Model design of salvaging robot for drilling bit

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Abstract. During the construction of bored cast-in-place piles, loosening of the connection between the drill bit and the drill pipe often occurs. When the drill bit falls out, it must be salvaged. In this paper, a method of replacing manual salvage with robots is proposed. Based on STM32F103 technology, a drill-bit salvaging robot is designed with host computer, USBL technology, 3D printing technology, NFR wireless transmission and reception technology, and ultrasonic detection technology, so as to improve economic benefits and reduce manual casualties.

1. Introduction
With the increase of project scale, the depth of bored cast-in-place piles becomes larger and larger. Too much sediment and too hard rock layers result in increased bit torque. During the construction process, the loose connection between the drill bit and the drill pipe often occurs, resulting in drill bit accidents. The causes of drill bit accidents of bored cast-in-place piles include drill drop, buried drill and stuck drill. It is often caused by low strength of drill pipe, fatigue damage caused by long service time of drill pipe, deformation of bore wall or partial collapse of bore wall during construction. Bits must be strong enough to break through hard rock, and high strength means high cost. Pile holes where the drill bit has fallen can not be set up further and can not be used. Because the drilling position should not be changed, the drill bit will be salvaged once it falls down in the project, which avoids the loss of the drill bit and design changes.

At present, the salvage methods adopted by construction units after drill bit accidents are as follows: 1) salvage with tools in shallow water; 2) salvage with divers down to the bottom of the bore hole. As the concentration of mud in the bore hole is too high, buoyancy gradually increases with the increase of depth, generally not exceeding the bore depth of 40 meters, divers can still dive, but when the bore depth exceeds 40 meters, divers are difficult to dive. Moreover, since the soil in the bore hole has not been reinforced, it is easy to collapse or cable break, so the safety of divers can not be guaranteed. Therefore, we put forward a system for drill bit positioning and salvaging using underwater robots to avoid the danger of manual salvage.

Underwater robot is an intelligent underwater ROV (Remotely Operated Vehicle), which carries different working tools to complete work in specific fields. At present, underwater robots have also been used in engineering. Li Zhongqun and others carried out actual inspection under water of dams of Yongkang Sanduxi Reservoir, Yangxi Reservoir and Jinhua Shali Reservoir by using ROV [1]. Yang Chao put forward requirements for hardware configuration and motion control of underwater robot crack detection platform for complex underwater environment based on application requirements of underwater crack detection for dam of Xinanjiang Hydropower Station [2]. In order to realize the installation of sacrificial anode for friction stud welding subsea pipeline, Deng Zhou-rong and others
designed and manufactured an underwater friction stud welding tooling based on underwater robot ROV [3].

The underwater robot proposed in this paper is a bit salvage system based on STM32F103 chip [4].

2. Model design of underwater positioning and salvaging robot
In the validation stage of robot model, the structure of printer arm based on 3D printing technology is adopted, 28BYJ-48 stepper motor is driven mechanically, ULN2003 is driven by stepper motor, which can generate large torque. Telepole potentiometer and 8-bit analog-to-digital AD conversion chip have higher frequency and accuracy to achieve accurate control.

STM32F103 single-chip computer is used in conjunction with host computer, USBL technology, 3D printing technology, NFR wireless transmission and reception technology, ultrasonic detection technology, IIC communication, so that high-precision ADC chip can cooperate with rocker potentiometer with high sampling frequency and accuracy, and mechanical arm with reasonable structure and 5-wire 4-phase stepper motor can move precisely under high torque and load. It enables the mechanical arm to fix the cable precisely in the lifting hole of the drill bit. This research can greatly reduce the damage caused by salvaging the drill bit. The drill bit will be salvaged and can be used again after salvaging. Save money and time [5].

3. Analysis of mechanical arm
3.1. System analysis and structure design
The system controller has designed a motion control system of mechanical arm based on stm32. The control system firstly analyses the overall structure of the designed system and then designs the hardware system online. The whole system is centered on the STM32 controller, which has an angular displacement sensor and an auxiliary rudder control circuit. A Fuzzy-PID is introduced as the software control strategy, making it possible to obtain a certain amount of control. The STM32 controller regulates peripheral equipment from it to precisely control the movement of the arm [6].

