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Design of a New Type of Tri-habitat Robot

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***Abstract* - With the exploration of various fields by human beings, more multi-functional and intelligent robots are playing an increasingly important role in the process of exploration and research. Therefore, it is of great significance for the research of water, land and air tri-habitat robots across different media. In order to adapt to the complex environment in the process of exploration, this paper proposed a new type of water, land and air tri-habitat robot to realize the functions of air flight, land travel and underwater operation. By analyzing the dynamics of the amphibian robot, the motion mode and mechanism in different environments were studied and designed. The description of the tri-habitat robot includes the mechanical design part, the establishment of the mathematical model and the dynamics modeling. The motion simulation of the established model was carried out to verify its feasibility.**

Index Terms - Tri-habitat robot. structure design. dynamic analysis. modeling and simulation.

I. Introduction

In recent years, robots are more and more widely used in our scientific exploration.Even in areas such as military reconnaissance, aquaculture and mapping, as well as in high-temperature,high-radiation environments, robots play an irreplaceable role.South Korea's defense ministry joint nanbert zhong university study of diving beetle, and on this basis, developed a new type of amphibious six-legged robot, Japan sichuan university for amphibious spherical robot has a more in-depth study, but due to our involvement in the situation of more and more complex, a single robot performance function has far can't meet our demand for scientific exploration.Facing the complex environment, we urgently need a multi-functional robot that can move across the medium.At present, there are relatively few researches on the design of the tri-habitat robots, which are mainly divided into two types: fixed-wing UAV and rotorwing UAV.

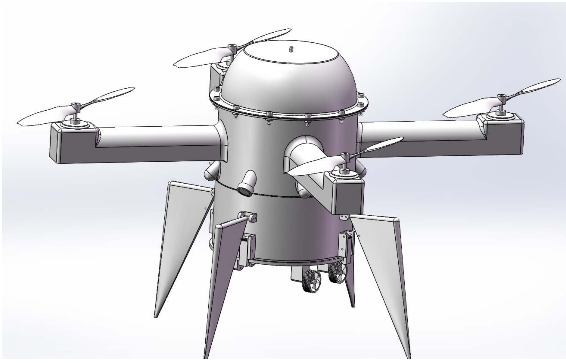
In 2016, Harbin haiying robot manufacturing co.LTD developed a water, land and air tri-habitat robot based on the shape of fixed wing. (a) in figure 1 is equipped with air cushion and engine at the bottom and tail, which is powered by fuel oil.On land, the robot has four wheels at the bottom to turn it into a car.When the robot comes to the surface, swamps and other terrain, the air cushion instead of the contraction of the wheel bulge, turning it into a hovercraft, so that the robot suspended on the ground or water about 100 mm.If the robot needs to fly at high altitude, whether on land or water, it can

(a) Fixed wing tripod robot (b) Rotary-wing three-legged robot
Fig. 1 Two kinds of three-legged robots.

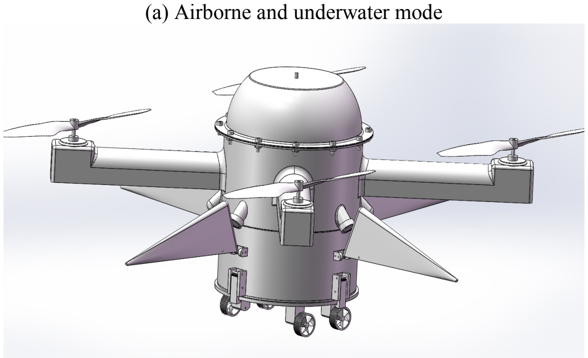
rely on the engine in the tail to generate power, and glide for a distance of about 30 meters before taking off.The robot can fly at a speed of 100 kilometers per hour and at an altitude of about 400 meters. It can reach a speed of 80 kilometers per hour on land and water. The robot itself weighs 54 kilograms and can carry a weight of 40 kilograms [1].

Parrot company released a three-perch UAV on land, sea and air in 2015, as shown in (b) in Fig. 1. Based on the appearance of four-rotor UAV, the three-perch function can be realized by means of splicing.It can be fitted with a pair of big wheels and turned into a drone-powered car, which can reach speeds of up to 13km/h and jump up to 75cm.Fitted with a plastic hull and two auxiliary balance pods below, the drone is transformed into four propellers that rotate 90 degrees perpendicular to the surface of the water.Because water is more resistant than air, the drone can travel at up to 9.5 kilometers per hour over water.If the drone were to fall parallel to the water while flying, its lift would lift the entire hull out of the water [2].

