Overview and prospect of underwater desilting robot

ABSTRACT:

The serious accumulation of sludge in the water outlet of the South to North Water Diversion Project poses a constraint on the sustainable development of the water ecosystem and the long-term development of the water storage system. Silt accumulation may lead to problems such as deterioration of water quality, damage to water ecosystems, and water level decline. In order to solve the problem of sludge accumulation, it is necessary to carry out dredging and dredging work for the water body at the outlet of the water outlet. Dredging can restore water capacity, maintain ecological balance, and contribute to the sustainable management of water systems. At present, there are still many shortcomings in the existing dredging technology for small and medium-sized water bodies on the market, which is difficult to meet the requirements of dredging in the South to North Water Diversion Project. Therefore, it is very important and necessary to develop new dredging robots to meet the environmental dredging needs. This article is based on the background of water dredging and control at the exit of the South to North Water Diversion Project. Through in-depth analysis of existing dredging robot technology and underwater robot technology, and combined with research status at home and abroad, it is planned to provide guidance and direction for the design and development of underwater dredging robot humans with environmental protection dredging functions in the future.

Keywords: Underwater robot; Desilting robot; Underwater operation

1.INTRODUCTION

In recent years, China's water conservancy projects have developed vigorously, and many hub projects, such as the Xiaolangdi Reservoir on the Yellow River, have been built, mainly for flood control and silt reduction, and meet the multiple goals of water supply, irrigation, power generation and environmental governance. These projects play an important role in the river management and development [1]. However, the widely distributed reservoirs in the major river basins of China face the inevitable sedimentation problems during their operation. Taking Xiaolangdi Reservoir as an example, as of October 2016, according to the sediment balance method and section method, the deposition amount of the reservoir area reached 3.899 billion tons and 3.2573 million cubic meters respectively, accounting for 45% of [2] of the designed sediment capacity. In order to solve this problem, usually use grab, pump, ordinary suction, environmental protection suction ship and other methods. These methods have good dredging results in shallow water, channel and broad lakes, but are difficult to apply [3] in deep water and small spaces. Compared with the dredging of lakes and rivers, reservoir dredging has the characteristics of large water depth and large internal drop, and many reservoirs are located in inland areas, and some reservoirs are even not suitable for navigation, so it is difficult to use large vessels for dredging operations.The dredging technology for the reservoir water body mainly includes drainage dredging, environmental protection dredging technology and underwater dredging [4].

Drainage and dredging technology refers to the first water discharge in the process of dredging, and then use excavators, high-pressure water guns and other equipment to directly dig or wash the silt to a specific place [5]. This method has the advantages of simplicity and low cost. However, it also has some limitations, including low drainage efficiency and may waste water resources, so these factors need to be considered with caution when using this technique. In some cases, especially in areas where water is scarce, drainage and dredging technology may need to be used in conjunction with other methods to minimize water waste. The core goal of [6] is to reduce the secondary pollution to the water body in the process of dredging, and to improve the self-purification ability of the water body and protect the ecosystem. This technology usually involves the improvement of the existing underwater dredging methods, using environmental protection dredging devices and high-precision auxiliary equipment, to ensure that the dredging process is more environmentally friendly, automatic, controllable, and improve the retention rate of the water and other indicators. However, there are still some shortcomings in environmental protection dredging technology, such as relying on huge ships, complex operation, poor controllability, high cost, limited dredging depth, dredging ship into the underwater dredging equipment agitation is still easy to produce disturbance.Underwater dredging technology is a method of underwater dredging work, usually using ships or robots as a platform, and carrying the corresponding dredging equipment. This technology has many advantages over the traditional drainage and dredging technology, including: no drainage, simple operation, small [7] affected by the weather and underwater obstacles. Underwater dredging technology can be divided into different types according to the specific operation methods, including digging bucket, bucket wheel, twisted suction, pump suction dredging and recently appeared dredging robot dredging. Each method has its own specific application scenarios and advantages and disadvantages. For example, digging bucket and bucket wheel dredging may cause secondary pollution due to water agitation, and the retention content of dredging is low. Pump suction dredging may face the problem of mud suction mouth blockage [8] or too much water inhalation requires secondary treatment [9]. Dredging robots are an emerging technology that do not need to rely on ships, so they are not limited by water depth and can be dredged in deep water areas. The robots can also provide environmentally friendly dredging functions to reduce secondary pollution. In recent years, significant progress has been made in the field of underwater robot and dredging robot, and a certain technical foundation has been accumulated. These developments are driven to improving technical capabilities, research input and government and private sector support for related sectors. To be specific, advances in underwater perception, control, navigation and communication technologies have made it possible to develop more flexible, intelligent and environmentally friendly dredging robots. The government encourages and supports innovation in the field of underwater robotics through project funding, policies and regulations, and research and development funding. Policies such as the 863 project have provided critical support for the robot industry. International cooperation and knowledge sharing will also contribute to the continuous progress of underwater robot technology and accelerate the research and development of dredging robots. The demand for water dredging is increasing, especially in the process of urbanization, which provides a broad market for dredging robots. The focus on environmental protection has prompted researchers and engineers to seek more environmentally friendly dredging methods, which has also driven the development of dredging robotics technology.

