Seafloor observatory capable of automatically adjusting attitude and maintaining the fixed position for observation

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Abstract

Seafloor observatory are becoming more and more important in multidisciplinary observations of the seabed, but real-time, long-term and fixed locations observation are still difficult to achieve. This paper describes a new technology that divides the seafloor observatory into three modules: mobile docker, scientific instrument cabin and in-situ gravity station and uses buoys or photoelectric composite cables to meet the above three requirements. After design and manufacture, the workflow of the seafloor observatory was simulated through a pool test. The handling performance of the mobile docker, the reliability of the docking between the three modules and the performance of the in-situ gravity station to adjust its attitude were proved. It has been preliminarily proved that this seafloor observatory has application value.

1 Introduction

With the continuous exploration of the deep sea by human beings, the development of seafloor observation systems and related technical equipment is also accelerating[1]. Deep sea observation systems are of great significance for research on major marine scientific issues, marine economic development, marine technology and marine engineering issues, disaster and environmental prevention and protection, navigation, and defense and military [2-4]. At present, observation methods mainly include satellite observation, aerial observation, marine survey ship, buoy, ROV, AUV, and submarine observation network[5, 6]. Among them, the submarine observation network has gradually become the third platform for observing ocean and earth processes. Because it can observe directly on the seafloor, it can be more directly applied to marine environmental monitoring and will become one of the main observation methods for understanding and predicting ocean processes in the future[7]. In the submarine observing network, the seafloor observatory plays a pivotal role in the entire network node. Seafloor observatory can overcome the limitations of traditional survey-based ships in collecting samples and can also meet near real-time and real-time data communication. It can also promote research in marine, climate sciences and seafloor observatories represent the latest technological advances in earth sciences[8].

The United States, Canada, Europe, Japan and various other regions as well as many plans for ocean observations. The United States has established observatories such as LEO-15, MARS, OOI-RSN, and ACO since the early days of seafloor observations [1, 9-12]. The goal of MARS is to provide the United States Ocean Observatories Initiative (OOI) with the test foundation, test new scientific instruments and sensor technologies and test the ability of ROV to maintain, deploy, and recover. OOI-RSN is part of the OOI. Its structure is a quadrangular platform. It can be equipped with seismic sensors, acoustic and environmental sensors (including ocean current meters, temperature and pressure sensors). As an infrastructure, ACO mainly uses abandoned transoceanic communication cables to observe the water properties, underwater camera and acoustic characteristics of the deep ocean (4726m), so as to study the biological, physical and chemical dynamics of the deep sea plain over time[9, 13].

The Canadian Cabled Submarine Observation Network is primarily responsible and managed by the Canadian Ocean Network (ONC). At present, it has established and operates 2 cabled submarine observation networks: NEPTUNE and VENUS [14, 15]. NEPTUNE is the world's first multi-node cable seafloor observatory [16, 17]. It can carry Temperature-salt depth meter (CTD), dissolved oxygen sensor, underwater total dissolved gas pressure meter (GTD), echo vocoder, sea current meter, high-definition video camera, turbidimeter, acoustic Doppler current profiler (ADCP), hydrophones, coastal marine applications radar, etc [18]. NEPTUNE has been used for various scientific observations, such as gas hydrate [19]. VENUS is connected to underwater scientific nodes through shore base stations and transmits data to the University of Victoria Data and Management Archives Center through shore stations [20]. The main observations are the circulation process, exchange process, zooplankton dynamics, deep water cycle, plagiarism and ocean currents in the Georgia Strait estuary [21].

Earthquake research scientists at the University of Tokyo in Japan established the ocean bottom cabled seismometer (OBCS) on the Pacific Rim cable, which mainly monitors seismic activity and tsunami at the sea level near the source area [22, 23]. The sensor can be upgraded or replaced through the underwater mateable connector (UMC). Provided a submarine early warning device for earthquakes and tsunami in the southern waters of Japan, realizing high-precision, wide-band real-time monitoring of earthquakes in the eastern waters of Japan [24].

Led by the United States, Canada, and Japan, European countries have also begun to establish their own deep-sea observatory, GEOSTAR [8]. GEOSTAR is the result of the joint efforts of scientists and industrial companies from Italy, Germany, and France with the support of the European Union [25]. The main purpose is to collect important data about offshore earthquakes, submarine volcanic disasters, magnetic field changes, water cycles and regional characteristics [26]. It is divided into two parts: mobile docker and bottom station. The instruments used for scientific observation are installed in the bottom station. The station is deployed and recovered through ROV, and the expected working time is 3-5 years. NEMO-SN-1 is Europe's first submarine real-time cabled observation station [27]. Its structure is similar to GEOSTAR, and it is mainly used for earthquake, marine physics, and ocean monitoring. It can be equipped with 3-C broadband seismometer, Hydrophone, Gravity meter, Scalar magnetometer, 3-C single point current meter, and CTD [28]. Many countries have also developed autonomous landing systems. The Netherlands has developed the bottom landing system "BoBo Lander" [29]. The British developed the "Dobo Lander" and "Bathysnap", which are mobile landing systems and bottom landing systems. Germany develops mobile landing system "Modular Lander" [7].

One of the main obstacles of obtaining the accuracy data is the seafloor observatory hard to stay in place due to the complexity of the seafloor. This article divides the seafloor observatory into three modules, the purpose is to enable the seafloor observatory to perform long-term real-time observation at a fixed position. Section 1 briefly introduces the research progress of seafloor observatory in different countries, and section 2 introduces the requirements and design schemes for seafloor observatory based on fixed observations, long-term observations and real-time observations. Section 3 introduces the structure and function of the three modules and the workflow of deployment and recycling. Section 4 introduces the pool test on the seafloor observatory, verifies the control performance of ROV and the reliability of the docking of the three modules, and then draws conclusions in section 5.

2 The Project Design

The observation requirements require us to focus on three aspects when designing the seafloor observatory: how seafloor observatories fix observations on the seafloor, how to achieve long-term observations, and how to achieve real-time observations. Explained separately below:

Fixed observation means that the seafloor observatories can always stay in the same position when observing. There are two methods can be adopted: piling or automatic leveling of the bottom station. If the piling scheme is adopted, although the bottom station can be more stable, it is not easy to recover and maintain, and it can only be discarded after use. If the automatic leveling method of the bottom station is adopted, it is easier to put the bottom station into the ocean floor, and it is also possible to maintain the same position for accurate measurement. If the posture of the bottom station changed due to factors such as ocean currents, the posture can be adjusted in time by the adjustment device. In addition, bottom station can be recycled and maintained, put into use again, reducing costs.

Long-term observations meaning that seafloor observatories can observe at the same location for 10 to 20 years. Because the instruments in the scientific payload need to be maintained and replaced after a period of use, they cannot be continuously operated for 10 to 20 years, otherwise the observation accuracy will be affected. So after 3-5 years of observations, the scientific payload module will be recovered to collect data and maintain instruments. In order to achieve the desired goal, it is necessary to consider the situation of repeating the recycling plan. Therefore, the bottom station is divided into two modules, namely the scientific payload module and the in-situ gravity station module. These two modules can be separated and connected, and only scientific payload is available for recycling.

Real-time observation means that ground stations can receive observation data at almost the same time. This can be achieved using photovoltaic composite cables and sea buoys. The data accepted by sea buoy can be transmitted to the satellite, and then the ground station will receive the data. The photoelectric composite cable has a fast transmission speed and is relatively stable, but the cost is higher if it is observed in the ocean. The buoy on the sea can transmit data to the satellite, and then receive the data from the bottom receiving station. This method can perform real-time observation in the open sea. It is better than the photoelectric composite cable, but with the development of technology, through the seafloor observatory - buoy - satellite - ground station works to stabilize data transmission. In combination, for real-time observation, photoelectric composite cables can be used offshore and buoys can be used far out to sea. This way can not only realize the function of real-time transmission, but also reduce the cost of scientific research.