Fixed-wing unmanned aerial vehicle (UAV) as the appearance of all-terrain robot, have strong loading capacity, long life, the advantages of the fast speed, usually powered by fuel, generally used in electric power inspection, military reconnaissance, etc need to be flexible deployment, remote real-time monitoring and low labor costs, long range of activities, and on the basis of the UAV rotorcraft tree-dwelling robot with flexible and controllable, flexible handle, can hover and low speed flight, can finish from close range, low speed movement or long time keep the same Angle observation tasks, not easy to be found .etc [3]. Advantage, often used in military, surveying and mapping, aerial, agriculture and other areas.Because the tree-dwelling robot has very strong environment adaptiveness, operating range, easy to wash and recycle, can serve as reconnaissance, rescue operation system, communication system of the carrier, perform the human cannot complete land, lakes, rivers and oceans, a variety of



(a) Airborne and underwater mode



(b) Land mode

Fig. 2 Overall model diagram of the three-legged robot.

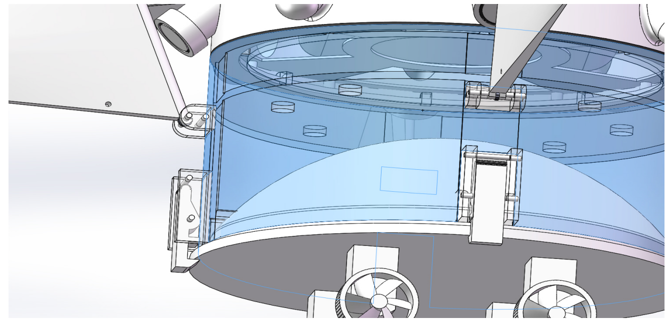


Fig. 3 Sub-engine room and locking part.

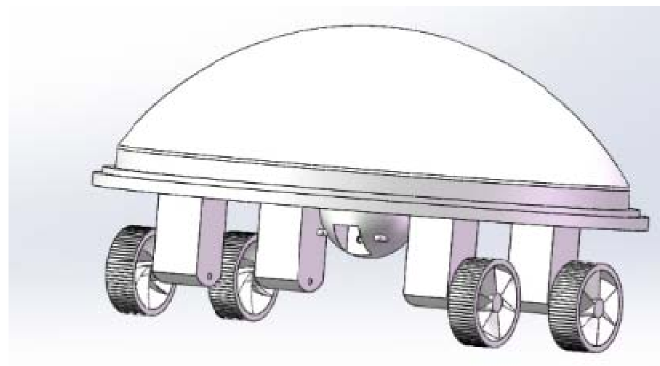


Fig. 4 Sub-machine model diagram

operations, rescue and task, therefore, design research new air tree-dwelling robot, has extremely important significance [4].

The design of the new structure of the three-legged robot in this paper will not only have important academic significance for the research on the mechanism design, kinematics, dynamics and control of the three-legged robot, but also have profound guiding significance for the practical application of the three-legged robot in the future.

The rest of this article is structured as follows.The second part mainly introduces the structure design of the robot.The third part introduces the dynamic analysis and modeling of the new three-legged robot.In the fourth part, MATLAB simulation of the three-legged robot is given to verify the feasibility of the preliminary function realization of the three-legged robot.In the fifth part, the relevant summary and the follow-up in-depth research work on the aquatic, land and air robots are made.

II. Mechanical Design

The design of mechanical structure is mainly concerned with the realization of three functions.Taking the shape of a rotorcraft UAV, the new-type three-legged robot has built a set of structure that can realize air flight, land travel, underwater stealth and cooperative activities of sub-machine and mother machine to complete tasks.It is mainly divided into flying shape design, land wheel driving design, and underwater stealth sub machine design. The overall structure design is shown in Fig. 2.

When the three-legged robot is in flight mode, the four streamlined support legs are in the position shown in figure 2 (a). The whole machine and the cabin differ with rotor 90°, so as to realize balanced distribution, in order to reduce the influence of stability of flight.When the three-legged robot is in the land driving mode, the four supporting legs will be attracted by the electromagnet above, so that the wheels of the sub-machine at the bottom will land on the ground, and then the sub-machine will be controlled to move the three-legged robot to realize the land driving function of the three-legged robot.When the three-legged robot is in the diving mode, the realization of the underwater six degrees of freedom is completed by the four rotors and the rotor propeller of the sub-machine.

