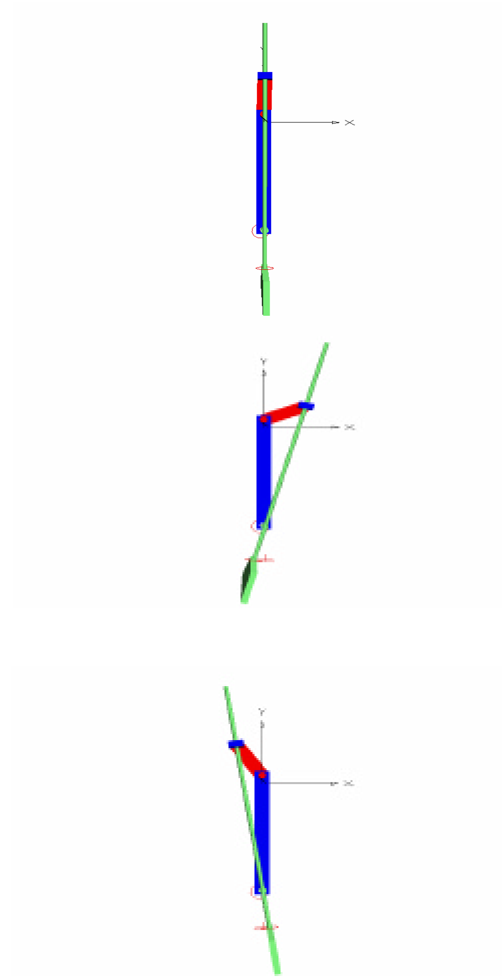


FIGURE.5
FIN MOVEMENT USING QUCK RETURN MECHANISM.

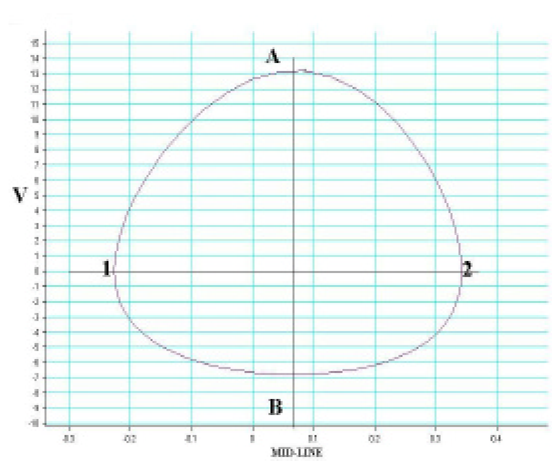


FIGURE. 6
VELOCITY PROFILE OF PROPULSOR TRAILING EDGE

Figure6 which highlight the velocity profile of the propulsor trailing edge with respect to the mid line of the oscillation, it can be observed that velocity increases from extreme position till the mid-line and then decreases,this is highlighted by 1-A-2 curve and it returns back following the 2-B-1 curve which means that higher reaction force acts on the fish during first half of the cycle compared to the second half,This velocity curve obtained is good for the acceleration reaction momentum transfer as the nature of this curve is near to the velocity curve in Figure3.

SCOTCH YOKE MECHANISM

Scotch yoke mechanism can be the best compact mechanism for converting the rotating motion into the oscillatory motion which can oscillate the fin with required frequency, Gear box can be used to increase the torque of the fin for the momentum transfer and it is possible to use high power DC motor which rotates at very high speed, this arrangement can be best suited for the high speed compact robotic fish using acceleration reaction momentum transfer mechanism.

