

# Design of Automatic Operated Modular Underwater Vehicle System for Marine Ranch Breeding

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## Original Article

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# Abstract

As terrestrial resources gradually cannot meet people's needs, Countries around the world gradually increase the development and utilization of marine resources. The emergence of marine ranching overcomes many disadvantages of traditional fishery, but there is still a distance from unattended intelligent marine ranch. In this paper, designed a kind of unattended modular underwater robot system which used in marine ranch, including the main body for cage monitoring, the robot module for cleaning and repairing of net clothes and recycling of dead fish, while designed a underwater interfacing apparatus for the main body and root module, This paper introduces the underwater vehicles system of marine ranching, and designs the main body and working module in detail. This paper simply describes the interfacing process of the underwater workstation with the main body and modules.

The research results of this paper compensate for the gaps in marine ranch engineering equipment and technology, and meantime proposed an underwater vehicle for cage repairing and dead fish recycling, which uses modular ideas, it can reduces costs and this paper strongly promotes the development of intelligence and automation level of marine ranching.

## 1. Introduction

Traditional marine ranching lack marine equipment and technology which has caused the decline of quality of seawater and aquatic product, destroyed the marine ecological environment and seriously restricted the development of marine ranching[1]. Marine ranching based on modern marine engineering equipment and technology scientifically cultivates and manages fishery resources in specific sea areas, more scientific and contributes to marine ecological protection[2]. Marine ranching farming operations include monitoring water quality, harvesting marine life, cleaning and repairing of nets and recycling dead fishes[3], There are many problems in traditional marine ranching, which hinder the development. According to statistics, more than 50% of the consumption is used for artificial breeding and fishing of divers[4]. With the emergence of unmanned underwater vehicles (UUV), marine ranching has entered a new era which replaces traditional manpower with UUV. Using UUV in marine ranching can improve living environment of fishes and repair net clothes in time, Especially in the case of large-area fish disease death, can be found in time to avoid economic losses[5]. The emergence of UUV is of great significance to the construction and development of marine ranching, from "disorderly breeding" to "orderly breeding" [6]. Nowadays, there have been some UUV for monitoring cages, fishing sea cucumber, cleaning net clothes and etc[7]. This paper first proposes an UUV for mesh repair and recycle of dead fish, and finally develops a modular underwater vehicle system for intelligent marine ranching. The research results will fill the gap in the field of UUV for marine ranching at home and abroad.

In the field of marine ranching UUV, foreign countries are ahead of domestic, in the 1960s, the US, Japan, Norwegian and Western developed countries as representatives first to study underwater vehicles. Due to technical backwardness, China began to study UUV about 1980s[8]. Canada has developed the world's

first fully portable UUV "DTX2ROV" for ocean ranching observation, as shown in figure 1. It can provide high-definition video, monitoring health of fish.

In 2018, Harbin Engineering University independently developed the "Intelligent Ocean Ranch" UUV system, including the central server system, "Little Whale" light cage observation UUV and "Giant Kun" heavy fishing sea cucumbers UUV, as shown in figure 2. Formation navigation and path planning are realized by navigation and acoustic communication among multiple UUV.

In 2019, the second underwater vehicle competition was held in the Ocean Ranch of Taizi Island. The target recognition, fixed-point autonomous capture project of UUV was held around the real environment of the ocean ranching.

In view of the current problems of marine ranch UUV system, the following problems need to be solved:

- (1) Underwater motion is often affected by waves and currents. the main body must be able to achieve dot hovering and automatic docking of different operating devices.
- (2) Cage inspection, observation of fish activity and growth, monitoring of water quality and cage nets.
- (3) The cage is placed in the sea for a long time and is easily attached by plankton in the sea, blocking the mesh,so need UUV for cage cleaning[9].
- (4) The pressure of seawater will cause cage damage and loss several tons of fish, so need automatically completes the repair of the net [10].
- (5) Dead fish sink directly at the bottom of the cage, causing water pollution,so need recycle dead fishes.
- (6) Docking technology. It is necessary to develop the docking device and technology in the future[11].
- (7) Underwater wireless charging and communication technology.Long-term underwater operation, energy supply and high-quality image data transmission to meet the net damage detection is necessary[12].

The marine ranching UUV system needs to carry out related research around key technologies. In this paper, described the intelligent marine ranching UUV system through modular research, including main robot used for cage monitor, net repair module, net clean module, dead fish recycle module. Fixed-point removal technical barriers to realize the future intelligent automatic operated marine ranching.

## **2. Structure Design Of The Marine Ranching Modularization Underwater Vehicle**

### **2.1 Modular architecture design and analysis**

Due to various problems existing in the cage, In view of modularization, design a modular marine ranching UUV system, According to the modular structural system, divided into main body, net clothes

cleaning, net clothes repair, dead fish recycle module and underwater station. According to the idea of hardware modularization, divided into power, control, frame, propeller, camera, lighting, floating , manipulator and working module. The main body is a remote operated vehicle(ROV) with cable from the workstation, which can be used separately for cage monitor to check the growth and living environment of fish. The modular UUV system of ocean ranching is shown in figure 4.

Main body is given path plan by workstation first, equipped with camera module for cage monitor. When found the cage sediment attached to a certain degree in the cage, dead fish or the damaged net clothes, main body sent information to the workstation, then through signal transmission, connect the required main body with the working module, control the working module to accomplish different tasks by wireless signals transmission.

The working module system is divided into three independent unit modules, each module has a standardized and universal connection interface and the control processor involved can work together. According to the different application environment and task, corresponding working module is combined with body to meet different requirements. Modular design facilitates improve performance, function expansion and convenient maintenance[13-14].

## 2.2 Modular Main Robot

In this paper, the main body include the visual system, the motion system, the battery and control system, the frame, and floating body and the docking device, as shown in figure 5. The motion system equipped with four horizontal thrusters, four vertical thrusters. The battery and control system include a control bay and two battery bay. The visual system include a camera located at the head of the control bin, a PTZ camera located at the top plate of the main body and two LED. The main body will be equipped more modules according to different work tasks, such as sonar to percept fish swarm and damage location of net clothes, wireless communication system to transmission information and etc. The main body head is streamlined to reduce the motion resistance. The propeller system is installed on the wing plate.

### (1) Visual system

The visual system includes the control cabin of built-in camera, the two LED lamps and the integrated cloud head system, which is used for close and long-distance observation and analysis respectively. It can better adjust the working condition in real time to complete the fish state analysis and the cage monitor.

### (2) Motion system

It includes four horizontal thrusters and four vertical thrusters. Through control in different ways, which can change the position and motion form of the vehicle.

The main body needs to carry different working modules according to different working conditions, so the balance of the main body is necessary. The following two schemes are described:

- (1) Supply with weight blocks or buoyancy materials;
- (2) Barycenter regulator and floating center regulator, as shown in figure 6.

## 2.3 Net clothes cleaning working module

If remove attachments on the net clothes, the net cage can increase the oxygen content, improve the fluidity of the water, increase the growth rate of the fish and reduce the frequency of the fish deaths. At present, the main working methods of underwater cleaning vehicle are brush, high pressure water jet, ultrasonic wave and so on[15-16].

The net clothes cleaning module is connected to the main body which carries the power system. The control signal is transmitted, analyzed and processed by the main body control system. The brush is driven by the motor to clear the attachment on the net cage.

Scheme one: The net clothes cleaning robot module adopts two roller brushes, which can not only clean the net clothes, but also drive the vehicle to walk on the net clothes. After working with Senkott Company to create a prototype, as shown in figure 7. It is found that the cleaning and driving effect is not ideal, and the secondary deposition rate of the net clothes is fast after cleaning and difficult to observe during the cleaning process.

Scheme two: Because the front and rear rollers are easy to destroy, so adopt the crawler and propeller to drive and add the cleaning brush at the bottom, which is driven by the motor installed at the tail of the vehicle. The front and rear rollers are only used for cleaning, as shown in figure 8.

In this paper, design a new cleaning brush with lateral hard hair and bottom soft hair. When cleaning the net clothes, the brush sinks into the net clothes and the length of soft hair is lower than the bottom of the crawler, so that soft hair can have enough allowance through the net clothes and can reduce the brush damage to the net clothes. The cleaning brush completes the large area cleaning work through the lateral hard hair, its bottom soft hair can carry on the deep cleaning attachment to the net clothing. The new brush and drive way are shown in figure 9.

In view of the problems in the test of the first generation prototype, using the second solution, the second generation of net clothing cleaning underwater vehicle model was built in collaboration with Senkott Company. Through experiments, it is found that under the dual function of the main cleaning brush and the auxiliary cleaning roller, the crawler is used to replace the roller to walk on the net, cleaning and walking effects are greatly increased. The model and material object after docking with the main body are shown in figure 10.

## 2.4 Net clothes repair working module

Under the action of natural such as wind and wave flow and biological factors, cage netting is easy to be damaged, resulting in property loss. For the traditional fishery aquaculture, the fishing net is pulled to shore by the staff to repair, which is time-consuming and inefficient. Therefore, need to design an UUC that can repair the net clothing automatically under water.

In this paper, the net clothes repair working module is composed of two sets of manipulator devices, which are divided into repair manipulator and wire cutting manipulator. The two manipulators cooperate with each other to complete the repair of net clothes[17]. As shown in Figure 11, pull the wire from the upper manipulator out and clench it, and then cut it by the lower manipulator.

### 1) Repair manipulator:

As shown in figure 11's upper manipulator, it is a multi-degree-of-freedom manipulator. The front end of the manipulator claw is responsible for the knot of the net clothes. Among them, knotting is to use a kind of binding device similar to stapler to tie and fix the net clothes.

### 2) Wire cutting manipulator:

As shown in figure 11's lower manipulator, it is mainly responsible for wire cutting. The manipulator has five degrees of freedom, The wire cutting process can be completed by using these five degrees of freedom to coordinate with each other.

In the repair process, one of the most important problems is the clamping problem of the wire head, because the repair manipulator claw must be separated and closed in performing the clamping action. It is especially difficult for the underwater environment. The wire cutting work is handed over to the wire cutting manipulator, so that repair manipulator claw can be free, which can solve this problem to a certain extent. The repair manipulator need to complete two opening and closing actions in a very small space, because the size of the net mesh is about 30 mm, so the size of the mechanical claw should below 20 mm. The size of the internal actuator is limited to 12 mm \*12mm. Adopt the micro hydraulic cylinder to complete the above action.