Specifically, during the execution of the task, the three-legged robot can also float on the water surface, release the sub-machine through the lock of the sub-machine cabin, and complete the task through the activity of the sub-machine. The lock is controlled by the electromagnet installed inside the cabin.The structure of sub-engine room and locking part is shown in Fig. 3.

The release device is composed of four locks, each lock is equipped with magnetic material inside, when the internal electromagnet is energized to generate magnetism, the upper part of the lock is attracted, thus moving at the same time, releasing the sub-machine.

Due to the need for underwater tasks, the sub-machine will be completely sealed to ensure the safety of internal electronic components.The inner part of the rotor wheel is propeller type, so that it can coordinate with the rotor for attitude adjustment and self-movement, supplemented by non-slip openings, so that it can better walk on land. A camera is installed at the bottom of the handset, and two illumination lamps are assisted twice in the camera to facilitate the sub-robot to travel underwater. At the same time, a hydraulic

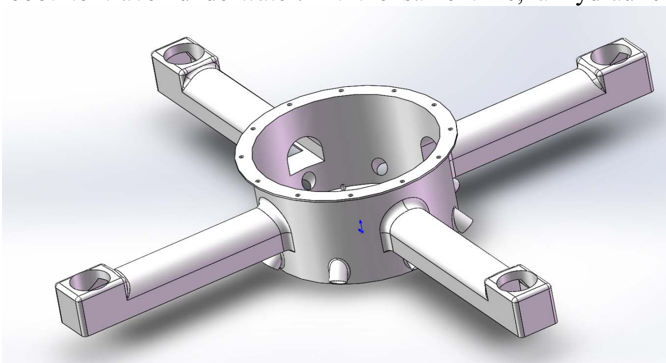
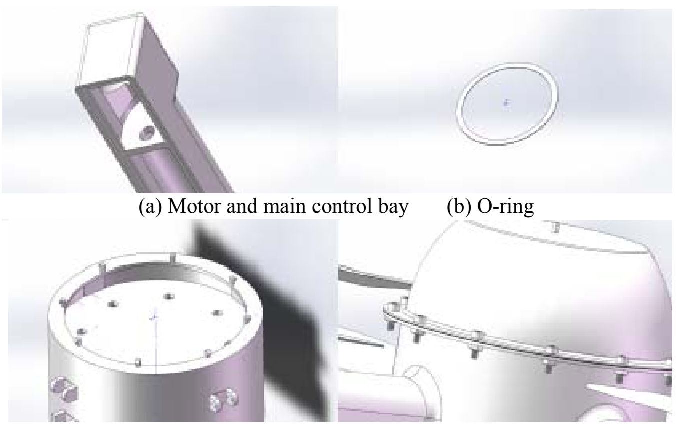


Fig. 5 Function extension interface



(a) Motor and main control bay (b) O-ring

(c) Cohesion tank (d) Sealing ring mounting section

Fig. 6 Sealing part

sensor is installed at the rear of the camera to measure the depth at which the handset is located.The sub-machine model is shown in Fig. 4.

In order to better adapt to the complex environment,tri-habitat has designed four functional expansion interfaces, as shown in Fig. 5. Each interface is located directly below the axis, facilitating the addition and installation of auxiliary functions in the later stage. At present, it is sealed by four sealing plugs.

As shown in Fig. 6, the sealing measures of each part are respectively. As it involves the movement of cross-media, in order to ensure the safety of internal electronic devices, the control board and some devices that cannot contact with water are placed in the main engine and sealed by sealing measures, so that they can be moved underwater for a long time.

III. Analysis Of Dynamic Mechanical

The flight of the tri-habitat robot designed in this paper adopts an x-shaped structure, and its stress is shown in Fig.7.The four endpoints in the figure respectively simulate the four rotors of the three-habitat robot, using 6050 type,M_1 and M_3 rotate clockwise,M_2 and M_4rotate counterclockwise.