In order to realize the repeat the recycling plan mentioned in "long-term observation", docking method must be considered because this is the most critical part. Capture docking, subsumption docking and bench docking can be used. Considering that the seafloor observatory is divided into three modules and the in-situ gravity station will remain on the seafloor, the use of capture docking requires the addition of capture device at the bottom of the scientific payload, and the in-situ gravity station should be equipped with rope or guide rod to guide the target, and the docking can be completed by moving the capture device along the guide device. This way can be omnidirectional docking, less affected by the environment and the docking reliability is higher, but the structure is more complex. The scientific payload is equipped with instruments required for observation. If the capture device is added, the number of installed instruments will be reduced, which is not conducive to multidisciplinary observation. The inclusive docking requires a tapered entrance device guide cover or cage structure on the mobile docking unit and the in-situ gravity station to guide the scientific payload so that it enters the predetermined track to achieve the docking of the mobile docking unit and in-situ gravity station. This way of docking allows the scientific payload itself to be free from the need for a particularly complex structure, and only requires the mobile docker and the in-situ gravity station to be designed according to the way of docking and this way can also protect the scientific payload after docking. Platform docking means that the scientific payload lands on the platform in manner of aircraft landing and locks the docking. This method has higher requirements on the dynamic system and automatic navigation system of the mobile docker. The main working modules of the seafloor observatory are the scientific payload and the in-situ gravity station, while the mobile docker serves only as a vehicle. If the control performance of the mobile docker fails to meet the requirements, the docking process will be seriously affected, leading to the docking failure. In order to realize the docking mode with higher reliability, less impact from the environment and the structure is simple, the combination of containment docking and capture docking is adopted. The docking part of the scientific payload is designed as a conical frame structure, and the top of the docking with the mobile docker is set with a capture needle. The docking part between the mobile docker and the in-situ gravity station is designed as a guide cone and a tightening device is arranged at the taper of the guide cone. A through hole is arranged at the end of the guide cone of the mobile docker to guide through the capture needle during the docking. This scheme combines the advantages of containment docking and capture docking to achieve the goal of simple structure, strong reliability and low environmental impact.

To sum up, the seafloor observatory is divided into three modules, namely the mobile docker, the scientific payload and the in-situ gravity station (figure 1). The main function of the mobile docker is to deploy and recover the scientific payload. The main function of the scientific payload is to carry the instruments that needed to complete the observation mission. The main function of the in-situ gravity station is to serve as the reference point of the seafloor to realize accurate and repeated deployment and recovery. Both the mobile docker and the in-situ gravity station are equipped with clamping devices to fix and clamp the scientific payload.

3 System Function And Structure

The seafloor observatory consists of a mobile docker, a scientific payload, and an in-situ gravity station, as well as a deck control unit that controls the mobile docker, as described below.

3.1 Mobile Docker

Mobile docker is a special deep sea ROV (figure 2). It is connected to the support vessel by umbilical cord cable and is used to carry scientific payload to deploy and recover it between the support vessel and the in-situ gravity station to realize multi-period and long-term observation mission. Its dimensions are: length 3.10 m* width 2.52 m* height 1.54 m, mass 804kg. The frame of mobile docker is made of aluminum and has a maximum load-bearing capacity of 80kN in water. Power is supplied by the support vessel at sea. The mobile docker is equipped with four symmetrical 100kgf electric thrusters on the horizontal surface to provide thrust, which is the overdrive system. At the same time, the propeller arrangement is shown in figure 3. The roving in the horizontal plane can be realized through differential speed control to ensure that the ROV maintains a balanced attitude on the horizontal plane during the operation. The vertical surface is equipped with two 100kgf electric thrusters arranged in front and rear symmetry to provide thrust, which is the underdrive system to control the inclination of the mobile docker. The mobile docker has telemetry capabilities and is equipped with an ultra-short baseline positioning system and a sonar positioning system for locating the station during deployment and recovery.

The docking process between the mobile docker and the scientific payload is the core step of the seafloor observatory and it is also the key to realize the long-term in-situ observation with multi-cycle recyclable. During the placement and recovery of the scientific payload, the mobile docker uses the altimeter depth gauge on the vertical surface to obtain the depth and the straight-line distance from the seafloor. On the horizontal surface, firstly, through ultra-short baseline positioning, it gradually approaches the sea area where the station is located; And then mobile docker uses sonar for precise positioning; Finally, the camera and spotlight are used for visual positioning and attitude docking.

3.2 Scientific payload

The scientific payload can be equipped with a variety of sensors within the allowable range and mission requirements for a variety of scientific research tasks to achieve object-oriented observation tasks (figure 4). Its dimensions are: 1.77m*1.77m*3.18m, mass 175kg. The main functions include: gravity measurement, magnetic measurement, tide level, attitude measurement; Wireless data transmission and wireless power transmission; Timing and emergency communication functions, etc. The scientific payload can also be used to install other equipment because it has additional mounting points and major technical standard interfaces. A probe needle is arranged on the top of the scientific payload, mainly for docking with mobile docker.

3.3 In-situ gravity station

In-situ gravity station mainly plays the role of fixing the position and grasping the scientific payload (figure 5). The size of the station is 7.28m*4.02m*2.61m, the mass is 1008 kg, the material is aluminum titanium alloy, and the power is provided by the battery in the station. The biggest characteristic of the station is that it has the technology to keep the same position for a long time, which is the key to ensure the datum measurement of the seafloor observatory, mainly including the base leveling, attitude adjustment and origin monitoring technology. Through the platform structure design, the in-situ gravity station can adjust its attitude and monitor its state after moving. A supporting base at the bottom of the station and an anti-sinking plate under the main frame can maintain position. The station control system controls the opening of the hydraulic support legs to increase the contact area between the in-situ gravity station and the seafloor, reducing base settlement and increasing base stability. With the hydraulic support leg, the station can be adjusted in a small range.

3.4 Deck control unit

Deck control unit mainly includes deep sea winch, umbilical cable, power distribution unit and mobile docker control room. The deep sea winch (figure 6) and umbilical cable are used for the deployment and recovery of the mobile docker, including the cable storage winch, traction unit and hydraulic pump station to provide power for the movement of the mobile docker. Umbilical cable is the key connecting carrier between underwater equipment and support vessel, which has the comprehensive functions of power transmission, optical fiber communication, copper cable communication, remote command transmission, video image transmission, retraction and release.

During the operation, the power distribution unit raises the low voltage of the support vessel and connects the high voltage to the winch. The transformer on the robot is moved to change the high voltage to low voltage. In the control room of the support vessel, various instructions can be issued to process sonar images and video images transmitted through the umbilical cable and record data.

4 Workflow

When we need to measure deep water parameters for a long time, such as gravity field, magnetic field, pH, temperature, conductivity, turbidity, dissolved gas and other parameters, or after completing the maintenance and replacement of instruments in the scientific payload and the goal of obtaining data, the seafloor observatory will be deployed to the seafloor. When it is necessary to maintain and replace the instruments in the scientific payload and obtain the data therein, the scientific payload will be recovered by moving docker (figure 6).

The working process of one cycle includes three processes: hoisting of the in-situ station, deploy the scientific payload and recovery of the scientific payload.

In-situ gravity station hoisting process: The support vessel suspends the in-situ gravity station to the seafloor by its own gravity. When the in-situ gravity station reaches the seafloor, the station control module controls the hydraulic support legs assembly from a contracted state to a supported state. In addition, the battery pack provides power, and the control module controls the acoustic positioning module to start.