The net clothes repair working module needs to complete the following actions, claw open—repair claw out—claw closed—complete the line fetching action—claw open—claw back—claw closed—hold the wire tight—wire cutting. Through this cycle complete the repair net clothes. Therefore, it is necessary to have a steering gear to control the closing and opening of the claw, a stepping motor to control the rotation of the wrist and a stepping motor to control the lead screw to carry out forward and retreat of the manipulator. As shown in figure 12.

If a metal bar material is to be cut off, its shear strength can be inquired by the corresponding material and is a fixed value  $M$ . The cross-sectional area of the material is  $S$  and the shear force required to cut the rod material is  $F=M*S$ . The shear force required is as long as the force of this  $F$  is reached on the shear

plane, it can be cut. This only reflects the size of the force, it has nothing to do with the sharpness degree of the cutting manipulator.

The design parameters of the net clothes repair working module are as follows:

#### 1. Wire cutting head parameters:

The material is No.45 normalizing steel, the wire cutting head size is  $l=a*b$ ;  $a=16$  mm,  $b=[0.35,0.42]$  mm;

#### 2. Working conditions of cylinder:

Inner diameter 5 mm, set the pressure as 4MPa, then the pressure is 78.5N.

#### 3. Wire clamp head parameters:

The material is No.45 normalizing steel, knurling process.

In the repair process, in the upper claw of the repair manipulator will have a nylon rope through the hole, the wire head is clamped by the claw shear block and the fixed block, then fixed in the front end of the repair manipulator. At this time, the claw is open, the lead screw slide rail system feed, and the repair manipulator is sent into the complete net mesh around the broken net mesh, as shown in figure 13, the squares in the figure are section diagrams of the repaired claws.

After entering the net mesh, the claw is closed, the wire head is loosened by the claw internal cutting wire block and the internal claw clamp wire block is clamped to complete the wire head exchange. Then the claw is opened in the same way and push the repair manipulator out of the damaged net mesh. A sewn nylon rope has been pulled out between the damaged net mesh. Then the repair claw is closed again, the repairing manipulator clamps the two nylon ropes that have been closed, and the repairing manipulator moves in the opposite direction and tighten the nylon rope. When it is tightened to the appropriate tightness, the fixing needle of the knot rope is fixed on the two nylon ropes by the repairing manipulator to complete the knot of the nylon rope, Then cut two nylon ropes at the back end of the knot by the wire cutting manipulator..

After the above work is completed, the repair manipulator internal fretting cylinder drives the claw shear block to cut the residual nylon rope wire head, and clamps the wire head again with the claw fixed block to open the next working cycle. After the docking of the net clothes repair working module and the main body, as shown in figure 14.

## 2.5 Dead fish recycling working module

In the process of marine ranching farming, the deposition of dead fish often occurs. If it can not be cleared in time, it will contaminate water, spread diseases, endanger the safety of deep-sea aquaculture

and is not conducive to the growth of other fish. At present, cage dead fish mainly adopts manual recycle, which is difficult to operate, high labor intensity and low working efficiency.

The fish will sink to the bottom of the net cage just after death and will not float on the sea until it rots, so it must be recycled before the dead fish rots. After the dead fish sink at the bottom of the cage, due to the action of the current, it will gradually gather in the corner of the net cage. Therefore, it is urgent to develop an UUV for the recycle of dead fish in net cages. In this paper, The dead fish recycle working module is docked with the main body to recycle dead fish, as shown in figure 15.

Because the dead fish pile up and gather in the corner of the bottom of the cage, the most favorable way of recycle is that the dead fish working module climbs on the bottom of the cage through the wheel or crawler. Relying on the friction with the net clothes, can achieve more stable run and higher recycle efficiency.

Based on the principle of broom and roller, the structure of slope plate (roller) and wheel (broom) is designed. The slope plate is a group of rolling bars with power, each rolling rod is covered with blunt thorns, similar to the transmission belt, the idea comes from the deep-sea mining vehicle[18-19]. The dead fish can be swept into the recycle device with the slope plate. The main structure is a set of sweeping wheel group, sweeping the dead fish into the recovery bin. The dead fish recycle working module is shown in figure 16.

The dead fish recycle module includes the slope plate transmission system, the sweeping wheel group system and recycling delivery and storage system.

#### 1. Slope plate transmission system:

Transport dead fish attached to the bottom of the net cage to the module temporary storage platform for easy recycle, mainly including slope plate, transmission rod, temporary storage platform and transmission system, as shown in figure 17. The sloping plate is a 35-degree circular slope that like a shovel to scoop up dead fish deposited in the net and send it up to the driving rod by thrust and frictional force; The transmission rod is made of nylon rod material with blunt spurs of rubber material on it to increase the friction force of the transmission. Eight transmission rods are distributed side by side to form a "track" to transport dead fish to the temporary storage platform; dead fish are cleaned periodically by the sweeping wheel group system after piling up on the temporary storage platform; the drive system is a gear drive, and the power is provided by the motor. The top drive rod is driven by the synchronous drive belt, and the idler gear transmits the power to make each drive rod move at the same speed and direction.

#### 2. Sweep wheel group system:

It consists of 24 special sweeping wheels fixed to a drive shaft by screws, as shown in figure 18. The drive shaft is a metal aluminum shaft which can effectively guarantee the strength. The power is provided by a waterproof motor through a bevel gear reducer. By controlling the rotation of the sweeping

wheel group, the dead fish collected from the slope plate transmission rod system is swept to the storage bin to realize the recycle of dead fish.

### 3. Recycle delivery and storage system:

It includes storage bin, transmission rods and transmission systems. as shown in Figure 19. The sweeping wheel group system sweeps dead fish into the storage bin. Due to gravity, dead fish will pile up on the edge of the transmission rods, so it is necessary for the transmission system to transport the dead fish to the deep in storage bin and maximize the use of storage space. The principle of transmission rod and transmission system is the same as that of slope plate transmission system.

The dead fish recycle working module docked with the main body to form dead fish recycle module vehicle in marine ranching, as shown in figure 20.

## 3. Design And Theory Of Docking Module

According to the whole and local relationship, modular underwater vehicle docking system for marine ranch is divided into main body and module docking with workstation and main body docking with working module. According to the characteristics, it is divided into structure docking and hardware docking. The hardware docking needs to do underwater insertion interface to complete insulation insertion which is very difficult. In this paper, solve the problem of underwater insertion interface. Next, the structure docking is described.

### 3.1 Docking module with underwater workstation

In order to realize the modular underwater vehicle system of unmanned intelligent marine ranching, it is necessary to have an underwater workstation platform. The workstation is the core of the system, transmits information to main body and modules for easy control, interaction with people on shore, vehicle power supply[20]. The workstation platform schematic diagram is shown in Figure 21.

1 is the main body warehouse, 2 is the substitution of main body, 3 is the module warehouse, and 4 is the vehicle lifting platform.

The three modules are placed in the module warehouse separately, and the interior of the warehouse can be rotated to realize the docking of the corresponding module with the main body. The workstation can store the module and realize wireless charging for the main body and the working module.

#### (1)Scheme 1: Lift type underwater workstation

When want realize certain function, the module bin is transferred to the corresponding module and aligned with the bottom of the lifting platform. The main body is located in the lifting board up and down to realize the docking, as shown in figure 22.

## (2) Scheme two: guide rail type workstation

The main body moves to the original docking position through sliding guide rail outside the module warehouse and then opens the module docking door to achieve docking, as shown in figure 23.

Because the first scheme is too complex and the positioning accuracy and navigation ability need to be especially high. Meantime, the main body needs to rise to the lifting board first, there is too much energy loss, so the second scheme is more suitable.

## 3.2 Docking module between main body and working module

Next, study the docking device between the main body and the working module. The traditional docking is realized by twisting bolts on the bottom of the main body and the top of working module. The stability is too weak, not firm and inaccurate, easy to separate and oscillate. It has a great influence on the motion accuracy of the vehicle. Therefore, this paper designed a new type of hydraulic pinhole type docking device for the modular underwater vehicle system of marine ranch.

It is composed of male head and female head. Male head composed of inner ring sleeve and outer ring sleeve and magnetic pole. As shown in figure 24, cut holes in the appropriate locations on the inner ring sleeve and install cap spring pins. When pushing the outer ring sleeve, two rings of cap spring pins on the inner ring sleeve are pressed into the first ring pin groove of the male head and the second ring pin groove of the female head under the action of the inner wall of the outer ring sleeve to realize the docking of the main body and the working module[21-22].

The inner wall of the outer ring sleeve and the cap spring pins together form a moving cam mechanism. The internal section of the male head is shown in the figure 25. In order to ensure that the outer ring sleeve in the process of pushing gently and no impact, it is necessary to ensure that the acceleration curve of the movement of the caped spring pin (cam follower) is smooth and no step, so the inner wall of the outer ring sleeve along the axial profile curve is designed as a quintic function curve, as shown in figure 26. Formula is as follows:

$$s(x) = h(10 \cdot (\frac{x}{a})^3 - 15 (\frac{x}{a})^4 + 6 (\frac{x}{a})^5)$$

Figure 27 shows the docking process and principle. When the main body and module begin to dock, firstly make the female head and the male head are coaxial, then through the male head magnetic pole on the main body and the female head magnetic pole on the module magnetic opposite phase for pre-docking. Then the docking device is operational, and the inner ring sleeve is pushed to the limit position in the direction of the female head by first oil-way. At this time, two rings of cap spring pins on the inner ring sleeve are pressed into the first ring pin groove of the male head and the second ring pin groove of the

female head, then pushing the outer ring sleeve by second oil-way, pressing the cap spring pins into the corresponding pin card slots on the magnetic poles of the male and female heads under the action of the inner walls of the outer ring sleeve.

When the connection is disconnected, the outer ring sleeve is pushed back, and the pin exits the pin card slot of the male and female magnetic poles under the action of the spring.

By adding a hydraulic hood and hydraulic valve wall inside the docking device, then open oil routes at specific locations of the male base, hydraulic hood and hydraulic valve walls. By means of hydraulic transmission, the pressure of oil is converted into mechanical energy to implement the above process by pushing the piston.