When each rotor reaches the same speed, the mutual torque force generated by the rotation speed between the rotors can be offset [5].OXYZ is the inertial coordinate system, oxyz is the spatial coordinate system of the robot.Habitat hypothesis three robots in ideal circumstances, the air temperature of 15 C, the temperature of 20 C.Set the speed of

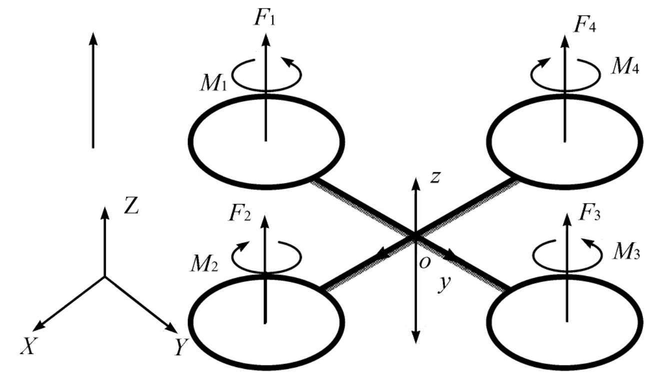


Fig. 7 Force diagram of the three-legged robot

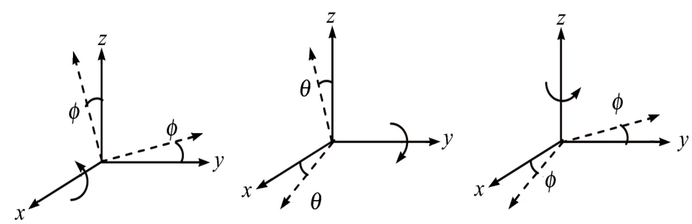


Fig. 8 Definition of attitude angle

the tri-habitat robot in the air is v_a , and the speed in the water is v_w .Then there is

$$R_e = \frac{\rho_a \bar{c} \Omega_a R}{\mu_a} = \frac{\rho_w \bar{c} \Omega_w R}{\mu_w} \tag{1}$$

Where R_e is the Reynolds coefficient, ρ is the fluid density, μ is the dynamic viscosity coefficient, $\bar{c}$ is the average chord length of the propeller, Ω is the propeller speed, and R is the propeller radius [6].From equation(1), the following relationship can be derived

$$\Omega_a = 14.5 \Omega_W \tag{2}$$

When the robot moves in the speed relationship of equation (2), the dynamic characteristics in the air and in the water are the same [7]. According to this mechanical property, the mathematical model of the underwater and aerial dynamics of the tri-habitat robot can be analyzed.Because the tri-habitat robot has the same six degrees of freedom in two different media: vertical, front and rear, left and right, tumbling, yaw, pitch. As an underactuated system, three attitude angles are now specified as shown in Fig.8.

Rolling angle ϕ : the angle between the body x axis and the coordinate z axis of the body, and the angle between the body coordinate axis and the ground coordinate Z axis;

Pitch angle θ : the angle between the body and the coordinate y axis of the body, and the angle between the