The deployment process of the scientific payload: the guide cone of the mobile docker is docked with the upper docking component of the scientific payload on the support vessel, and the grasping component below the mobile docker is used to hold the upper end of the docking component above the scientific payload. The support vessel puts the docked mobile docker and the scientific payload into the water. The operator on the support vessel controls the mobile docker and the acoustic positioning component of the in-situ gravity station through the umbilical cable to perform low-precision positioning. After moving to the distance of about 4-10m from the in-situ gravity station, the visual positioning component of the mobile docker is used to perform high-precision positioning. They will move over the in-situ gravity station. Then slowly move down, the docking component under the scientific payload is docked with the guide cone of the in-situ gravity station, and the battery pack of the scientific payload charges the station battery pack through the power transmission component. Finally, the gripping assembly of the mobile docker is released, leaves the scientific payload and rises to the surface (figure 7).

Recovery process of the scientific payload: the support vessel lifts the ROV into the water, firstly uses the acoustic positioning module for low-precision positioning and moves to a distance of about 10m from the in-situ gravity station, then uses the visual positioning module of the mobile docker for high-precision positioning to move above in-situ gravity station. The mobile docker moves downwards, the lower guide cone is docked with the docking component above the scientific payload. After grasping by the clamping component, the support vessel lifts the two docked parts by winch, and the scientific payload is separated from the in-situ gravity station and it will be carried back to the sea by mobile docker (figure 8).

The deployment and recovery of scientific payload is the focus of the entire workflow. During the docking process, the docking is performed by sliding the guide cone and the capture pin after the collision. If the force of the collision is too large, it will affect the docking accuracy and even cause hidden dangers to the docking component. Therefore, the operating performance of the mobile docker plays a very important role in this process, and it is necessary to control its own speed when docking.

5 Pool Test

This pool test simulates the process of recovering (Figure 9) and deploying (Figures 10 and 11) the Scientific payload of the mobile docker. The depth of the pool is 25m. The camera is placed around the pool and on the mobile docker. Lighting equipment is installed at the bottom of the mobile docker. The main purpose of the test is to observe the control performance of the mobile docker and whether it can complete the intended docking task.

The above figures show the deployment process of the scientific payload. The vertical approach speed is 0.03-0.06 m/s, and the horizontal approach speed is 0.04 m/s. In the process of completing the docking task, due to the docking collision between the scientific payload and the in-situ gravity station, the displacement of the station after automatic adjustment was less than 0.5mm, which met the goal of accurate measurement, and the docking task was also successfully completed. It can also be seen from the above figures that the visual component on the mobile docker work well, and the in-situ gravity station can be clearly observed.

The picture above shows the process of finding the Scientific payload by moving the lifting unit. The vertical speed of the mobile hoisting unit is 0.05-0.10 m/s, and the horizontal speed is 0.06 m/s. During the docking process of the guide cone of the mobile hoisting unit and the capture, the maximum pitch angle of the mobile hoisting unit is 25.6° and the maximum roll angle is 22.8°, and the docking device can successfully complete the docking task. And it was measured that the heading angle of the mobile hoisting unit was kept within 3°, the speed deviation was kept within ± 0.005 m/s, the depth was kept stable, and the control performance was good.

Based on the above experiments, it can be concluded that the mobile docker has better control performance and meets the requirements for the deployment and recovery of Scientific payloads. The docking of the scientific payload with the in-situ gravity station is also very smooth. The attitude change caused by the docking process to the station can also be ignored after the station is automatically adjusted and accurate measurement will be achieved.

The figures above show the recovery process of the mobile docker after it is connected to the Scientific payload through the clamping assembly. During recovery, the vertical speed is 0.10-0.20 m/s and the horizontal speed is 0.04 m/s. When moving vertically, the tilt angle of the mobile docker and the Scientific payload is less than 3 °, and when it is moving horizontally, the tilt angle is less than 6 °. When the mobile docker carries the instrument cabin, the speed deviation remains within ± 0.01 m/s, which can still maintain good control performance. After the docking was completed, the Scientific payload and the in-situ gravity station successfully completed the release action, and then completed the task of recovering it.

According to the above experiments, it can be concluded that the mobile docker has better control performance and meets the requirements for the deployment and recovery of scientific payloads. The docking of the scientific payload with the in-situ gravity station is also very smooth. The attitude change caused by the docking process to the station can also be ignored after the station is automatically adjusted, and accurate measurement is achieved.

6 Conclusions

The seafloor observatory described in this article is proposed to meet the requirements of long-term accurate measurement required by many disciplines. It can perform long-term observation, real-time observation and fixed-position observation. It can be used in the offshore and the areas far out to sea and can be independently measured on the seafloor It can also be used as a node to form a subsea survey network. At present, the detailed design and prototype manufacture of the seafloor observatory have been completed. At the same time the pool test verified that the mobile docker has good handling performance. The three dockings between mobile docker, scientific payload and in-situ gravity station are reliable. The station can also have a good attitude adjustment ability. However, since no field tests have been performed, the workability in actual situations needs further verification.

Declarations

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Availability of data and materials

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

Authors' contributions

The author' contributions are as follows: Wen-Jie Tian was in charge of the whole trial; Lu-Ke Deng, Zhan-Feng Qi wrote the manuscript; Jing-Sheng Zhai,Zi-Qian Shen and Guang Yang 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