In this paper, adopts hydraulic type to realize the docking of the main body and working module.

## 4. Conclusions

This paper introduces the working modules of marine ranching underwater vehicle for net clothes clean, net clothes repair, dead fish recycle and the main body. Then introduces docking of main body with module and main body, module with underwater workstation. For the above marine ranching underwater module vehicle, main body equipped with floating material to achieve balance with gravity and buoyancy, it also should be realized for each working module.

1. In the net clothes cleaning module, although the increase of disc brush greatly improves the cleaning efficiency, but there is still a problem of the Image blur. When module vehicle clean the net clothes, plankton, water grass and other attachments seriously interfere with the image effect of the camera, which can not be improved by image repair, image enhancement and other image processing technology, so need to further improve the net clothes cleaning working module's structure.
2. In the net clothes repairing module, through the cooperation between the repair manipulator and the cutting manipulator, solved the biggest problem in the net clothes repair, then can use to maintain the cages at marine ranching. Solve the problem of serious production reduction caused by the escape of breeding organisms from the holes in the cage in time. At present, net clothes repair only exists in theoretical analysis, this paper lays the foundation for the further development of the net clothes repair underwater vehicle.
3. In the dead fish recycling module, The main innovation is to design a transport transmission system, including the structure of the transmission rod, which can transport the dead fish from the bottom of the net clothes to the temporary storage platform. The difficulty of the recycle device is how to recover the dead fish without destroying the fish body. This may require experiments or data to illustrate the problem. In addition, how to bring the dead fish from the bottom of the cage to the height that the recycle device can recycle — that is, the design of the slope plate, is also a difficult point. Use the form of similar drive belt (transmission rod) to raise the dead fish from the bottom of the cage to complete recycle.

4. In the docking device, In this paper, a new type of hydraulic pin docking type device is proposed for the docking between the main body and the working module. Multiple positioning and multiple locking can be realized through the inner and outer ring sleeve, base and magnetic pole, which can avoid the instability and vibration caused by the unstable docking between the main body and the working module of the modular underwater robot, and avoid the serious decline of the movement effect.

5. In the underwater workstation, In this paper, present two types of docking with underwater workstation, lifting table type and sliding guide rail type. A manipulator fault diagnosis system may be added to the workstation in the future. When the main body and the three working modules reach the workstation, them not only can charge by wireless, but the module can be diagnosed by data transmission and repaired by the manipulator.

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The datasets supporting the conclusions of this article are included within the article.

### **Authors' contributions**

The author' contributions are as follows: ZhongRen-Zhang was in charge of the whole trial; ZhongRen-Zhang wrote the manuscript; ZhongRen-Zhang assisted with sampling and laboratory analyses.

### **Competing interests**

The authors declare no competing financial interests.

