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Design and Bionic Analysis of the Driving Mechanism for the Tail of a Bionic Fish Robot

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Abstract. All along, human exploration of the ocean has never stopped, and bionic fish robots have been produced. Currently, bionic fish have been used in a range of fields, including underwater archaeology, water quality monitoring, and other fields, because of their camouflage and flexibility. The bionic fish also can perform observation, reconnaissance, and other jobs, reduce battle risks, and play a crucial role in contemporary military tasks. It is increasingly being implemented in the military sphere. The efficacy of the bionic fish's tail mechanism in terms of swimming and reconnaissance is crucial to the design of the fish. However, multiple servo joints are frequently used in the current bionic fishtail system, which increases the likelihood of failure. This research suggests a fishtail design strategy based on the transmission mechanism to operate more steadily. After analyzing the existing bionic fish mechanical structures, research proposes the schemes of living in three mechanical structures. By combining the actual fish body size, the comprehensive modeling design was carried out using Solid Work software, and the motion performance analysis of the mechanism was analyzed by Adams software. The experimental results provide a theoretical and reference for the actual design of bionic robotic fish.

Keywords. Bionic fish; Drive mechanism Bionic; Cam mechanism; Motion simulation

1. Introduction

Bionic fish have been applied in various fields and play an important role. On the one hand, it can complete daily tasks such as cruising and obstacle avoidance, water quality detection, foreign object detection on the water surface, remote control of water sample collection, and material placement. In military terms, due to its flexibility and concealment, bionic fish can also complete tasks such as detection and surveillance.

Scientists have numerous insights and experiments on the design of bionic fish in existing research. Wang et al. introduced and analyzed the current status of scientific research from three aspects and summarized development trend and application prospect of BCF bionic fish [1]. Van et al. introduced OpenFish, a soft robotic fish that

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scientists have optimized for speed and efficiency. But its development progress is slow [2]. Zhang et al. proposed a new mechanical structure for robotic fish at the component level by analyzing the movement of fish and the effects of various parts. They explained the reasons why these mechanical structures are more optimized and their operating modes [3]. Wang has designed a new type of twin fish tail bionic robotic fish. The influence of tail fin shape and wake structure on the propulsion efficiency of bionic fish was analyzed. And by analyzing the swimming posture of the bionic fish, a control strategy was set for it, and underwater prototype experiments were conducted on the bionic fish [4]. Xia et al. applied highly flexible origami technology to fish tails, significantly improving energy efficiency. The experimental results show that the robotic fishing gear has good straight swimming direction and turning ability [5]. Zhu et al. designed an underwater robot that mimics the swimming of a turtle and analyzed the force acting on the robot during operation in water. The bionic robot is responsive and stable in operation [6]. Ankur et al. proposed an electro-echanical dynamic modeling of a bionic thruster based on undulating ribbon fins. The proposed model has been used to evaluate the speed and thrust of bionic systems [7]. Xia et al. used SMA wire to create a bidirectional flexible actuator, and used this flexible actuator as a fish tail to design a robotic fish that mimics the catfish family [8]. He et al. developed micro bionic fish, which has advantages such as perception, positioning, communication, and less maintenance. But the internal environment of the transformer miniature bionic fish is relatively complex [9]. Chen et al. design a multi-link fishbone structure based on bonito, realizing body/tail fin propulsion. Afterwards, Adams is used for motion simulation, and prototype experiment is also carried out [10]. Li uses the carp of the family Curioaceae as the bionic object to improve the propulsion efficiency of the robot fish, and models a bionic robot fish with a flexible body tail fin structure by using Solid Works [11]. Gao develops an SMA-driven bionic tail that can achieve substantial swing, also CFD simulation and calculation are performed [12].

However, in existing research, the tail mechanism design often uses multiple servo joints, which are prone to malfunctions. Therefore, this paper discusses and studies the tail mechanism of the joint, for example, using modeling software for mechanism design, and using motion simulation software for simulation and comparison of results.

2. Methodology

2.1 Introduction of Three Mechanical Mechanisms

Mostly, the movement of fish depends on the swing of the tail. Therefore, we present three fishtail mechanical structures, including a cam mechanism, pinion and rack mechanism, and crank shaper mechanism.