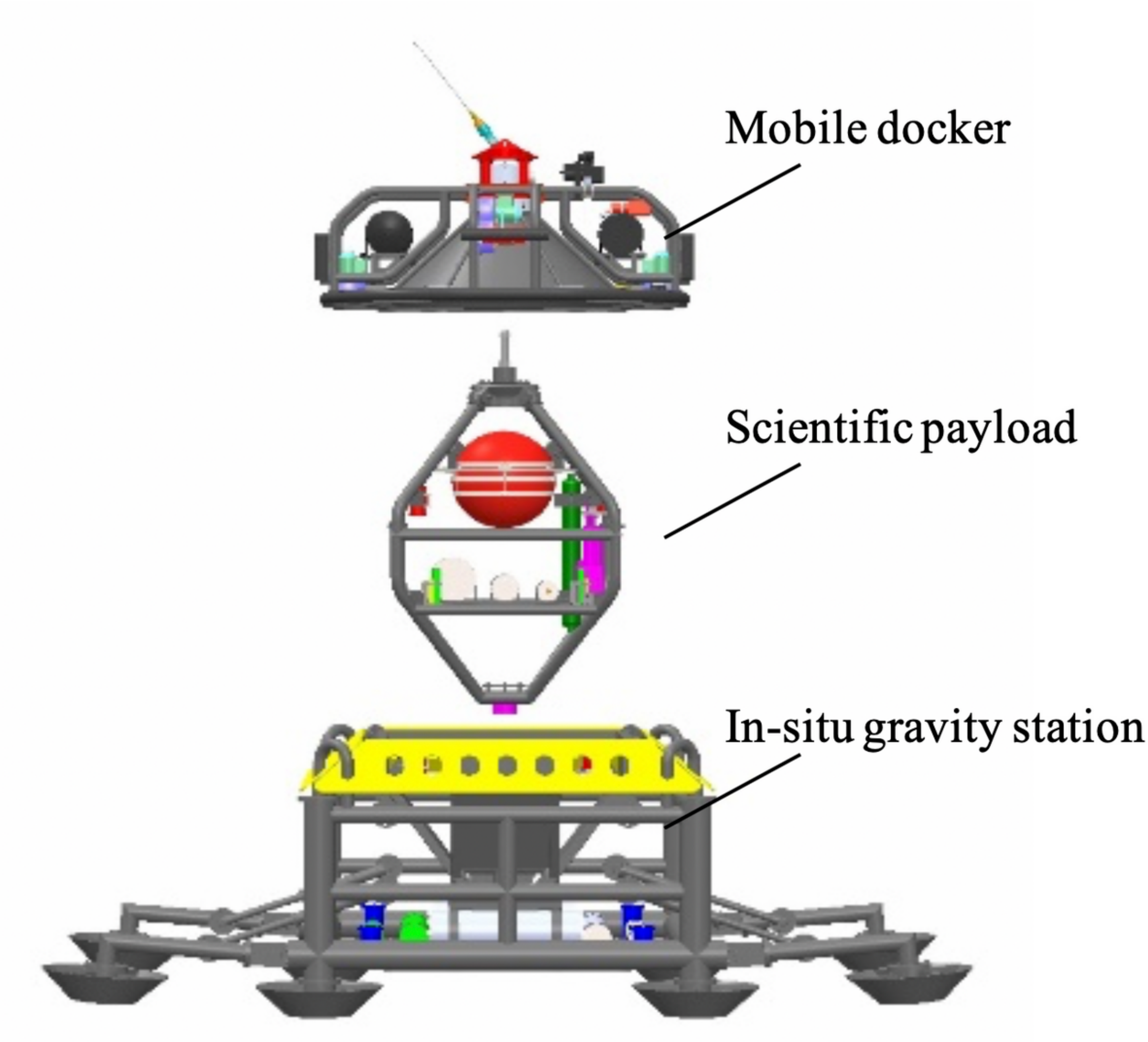


Figure 1

Overall schematic of a seafloor observatory

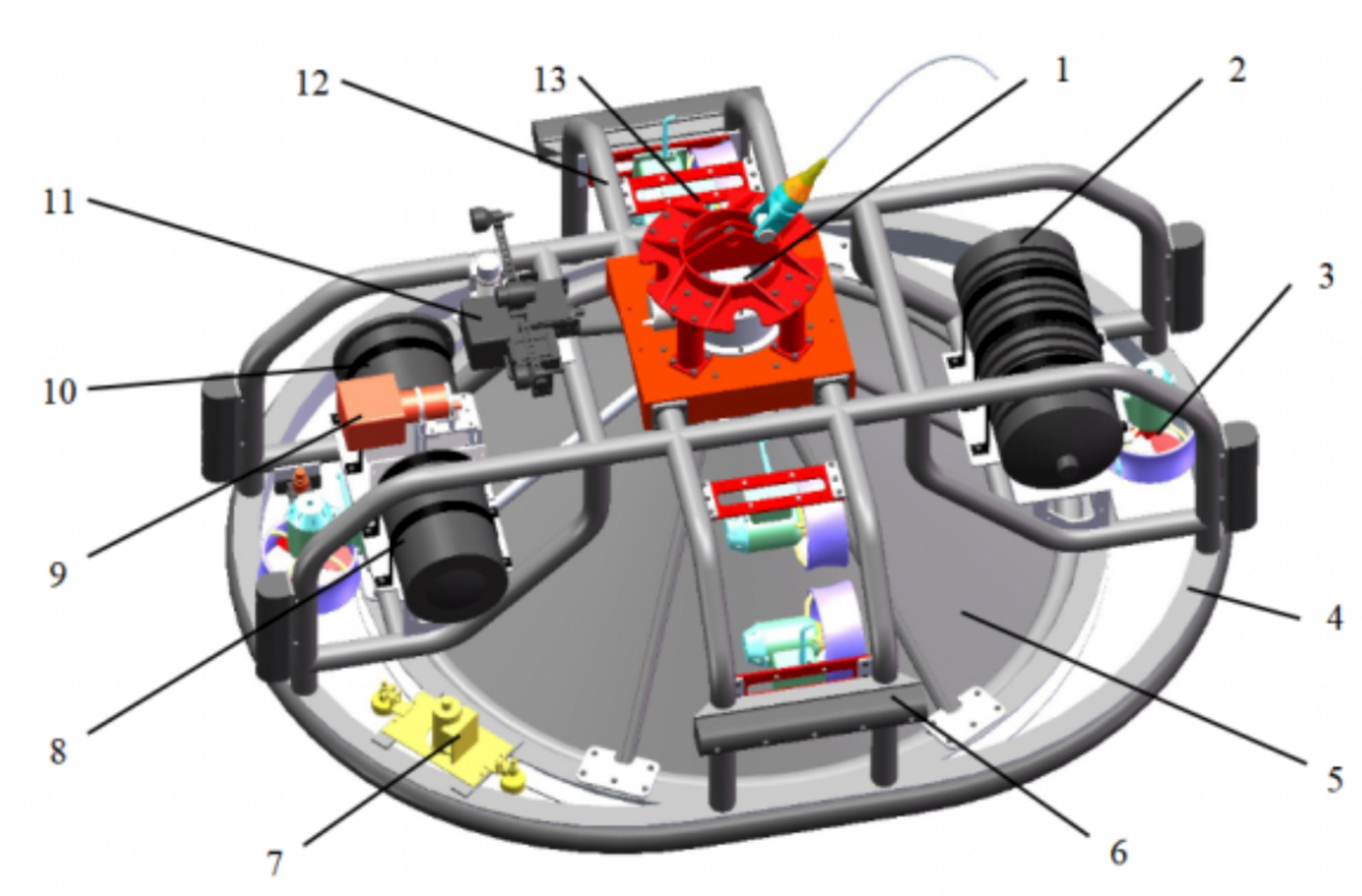


Figure 2

Schematic Diagram of Mobile docker. In the figure: 1. Clamping component; 2. Power supply compartment; 3. Propeller; 4. The bottom ring; 5. Tapered guide hood; 6. Rubber buffer ring; 7. Camera lighting; Control module; 8. 9. Sonar components; 10. Power compartment; 11. Forward-looking components; 12. The stent; 13. Load-bearing components.