### **Consent for publication**

Not applicable

# Ethics approval and consent to participate

Not applicable

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## Figures



Figure 1

Canadian "DTX2ROV" underwater vehicle

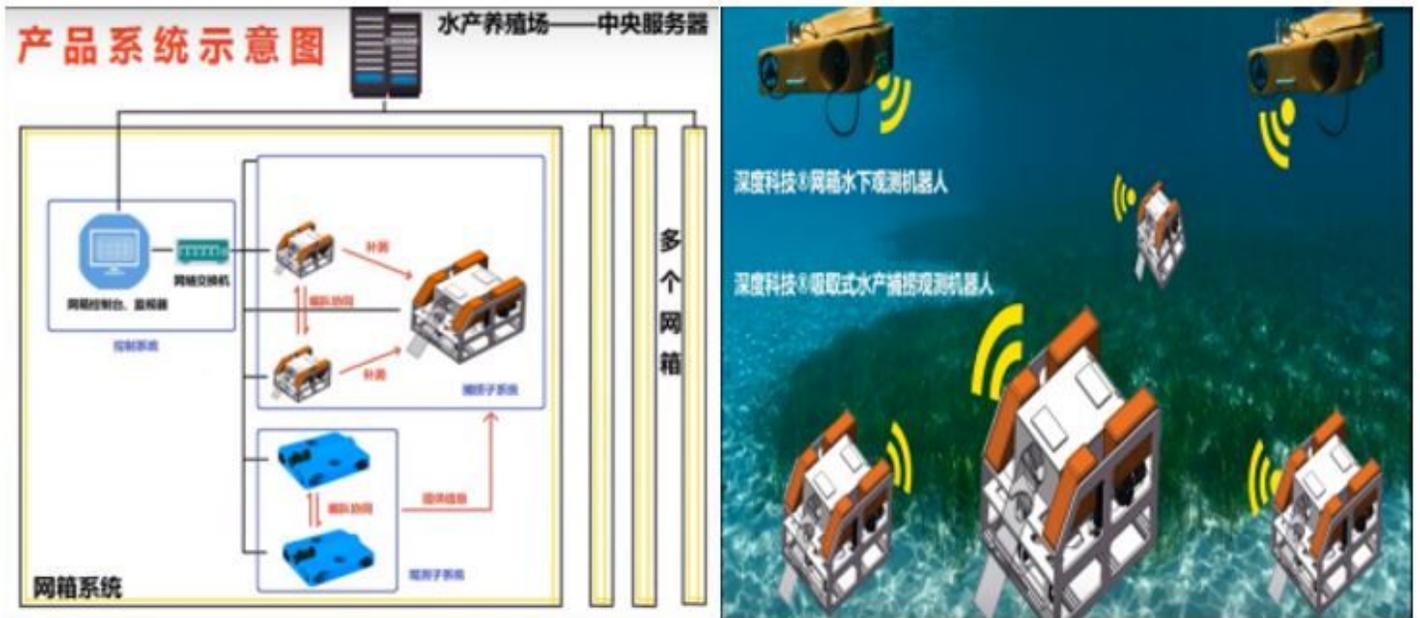


Figure 2

"Intelligent Ocean Ranch" UUV system

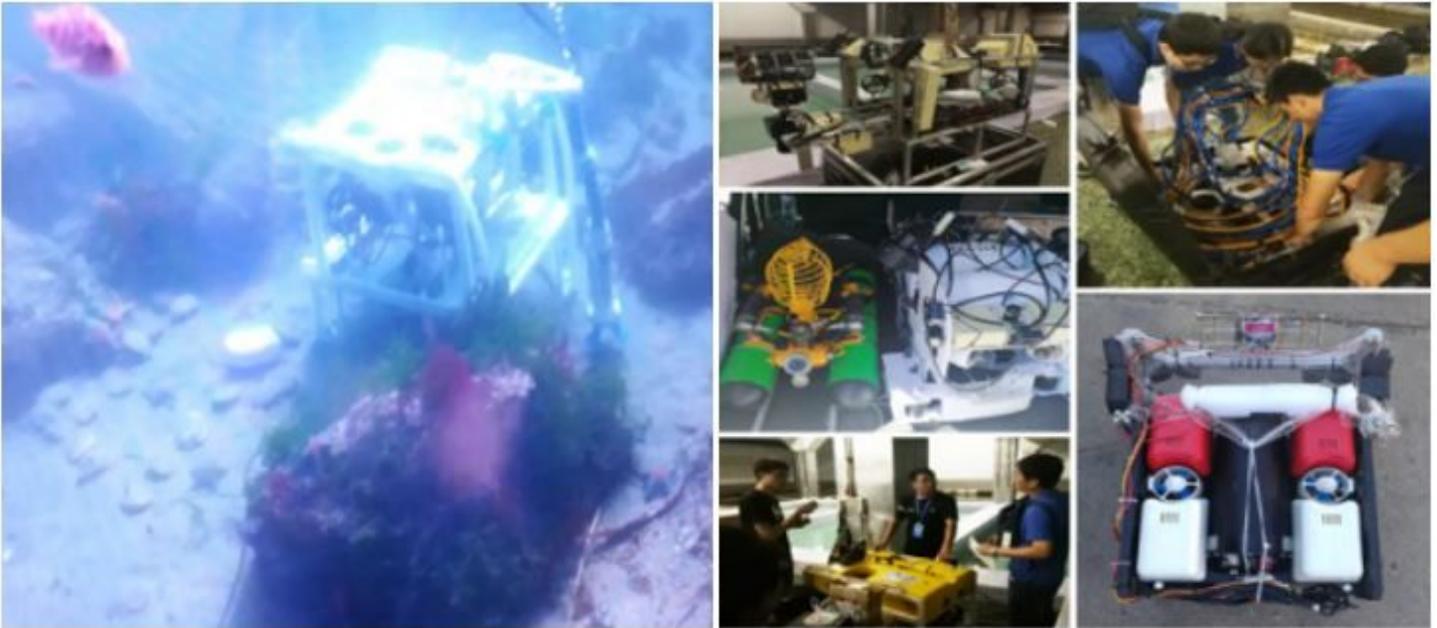


Figure 3

Marine ranch underwater vehicle competition

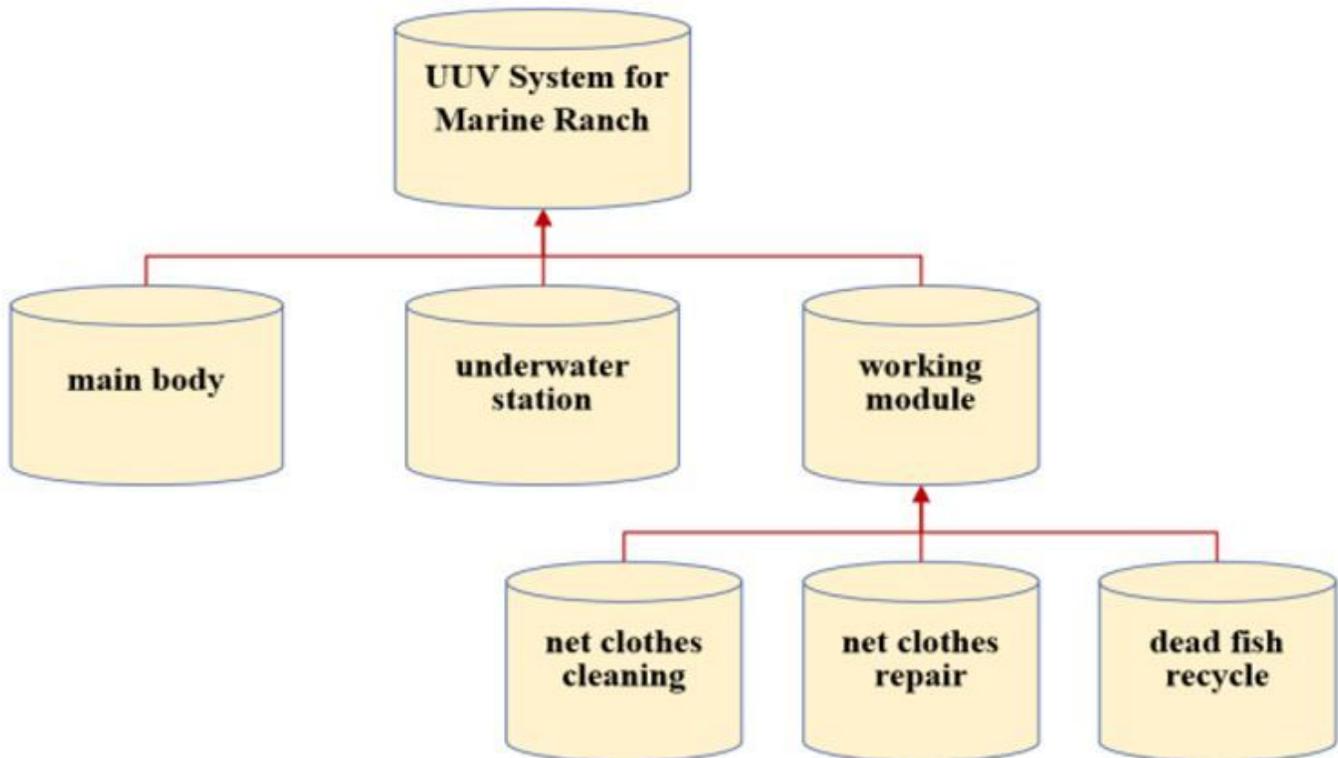


Figure 4

Modular UUV System for Marine Ranch

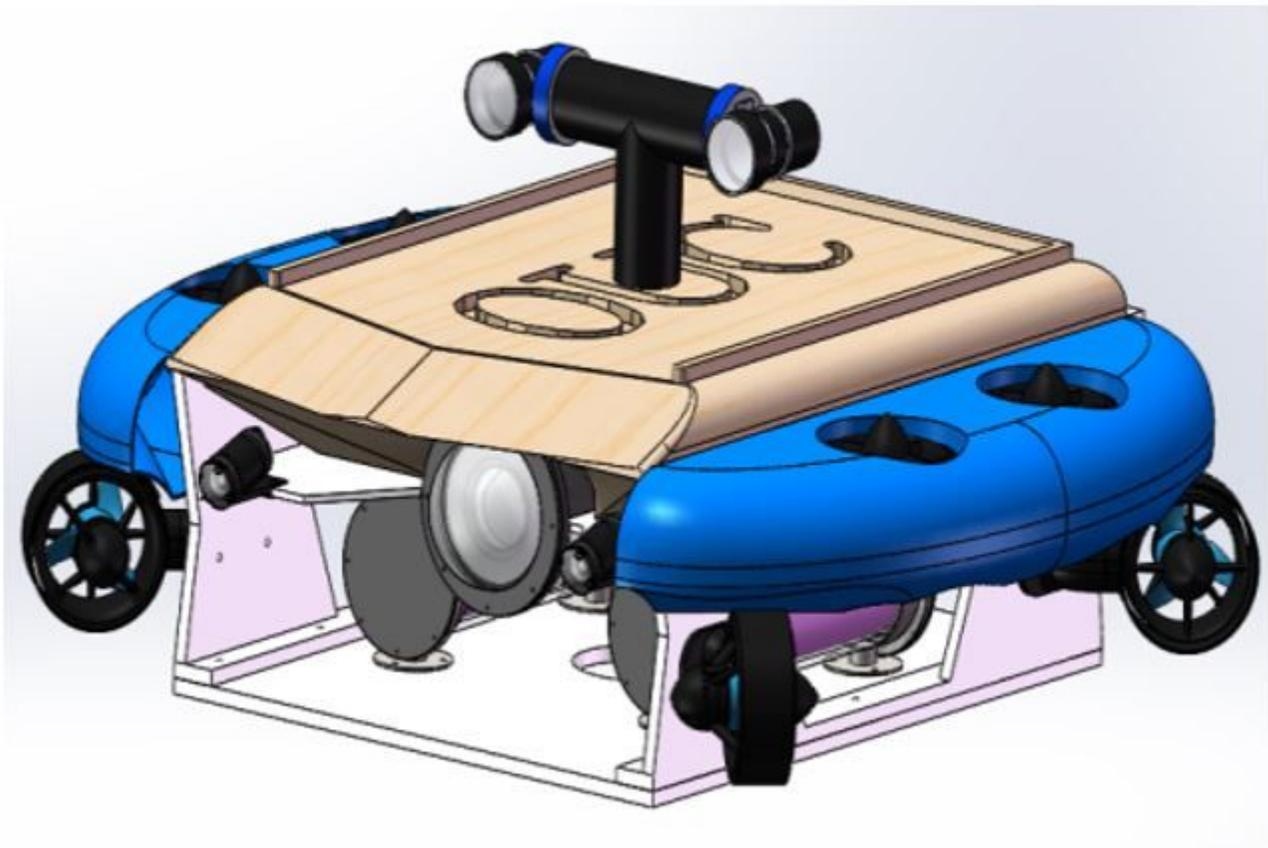


Figure 5

Modular underwater vehicle main body