Figure 1 shows a mechanism. In terms of cam, it is a component with a curved profile, which is an active component and undergoes constant rotational motion. Its dimensions are shown in Table 1, with a maximum radius of 150mm and a minimum radius of 20mm. The rocker, as a follower, contacts the contour of the cam and transmits power for reciprocating oscillation, with a length of 250mm.

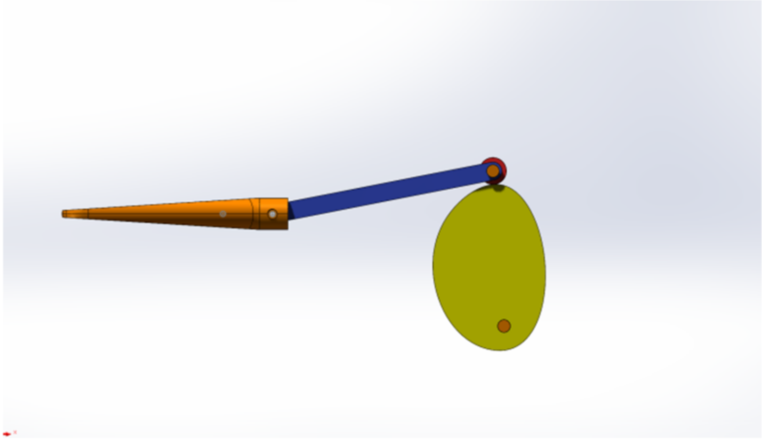


Figure 1. Cam mechanism

Table 1. Dimensions of each component of the cam mechanism.

Cam Mechanism		
Cam	Minimum Radius	20mm
	Maximum Radius	150mm
	Thickness	5mm
Rod	Length	250mm
	Radius	10mm
	Thickness	5mm
Tail	Length	210mm

Figure 2 and table 2 are pinion and rack mechanism, the reciprocating motion of the rack drives the gear and rod to swing, causing the fish tail to swing.

The rack does reciprocating motion, driving the gear and rocker to swing, thereby achieving mechanical fish tail swing. The size of the fixing bracket is 500mm×500mm, and the length of tail of robotic fish is 400mm.

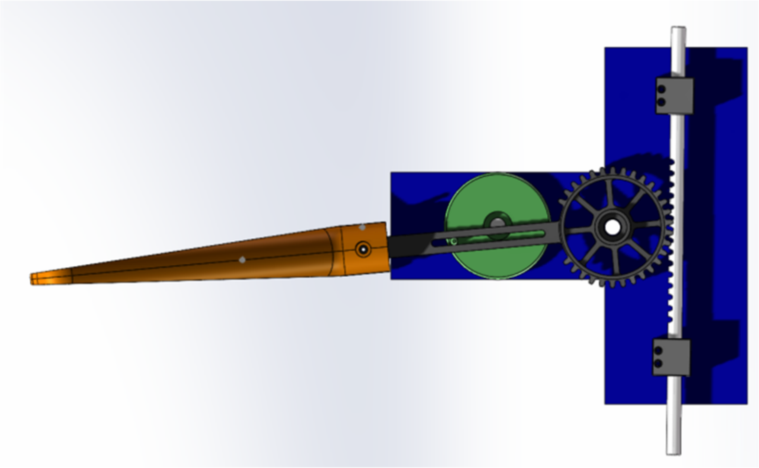


Figure 2. Pinion and Rack Mechanism

Table 2. Dimensions of each component of the Pinion and Rack Mechanism.

Pinion and Rack Mechanism		
Fixing Frame	Length	500mm
	Width	500mm
	Thickness	20mm
Rack	Diameter	20mm
Gear	Diameter	136mm
	Rod Length	280mm
	Thickness	10mm
Fixed Block	Length	50mm
	Width	52mm
	Thickness	40mm
Tail	Length	400mm

In Figure 3, the red rod rotates while the blue rod is driven to swing, causing the fish tail to swing. The orange rod is a fixed rod. The orange pole corresponds to rod A, while the red fish and blue rods correspond to rods B and C respectively, with dimensions corresponding to Table 3. This article will select this mechanical mechanism for analysis.