The mechanical arm is composed of connecting rod and rudder, in which the rudder rod acts as a link and support, and can control the motion size of the mechanical arm, mainly controlling its motion and angle. In this system, several rudders are used as actuators of motion control of mechanical arm, STM32 is used as controller and Fuzzy-PID is introduced as software control strategy to adjust.

The overall structure diagram of the system is shown in the Figure 1. The user pre-defines the motion path of the mechanical arm. The control system collects the real-time motion track of the mechanical arm. After receiving the motion track of the mechanical arm, STM32 calibrates the motion path. A certain amount of command is obtained by using the motion track and calibrated motion path. It is introduced into the controller by using the Fuzzy-PID. Then the control unit controls the rudder according to the command quantity, thus accurate motion can be obtained.

![Figure 1. Operating logic of mechanical arm system.](image-url)
3.2. Design for system hardware unit
The mechanical arm adopts the fully open source 3D printing robot arm. According to the functional requirements and the overall design of the mechanical arm motion control system, the mechanical arm motion control system is divided into user operating unit and action execution unit. The user operating unit mainly includes LCD touch screen circuit and function key circuit. The motion path is predetermined through the LCD touch screen and the motion state of the arm is observed. Function keys include pause, start and stop three function keys, so that the user can control the mechanical arm in emergency. The main control unit mainly includes stm32f103c8t6 controller and crystal oscillator.

The motion track of the mechanical arm is acquired in real time and converted into an electrical signal. The communication in the main execution unit is processed by the controller and the motion execution unit is mainly composed of the rudder. The rudder in the circuit is controlled by PWM and the rotation can be adjusted to control the motion path of the mechanical arm. The user enters the calibrated motion path signal into the controller via the LCD touchscreen, which continuously receives the monitoring signal from the angular displacement sensor and transmits the monitoring results to the LCD touchscreen for display.

At the same time, the controller obtains the control quantity through the control strategy and outputs the PWM wave to adjust the dynamics of the gear to adjust the motion of the steering gear, thus realizing the accurate control of the motion path of the mechanical arm.

3.3. Design for system software unit
The system software device mainly implements three main functions: hardware function initialization, motion track judgment and PWM output. In this design, "Fuzzy-PID algorithm" is used as the control strategy of the software unit of the mobile control system of the manipulator to calculate the correctness of the motion track. The calculated control quantity is transmitted by STM32F103C8T6. Adjust the rudder by PWM waves.

When the hardware function is initialized, the program starts the process of determining the motion track, in which the determination of the motion track mainly depends on the Fuzzy-PID algorithm. The purpose of determining the motion track is to calculate the offset between the current motion track and the predicted motion path. The result of this determination is the key to affect the accuracy of the whole system and to determine the efficiency of the system.

4. Analysis of the underwater ROV

4.1. Technical analysis
The robot is designed with an Ardusub ROV controller, which is a fully open solution providing remote operation control and full automatic execution. The Dronecode software platform allows it to continue to use ground control station software, monitor vehicle telemetry, and perform robust task planning activities.
In addition to the standard load sensor (IMU, compass), the Ardusub controller supports a number of external sensors, including pressure/depth sensors, which can be used for automatic depth measurement and maintenance, and GPS on the ground.

The backforce generated by the rotation of the electric propeller is the power source of the ROV, and the position, placement direction and number of motors directly determine the type of motion that the ROV can achieve.

The robot is designed using Vctored ROV supported by Ardusub with eight propellers, 6 degrees of freedom control and heavy cargo lifting capability, and is ideal for precise operation in limited space for drilling holes.

4.2. Power analysis
The power is driven by an Outer-Rotor brushless DC motor, which rotates slower than the inner-rotator motor and provides greater torque. Generally, Outer-Rotor brushless DC motors with KV values between hundreds and thousands can drive propellers directly, eliminating the cumbersome deceleration structure.

A culvert fan propeller is used in the propeller. The culvert fan propeller increases the culvert housing relative to the general propeller, which reduces the impact noise and induced resistance during the rotation of the propeller, and greatly improves the efficiency.

With the vector culvert design, the rudder directly drives the culvert fan to rotate and adjust the angle, the power output turns more directly and thoroughly, the design of the rudder is omitted, and the resistance caused by the rudder is directly removed, which makes the underwater operation more sensitive and accurate.