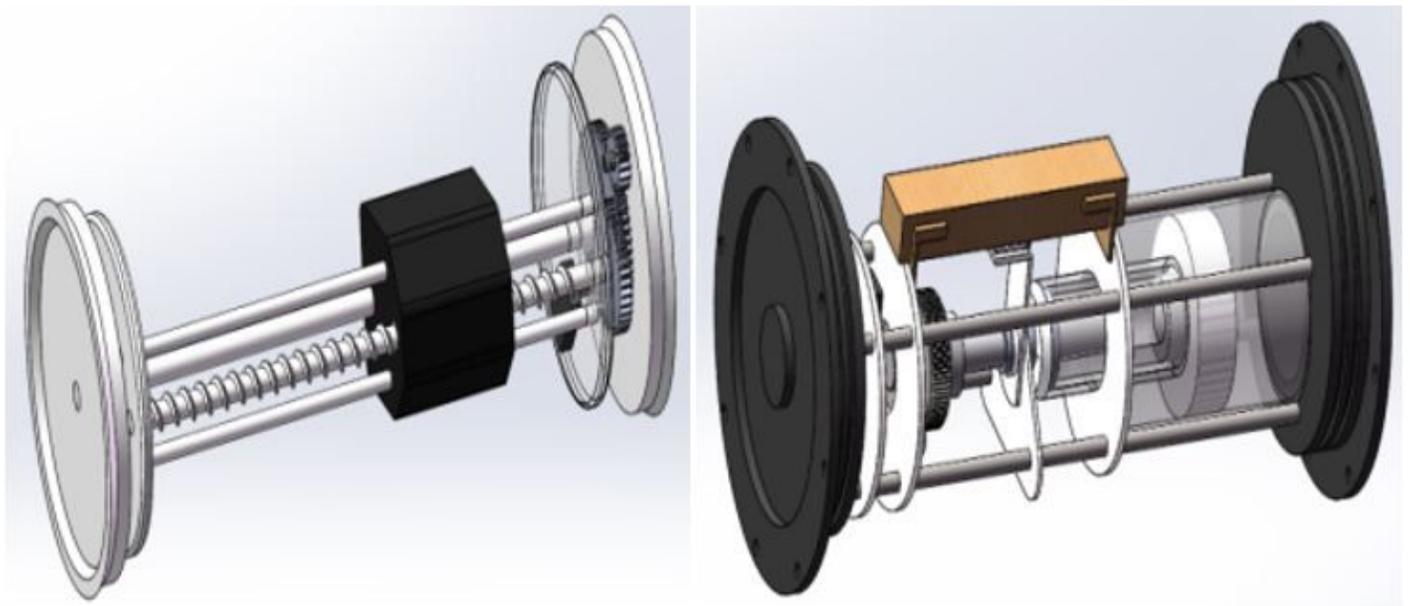


Figure 6

Barycenter regulator and floating center regulator

Figure 7

Scheme 1 net clothing cleaning module and prototype

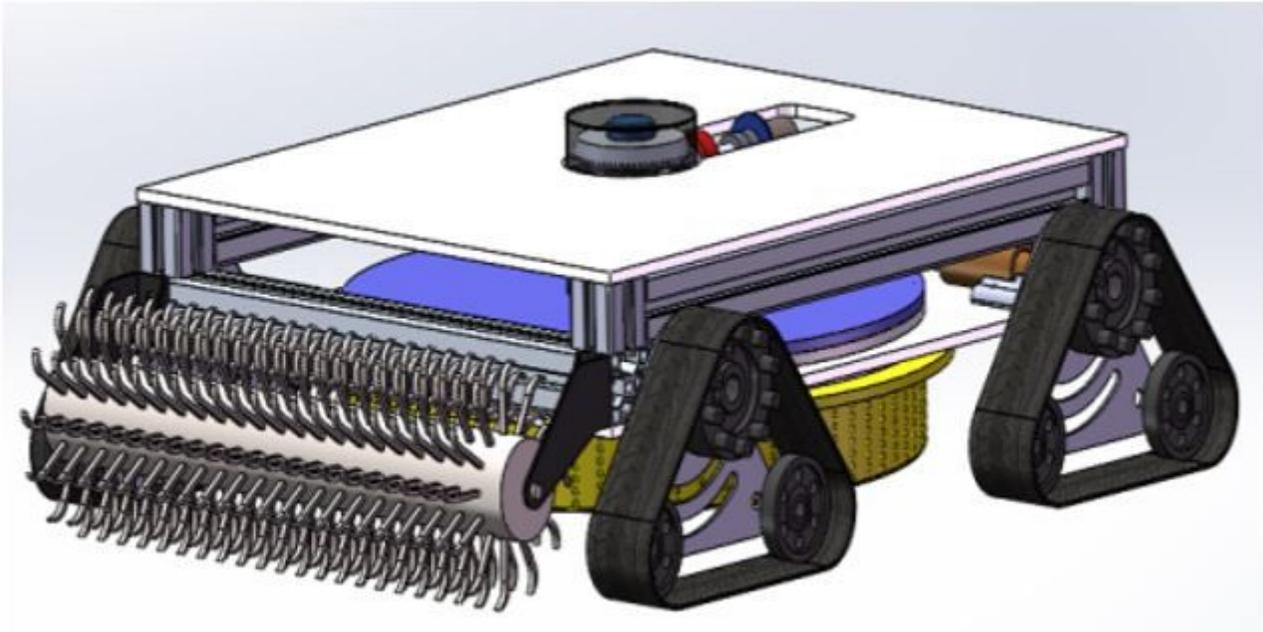
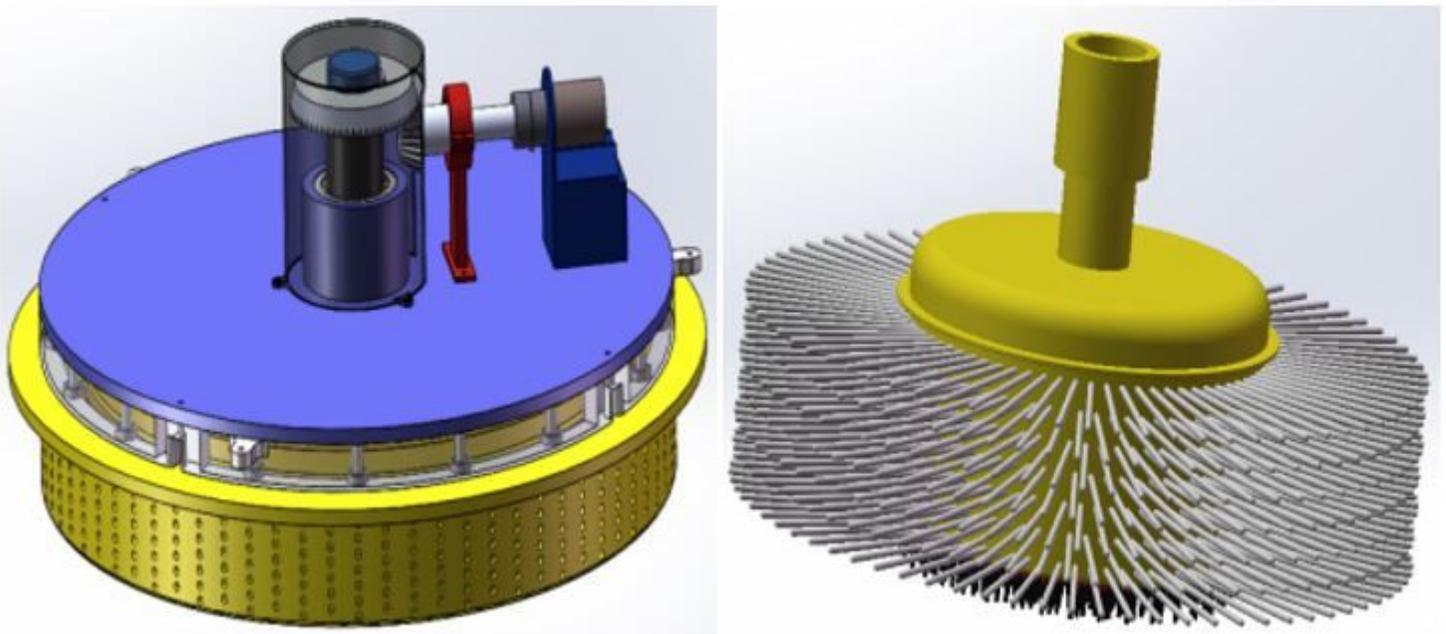


Figure 8

Scheme 2 Net clothing cleaning working module



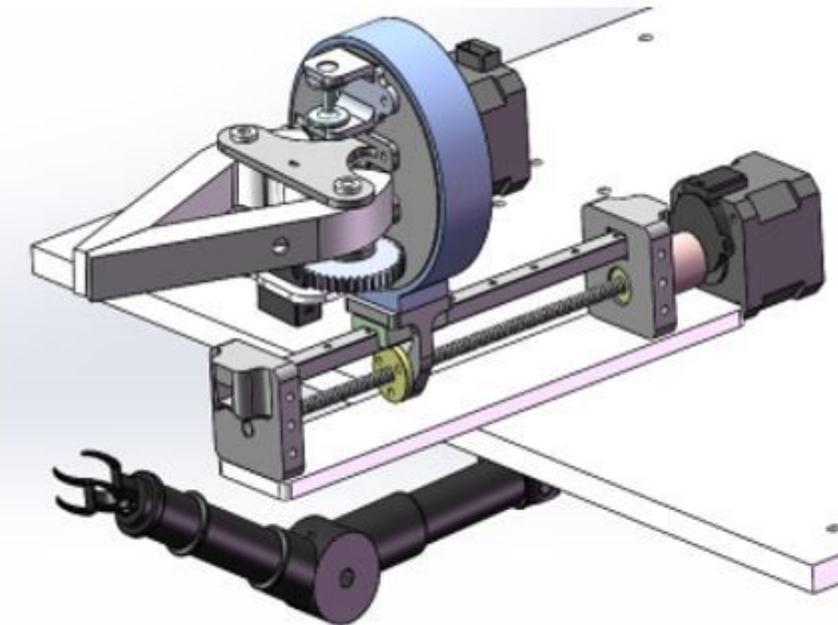
**Figure 9**

The new brush and drive way



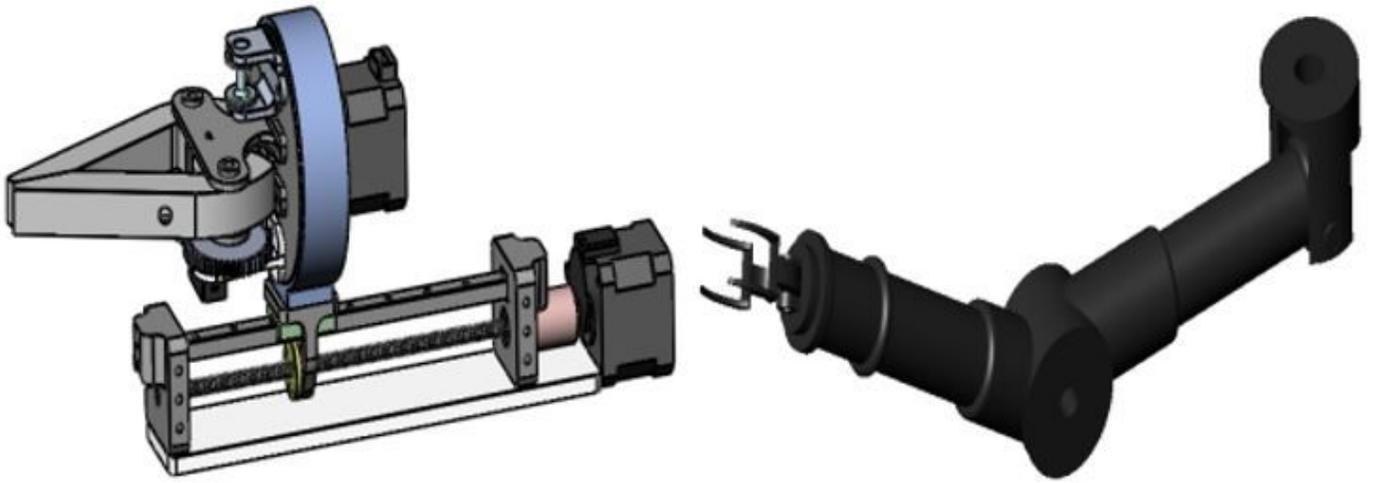
**Figure 10**

Scheme 2 net clothing cleaning module and prototype



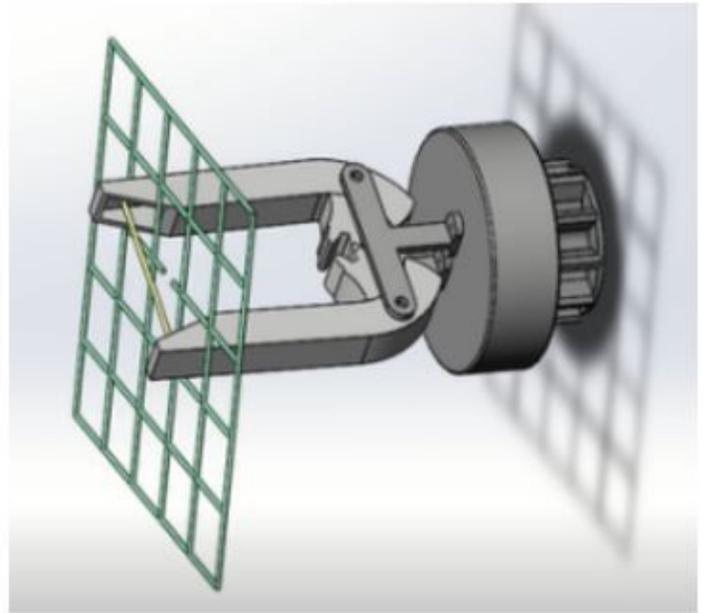
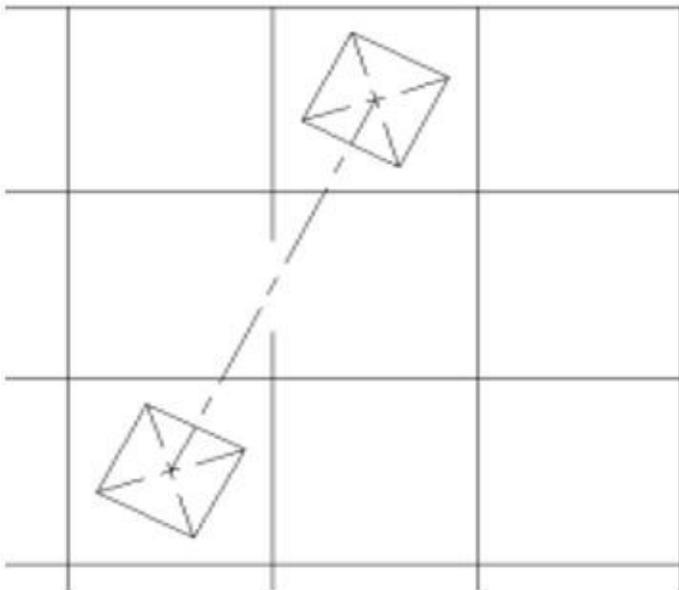
**Figure 11**