2. Research status at home and abroad

2.1 Research status of underwater robots at home and abroad

Underwater robots can be classified according to their control mode and design characteristics. Usually, under are divided into manned underwater robots (HOV) and unmanned underwater robots (UUV). Among them, unmanned underwater robots can be divided into three types of [10-15]: autonomous underwater robot (AUV), cable controlled underwater robot (ROV), and autonomous and cable controlled composite underwater robot (ARV). As a cable-controlled underwater robot, ROV has many advantages, such as simple operation and control[16], high flexibility, strong interaction, easy maintenance and so on. They are usually used for tasks that require real-time control and intervention, such as deep-sea survey, underwater construction and maintenance, dredging of water bodies, etc. The ROV has the potential for underwater dredging, allowing for remote manipulation to solve water siltation problems, while reducing personnel risks and costs. Research and development of ROV underwater dredging robot is a promising field, which is expected to play an important role in water ecological protection and water resources management[17]. Therefore, this paper mainly conducts research and outlook on ROV underwater dredging robot.

2.1.1 Foreign research status of underwater robot

The development of ROV has gone through three stages, [18], which reflect the evolution of ROV technology and the continuous expansion of its application fields.

The first stage is the initial stage of ROV development (1953-1974). The early stages of ROV focused on the 1960s and 1970s and were intended to provide a solution to artificial divers for deep-sea oil and gas exploration. These early ROV usually design simple, mainly used for inspection and maintenance of submarine facilities, such as the Americans in the 1950s the first camera with transparent material sealed on the sea to obtain underwater image data [19], in 1960 the United States successfully developed the world's first generation ROV-CURV 1 ROV, as shown in figure 1 (a), type CURV 1 ROV 20] joint "alvin" AUV after after hydrogen bomb opened the ROV development era [21-22].The second stage is the rapid development

stage of ROV development (1975-1985). As ROV technologies matured, they gradually expanded into multiple fields, including scientific research, ocean survey, underwater archaeology, and underwater construction. Multi-purpose ROVs are more complex in design, with more functions and sensors, and capable of performing a wider range of tasks. In 1975, Hydro Products developed the RCV-125 ROV [23], which is mainly used for underwater oil field observation. In 1980, the company developed the RCV-150 ROV [24] based on the improvement of the "RCV-125", as shown in Figure 1 (b).The third stage is the intelligent development of ROV development (after 1985). In recent years, ROV technology has been

further developed to operate in deeper waters, including deep-sea mineral exploration and deep-sea scientific research. In addition, ROV is also widely used in industrial applications such as seabed engineering, underwater maintenance and dredging. In 1988, Jason I ROV developed by "WHOI" was successfully measured at [25], and in 2002, JasonII ROV [26] was successfully developed, with a submersible depth of up to 6500m. In 1996, the KAIKO ROV developed by Japan (as shown in Figure 1 (c)) successfully dived to the bottom of the

Mariana Trench, setting a world deep dive record.

(a) CURV 1 (b) RCV-150 (c) JASON ROV

Figure 1 Representative during ROV development

Usually, the ROV with the size within 2 meters and the normal water depth within 300 meters is defined as small ROV [27] according to the size and working water depth. The development trend of small ROV is indeed of great significance, especially in the application of urban water and shallow water areas. These small ROVs usually have the following advantages: mobility, portability, cost-effectiveness, and maneuverability. With the continuous development of urbanization and the increasing demand for the management of urban water bodies, small ROV will play an increasingly important role in the maintenance, monitoring and research of urban water bodies and underwater infrastructure. In addition, small ROVs can also play a role in environmental protection, water quality monitoring, underwater construction and safety inspection. At present, small ROV technology is the United States, Russia, Japan and other countries. The VideoRay Explorer ROV [28] from VIDEORAY is mainly used for underwater monitoring.As shown in Figure 2 (a), it adopts a streamlined design and is equipped with sensors such as the magnetic compass to enable it to realize underwater monitoring tasks.