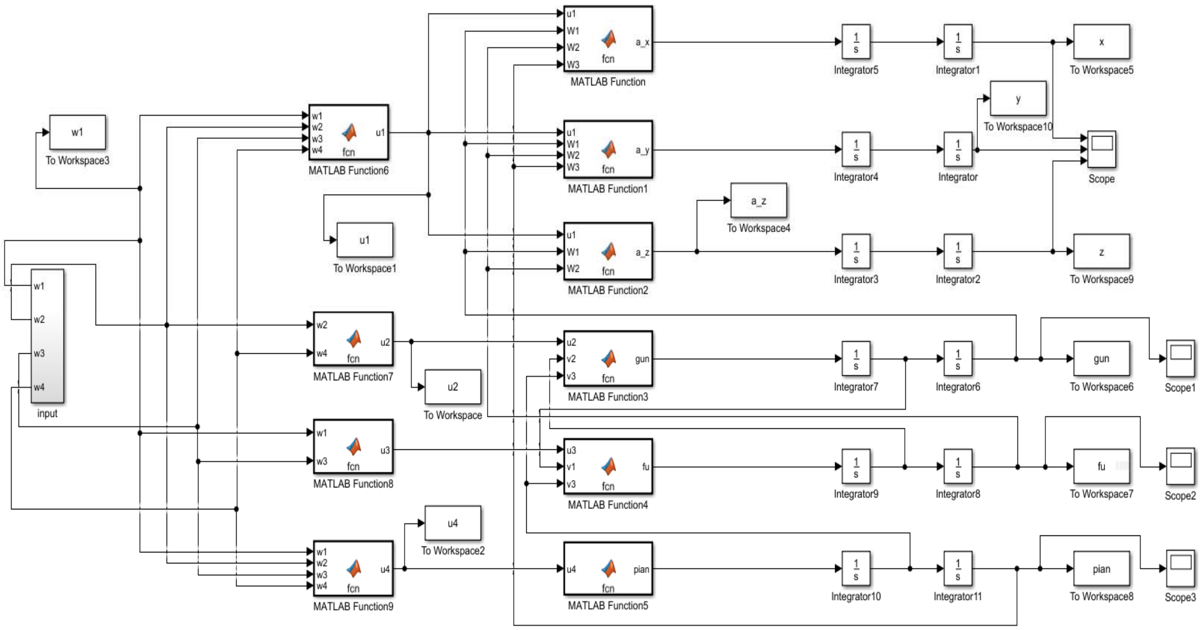


Fig. 9 Simulink simulation model.

coordinate x axis of the body and the X coordinate of the ground coordinate;

Yaw angle φ :the angle between the body and the coordinate z axis of the body, and the angle between the coordinate y axis of the body and the Y coordinate of the ground coordinate [8];The force analysis of the tri-habitat robot is carried out in the ground inertial coordinate system, and the resultant force can be expressed as:

$$\sum F^E = \begin{bmatrix} \sum_{i=1}^{4} T_i(\cos\phi\sin\theta\cos\varphi + \sin\phi\sin\varphi) \\ \sum_{i=1}^{4} T_i(\cos\phi\sin\theta\cos\varphi - \sin\phi\sin\varphi) \\ \sum_{i=1}^{4} T_i\cos\theta\cos\varphi - mg \end{bmatrix} = m\begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (3)$$

T is the lift of the propeller, mg is the gravity of the tri-habitat robot, and $\sum F^E$ is the resultant force of the tri-habitat robot in the inertial coordinate system[9].J represents the overall moment of inertia matrix of the robot.Can be expressed as

$$J = \begin{bmatrix} J_{xx} & 0 & 0 \\ 0 & J_{yy} & 0 \\ 0 & 0 & J_{zz} \end{bmatrix} \quad (4)$$

At the same time, we assume that the gravitational acceleration g takes a fixed value, the center of gravity coincides with the origin o, and it is regarded as a rigid body with geometric symmetry and uniform mass distribution, regardless of the influence of the earth's rotation and revolution, regardless of the propeller's waving characteristics, neglecting the gyro effect The impact of tri-habitat robots [10].

A simplified mathematical model that gives the robot position and attitude angle representation as formula (5)

U1 is the vertical lifting control quantity, U2 is the rolling motion control quantity, U3 is the pitching motion control quantity, and U4 is the yaw motion control quantity [11].Among them, the value of moment of inertia can be measured from the three-dimensional model.

$$\begin{cases} \begin{cases} m\ddot{x} = U_1(\cos\phi\sin\theta\cos\varphi + \sin\phi\sin\varphi) \\ m\ddot{y} = U_1(\sin\phi\sin\theta\cos\varphi - \cos\phi\sin\varphi) \\ m\ddot{z} = U_1\cos\theta\cos\varphi - mg \end{cases} \\ \begin{cases} J_{xx}\ddot{\varphi} = (J_{yy} - J_{zz})\dot{\theta}\dot{\phi} + U_2 \\ J_{yy}\ddot{\theta} = (J_{zz} - J_{xx})\dot{\varphi}\dot{\phi} + U_3 \\ J_{zz}\ddot{\phi} = (J_{xx} - J_{yy})\dot{\varphi}\dot{\theta} + U_4 \end{cases} \end{cases} \quad (5)$$

IV. Simulated Analysis

Through the dynamics analysis in the third chapter, the corresponding mathematical model was established, and the three-legged robot model was simulated in Matlab/simulink to