Net clothes repair working module



**Figure 12**

Repair and wire cutting manipulator



**Figure 13**

Net clothing damage repair diagram

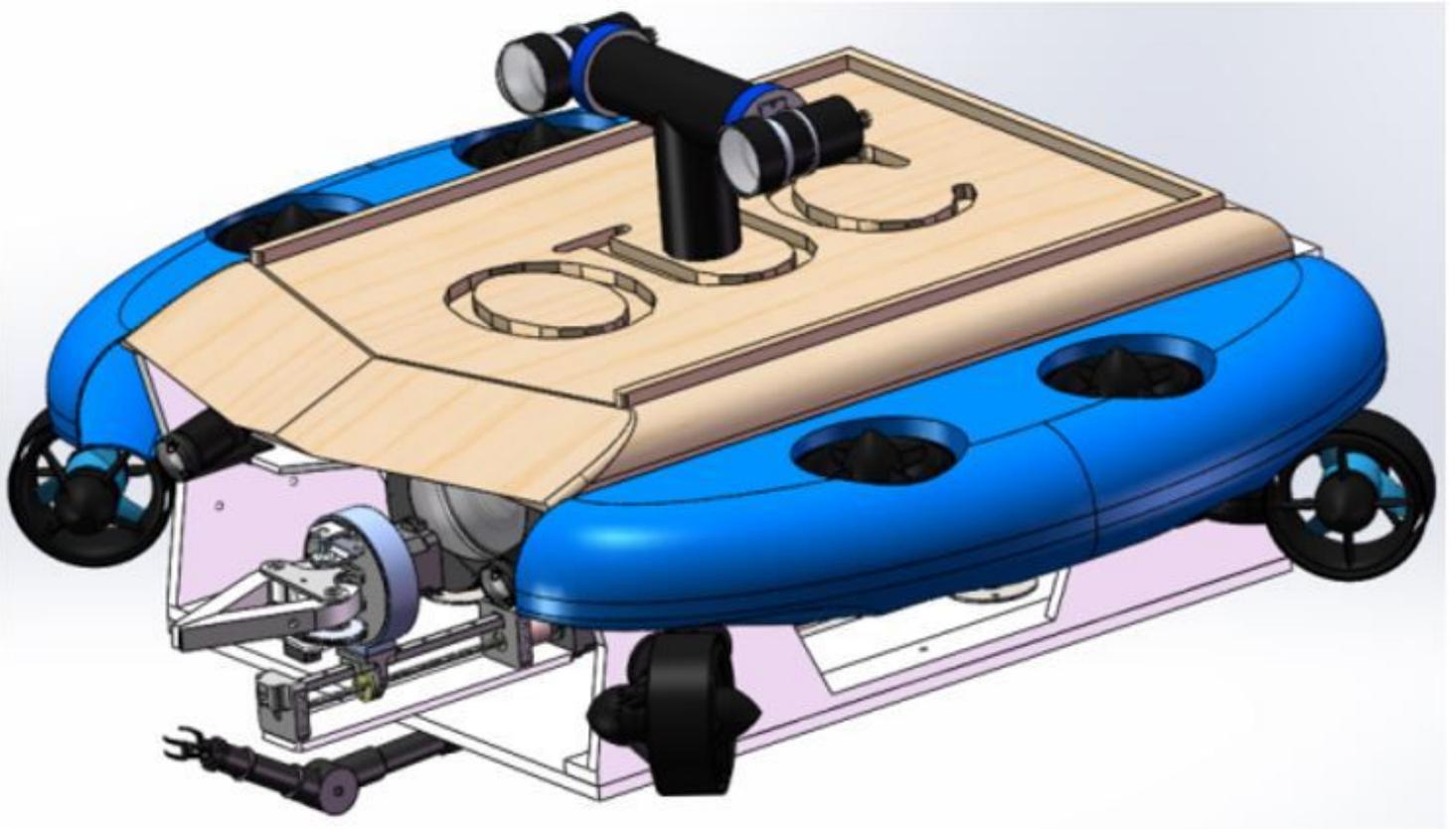
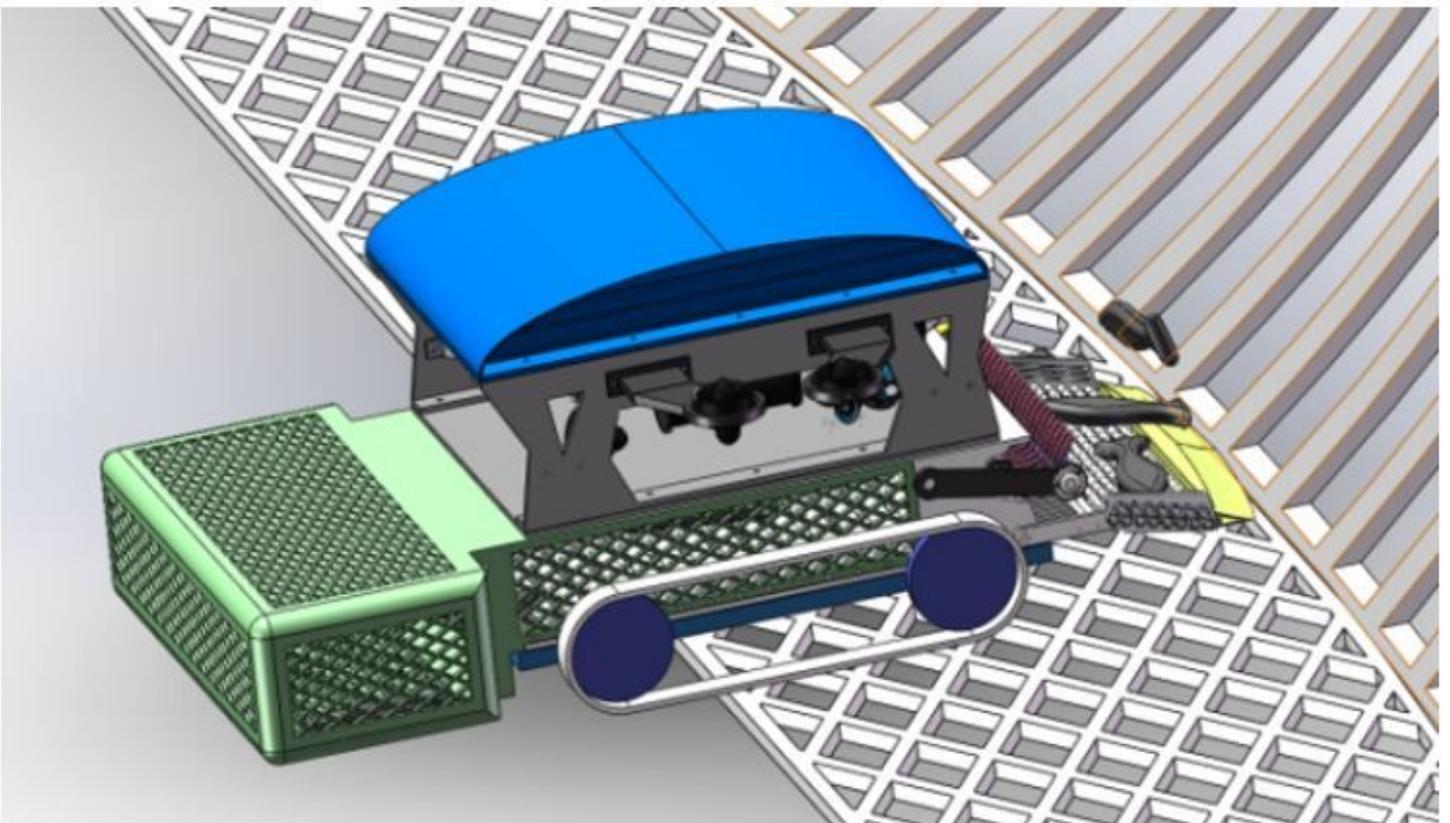