This ROV may be used in marine science, underwater archaeology and environmental monitoring; Its characteristics are small, flexible, and convenient to carry; Easy to operate (one person can complete it), capable of quickly completing large-scale underwater inspections or surveys, without seasonal or usage time limitations.the AC-ROV100 ROV [29] with box-type design and angle-specific vector propulsion scheme, as shown in Figure 2 (b), there are six thrusters, including four horizontal and two vertical. This design makes it flexible underwater and suitable for various underwater operations, including inspection, maintenance and monitoring; the Little SunFish ROV [30] developed by Toshiba Corporation of Japan is mainly used for nuclear leakage detection. As shown in Figure 2 (c), it adopts streamlined design, equipped with multiple thrusters, radiation dosimeters and cameras, enabling them to perform tasks in high radiation environment such as nuclear power plants; The FALCON ROV [31] developed by Saab Seaeye in Sweden adopts frame design, as shown in Figure 2 (d), equipped with multiple thrusters, adjustable lights and cameras, with strong mobility and adaptability. It can increase the working depth from 300 m to 1000 m for deepwater operations; The above four types of ROVs are all more focused on functional requirements such as underwater exploration and monitoring. In addition, there are also ROVs that can be operated underwater using equipped mechanical devices for practical operations.the Seamor ROV developed by Inuktun Services [32] has a frame design, as shown in Figure 2 (e), carrying multiple thrusters and manipulator for underwater hull maintenance and underwater detection tasks. This ROV is useful for meticulous handling; India-Partner Super GNOM Pro[33] has a frame design with magnetically coupled thrusters, scanning sonar and manipulator. As shown in Figure 2 (f), it is mainly used for underwater monitoring and underwater nuclear power plant maintenance tasks.