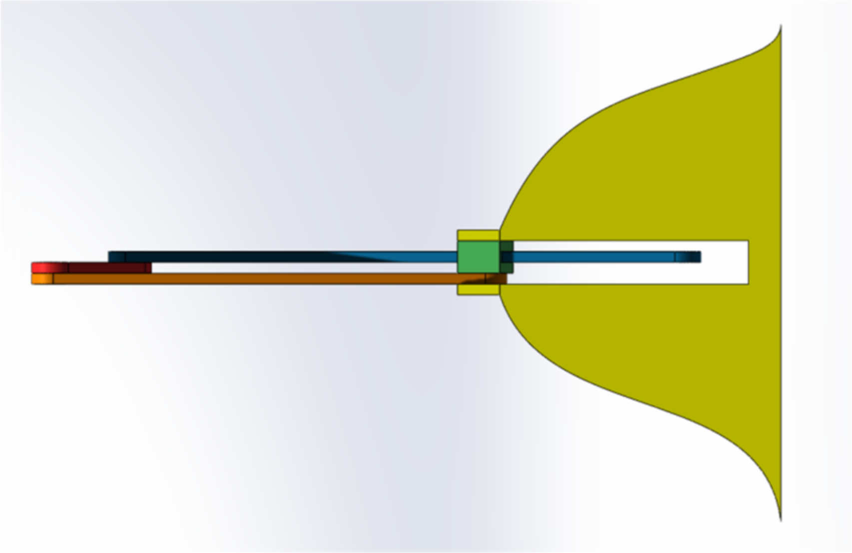


Figure 3. Crank shaper mechanism

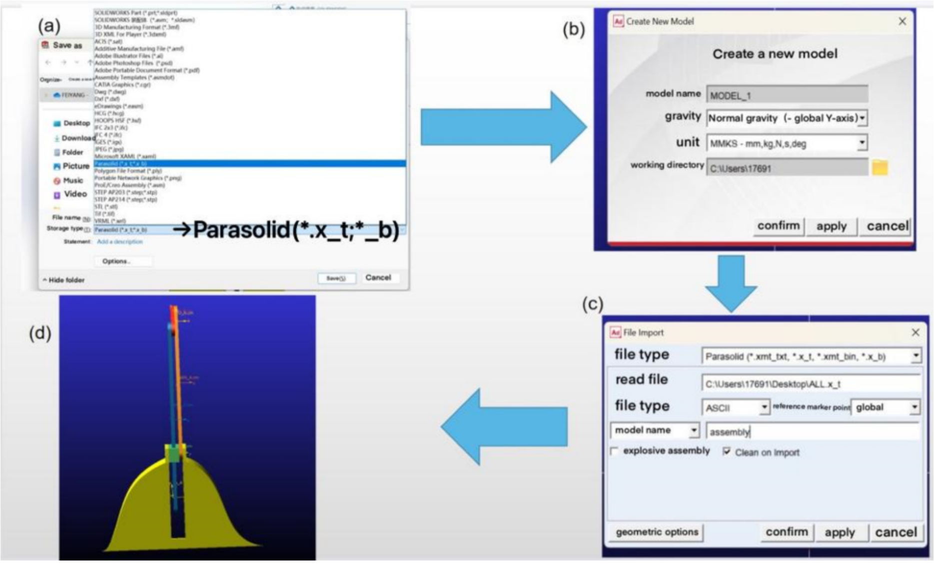
Table 3. Dimensions of each component of the Crank shaper mechanism.

crank shaper mechanism		
Rod A	Length	200mm
	Radius	10mm
	Thickness	5mm

Rod B	Length	50mm
	Radius	10mm
	Thickness	5mm
Rod C	Length	260mm
	Radius	10mm
	Thickness	5mm
Chute	Length	30mm
	Radius	20mm
	Thickness	15mm
Tail	Length	120mm

2.2 Simulation Methods

Adams is a software that can achieve motion simulation and process data of simulation, such as displaying data diagrams. Hence, we use Adams for motion simulation. Motion simulation is a significant part of the research, which will enable the mechanical mechanisms to move and produce data during its movement. Therefore, the process of conducting motion simulation on one of the mechanical mechanisms will be introduced. Figure 4 is the process of motion simulation.



