Bionic design and experiment of multidimensional propulsion device on water

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Abstract. In view of the present situation that the output thrust of traditional surface platform propulsion device is unidimensional and its amphibious capability is limited, based on the high-speed movement principle of basilisk treading water, this paper designs a multidimensional surface propulsion device to realize the multidimensional output of torque, lifting force and propulsion force. Combined with the square platform, the controllable parameters of the multidimensional surface propulsion device are analyzed from the perspective of navigation dynamics. Finally, the prototype test, the water cube propulsion drive car body realizes high speed sailing boat type water skiing, with an average elevation of 10.6°.

1. Introduction
Amphibious platform can improve the efficiency of water and land transportation mode conversion and reduce the travel time cost. The propulsion device is the core part of the amphibious platform, but the propeller and the water jet propulsion device of the traditional surface platform, which output one-dimensional thrust, cannot be applied to the land driving. The onshore platform is dominated by wheeled vehicles, and the rotary propulsion of wheels in water cannot meet the efficiency requirements[1]. Therefore, the research of amphibious platform needs to innovate the propulsion device and improve its driving performance.

In recent years, the research on animal motion behavior has been advanced continuously, among which the general propulsion movement on land and water adapts to the environment through natural evolution, providing inspiration for the research on multi-dimensional propulsion device on water.

Podicipedipeds and North American podicipedipeds can get the supporting force, propulsive force and balancing torque by stepping into water. The driving force has more output dimensions, and in animals of the same quality level, the surface movement speed is faster[2-4]. Therefore, based on the high-speed movement behaviour of basilisk lizards, this paper designed a multi-dimensional surface bionic propulsion device to provide three-dimensional driving force and improve the movement speed of the surface device.

2. Structural design
The basilisk lizard, which lives in the jungles of South America, turns its femur thigh around its pelvis and then moves its hind legs alternately to trample on the water. Basilisk lizards can be divided into three stages when trampling on water: slap, stroke and recovery. A trample cycle of an 87.7g basilisk...
lizard is shown in Fig.1, Fig.1 (a) is the slap stage, the sole of the foot is parallel to the water surface, and then it quickly steps down to the water. Fig.1 (b) shows that after the foot hits the water surface downward, the sole of the foot rotates and paddles backward; Fig.1 (c) shows the leg recovery stage, moving quickly up out of the water for the next step. Fig.2 shows the trajectory of the basilisk’s knees, ankles, and feet during movement.

![Figure 1. Kinematic phases of a stride](image)

You can see from Fig.1 (a), the soles of your feet underwater turn around the ankle, foot plane relative to the horizontal plane rotation Angle of 180°.

![Figure 2. View of limb points relative to the hop](image)

Meanwhile, the motion trajectory of the ankle relative to the hip is oval, as shown by the red solid line with a circle in Fig.2. If the ankle in the recovery stage indicated by the solid red line is retracted forward, it will be retracted backward, and the underwater motion trajectory is approximately semi-circular, as shown by the dotted red line in Fig. 2. The feet underwater 180° Angle of rotation and semi-circular trajectory can be implemented by rotating at the same time.

![Figure 3. Schematic diagram of structure and movement principle of water-surface vector propeller](image)

Therefore, the rotary water striking mode is used to replace the reciprocating water treading. Based on the flat plate simulation of the sole of the foot, a multidimensional surface propulsion device is
designed, as shown in Fig.3 (a), which is composed of hub, spokes, expansion links and blade. Sports: by blade Angle 60°with spokes benchmark set, matching in Fig.1 foot stepped into three phases of water, leaf next step, after stroke and recovery phase, respectively, as shown in Fig.1 (a) and Fig.1 (b) and Fig.1 (c), and the telescopic rod adjustment blades and spokes Angle theta. In terms of driving output, it imitates basilisk lizard to step on water to support weight, push forward and maintain balance. The propulsion device outputs lifting force, thrust and torque by rotating the plate around the flow. Structural parameters: blade size 0.06m 0.005m 0.05m, spoke length 0.03m, hub diameter 0.04m, as shown in Fig.3 (b).