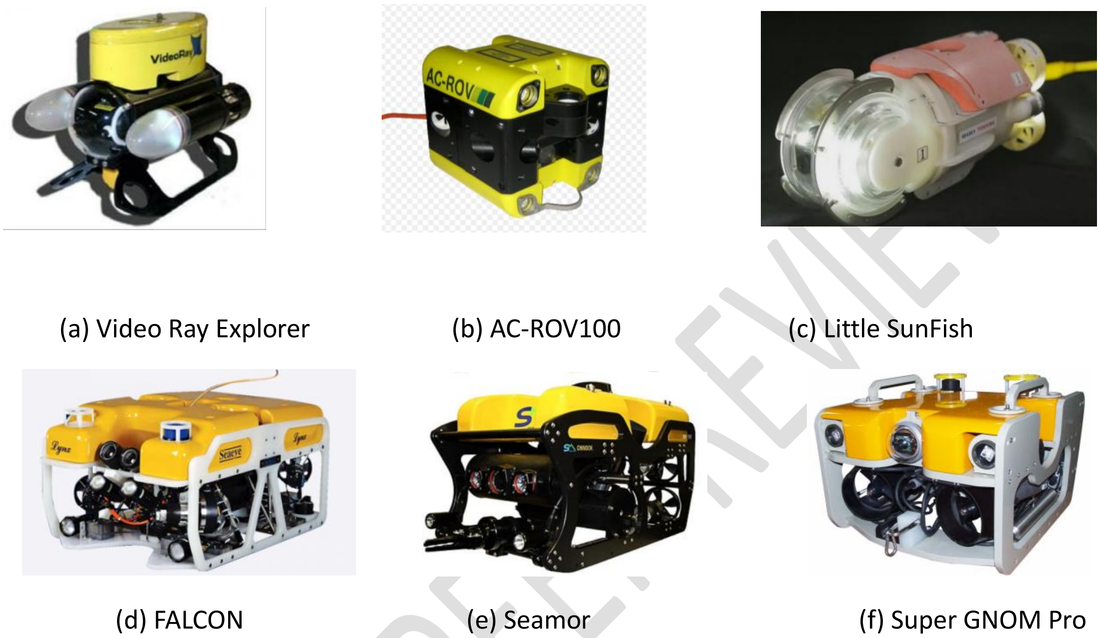


Figure 2 Small ROV developed abroad

2.1.2 Domestic research status of underwater robots

Although the development of ROV in China is relatively late for [34], China has also made significant progress in the field of ROV, thanks to the strong support and continuous investment of the country. China's early development of research in the field of ROV mainly relies on domestic scientific research institutions and institutes, such as Shenyang Institute of Automation of Chinese Academy of Sciences, China Shipbuilding Research Center, Shanghai Jiao Tong University, Zhejiang University and Harbin Engineering University and other [35]. These institutions play a key role in the research and development of ROV technologies. In 1981, Shenyang Institute of Automation of Chinese Academy of Sciences and Shanghai Jiao Tong University successfully developed the first operational ROV [36] independently developed by China, which was named "Haiquan No.1". This milestone event marks the beginning of the ROV development in China. As shown in Figure 3 (a), the ROV adopts a streamlined design, equipped with a six-DOF manipulator and other functions, with a maximum depth of 200 meters,Equipped with a 6-function master slave servo robotic arm with tactile sensation, including an electric master hand and a hydraulic slave hand, the master and slave hands use bidirectional feedback to form a sense of force, and a control and communication system equivalent to the robot's brain and nerves is composed of advanced multi chip microcontrollers at that time. Over time, China's ROV technology made continuous progress;; in 2004, Shanghai

Jiao Tong University developed ROV [37] with diving depth of 3500 meters, becoming one of the largest diving depth and strongest ROVs in China at that time. See Figure 3 (b), it adopts a frame design, equipped with 7 thrusters, 2 heavy manipulator, 5 cameras, and [38], mainly used for deep-sea sampling, deep-sea investigation and deep-sea search. In 2014, many Chinese research institutions jointly developed RAV "Haima" [39] with diving depth of 4500 m. This [40] is one of the ROVs with the largest diving depth, the largest system scale and the highest localization level in China. As shown in Figure 3 (c), it adopts a frame design, equipped with 3 manipulator, 4 cameras, sonar and other equipment, and solves many technical problems in the field of ROV, including [41] for lifting compensation. In addition, it also has the submarine layout system compared to the usual ROV system.

（a） hairenyihao ROV (b) hailonghao ROV (c) haimahao ROV

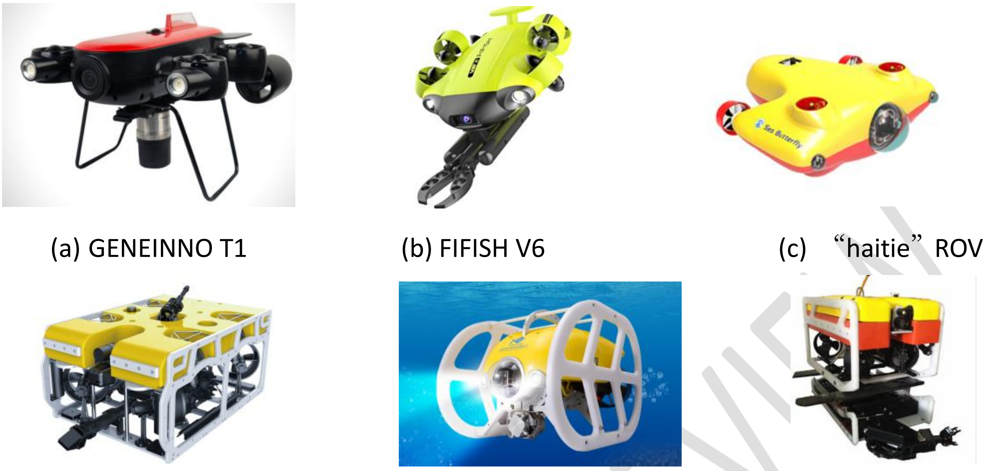
Figure 3 ROV developed in the early stage

In the later stage, ROV development gradually developed towards the trend of miniaturization and intelligence. There are not only domestic scientific research institutions participating in it, but also many high-tech companies have emerged. The ROV product structure of these companies is mainly divided into streamlined and frame types. The following are some examples:

Streamline ROV: GENEINNO T1 ROV developed by Shenzhen Jiying Technology Co., Ltd., as shown in Figure 4 (A), is equipped with 6 thrusters and HD cameras, which support mobile phone APP control, has strong real-time interaction and can achieve 360-degree full attitude control. The FIFISH V6-type ROV developed by Shenzhen Fin Technology Co., Ltd., as shown in FIG. 4 (b), is equipped with 6 thrusters and a 166-degree ultra-wide Angle camera, which can realize accurate hovering at any arbitrary underwater perspective (full attitude motion control). The sea butterfly ROV developed by Tianjin Hanhai Lanfan Marine Technology Co., Ltd., as shown in Figure 4 (c), is equipped with 4 thrusters and 2 LED flash lights, which can be used for underwater microscopic detection.