Create a new model
model name MODEL_1
gravity Normal gravity (- global Y-axis)
unit MMKS - mm,kg,N,s,deg
working directory C:\Users\17691

file type Parasolid (*.xmt_txt, *.x_t, *.xmt_bin, *.x_b)
read file C:\Users\17691\Desktop\ALL.x_t
file type ASCII reference marker point global
model name assembly
☐ explosive assembly ☑ Clean on Import

Figure 4. Flow chart for motion simulation

After completing the mechanism modeling in solid work, in order to import the modeling into Adams, the file needs to be saved in Parasolid (*.x_t) format. Open the Adams software, we need to choose a new model, and Import in the file is selected after the window pops up. Ensure that gravity is theoretical gravity. Then we are supposed to select the file type as Parasolid (*.x_t) format, select and name the saved mechanism model after we double-click to read the file. If the modeling does not appear after clicking confirm, clicking refresh in the view may work. Figure 5 demonstrates the addition of kinematic pair.

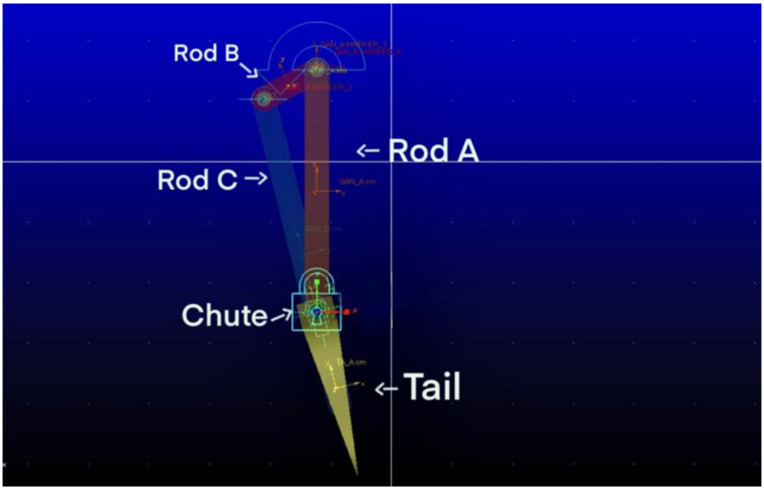


Figure 5. Addition of kinematic pair

The most important step of dynamic simulation is to add a kinematic pair. Firstly, the orange pole needs to be fixed to the ground. Next, we should add a revolute joint between different rods. A position is selected at the center of the intersection of rod A and rod B. The operation of rods B and C is the same as the previous step. In addition, another rotating pair should be added to the center of the chute. Afterward, a translation pair need to be added between rod C and chute, and the position of it is chosen at the center of the chute.

3. Experiments and Results

After the data is generated, the acceleration and velocity of the fish tail in three directions will be analyzed. This article uses three driving speeds of 5 r/min, 10 r/min, and 15 r/min for research and comparison, and analyzes the optimal speed. Figures 6 and 7 represent the acceleration and velocity, when the rotational speed is 5 r/min respectively.

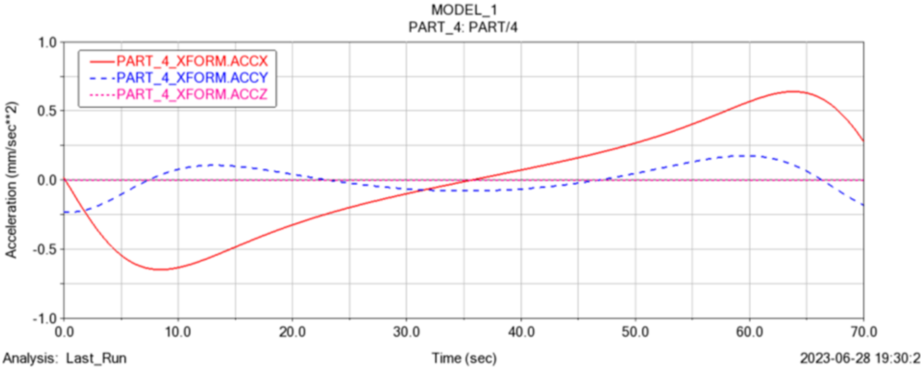


Figure 6. The acceleration of the tail (rotational speed is 5r/min)