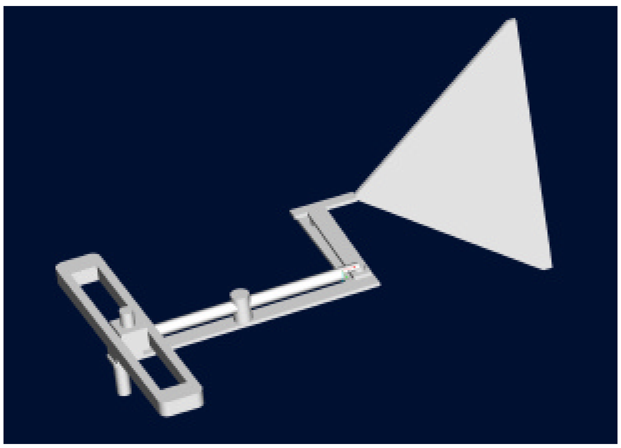
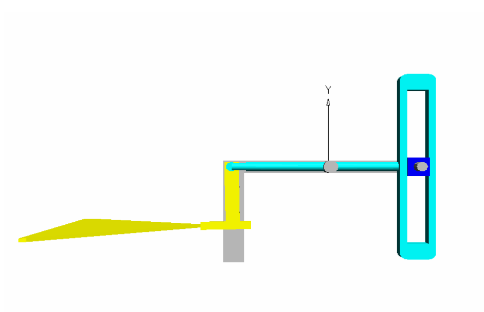


FIGURE. 7
PRO-E MODEL FOR THE SCOTCH YOKE MECHANISM WITH THE PROPULSOR.

VISUAL NASTRN4D ANALYSIS



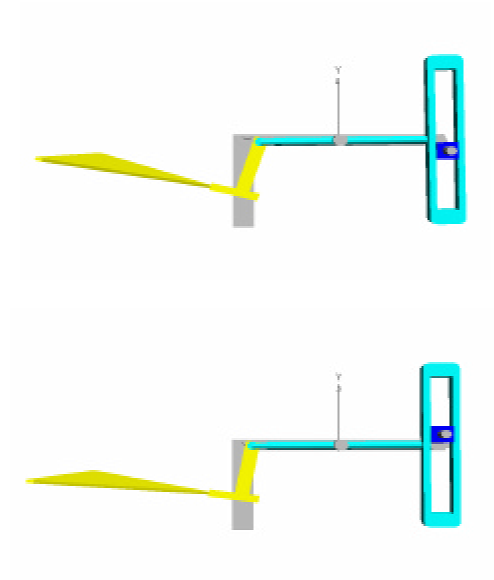


FIGURE. 8
FIN MOVEMENT USING SCOTCH YOKE MECHANISM.

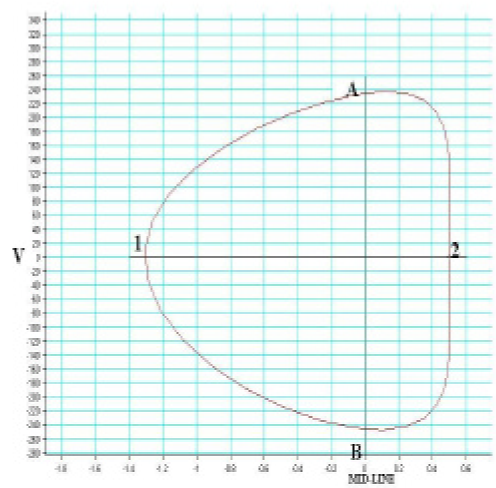


FIGURE. 9
VELOCITY PROFOIL OF PROPULSOR TRAILING EDGE.

Figure9 highlights the velocity profile of the propulsor trailing edge with respect to the mid-line of the oscillation,it can be observed that the velocity increase from position “1” till position “A”and then decreases abruptly and the nature is similar for the return curve ,this particular nature of curve will tend the robot fish to move in a circular path and this can be controlled by adjusting the length of the crank.

This mechanism is suitable when the speed of the robot required is high as the frequency of tail depends on the rotation speed of the crank,the amplitude of the tail oscillation can be controlled by controlling the crank length.

DOUBLE CRANK MECHANISM

This mechanism is used when the tail beat frequency required is not high ,servo motor is used for the propulsion ,as servo motor can be directly controlled by microcontroller and the degree of rotation can be controlled accurately this mechanism is good for the maneuverability of the robot as the turning radius can be controlled by adjusting the offset to the oscillation of the tail about the mean position.Maneuverability is defined as the ability of the robot to swim in closed volume and also as ability to change the direction with small turning radius.

The speed attained by the robot is less as the oscillation of tail depends on the oscillation of the crank and it is observed that for increase in the frequency of the oscillation the amplitude was decreased so their is a compromise between the amplitude and the frequency of the tail.