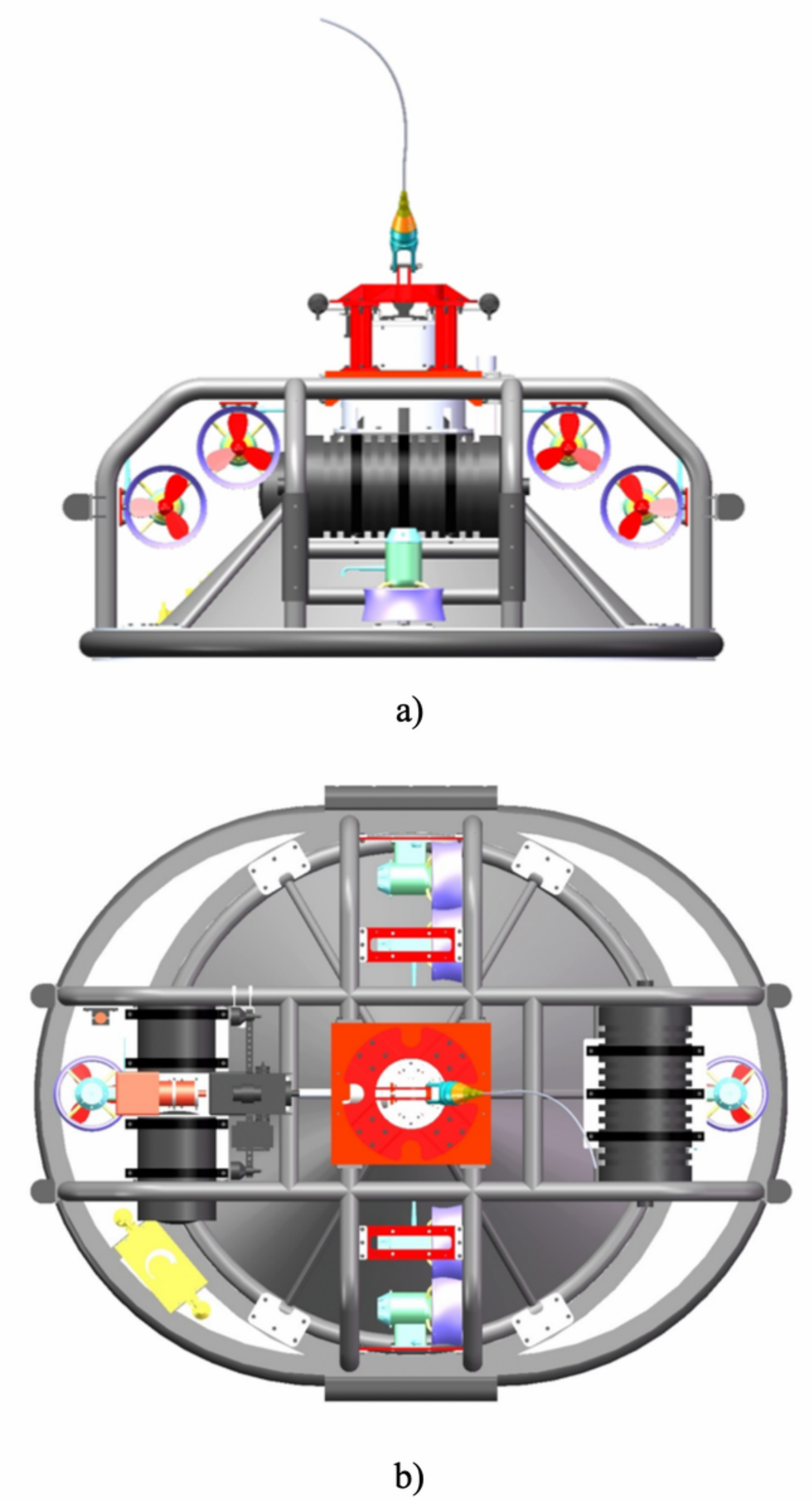


Figure 3

(a) Schematic diagram of propeller horizontal arrangement. (b) Schematic diagram of propeller vertical arrangement.

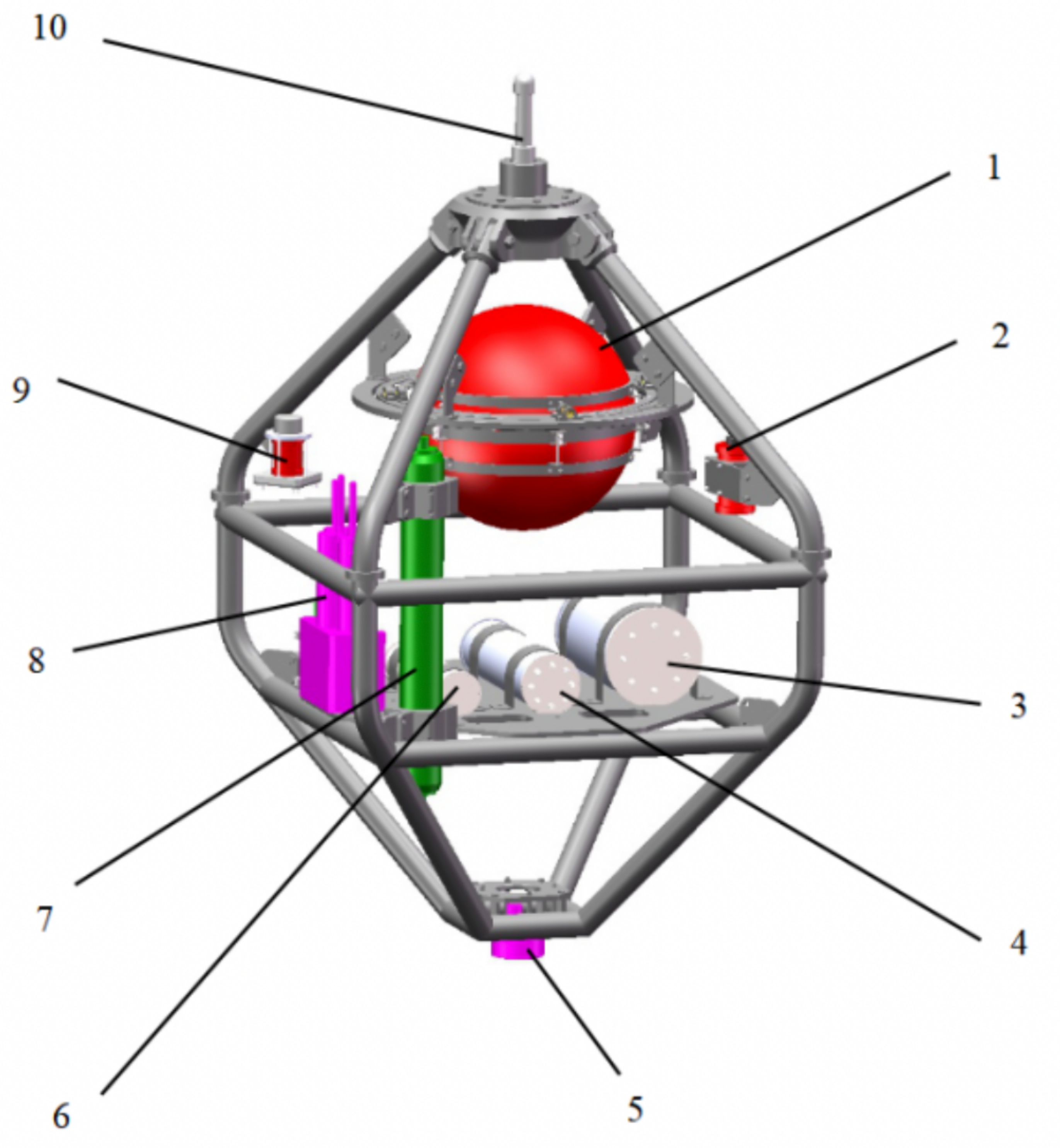


Figure 4

In the picture, 1.Gravity meter; 2.Transponder component; 3.Control module; 4. Voltage conversion module. 5.Wireless charging module; 6.Photoelectric conversion module; 7.Magnetometer; 8.Timed release module; 9.Acoustic communication components; 10. Capture pin.