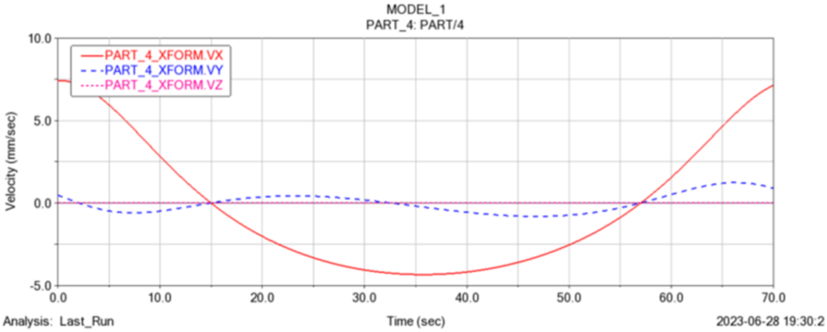


Figure 7. The velocity of the tail (rotational speed is 5r/min)

According to the Figures 6 and 7 the maximum acceleration and velocity in x-direction, also known as horizontal direction, is 0.7mm/sec**2 and 7.5mm/sec respectively. In the y direction, the maximum acceleration and velocity of tail is 2.5mm/sec**2 and 1.2mm/sec. The minimum speed and acceleration in all directions are 0. In addition, The period of curve of acceleration is 75s, and of velocity is 70s. The acceleration and velocity at the rotational speed is 10r/min are shown in the Figure 8 and 9.

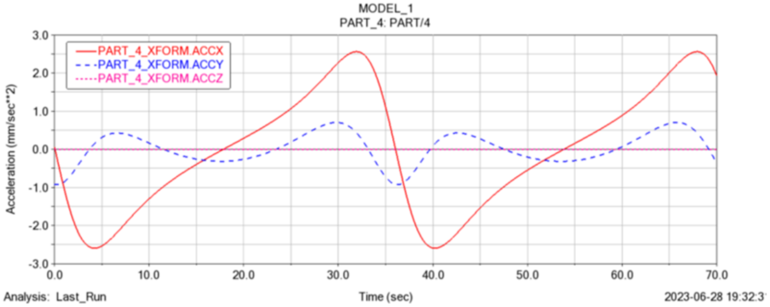


Figure 8. The acceleration of the tail (rotational speed is 10r/min)

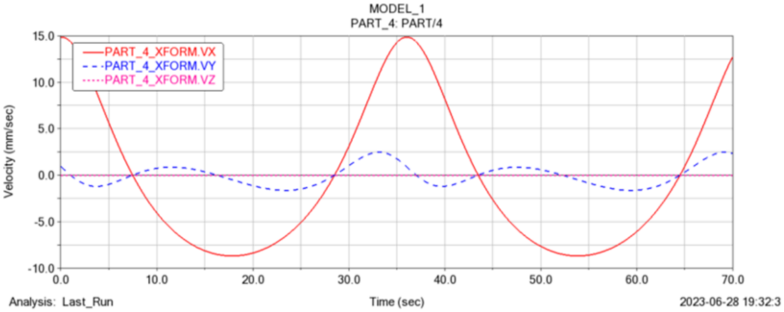


Figure 9. The velocity of the tail (rotational speed is 10r/min)

According to the Figures 8 and 9, the maximum acceleration of fish tail is 2.5mm/sec**2 in horizontal direction and 1mm/sec**2 in vertical direction. The period of the curve of acceleration is 36s. In terms of velocity, the maximum velocity of tail is 15mm/sec and 2.5mm/sec in each direction, and the period of it is 44s. The acceleration and velocity of tail are displayed in the Figures 10 and 11 table 4 when the rotational speed is 15r/min.