3. Platform navigation dynamic

The multi-dimensional propulsion device is applied to a square platform, and its side view is simplified as a flat plate\cite{5}, ignoring the aerodynamic force of the platform, the platform was subjected to the dynamic lift force $F$ in the course of water skiing $D$, static pressure $S$, gravity $G$, friction resistance $F$, and lifting force $F$ output from the propulsion device $L$, thrust $T$ and the torque $M$ is shown in figure 4. Based on ЦАГИ method, the force and lever expressed as follows\cite{5}.

![Figure 4. Mechanical analysis of amphibious vehicle in the hydroplaning state](image)

Lift force $F$ affected by the platform $D$, and static pressure $S$:

$$F_D = \frac{0.7\pi\lambda\alpha}{1+1.4\lambda} \frac{1}{2} \rho\nu^2 B_u^2$$

$$F_S = \frac{\lambda - 0.4}{\lambda + 0.4} \frac{\lambda^2 \alpha}{F_B^2} \frac{1}{2} \rho\nu^2 B_u^2$$

In above,

$\lambda = \frac{l}{B_u}$, $l$ is the wet length and $B_u$ is the effective wet width, $F_B$ is the froude number, $\alpha$ for the Angle of attack, $\rho$ is water density, $\nu$ for the platform speed.

The distance $l_D$ from the action position of dynamic lift to the axle. And the distance $l_S$ from the static pressure acting position to the axle:

$$l_D = l - \left(0.75 + 0.08 \frac{\lambda^{0.865}}{\sqrt{F_B}}\right)l$$

$$l_S = l - \frac{\lambda - 0.8}{3\lambda - 1.2} l$$

$l_D$ is the distance from the wheel axle to the end of the platform.

Friction resistance $F$ mainly acts on the bottom of the platform \cite{6}

$$F = fA\nu^{1.8}$$

$A$ is the wet area and $f$ is the friction coefficient.

The horizontal and vertical decomposition of the forces on the amphibious platform can obtain:

$$F_x = F_L - (F_D + F_S) \sin \alpha - F \cos \alpha$$

$$F_y = F_L + (F_D + F_S) \cos \alpha - G - F \sin \alpha$$

Further, the torque relative to the axle is obtained
\[ M_i = M_o + F_l + F_D l_D - F_S l_S - G l_o \cos \alpha \]  

(8)

In which, \( l_F \) is the torque of \( F \) relative to the axle.

Horizontal component \( F_x \) is the direct power of platform propulsion; Vertical component \( F_y \) can reduce the draft depth and reduce the forward resistance; The torque \( M_i \), the displacement to water skiing can be realized by keeping the platform tilting forward. During the voyage, on the platform \( F_x \), \( F_y \) and \( M_i \) in the output, the propulsion device drive is the only active regulating factor; The shaft height and speed are controllable parameters of the propeller.

4. Experiment

Combined with the 3d driving force output characteristics of the multidimensional surface propulsion device, it is applied to the surface platform with large square coefficient. The new type of surface platform is composed of a rectangular body and a pair of multi-dimensional propulsion devices. The propeller wheel shaft is located at the middle and rear. The experimental prototype is shown in Fig 5.

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![Figure 5. Test prototype](image)

On the basis of the traditional one-dimensional propulsion output, the multidimensional surface propulsion device increases the lifting force and torque output, and realizes the water-skiing navigation of high-speed boat type on the surface platform, as shown in Fig. 6 (a). Using gyroscope and accelerometer for the platform elevation change curve as shown in Fig.6 (b), an average elevation of 10.6° in the process of water skiing.

![Figure 6. Navigation experiment of water surface device](image)

5. Conclusion

In this paper, the water treading mechanism of basilisk lizards was studied, and the multi-dimensional surface bionic propulsion device was designed. Combined with the surface platform, some controllable parameters of the output were obtained based on the platform navigation dynamics analysis, and the influence of controllable parameters on the driving performance was studied. Finally, experimental verification is carried out.

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