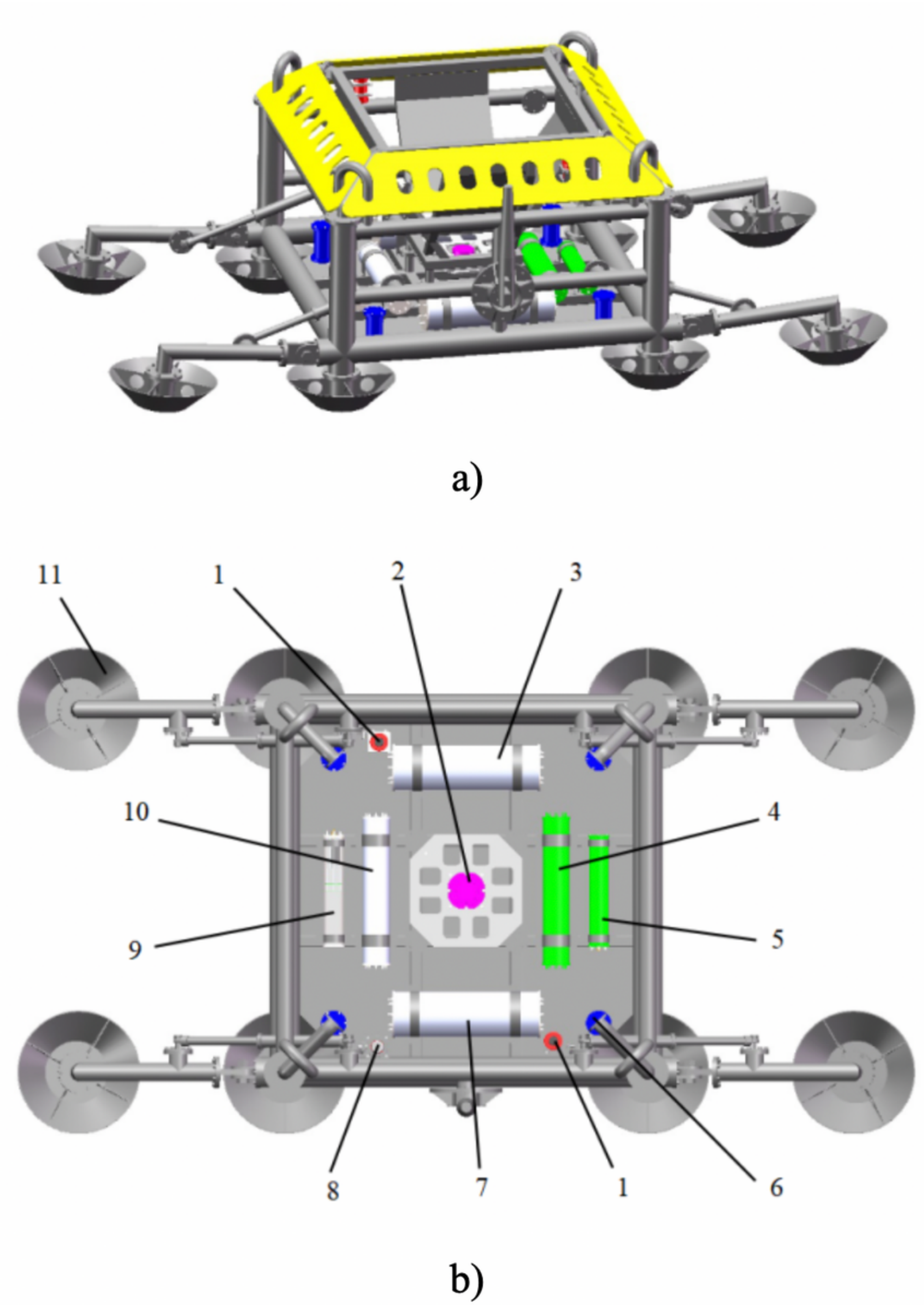
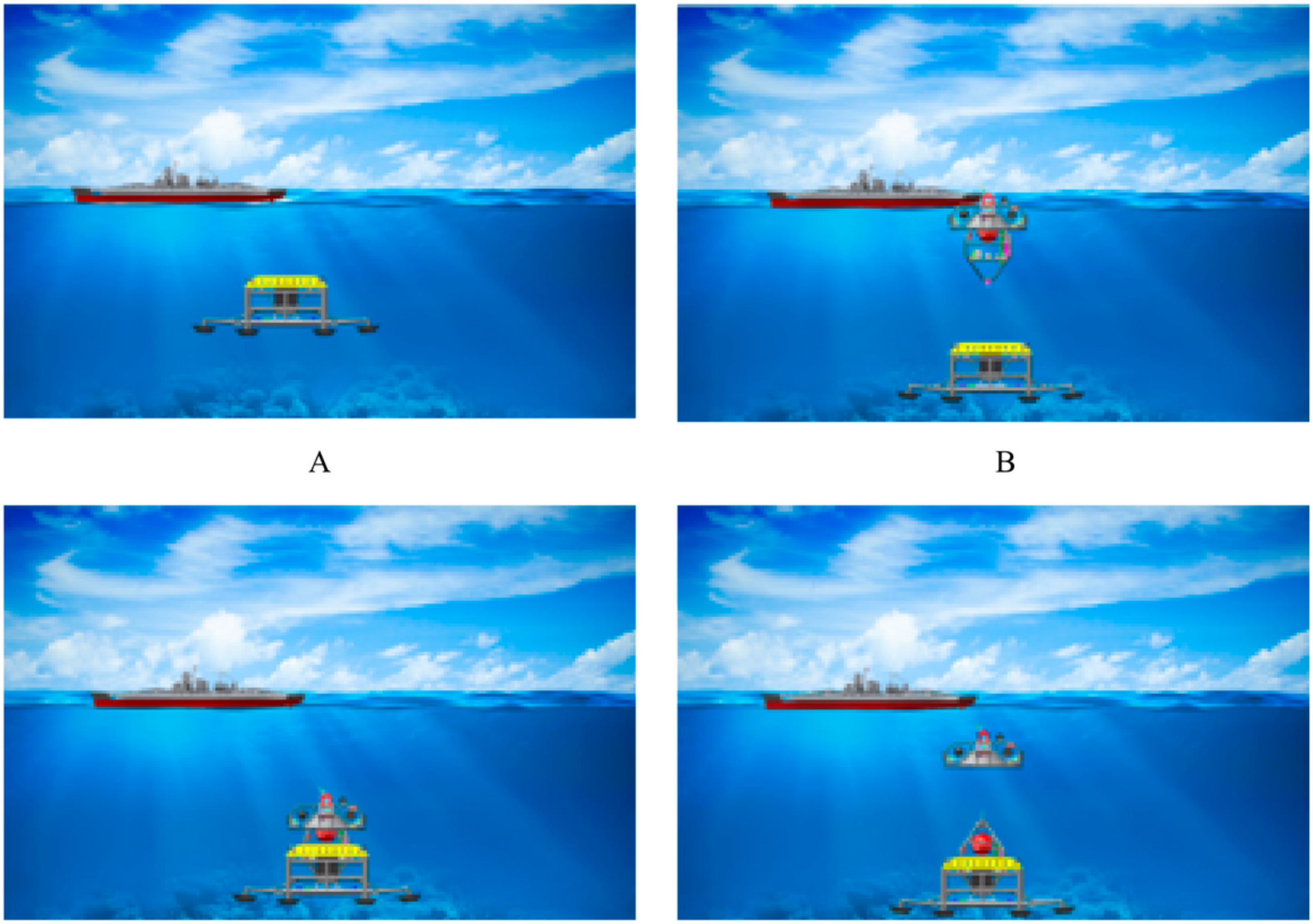


Figure 5

a) Overall schematic diagram of the in-situ gravity station. b) Internal structure of the station. 1. Transponder component; 2. Wireless charging component; 3. Main control cabin; 4. Photoelectric conversion cabin; 5. Sub-control cabin; 6. Valve-controlled assembly (four in total); 7. Voltage conversion cabin; 8. Acoustic communication components; 9, 10: spare compartment; 11. hydraulic support legs



A

B

C

D

Figure 6

Seafloor observatory workflow diagram. a) The base landed on the ocean floor by gravity. b) The process of mobile docker carrying the instrument cabin to find the station. c) Docking the instrument cabin to the station. d) mobile docker leaves the instrument cabin and returns to the support vessel.