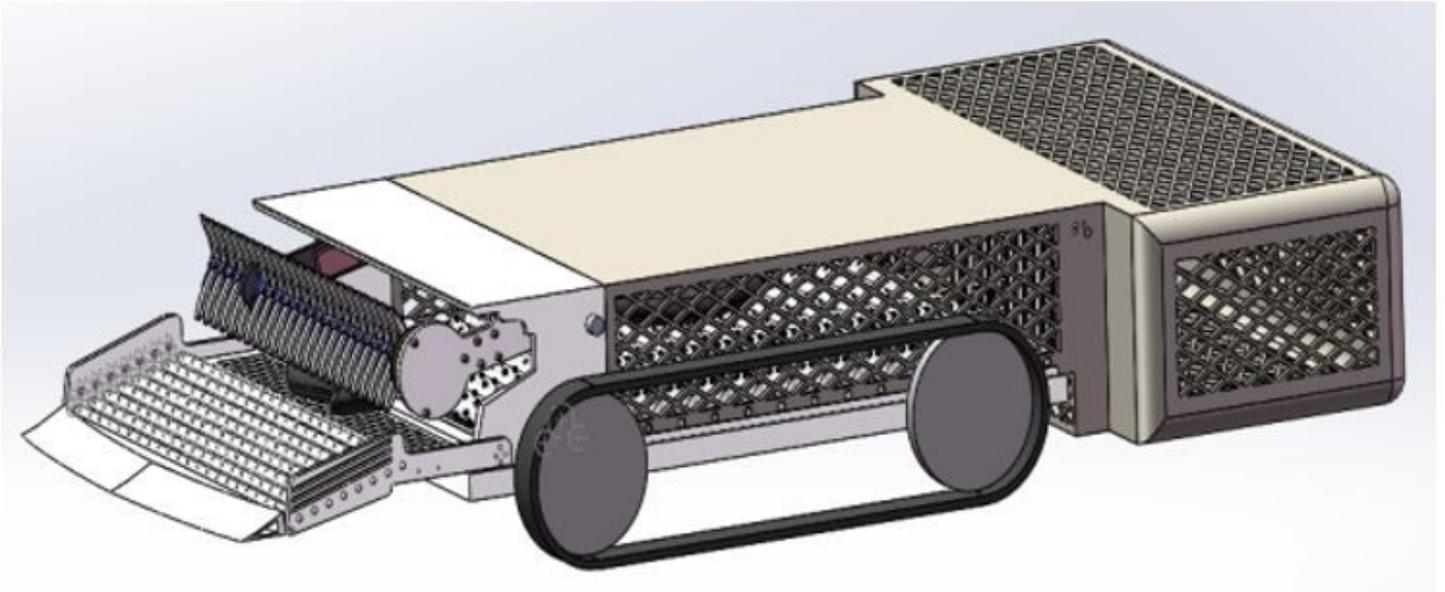
Figure 14

Net clothes repair underwater vehicle



**Figure 15**

Dead fish recycle modular underwater vehicle



**Figure 16**

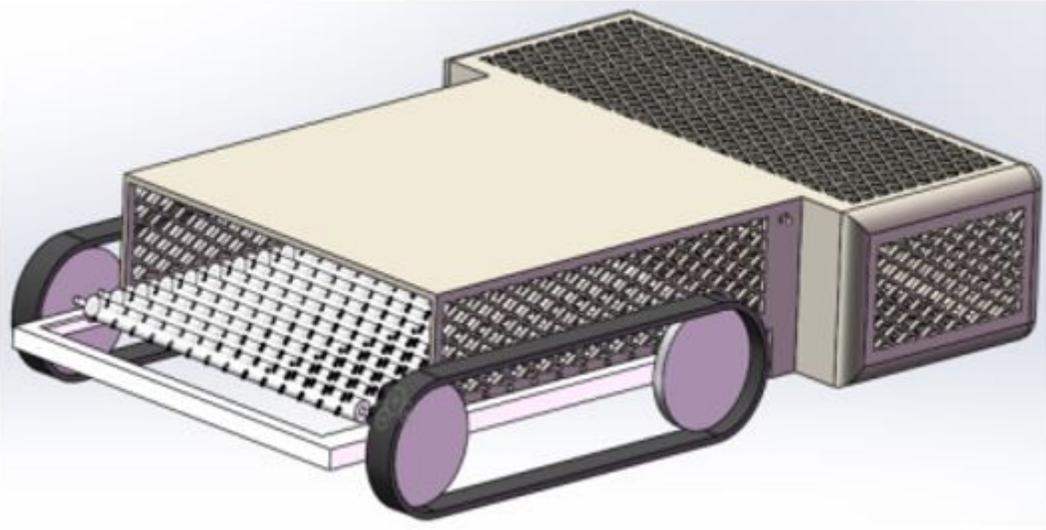
The dead fish recycle working module

**Figure 17**

Slope plate drive system

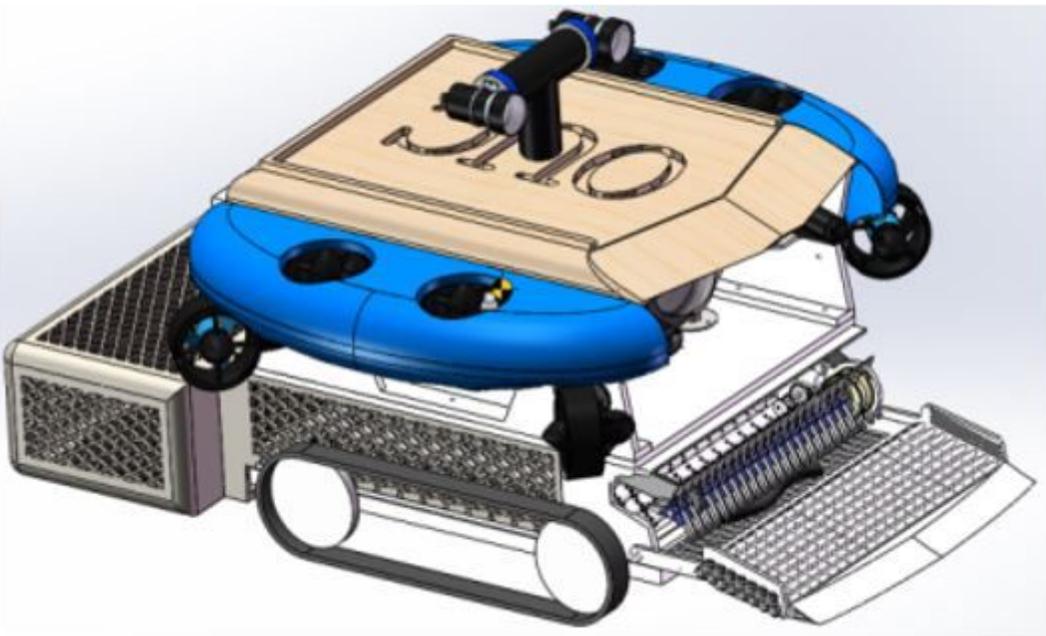
**Figure 18**

Sweep wheel group system



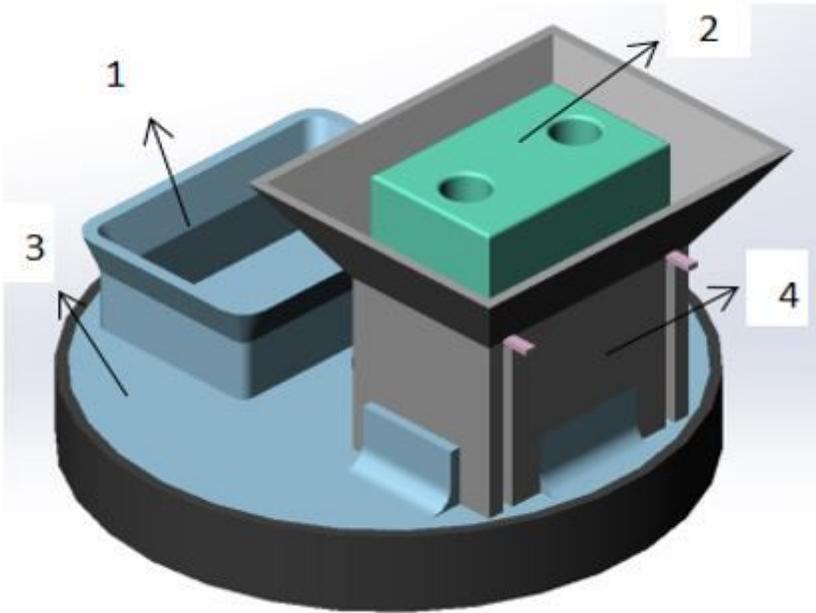
**Figure 19**

Recycle delivery and storage system



**Figure 20**

Dead Fish recycle module vehicle

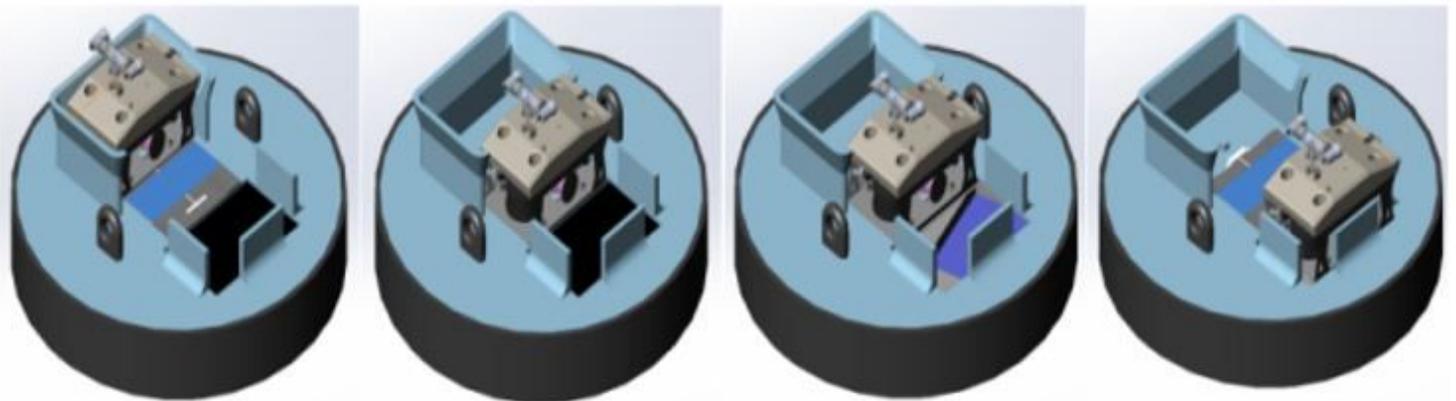


**Figure 21**

The underwater workstation schematic diagram

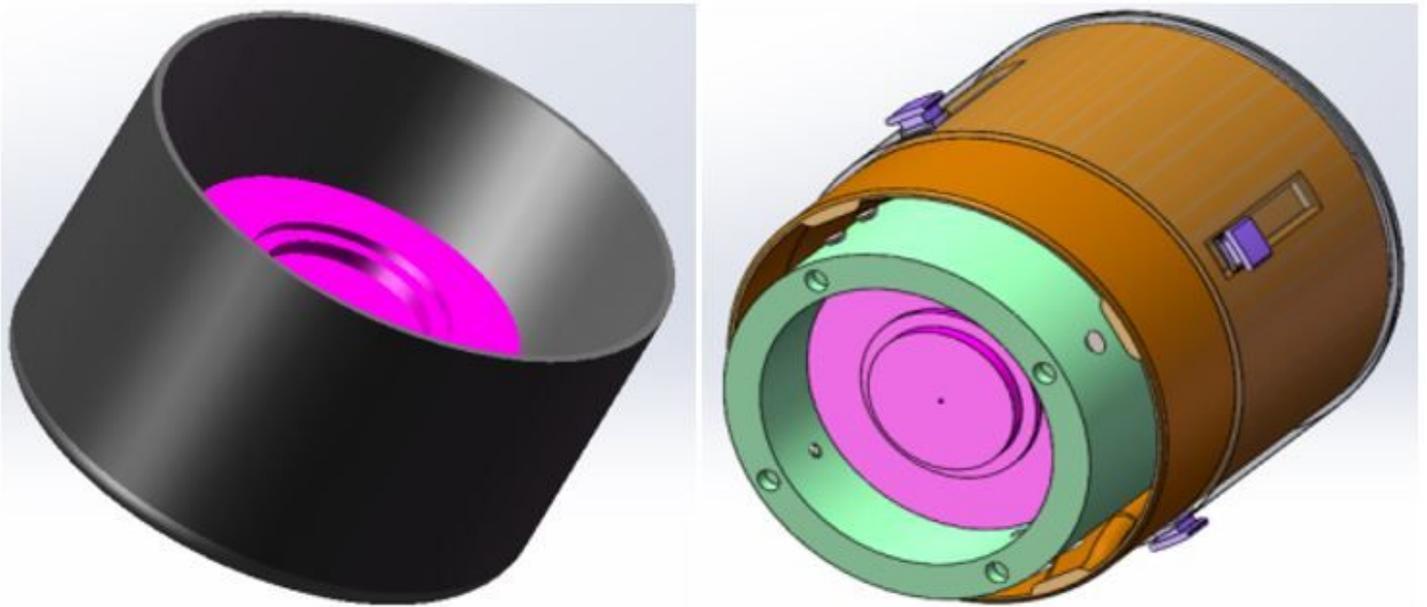