Frame ROV: Dolphin ROV developed by Tianjin ShenzhMarine Equipment Technology Co., Ltd. As shown in Figure 4 (d), is equipped with 8 thrusters and HD cameras, with strong expansibility. It can be assisted with two manipulator at the same time, and with sonar, USBL, DVL and other sensors to achieve accurate control. The LBF-300A ROV developed by Qingdao Luobofei Marine Technology Co., Ltd., as shown in Figure 4 (e), is equipped with two large thrust thrusters, four ordinary thrusters and HD cameras, which can be equipped with manipulator, sonar and other auxiliary underwater operation tools as needed to adapt to the strong sea current waters. The SYSROV T300 ROV developed by Tianjin Skart Technology Co., Ltd., as shown in Figure 4 (f), is equipped with 5 magnetically coupled brushless DC thrusters, pitch-adjustable high-definition color camera, manipulator, etc., which adopts distributed intelligent control and is highly scalable.

The development of these ROVs represents progress in underwater robotics, especially in miniaturization and intelligence. These robots will play an increasingly important role in underwater exploration, scientific research, resource development and other fields.



(a) GENEINNO T1 (b) FIFISH V6 (c) “haitie” ROV T300

(d)haitun ROV (e) LBF-300A (f) SYSROV T300

Figure 4 The ROV developed in China in the later stage

Comprehensive analysis of the underwater robot research status at home and abroad, it does show that underwater robotics has made significant progress and is widely used in various fields of underwater operations. In this context, it is a reasonable and feasible research and development direction to realize the underwater dredging function by improving the existing underwater robots and adding dredging modules. It is also reasonable to choose a small cable-controlled underwater robot as the basic principle prototype of the research and development results, because this type of robot has the advantages of high mobility, easy operation and control, strong scalability, and is suitable for simulation principle demonstration and basic function verification. This can effectively reduce the cost and technical threshold, enable more people to understand and participate in the research and development of underwater dredging technology, and provide more solutions for the dredging work of small and medium-sized cities. In general, combining the existing underwater robot technology with underwater dredging needs, the development of small cable controlled underwater dredging robot is a promising research direction, which can provide innovative solutions for water dredging and ecosystem protection. At the same time, it also requires continuous technical research and development to meet the diversity of different water environments and task requirements.

2.2 Research status of dredging robot at home and abroad

2.2.1. Research status of dredging robot abroad

In the early research of dredging robot mainly focused on pipeline dredging robot, the development of this field can be traced back to the 1950s. The UK was the first to design the

PIG cleaner [42] (Pipeline Inspection Gauge, Pipeline Inspection Specification), a robot used to clean the interior of pipes. However, PIG pig has some technical problems, such as uncontrollable speed, which leads to its difficult to popularize and apply. Company Automatika in the United States designed and developed the TIGRE [43] (Treaded In-pipe Inspection and Grooming Robot for Exploration) to solve the problem of pipeline blockage caused by impurity deposition after long-term transportation of oil pipelines. TIGRE is a foot-pipe dredging robot that uses leg-push walking to clean the inside of the pipe. However, TIGRE has a complex structure and a low walking efficiency, so it is still in the theoretical research stage [44]. These early studies of pipeline dredging robots represent a response to pipeline cleaning requirements, but they have limitations in practical applications due to challenges such as technical problems and complexity. Since the 1970s, with the development of computer technology and other technologies, the design of pipeline dredging robot has gradually been optimized [45] and achieved some remarkable achievements in [46]. At the beginning of the 21st century, the University of Florida successfully developed a wheeled pipe dredging robot, called OPCR-OH'S [47]. The specific structure is shown in Figure 5 (A). The robot works by using the rotating blade of its head to chop the blockage [48] inside the pipe, so as to realize the dredging of the pipe. The robot's design is expected to improve dredging efficiency. The South Korean technical team also designed [49], a crawler pipe scale cleaning detection robot, which works similar to OPCR-OH'S. The specific structure is shown in Figure 5 (b). The robot uses a tracked chassis and is equipped with cutting equipment to remove deposits from the pipe. The robot was designed to facilitate pipe cleaning and maintenance efforts. These new generation of pipeline dredging robots use advanced technologies such as computer control and cutting equipment to improve dredging efficiency and accuracy, However, the drawbacks of these two types of dredging robots are also relatively obvious. The working conditions are limited by the shape and size of the pipeline, making them unable to be widely used in various working situations. In the face of severe blockage situations, such as when the blockage is hard or there are sharp small foreign objects, it is easy to cause damage to the machine.