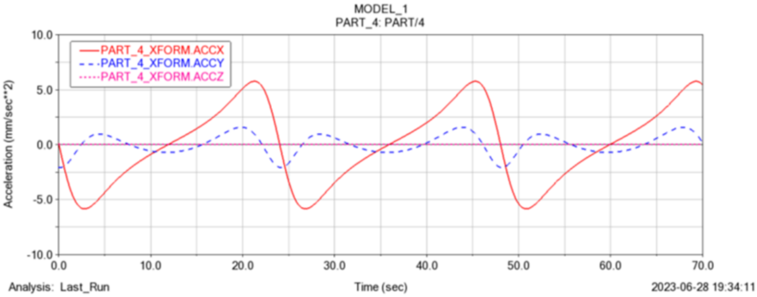


Figure 10. The acceleration of the tail (rotational speed is 15r/min)

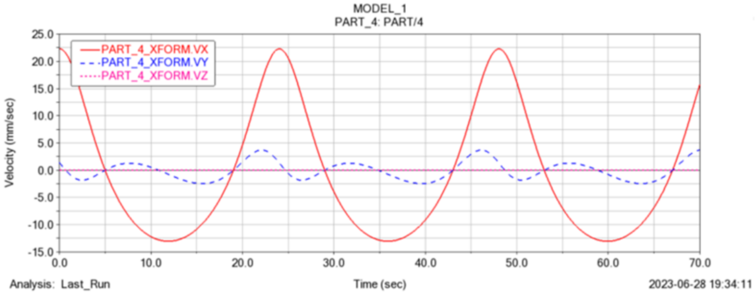


Figure 11. The velocity of the tail (rotational speed is 15r/min)

The fish tail's maximum acceleration in the x-direction is 6mm/sec**2 , and its maximum velocity is 22.5 mm/sec, as shown in Figures 10 and 11. The highest velocity is 2.7 mm/sec**2 and the maximum acceleration is 2.4 mm/sec in the y-direction. In addition, the acceleration and velocity curve has a period 24s.

Overall, all curves related to the y direction do not have a specific period, and there is no velocity or acceleration in the z-direction.

Table 4. The maximum and minimum values of acceleration and velocity at the fish tail at different rotational speed.

Rotational Speed:5r/min	Acceleration (mm/sec**2)	X Maximum	0.7
		X Minimum	0
		Y Maximum	2.5
		Y Minimum	0
		Z Maximum	0
		Z Minimum	0
	Velocity(mm/sec)	X Maximum	7.5
		X Minimum	0
		Y Maximum	1.2
		Y Minimum	0
		Z Maximum	0
		Z Minimum	0
Rotational Speed:10r/min	Acceleration (mm/sec**2)	X Maximum	2.5
		X Minimum	0
		Y Maximum	1
		Y Minimum	0
		Z Maximum	0
		Z Minimum	0
	Velocity(mm/sec)	X Maximum	15

		X Minimum	0
		Y Maximum	2.5
		Y Minimum	0
		Z Maximum	0
		Z Minimum	0
Rotational Speed:15r/min	Acceleration (mm/sec**2)	X Maximum	6
		X Minimum	0
		Y Maximum	2.4
		Y Minimum	0
		Z Maximum	0
		Z Minimum	0
	Velocity(mm/sec)	X Maximum	22.5
		X Minimum	0
		Y Maximum	2.7
		Y Minimum	0
		Z Maximum	0
		Z Minimum	0

4. Conclusion

The swing of tail is a key factor of movement of fish, so three type of mechanical structure of fish tail are introduced, including cam mechanism, pinion and rack Mechanism and crank shaper mechanism. After the modeling of these structures, Adams is used to process simulation of motion and generate graphs of data after analysis.

It is found that the tail only swings in one direction, because it has no velocity in the z-direction. And when the driving speed increases from 5r/min to 10r/min, the maximum velocity of the fish tail also doubles. Conversely, the period of curve reduces by half. Therefore, it can be inferred that the velocity is directly proportional to the rotational speed which means the higher driving speed, the faster speed of swing of tail. When driving speed is 15r/min, no matter if it is in the x or y direction, the velocity of tail is the fastest among the three driving speeds. As a result, 15r/min is the most efficient speed among the three different rotational speeds.

In the further research, the general prototype will then be developed, and underwater testing will start. Regarding the experiment's findings, consider the overall driving effectiveness. To effectively design and develop the bionic fish, the mechanical mechanism is repeatedly altered based on the results of the analytical process.

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