VISUAL NASTRAN 4D ANALYSIS

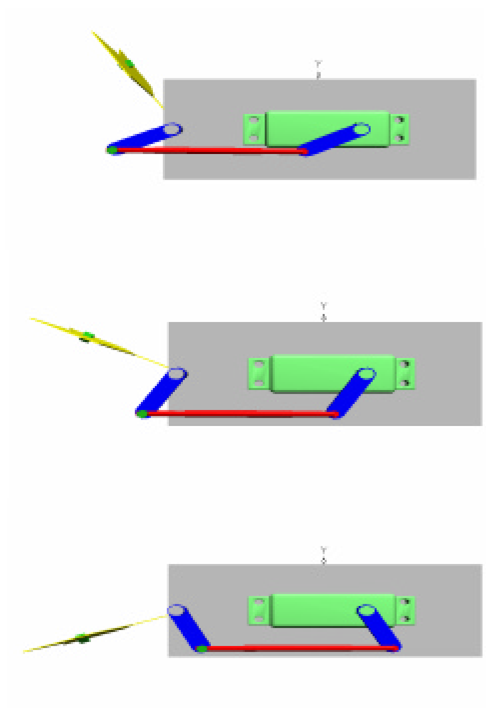


FIGURE. 10
FIN MOVEMENT USING THE DOUBLE CRANK MECHANISM.

Figure11 highlights the velocity profile of the propulsor with respect to the mid line ,this profile is similar to the profile plotted for the quick return mechanism the only change is that the maximum velocity values are same in both the half of the cycle,this nature makes this mechanism more favourable than quick return mechanism.

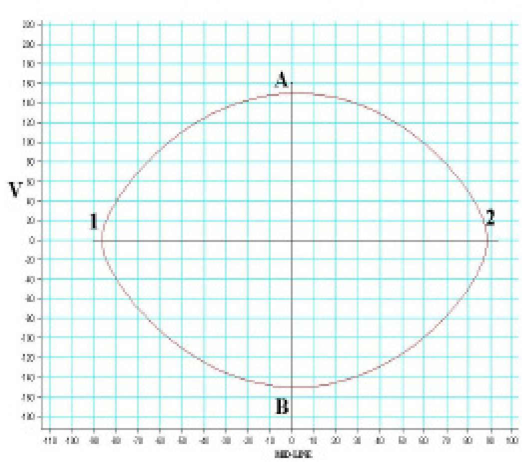


FIGURE. 11
VELOCITY PROFILE OF PROPULSOR TRAILING EDGE.

MECHANISM SELECTION

In real aquatic life the muscles of the fish contracts its body which in turn provokes the reactive forces from the surrounding medium, thus it is the result of momentum transfer from the fin/propulsor to the surrounding medium.

Boxfish uses acceleration reaction mechanism for the momentum transfer, in which there is change in the kinetic energy of the water surrounding the propulsor due to the accelerating propulsor, this phenomenon must obey the Newton’s law in the water and must provokes reactive forces on the propulsor which results in the locomotion, based on this study it is clear that their should be change in the propulsor velocity while oscillating about the mean position, as the propulsor oscillate about the fixed point about the mean position the transverse velocity curve plotted against the mid line should be similar to the Fig3.

Transverse velocity and acceleration curves of the propulsor will be the selection criteria along with the compactness and manufacturability of the mechanisms in the limited time.

QUICK RETURN MECHANISM

Figure6 reflects the nature of velocity profile plotted against the position of the propulsor about the mid line which reflects that velocity increase from one end till the mid line and then decreases to zero at other end, the maximum value of velocity attained in the next half of the cycle is near about half of velocity attained in the first half of the cycle, this nature of the velocity profile makes quick return mechanism favorable for the acceleration reaction momentum transfer mechanism.

The construction of this mechanism is intricate compared to the double crank mechanism, if the velocity profile with the double crank mechanism is favorable then it will be the better choice as it is easy to develop this mechanism.