**Figure 22**

Lift type underwater workstation



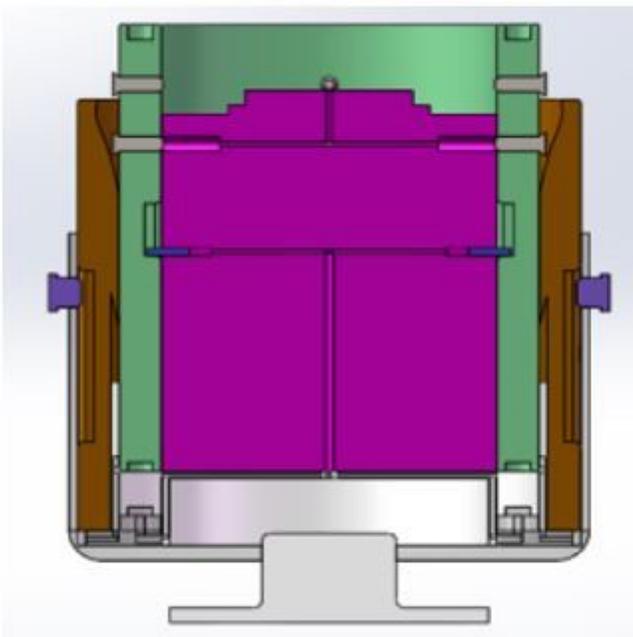
**Figure 23**

Guide rail type workstation



**Figure 24**

Hydraulic docking device male head and female head



**Figure 25**

The internal section of the male head

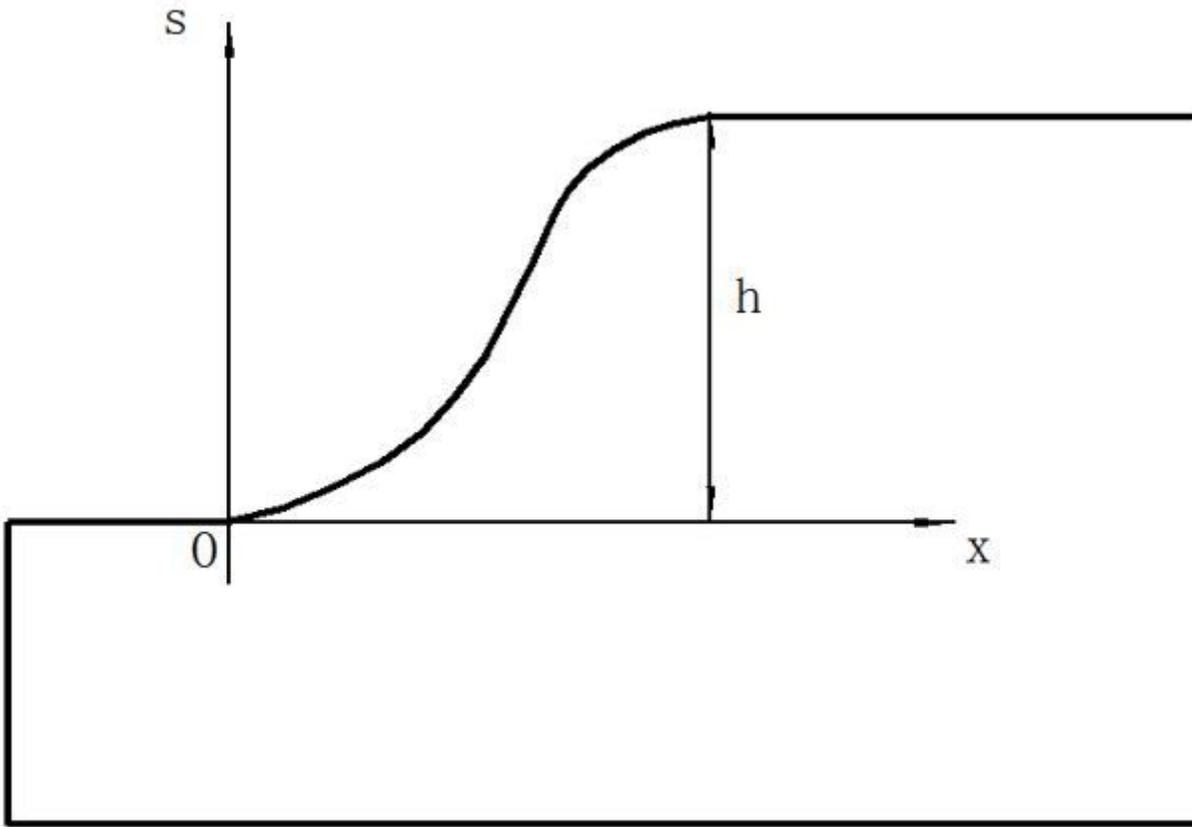
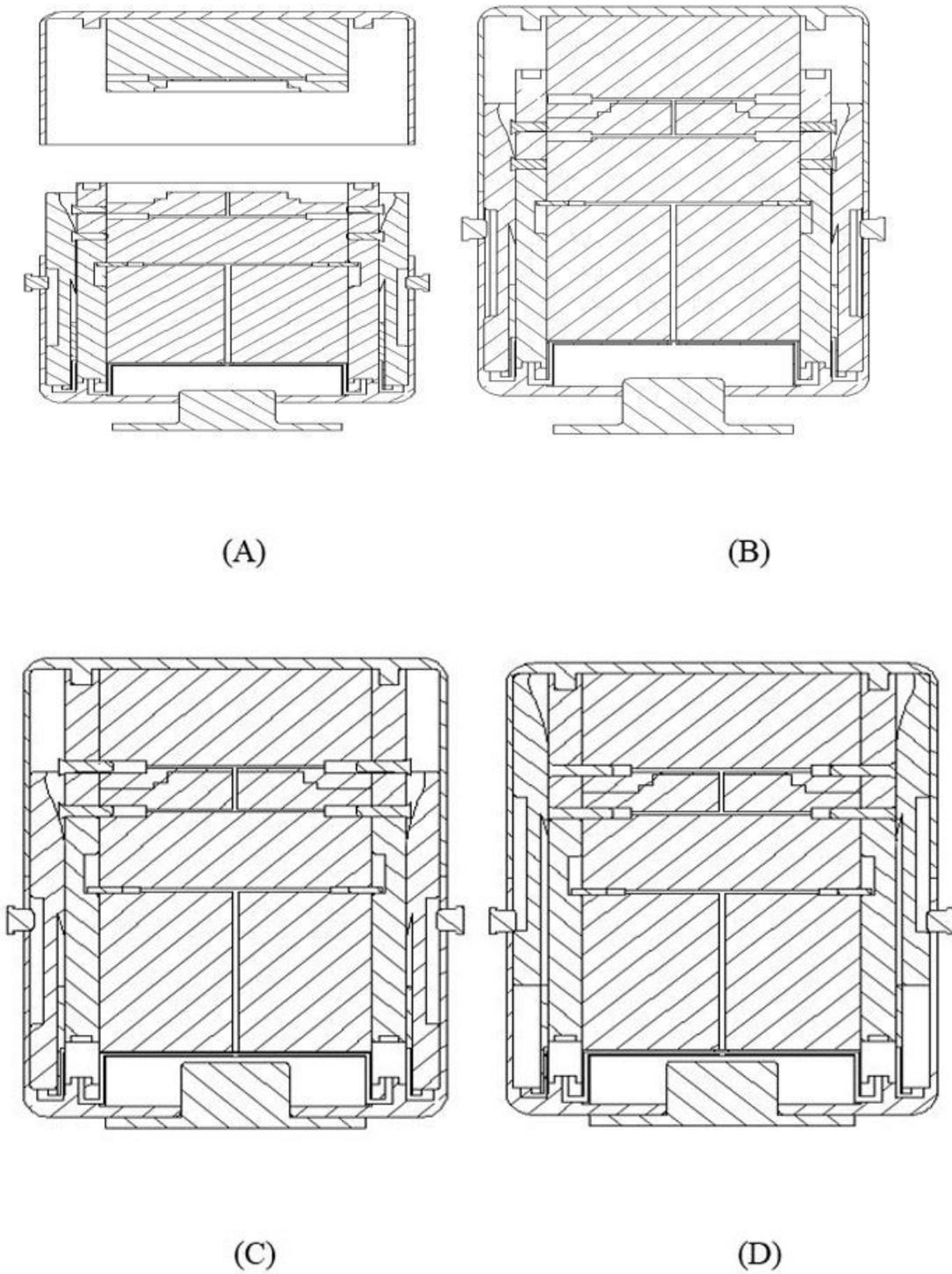


Figure 26

Outer ring sleeve quintic polynomial inner wall



**Figure 27**

A) male and female heads were coaxial B) magnetic electrode phase adsorption C) push the inner ring sleeve to the limit position D) push the outer ring sleeve to the limit position Docking process of hydraulic docking device