TABLE I
PARAMETERS OF THE THREE AQUATIC, LAND AND AIR ROBOTS

para meter	Numerical value	unit	param eter	Numerical value	unit
m	0.45	Kg	J_{xx}	0.004	kg/m^2
l	0.25	m	J_{yy}	0.004	kg/m^2
K_t	3.1×10^{-7}	$N\cdot s^2$	J_{zz}	0.001	kg/m^2
K_d	1.12×10^{-7}	N/s^2	g	9.8	m/s^2

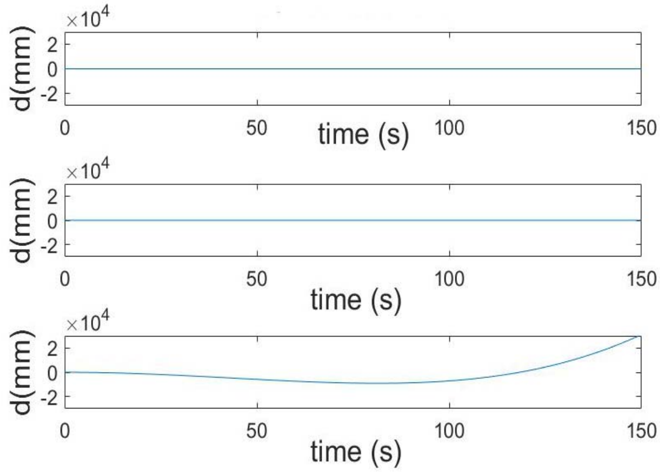


Fig. 10 Variation of displacement under vertical motion

verify the translational and angular motion states of the new three-legged robot.

The values of the parameters involved are shown in Table 1, where m is the mass of the tri-habitat robot model, l is the length of the tri-habitat robot connecting rod, K_t is the coefficient of relationship between lift and speed, and K_d is the drag coefficient of air, the moment of inertia for the tri-habitat robot in three corresponding directions is J_{xx}, J_{yy}, J_{zz}. g is the acceleration of gravity [12].

In Matlab/simulink, the model built is shown in Figure 9. Among them, four propeller angular velocities are used as input values, three coordinate displacements and three yaw angles are output [13,14]. During the simulation, the displacement and deflection angle changes are obtained by changing the values of the four propeller angular velocities.

When $\omega 1 = \omega 2 = \omega 3 = \omega 4$, that is, the four propellers rotate at the same speed, the propeller speed gradually increases. When it increases to a certain value, the vertical rise and fall of the aircraft can be realized, and the angular velocity signal source is set to a ramp signal with a slope of 20 Simulation[15], simulation time is 150s, the results are shown in Fig. 10. It can be found that the tri-habitat robot has only vertical displacement. At the beginning, the z coordinate decreases first and then increases after 80s, indicating that the lift is small at the beginning, the aircraft is descending, and the rotational speed is greater than 1600r/min. The aircraft can take off, and the three deflection angles are always zero during this process.

It has been verified that at 1873r/min, the tri-habitat robot can be in a suspended state in the air without any other factors, considering that the water resistance is 15 times that of the air [16], that is, when the water reaches 125r/min, the tri-habitat robot It can be in a suspended state in the water.

When simulating the tri-habitat robot to do the tumbling motion, set $\omega 1 = \omega 3 = 1873$, $\omega 2 = 1773$, $\omega 4 = 1973$ and simulate with the step signal as the signal source. The time is 3s, and the simulation result is shown in Fig. 11.

When simulating the tilting motion of the tri-habitat robot, similar to the tumbling motion, the propeller speed can be set to $\omega 1 = 1750$, $\omega 3 = 1930, \omega 2 = \omega 4 = 1874$, and the step signal is used as the signal source for simulation. The time is 3s, and the simulation result is shown in Fig. 12.

When simulating the tri-habitat robot's pitching motion, simulate with the step signal as the signal source [17] and set $\omega 1 = \omega 3 = 1850$, $\omega 2 = \omega 4 = 1900$. The time is 3s, and the simulation result is shown in Fig. 13.

At the same time, the displacement change at this time is as shown in Fig. 14. The results show that the yaw angle changes, it becomes -5.5 at 3s, the z coordinate becomes -5, and the remaining output values remain at zero, indicating that the yaw angle is increased in the case of descent.

