Design and Research of Underwater Spherical Robot

Yuyi Zhai\textsuperscript{a}, Zihang Ding\textsuperscript{b}, Yunjia Liu\textsuperscript{*} and Shaohua Jin\textsuperscript{c}
School of Mechatronic Engineering and Automation, Shanghai University, Shanghai, China

\textsuperscript{*}Corresponding author e-mail: yjliu2017@shu.edu.cn, \textsuperscript{a}yyzhai@shu.edu.cn, \textsuperscript{b}1242193340@qq.com, \textsuperscript{c}845895979@qq.com

Abstract. Underwater detection has always been a hot area of technical research. The completely symmetrical structure of the spherical robot gives it a unique advantage in underwater exploration. This paper designs a new spherical robot that can move freely under water. It contains two propellers on the outside, which are driven by the motor to achieve forward, backward, and steering. Furthermore, the robot can float and sink by changing the volume of the ball by means of buoyancy. Finally, static and dynamic simulations will be performed to demonstrate the feasibility of the design.

1. Introduction

Since the beginning of the new century, the development of science and technology has entered a high-speed period, and various technologies have continuously appeared and applied to various fields. Underwater robots are used for searching targets under the ocean or lake, detecting underwater environment, gathering underwater geological sampling, and archeology, etc. [1]. The unique spherical structure has strong underwater pressure resistance, and the complete symmetry of the structure makes it possible to ignore the coupling relationship between different degrees of freedom during motion analysis and modeling which can use the same fluid dynamic parameters for fluid flow kinetics analysis. In addition, compared to other under-actuated robots [2], the spherical robot structure is reliable and stable. Its internal closed structure can isolate the environment and avoid direct contact between water and internal electronic devices. In recent years, with the continuous development of robotics research, robots are being used in various fields of social life and production [3]. In 2000, J. Batlle, at the University of Girona, Spain, developed an underwater spherical robot named URIS [4]. In 2011, Professor Waston of the University of Manchester in the United Kingdom developed an underwater spherical robot uAUV, which had been tested successfully to a depth of 6m with a diameter of 150mm [5]. In 2012, Professor X. Lin from the University of Electronic Science and Technology designed an underwater hydrojet spherical robot, which can be kept sealed at a depth of 15m with a diameter of 400mm [6].

It is worth mentioning that the team of Professor H. Sun from Beijing University of Posts and Telecommunications began to study prototypes of spherical robots and obtained a number of invention patents. Thereafter, he researched BYQ series spherical robots and BYSQ series underwater spherical robots. In 2008, the BYQ-4 spherical robot [7] was researched, and the posture of underwater spherical robot BYSQ-2 [8] was adjusted by two motors placed vertically to drive the weight.

Research on underwater spherical robots has been a hot topic. The underwater spherical robot has a unique advantage because of the shape of the sphere. This paper mainly designs a new type of
underwater spherical robot. The unique floating mechanism is used to realize the sinking and floating movement of the ball. Two propellers are set outside to realize the movement in the same plane, which can reach any position allowed by space to perform the detection task.

2. Structural analysis
In this design, the spherical robot can reach any position underwater, and its structure is shown in Figure 1.

![Figure 1. Overall diagram of the underwater spherical robot.](image)

As shown in Figure 1, the ball can be driven forward and backward by the two propellers. By changing the different speeds of them, it can accelerate or decelerate; by changing the speed difference of the propellers, the sphere can turn. In addition, the robot is provided with a sinking and floating mechanism, and the up-and-down motion will be realized by changing the volume of the sphere. They are introduced separately below.