(a) OPCR-OH'S wheeled pipe dredging robot (B) Pipeline scale cleaning and detection robot

Figure 5 Pipeline dredging robot developed in abroad

In recent years, the research and development of foreign pipeline dredging robot is still continuing, constantly promoting the progress of dredging robot technology. The ROV SRD-6EC of Ellicott Dredge Technologies company is a dredging robot developed by Ellicott Dredge Technologies company, as shown in Figure 6 (a). It uses a tracked chassis and a hydraulic drive scheme, equipped with a front-facing screw cutter, which can chop the silt, and then use the corresponding silt suction pump to absorb the silt and transport it to the silt post-treatment system for treatment. The robot is expected to improve the efficiency and accuracy of dredging. The Toolbot of Toolbot robotics company in the Netherlands is a dredging robot developed by Toolbot robotics company. As shown in Figure 6 (b), it uses a tracked chassis and screw drill scheme and can be operated remotely. Toolbot With the characteristics of small size, easy operation, accurate movement and environmental protection dredging, it is expected to play a role in various dredging applications. Bull-ROV from Italy companies DRAGFLOW and GEROTTO FEDERICO SRL is a new dredging robot designed by Italy companies DRAGFLOW and GEROTTO FEDERICO SRL. As shown in Figure 6 (c), it successfully combines the advantages of a heavy dredging pump and a ROV (remotely operated vehicle). With a specially designed front stranded brush, it can collect the silt and then pump it away directly through a heavy dredging pump. This design helps to deal with high silt retention rates. These types of dredging robots have good results in handling large-scale watershed dredging work, but it is difficult to use these large-scale dredging equipment under relatively narrow working conditions, such as cleaning sludge from urban wastewater treatment plants or artificial river branches, main channels, and tax refund gates.

(a) The US for ROV SRD-6EC (b) The Toolbot of the Netherlands (c) The BullROV in Italy

Figure 6 Dredging robot developed in abroad

2.2.2 Domestic research status of dredging robot

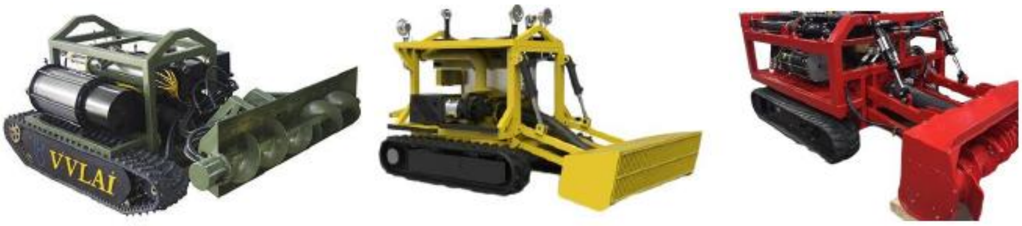
The research in the field of pipeline dredging robot in China started relatively late, only getting involved in [50] in the 1970s and 1980s. However, the Chinese government has been actively promoting the development of the robot industry, and has attracted domestic universities and high-tech companies to participate in the research through policy and financial support, thus accelerating the development of domestic dredging robot technology [51]. The National 863 Project is a high-tech research and development program funded by the Chinese government, which provides financial support and policy incentives for the field of dredging robots and promotes the development of related research projects. Domestic universities and research institutions have actively participated in the research of dredging robots. They have carried out related projects, trained a number of professionals, and promoted the development of dredging technology. In addition, some domestic high-tech companies have also invested in the research and development of dredging robots. They provide new solutions for the field of dredging. The accelerated development of domestic dredging robot research is expected to solve the problems of domestic waterway maintenance and environmental cleaning. Although starting relatively late, some remarkable achievements have been made in China, and there is still great potential in the future, especially in addressing the challenges of waterways and sewage treatment arising in the process of urbanization. Government support and active investment from the industry will continue to drive this sector.

Domestic universities have made important progress in the research field of pipeline dredging robot, and solved the development of different types of robots. Huang Yue from Beijing Jiaotong University has designed a new pipeline dredging robot, which is controlled by full pressure transmission. Its working principle is to pump the broken silt passed by the import mechanism to the export mechanism through the dredging pump, and then transport the silt to the collection truck outside the pipe. The detailed structure is shown in Figure 7 (a), the design of the robot is expected to solve the problem of flammable and explosive environment of municipal pipelines and artificial dredging; Zhu Xinzhong of Northeast Petroleum University designed a new pipeline dredging robot [53], which is cleaned and cleaned. The design of this robot is expected to improve the dredging efficiency, the specific structure is shown in Figure 7 (b); Wang Liang of Tianjin University designed a cable dredging robot [54] with its own power supply for the special environmental problems of the sewage system of metallurgical steel plant. The robot uses chain bucket excavation and broken silt to clear the ditches, without requiring external power supply. The design of this robot is suitable for some environmental robots requiring special treatment. The specific structure is shown in Figure 7 (c). These types of dredging robots are all suitable for dredging work under specific conditions and cannot adjust themselves according to different working conditions to meet the needs of dredging work under different working conditions.