With the layout scheme of eight drivers, it can move in six directions from top to bottom, from left to right, and from back to right. It can also perform some small micro-manipulation, which provides a stable and flexible mobile platform for the drill salvage process, and facilitates the manipulator to complete the next salvage work. The placement angle and position of the eight drives are carefully calculated and tested to ensure that the flow of water ejected from the eight drives does not interfere with each other and completes six degrees of freedom movement steadily.

5. Power supply of the robot
Considering the extreme conditions, eight drivers operate at full power at the same time, which requires about 600W power supply. This design uses cable power supply. Because the robot is relatively small and operates underwater, it uses passive heat dissipation and DC power supply.
Considering the need of the robot for 12V voltage power supply and the ability of the robot to design voltage reduction, 100V direct current is used to power the robot. The ground station connects 220V AC power supply to convert the AC power supply to 100V DC power supply for the robot. The DC-DC module is used on the robot side to convert the 100V DC current from the ground station to the 12V DC current available to the robot to ensure the normal operation of the robot. A zero-buoyancy cable with a cross-section of 1.5 square millimeters is used between the ground station and the robot. Because the zero-buoyancy cable has proper buoyancy in the water, it will not affect the underwater motion of the robot because of its own buoyancy or gravity. Most underwater vehicles use zero-buoyancy electricity.

6. Signal transmission and vision system

6.1. Underwater signal transmission
The working environment of drilling bit salvage robot for bored piles studied in this paper is the bore hole of bored cast-in-place piles. The bore hole is narrow and slender. All of them are underground structures with turbid mud in the holes. Water is the conductor, which absorbs electromagnetic waves. Electromagnetic wave will be exponentially attenuated in the mud. Therefore, the remote operation of the robot adopts the way of wired signal transmission. However, considering bored cast-in-place piles with hole depths up to tens of meters, long cable distances, uncontrollable without fixing method, the number of cable should be reduced. Under the condition of existing power cables, power carrier communication can be used. Moreover, the 100V DC power supply mode of the robot will not cause the pulse interference to the signal caused by the peak AC power in the traditional power carrier. In conclusion, the robot uses power carrier communication mode.

6.2. Underwater vision system
This design uses the combination of high pressure pump intensified light searchlight and high definition CCD camera as the underwater vision system of the robot. The underwater searchlight uses a waterproof bright LED light source with a luminosity of 5000 and an effective underwater illumination distance of 50 meters. The robot itself carries a small water tank to provide clean water. The pulse high pressure pump can provide 8 kPa pressure. Clear water pressurized by the high pressure pump is ejected through a special nozzle. The ejection is fan-shaped. The fan-shaped water surface can provide a clear field of vision of 5 to 10 centimeters for the robot. At the same time, the farther the fan-shaped water surface is, the faster the energy decay, and the inner wall of the stake hole will not be damaged. The high pressure pump spraying mode uses the point pulse spraying, which does not disturb the mud continuously by the water flow and affects the mud performance, effectively preventing the collapse of the inner wall of the pile hole caused by the mud performance destruction. At the same time, the water flow from the Pulse High Pressure Pump can also be ejected as a continuous flow of water, which can wash away the sediment on the drill bit and prepare the drill bit for accurate finding and hoisting.

Figure 5. Underwater vision system.  
Figure 6. CCD photosensitive element.
The high-definition CCD camera is composed of encapsulation, photosensitive element, image data processing circuit, etc. The most important component is the photosensitive element, which uses the CCD photosensitive element, which converts the light signal into an electrical signal component. Under very weak light in the pile hole, it is necessary to have a very high sensitivity to light and a certain ability to reduce noise. Visual image information is transmitted by power carrier communication, DC power carrier transmission interference is small, and underwater vision system using CCD as the sensor is sufficient to ensure that the ground station can receive real-time images with high resolution, high resolution and low noise. It provides visual guarantee for accurate and low-latency work of the mechanical arm and improves the success rate of drill salvage.

7. Conclusion
In recent years, bored cast-in-place piles have been widely used in the construction of high-rise buildings, road bridges, harbors and other projects. The salvage work when the drill bit falls off has become a problem that every project must face. The model design of salvaging robot for drilling bit has far-reaching significance and wide market demand, which lays a foundation for the practice and popularization of the salvaging robot for drilling bit.

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