SCOTCH YOKE MECHANISM

This mechanism can be very useful during high frequency oscillation requirements of the robot for higher speeds but present requirement is to understand the relation between the tail beat frequency and speed which can be understood with double crank mechanism with better velocity distribution about mid-line.

DOUBLE CRANK MECHANISM

This mechanism also reflects the curve characteristics similar to the quick return mechanism but this mechanism can be developed very soon and the kinematics can be changed by controlling the servo motor making this mechanism favorable.

Figure11 reflects the velocity profile of the propulsor about the mid line which shows that velocity is max at the mid line and zero at the extreme ends and both the half of cycle is symmetrical making this mechanism as best mechanism for the present condition.

BODY DESIGN

Body of the actual boxfish is not streamlined and it is not flexible because of the fused scales, this can be the great advantage as flexible hull will require extra mechanism than the rigid body and in real world all the underwater vehicles are rigid.

Body of this fish is developed from the Balsa wood because of its light weight and good strength, the body dimensions are so decided that the driving motor will be outside the water so there will be no need of water proofing the system.

The dimensions of the body and the shape of the body are so designed that center of gravity and the center of buoyancy will lie near to each other on the longitudinal axis of the body, this is achieved by inserting lead in the body as lead is very dense material so the required ballast weight is obtained from lead bar. This weight also takes care of roll action of the body as this is Ostraciiform mode of propulsion in which the side thrust cannot be avoided which tends to roll the body, this phenomenon will increase with increase in the frequency of the oscillation. It is observed that position of center of gravity along the longitudinal axis of the fish controls the yaw amplitude of the nose, higher the distance between the nose and C.G higher the yaw amplitude.

The roll stability of the fish is also increased by increasing the righting arm which is increased by increasing the flare and freeboard, lower freeboard and flare will provide a small righting arm and less stability, dorsal part of the robot is kept out of water to prevent the servo motor(Figure 16).

This wooden body of the robot is covered with the rubber skin of the toy fish which prevented the wood and other elements in the fish and gave a realistic look to the fish .

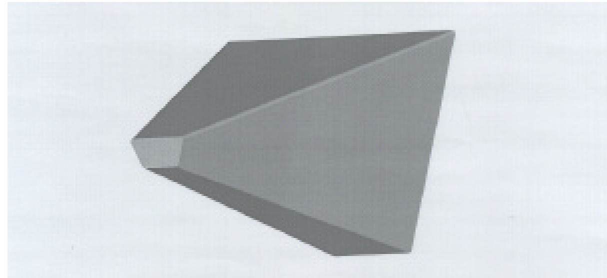


FIGURE. 12
HEAD PART OF THE ROBOT BODY MADE OUT OF BALSA WOOD.

The center of gravity is shifted downwards or below the center of buoyancy by providing a cavity at the bottom which will be filled with a dense metal like lead, the cavity is visible in the Fig13

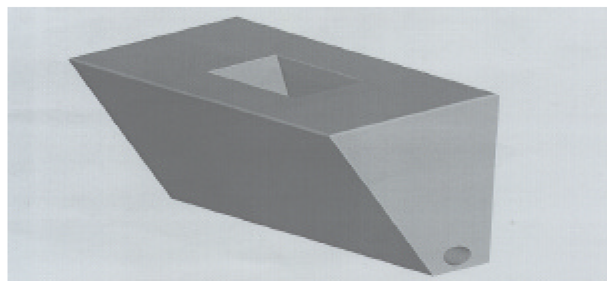


FIGURE. 13
ROBOT BODY WITH THE CAVITY TO FILL THE LEAD (BALLAST).

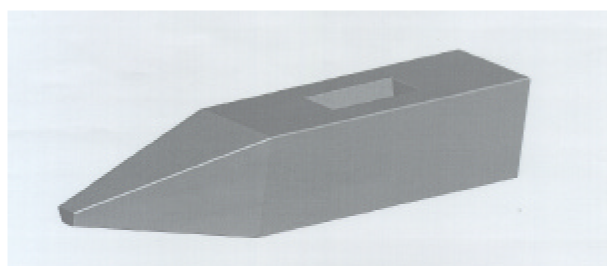


FIGURE. 14
COMPLETE BODY OF THE ROBOT FISH MADE OUT OF BALSA WOOD.