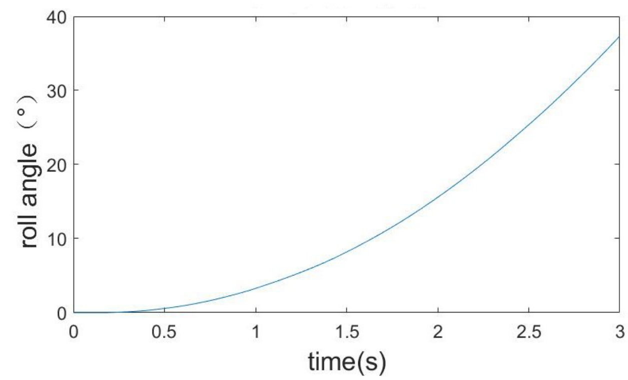


Fig. 11 Roll angle change

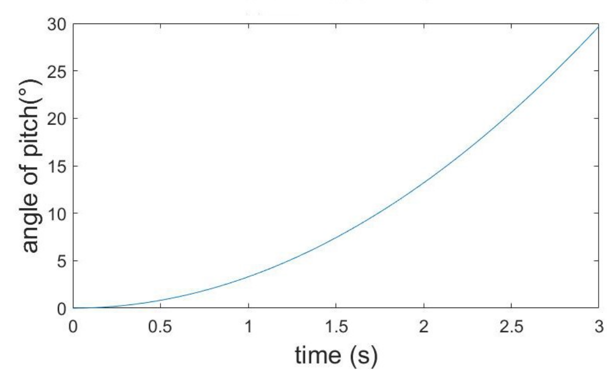


Fig. 12 Pitch angle change

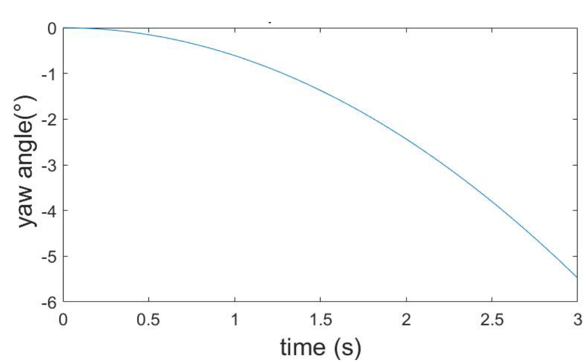


Fig. 13 Yaw angle change

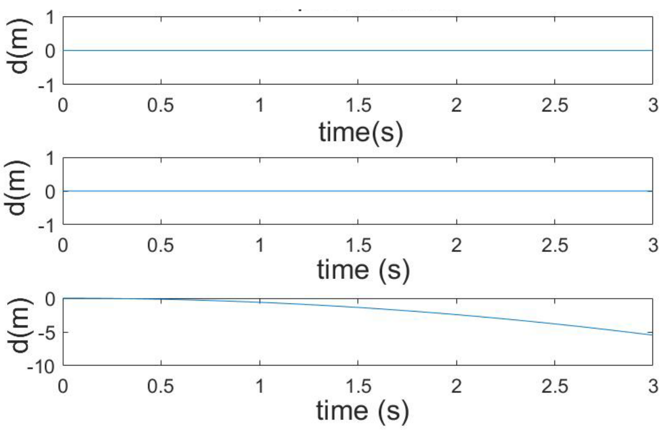


Fig. 14 Variation of displacement during yaw

The land travel mode uses four-wheel drive, and the power comes from the mother machine, thus realizing the overall movement of the tri-habitat robot in a two-dimensional plane [18]. The four wheels are divided into left and right rows. When the rotation directions of the two rows are the same, if the left row speed is greater than the right row, the robot turns right. If the left row speed is smaller than the right row, the robot turns left; the four wheels simultaneously Forward and at the same speed, the advance is achieved, and the four wheels are reversed at the same time and at the same speed, or back.

V. Conclusions And Future Work

In this paper, a new type of water, land, air and tri-habitat robot was designed based on the rotorless drone. The structure was divided into compartments, which realized the flight mode of the tri-habitat robot, the land driving mode and the underwater working mode. Meanwhile, the design of the sub-machine made the tri-habitat robot more flexible. It would be more convenient for jobs in complex environments. At the same time, the preliminary modeling and motion simulation of the tri-habitat robots were carried out, which verified that the new structure could initially realize the basic functions of water, land, air and amphibious. In the future, the tri-habitat robot can realize three motion modes, and can also cooperate with multiple robots to achieve underwater cooperative positioning.

Acknowledgments

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