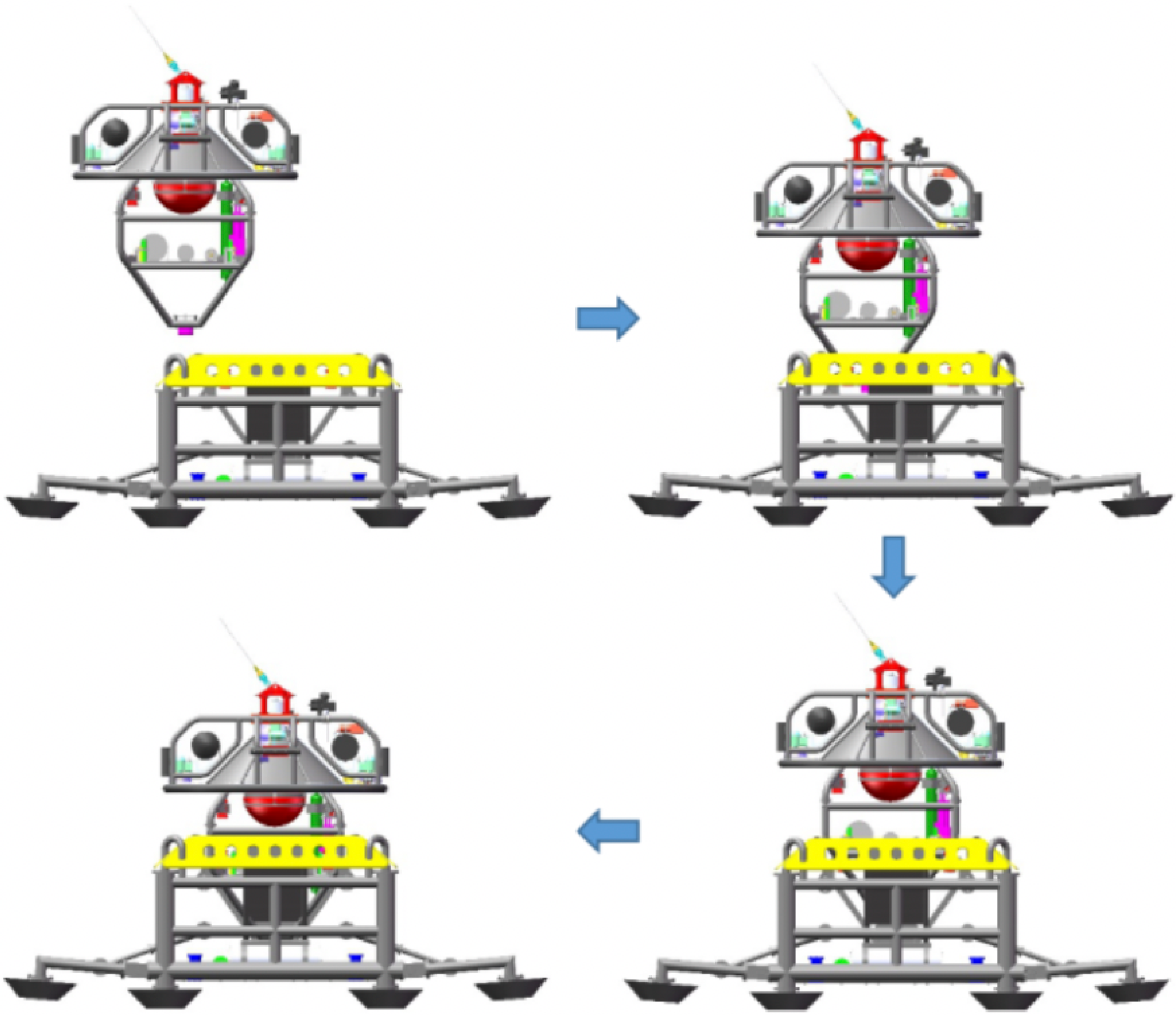


Figure 7

Deployment process

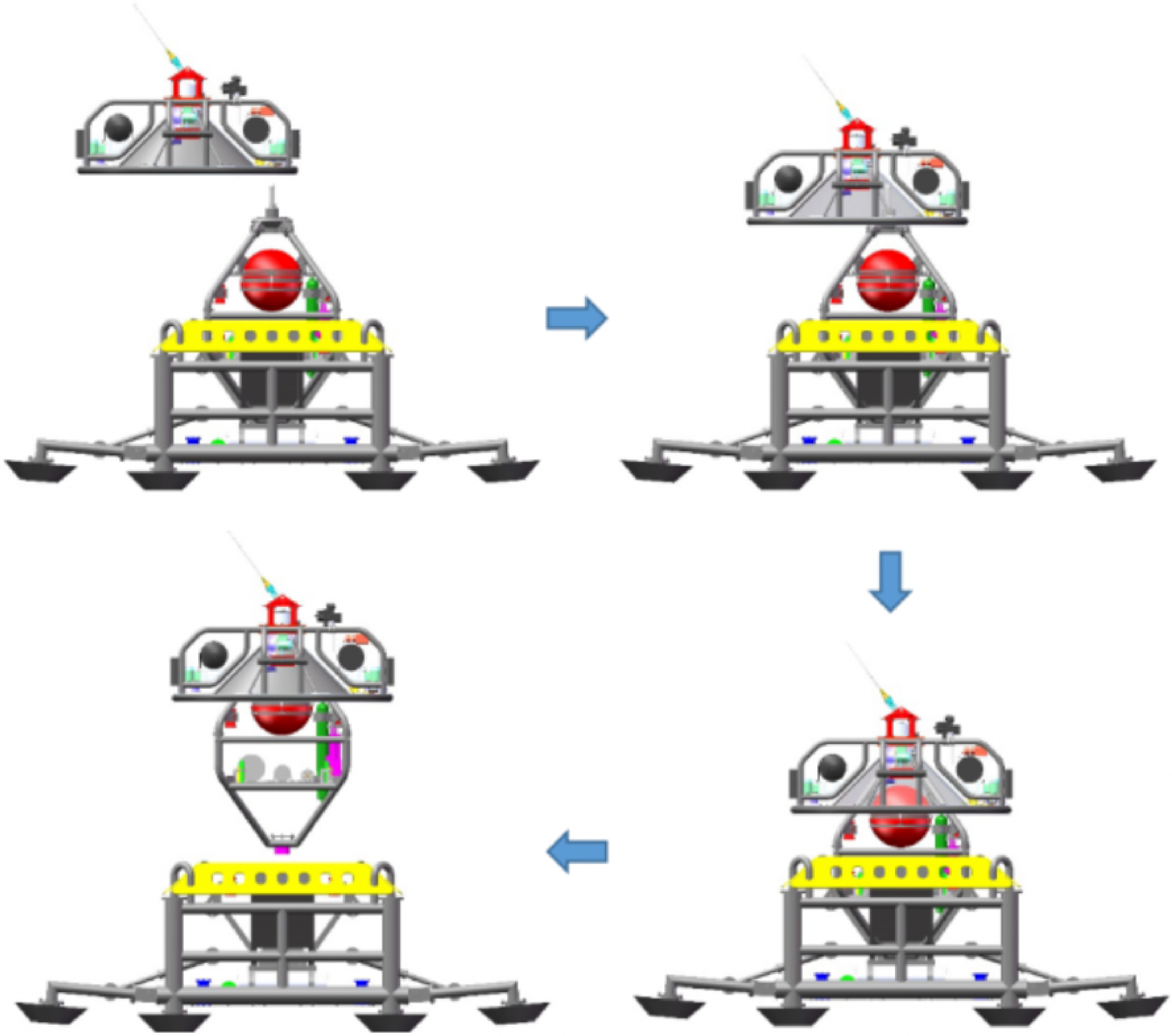


Figure 8

Recovery process

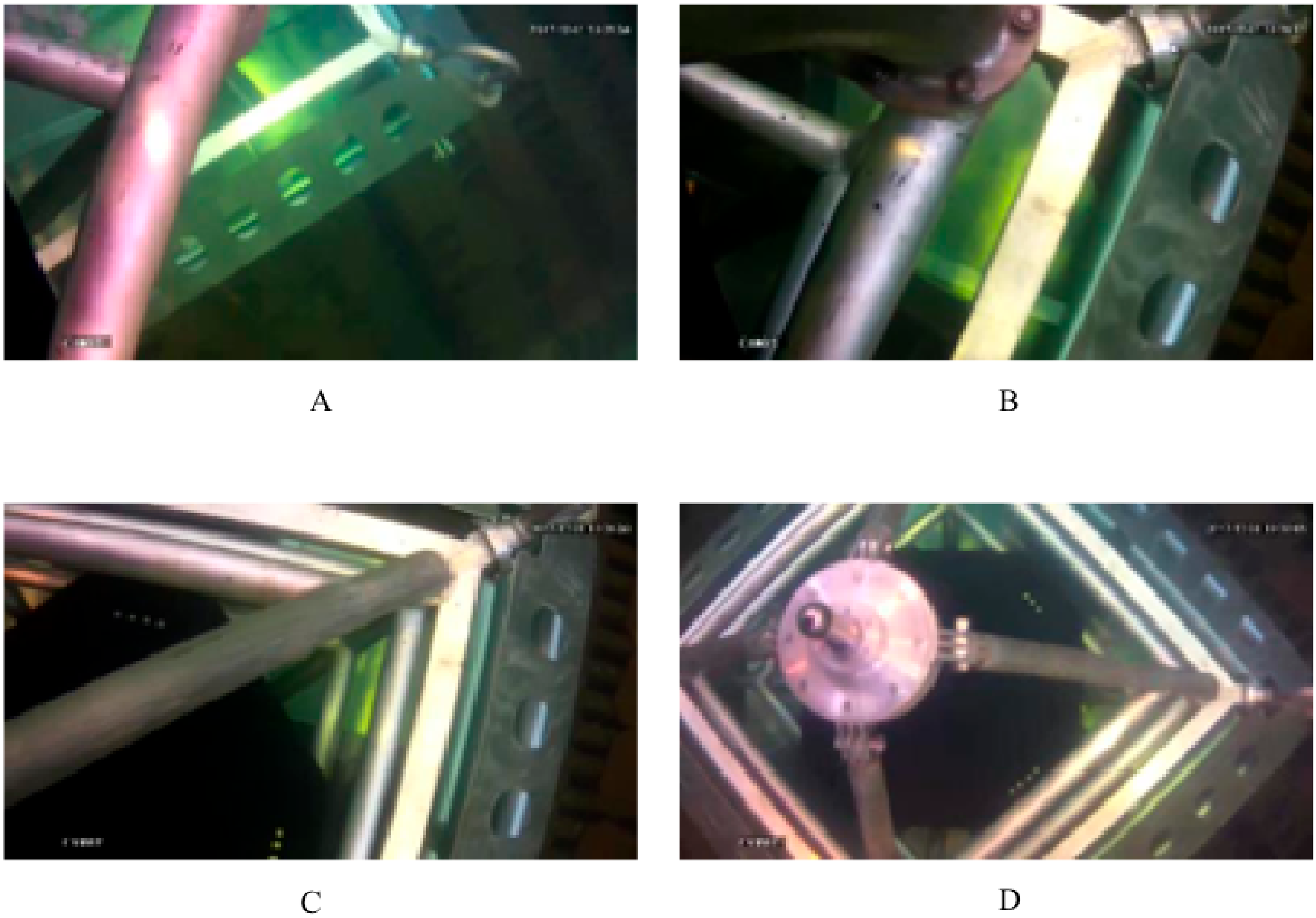


Figure 9

Deployment process of scientific payload. a) Mobile docker carries the scientific payload to dock with the in-situ gravity station. b) Docking is completed. c) Mobile docker releases the scientific payload. d) Mobile docker leaves the scientific payload.

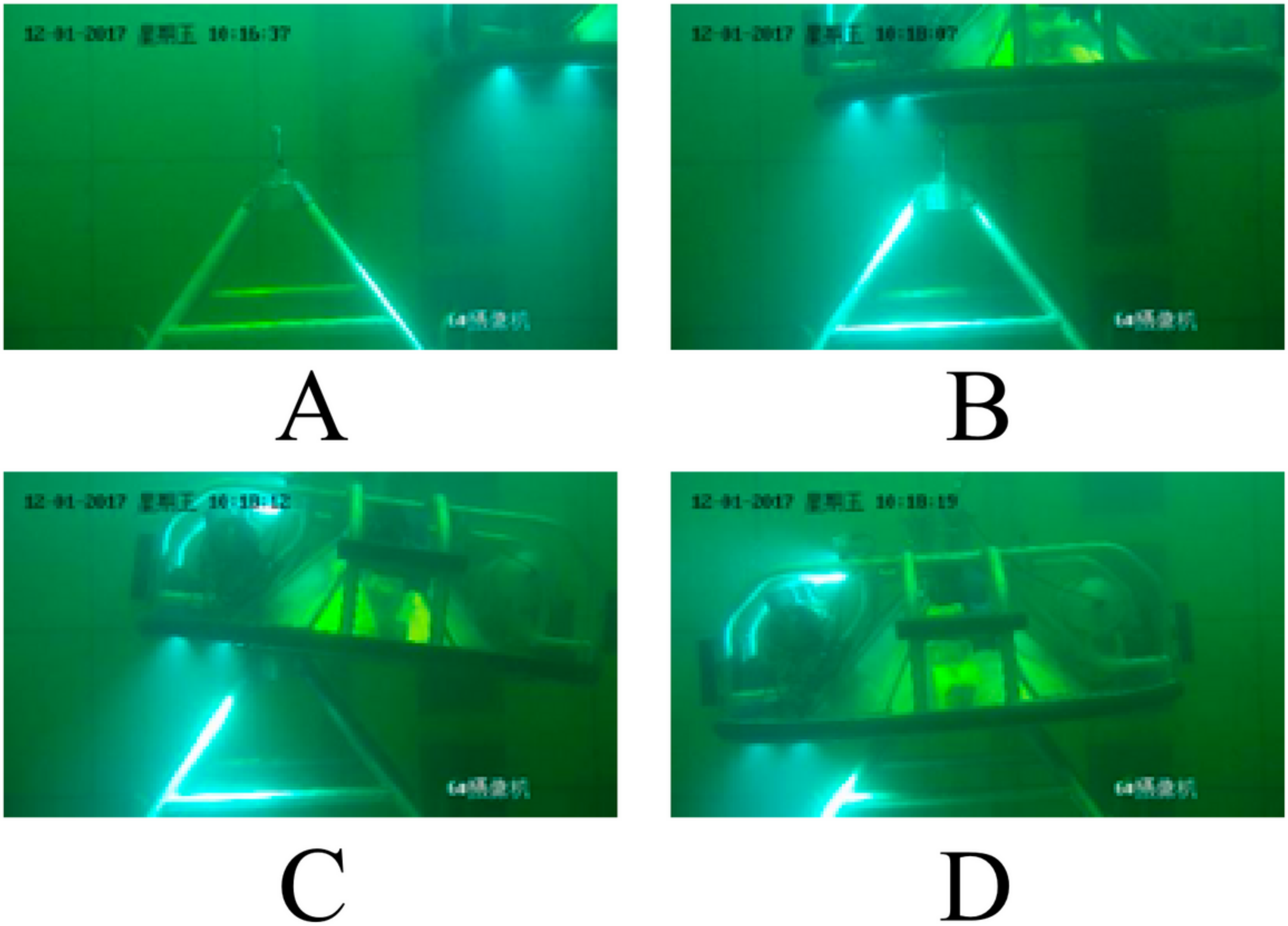


Figure 10

The process of searching the Scientific payload by mobile docker. a) Mobile docker is searching for scientific payload; b) Mobile docker starts to dock. c) The capture needle of scientific payload move along the guide cone of mobile docker. d) Docking is completed.

a)

b)

Figure 11

The process of lifting the scientific payload by the mobile docker. a) The mobile docker is docked with the scientific payload and the scientific payload is tightened. b) The mobile docker carries the scientific payload off the in-situ gravity station.