CONTROL

It is decided to use the Double crank mechanism for the propulsion of the robot, as this mechanism requires the servo motor and due to which there is no need of external gear box to increase the torque requirements as it can be required for the scotch yoke mechanism and the quick return mechanism.

Handy board is used to control the servomotor which controls the propulsion; C code is loaded in the microcontroller to run the propulsor with desired kinematics.

The Handy board is hand-held, battery-powered micro controller board ideal for robotics projects. The handy board runs Interactive C code.

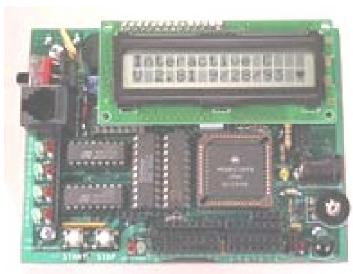


FIGURE. 15
HANDYBOARD FOR THE SERVO MOTOR CONTROL.

SWIMMING PERFORMANCE

The test for the swimming performance of this compact robot is carried out in the small indoor swimming pool placed in the robotics lab at WSU.

The area of interest is to find out the effect of frequency of the propulsor oscillation on the swimming speed of the fish, the frequency of the propulsor can be changed by the handy board. The mechanism used is double crank as stated earlier due to its compactness and light weight servomotor shaft acts as a crank connected to the rocker of the propulsor through connecting rod.

The experimental setup consist of round water tank with white base marked with dark black grid, this grid help to observe the position of the fish with change in time, fish is made to swim with different tail beat frequency and with different fin material (material A, materialB, materialC in order of decreasing flexibility) to gather data for the effect of frequency and material flexibility. (Refer Figure17).

The tail is visible in Figure16 which is made up of flexible plastic material fixed with the rigid wooden part which swivels about the pivot provided in the body.

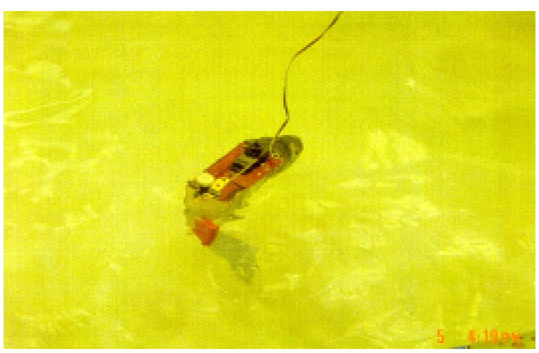


FIGURE. 16
SWIMMING PERFORMANCE TEST VEIW.

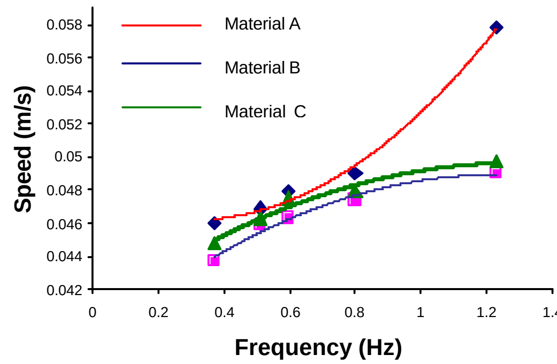


FIGURE.17
FREQUENCY -SPEED RELEATION OF THE FISH.

The above graph projects the effect of tail beat frequency on the speed of the fish robot for 11cm amplitude sweep of the tail, It can observed that the speed increase with increase in tail beat frequency, and it is more for higher flexible material.

CONCLUSION

The forward swimming of the robot is found satisfactory with the double crank mechanism, and as observed from the figure 9 the scotch yoke mechanism is good for the maneuverability.

The forward swimming speed increase with increase in the frequency of oscillation and the speed is highest for the propulsor with flexible material of .058m/s.

As a result of this mechatronics course project, basic characteristic of the swimming rigid body with oscillating foil are understood.

Biopropulsion is the substitute for the conventional propulsion system for the aquatic vehicles. For the next subject, we would like to improve the shape of the robot body and the maneuverability of the robot by improving the propulsing mechanism.

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