(b) Beijing Jiaotong University (b)Northeast Petroleum University (c) Tianjin University

Figure 7 Pipeline dredging robot developed by domestic universities

The participation of domestic high-tech companies is crucial to the promotion of dredging robotics technology. These companies have invested great resources in research and development to meet the market demand for dredging technology. Such as Shandong Future Robot Co., LTD., Shenzhen Lande Intelligent Robot Co., LTD. Thanks for providing detailed information about the domestic underwater dredging robot. The development and use of these robots show that significant progress has been made in the field of underwater dredging technology, providing strong support for water engineering and environmental protection; VVL-QY 270-130A underwater dredging robot of Shandong Future Robot Co., Ltd. adopts frame structure, crawler chassis, front spiral dragon, slurry pump suction dredging, full hydraulic drive and cable control scheme. As shown in Figure 8 (a), the working principle is to use the spiral twisted dragon to collect silt and remit into the mud suction mouth, and then the collected silt is inhaled and pumped to the surface of the water through the slurry pump to achieve dredging. The robot is suitable for dredging work in different environments, such as DAMS and reservoirs. Shenzhen Lande Intelligent Robot Co., Ltd. 's underwater automatic dredging robot is similar to Shandong's future robot solution, but it has the function of automatic cable rolling. It can be used for automatic dredging operations, adapt to various water environments, and improve dredging efficiency. The specific structure is shown in Figure 8 (b); the working mileage of KJBD-X03 dredging robot of Liaoning Bodao Building Materials Technology Co., Ltd. has reached more than 1730 km, and can be equipped with professional muddy water camera for monitoring and dredging work. This robot shows reliability and stability in long use, and is suitable for different types of water dredging tasks. The specific structure is shown in Figure 8(c).



(c) Shandong Company (b)Lande Company (c) Bodao Company

Figure 8 A dredging robot developed by domestic high-tech companies

3.RESERCH OUTLOOK

3.1Overall design scheme

Because most of the existing dredging robots use the crawler chassis with high grip and high obstacle crossing ability and the stranded suction dredging scheme with small secondary pollution to the water body, the development of the underwater dredging robot should also use the crawler chassis design.

Considering the expected specific working environment of the South to North Water Diversion Exit, and based on actual engineering requirements, it is known that the water depth at the exit of the South to North Water Diversion Exit is about 10 meters, and the accumulation of sludge is unavoidable due to natural causes. It takes about 1-2 years to accumulate a thickness of 1-1.5 meters. It is required to carry out sludge cleaning work without stopping water supply, and the dredging robot has a high degree of automation, easy operation and maintenance, and stable posture in dynamic water, And the structure of the dredging robot is not easy to cause damage to the main body of the building itself.

Based on the above requirements and in combination with existing formed dredging and dredging devices on the market, a new type of underwater dredging device is designed. The device adopts a bottom mounted twisted suction dredging and twisting dragon scheme [55], which can effectively avoid damage to the building body. At the same time, the twisted suction type is fixed by a connecting ring, and vertical and horizontal movements are controlled by electric push rods and electric screw slide rails. Through the above mechanism, The underwater dredging robot can adjust its posture to adapt to different dredging situations. At the same time, the high-speed rotating Jiaolong blade can handle the majority of hard sediment, with high dredging efficiency. Through cable control, there is no need to consider issues such as range and control stability. At the same time, considering the harsh working environment of underwater robots, the modular self reconstruction scheme is adopted by underwater dredging robots [56] to solve the common problems of underwater robots, such as the need to improve their environmental adaptability and weak self recovery ability. The overall plan is highly feasible and stable, which can solve the problems raised for the South to North Water Diversion project.

3.2Expected functional conception

3.2.1 Structural strength expectations

From the operation of Xiaolangdi Reservoir to October 2019, the peak elevation of the delta in the reservoir area has reached 212.70 m, and the peak is about 10.3 2 km from the dam. According to the basic conservation laws of fluid mechanics, the following control equations are established for the study of water flow, sediment, and riverbed[58].