2.1. Propeller
Robot propulsion is a very important part of robot motion. Propeller, as a widely used propulsion device, it has unique advantages. Comprehensive consideration of efficiency and mutual interference, the propeller in this paper has 3 blades, diameter $D = 80\text{mm}$. In the design of the propeller, the relationship between the thrust $F$, the torque $T$, the speed $n$ is mainly obtained. According to the working principle of the propeller, its expression is as Formula (1), (2).

$$F = K_F \rho n^2 D^2$$  \hspace{1cm} (1)
$$T = K_T \rho n^2 D^2$$  \hspace{1cm} (2)

In these Formulas: $K_F$ is the thrust coefficient, and $K_T$ is the torque coefficient. $K_F$ and $K_T$ are coefficients related to the speed ratio $J$, which can be gained by the propeller water flowing characteristic curve.

2.2. Floating Mechanism
The propeller can only move on the same horizontal plane. The ball can be suspended due to buoyancy in the water. Therefore, the volume can be changed to realize up and down. The design is shown in Figure 2.
Figure 2. Schematic diagram of floating mechanism.

It is driven by a motor by means of screw drive, then make the water-stop Sheet to move, next change the volume of the ball, final achieve sinking and floating. The entire process of the sphere is sealed. In order to solve the problem of excessive torque, gears are used.

2.3. Flywheel mechanism
In order to maintain the posture of the sphere, a flywheel mechanism is designed in this paper. With its gravity, barycenter of the ball is always in the lower half of it. It can still maintain the predetermined state without affecting normal operations even if it encounters water flow only on the one side in a complex underwater environment.

3. Static and dynamic analysis
The maximum force limitation of underwater spherical robots comes from the pressure of water. The static and dynamic analysis of the robot will be performed below.

In this paper, the outer surface of the ball which is under major hydraulic pressure is mainly wrapped by a transparent shell. The maximum pressure can reach 5.49MPa through simulation. Therefore, glass material can fully meet the requirements on stress.

3.1. Static and dynamic analysis of propeller
The propeller is the most important propulsion component in this research. The propeller blades rotate to push the water continuously backwards, generating forward thrust. The force situation in the analysis is more complicated, and it is generally gained through its water flowing characteristic curve.

Figure 3. Strain analysis of Propeller.
The static analysis of the propeller is shown in the Figure 3, and its maximum deformation is 0.086mm.

During operation, the propeller spins, and then the blades propel the water to move backward to obtain a reverse force, which in turn drives the sphere to move forward. When the speed of the propellers on both sides is the same, a forward or backward movement occurs, and the forward speed is proportional to the propulsive force. When the two speeds are different, a steering torque will be generated. Assuming that one side does not rotate and one side reaches a predetermined maximum required force and the coordinate origin is set for barycenter of the latter, the posture of the robot will be obtained through simulation software, as shown in Figure 4(a).

![Figure 4](image)

**Figure 4.** (a) The movement path of the propeller; (b) The curve of the propeller’s Angular Velocity-Time and Angle-Time.

In order to further analyze the angle change of the propeller-driven rotation, the angular velocity-time and angle-time curves are obtained, as shown in Figure 4(b). By analyzing the change of the curve in this figure, it can be obtained that the rotation angle and time are approximately proportionally changed, and the steering can be completed within 2 minutes. It meets the predetermined requirements.

### 3.2 Stress analysis of floating Mechanism

The floating mechanism is used to realize the up and down movement of the robot, which is mainly realized by means of the screw drive. According to the analysis of the motion characteristics, the possible failure point is at the meshing point and the outer surface. The simulated stress diagram is shown in Figure 5. The analysis chart found that the maximum strain was 0.2903 mm, which was within the allowable range.

As for the transmission, it mainly comes from the rotation of the motor, and uses two sets of gears to reduce the speed and increase the torque. It can realize the movement of the baffle in the direction of the screw rod, and achieve the desired effect of changing the buoyancy of the ball.
4. Conclusion
Overall, this paper designs a new underwater spherical robot for detection. The robot is able to move freely under water with two propellers and floating mechanism. The static and dynamic analyses were carried out according to the design situation. It was concluded that the robot design is feasible and can adapt to the underwater operating environment.

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