Table 1: Corresponding Table of Control Equation Terminology

term	meaning	term	meaning	term	meaning	term	meaning
x	Water flow direction coordinates	ρ	Clear water density	Z_b	Riverbed elevation	s	Sand content
y	Vertical coordinates	v_t	Turbulent viscosity coefficient	u	Flow velocity along the direction of water flow	S_a	Bed sediment content
ω	Sedimentation rate of sediment	h	Water depth	v	Vertical flow velocity	S_a^*	sediment-carrying capacity
p	pressure	ε	Turbulent diffusion coefficient of sediment	P_γ	Sediment porosity	γ'	Dry bulk density of sediment

Continuous equation of water flow:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

Water flow equation of motion:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v_t(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}) \quad (2)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g-\frac{1}{\rho}\frac{\partial p}{\partial y}+v_t(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}) \quad (3)$$

Equation of motion of the suspended mass:

$$\frac{\partial hs}{\partial t}+\frac{\partial hus}{\partial x}+\frac{\partial h(v-\omega)s}{\partial y}=\varepsilon(\frac{\partial^2 hs}{\partial x^2}+\frac{\partial^2 hs}{\partial y^2}) \quad (4)$$

River bed deformation equation：

$$\frac{\partial Z_b}{\partial t}=\frac{P_\gamma \omega(s_a-s_a^*)}{\gamma'} \quad (5)$$

Where x is the coordinate along the flow direction; y is the vertical direction coordinate and upward positive direction; ω is the sediment settling speed; p is pressure; ρ is the density of clean water; is the turbulent viscosity coefficient; h is the water depth; ε is the sediment turbulent diffusion coefficient; is the riverbed elevation; u is the flow rate along the flow direction; v is the sediment porosity, s is the sediment content and the sediment force and sediment dry bulk weight.

In order to closely link the water level function ξ (x, t) and the momentum equation, the pressure is divided into the sum of dynamic water pressure and hydrostatic pressure, namely p = pd + ps. The pd is dynamic water pressure, which is the additional pressure caused by streamline bending and uneven flow rate during water flows; ps is hydrostatic pressure, ps = ρ g [ξ (x, t) -y]. After the pressure is decomposed, the pressure gradient can be changed separately[60-62].

$$-\frac{\partial p}{\partial x}=-\frac{\partial p_d}{\partial x}-\rho g\frac{\xi(x,t)}{\partial t} \quad (6)$$

$$-\rho g-\frac{\partial p}{\partial y}=\frac{\partial \rho_d}{\partial y} \quad (7)$$

The structural materials and mechanical domain selected by the lower dredging robot shall be able to withstand the bottom pressure of the reservoir drainage outlet calculated by the above formula (1) ~ (7) under the conventional water level conditions.

3.2.2 Work ability expectations

It is known that the siltation elevation of Xiaolangdi Reservoir from 1.32 km to October 2019 in front of the dam is raised from 137.50 m to 181.64 m, the siltation rises 44.14 m, and the siltation elevation at 60 m in front of the ininlet tower is 176.18 m. The cumulative workload is huge, and due to the water storage and drainage capacity of the reservoir itself. Therefore, the underwater dredging robot should be able to work in a single stable operation for 12h or more, the amount of sand and mud removal within a unit hour should reach 310 kg and 1550 kg [59], in special circumstances should be able to meet the single stable work for 18 hours or more.

3.2.3 Functional expectations

The underwater dredging robot has the ability of image transmission and environmental sensing, and has semi-automatic operation. It can improve the efficiency, accuracy and safety of dredging tasks, and become an important tool for water cleaning and maintenance.

3. Conclusion

Through in-depth analysis of existing dredging robotics and underwater robotics, And to investigate the current research situation at home and abroad, Proposed a kind of small cable controlled underwater dredging robot simulation principle prototype (underwater dredging robot for short) with environmental dredging function design, Then, the structural design, control system research, test experiment and analysis work of the underwater dredging robot were completed successively, Finally, it aims to develop an underwater dredging robot with underwater multi-freedom motion, real-time feedback of underwater state information, underwater image information display, track chassis movement, dredging function demonstration and other functions, The working principle of this underwater dredging robot is to use tracks for movement to avoid situations where it cannot move in the mud at the bottom of the water. The working method is to break up the sediment through the high-speed suction cutter head, and the sediment is mixed with water before being pumped to the shore through a mud pump for subsequent treatment. In order to meet various dredging work conditions, The Jiaolong blade can move vertically and horizontally through electric push rods and electric screw slide rails, and can be adjusted for multiple postures underwater. The overall plan adopts a control type design, which is stable and does not need to consider underwater endurance issues. The final plan can effectively handle the sludge accumulation at the exit of the water gate under narrow working conditions, meeting the practical needs of the project. The robot is suitable for a variety of water dredging tasks, including reservoirs, rivers, lakes, waterways, etc., Can effectively help to maintain the water ecological balance, Improving the water quality, It also reduces the risk of people in a harsh environment. It provides a practical and feasible robot underwater dredging solution for the dredging of the sluice along the south-to-north water diversion project.

COMPETING INTERESTS:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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