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Design of an autonomous seafloor observation prototype system for deep seafloor observation

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Abstract. The deep seafloor is closest to the Earth's interior and the physical, chemical and biological processes of the seafloor interact complexly. Therefore, the observations of the deep seafloor are critical to the study of global climate change and the change laws of ecosystems in complex environments. For the requirements of long-term observation of the deep seafloor and remote real-time data transmission in the South China Sea, an autonomous seafloor observation prototype system is designed, which combines the sea surface buoy and the seafloor junction box with the Electro-Optical-Mechanical cable. At the same time, according to the requirements of marine environmental parameters, dynamic parameters and biodiversity information collection, this paper proposed a distributed data management model based on the CAN bus to improve the data transmission efficiency and ensure the data quality. In this paper, the design of each component of the autonomous seafloor observation system was described in detail, including its hardware, software and communication system. The observation data from the experiment were given. In the sea experiment, the seafloor observation data were transmitted to the shore-based control center in real time through the satellite communication network and stored in a database. 99.4% of the data were successfully received. The results of the sea experiment show that the system can meet the requirements of long-term observation and remote real-time data transmission, and the reliability of the system is verified.

1. Introduction

The deep seafloor is closest to the Earth's interior and the physical, chemical and biological processes of the seafloor interact very complexly. Therefore, long-term and continuous seafloor observation is crucial to study the link between climate change and changes in the marine environment [1].

With the development of technology, all the sensors were deployed on the seafloor, and the shore-based stations were connected by optical cables, which established long-term and permanent seafloor observation stations and networks[2]. Currently, the seafloor observing network has been established in the world includes: Canada (NEPTUNE - North East Pacific Time-series Underwater Networked Experiments)[3], Japan (DONET - Dense Ocean floor Network system for Earthquakes and Tsunamis)[4], Europe (EMSO - European Multidisciplinary Seafloor Observatory)[5] and USA(MARS- Monterey Accelerated Research System)[6]. In recent years, China has made great progress in the research of key technologies for seafloor observation networks, especially the cabled seafloor observatory powered by shore-based stations, including the Xiaoqushan seafloor observatory



established by Tongji University[7] and Zhairuoshan seafloor observatory established by Zhejiang University [8].

Although China's seafloor observation technology is constantly improving, there is still a big gap in the observation of multi-space scales compared with many developed countries, particularly the seafloor observation for deep sea areas, which result in the uneven distributed spatial sample[9]. Remote real-time data transmission and power autonomy are still the major limitations for the seafloor observation in deep sea areas [10]. In order to solve these problems, an autonomous seafloor observation system (ASOS) is designed, which combines a sea surface buoy and a seafloor observation node with the Electro-Optical-Mechanical (EOM) cable. The seafloor observation node is equipped with a variety of sensors to obtain seafloor environmental information in real time. The sea surface buoy utilizes wind and solar energy to power the seafloor observation nodes and transmits the data to the shore-based control center through a satellite communication system. Compared with the traditional seafloor observation systems, ASOS has a lower cost of deployment and maintenance, which is not limited by the observation space scale. It meets the requirements of long-term observation and remote real-time data transmission, so it is more suitable for long-term seafloor observation in the deep sea.

The structure of this paper is as follows: Section 2 introduces the system design of ASOS, including sea surface buoy design, seafloor observation node design and shore-based control center. In Section 3, we describe the sea experiment of ASOS and give detailed experimental observation data. Finally, Section 4 gives the discussion and conclusion.

2. ASOS System Design

The ASOS is composed of a seafloor observation node, a sea surface buoy and an Electro-Optical-Mechanical cable. The system structure is shown in Figure 1. The seafloor observation node is equipped with a variety of sensors to obtain the seafloor environmental parameters and transmit data with the sea surface buoy through the EOM cable. The diameter of EOM cable is 17.30mm (Rochester Engineered Cable NO. A302351), which is composed of an optical fiber watertight connector and a watertight copper connector. The optical fibers are used for data transmission, and the copper wires are applied to transmit power.

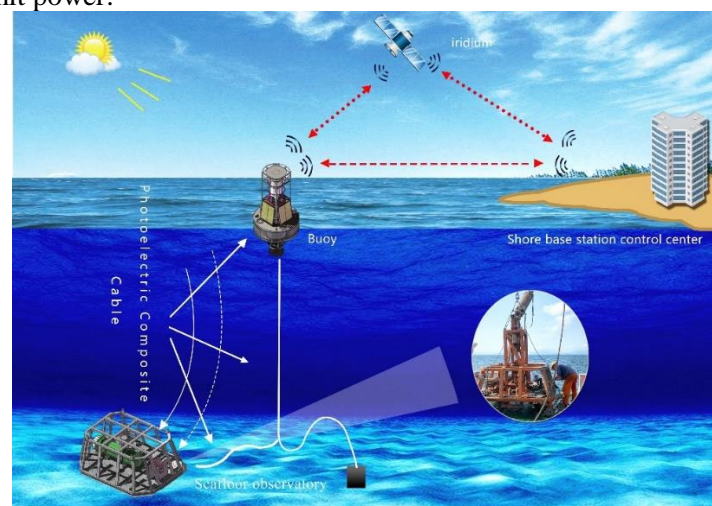


Figure 1. System structure of ASOS

2.1. Design of the sea surface buoy system

The sea surface buoy has a maximum diameter of 3 meters, a bottom diameter of 1.5 meters. The weight of the buoy is 4.2 Tons. In the experiment, the buoy utilizes wind and solar energy to provide power for the seafloor observation node and transmit the data to the shore-based control center through the satellite communication system. At present, the buoy carries Gill MetPak for

meteorological observation, from which wind speed and direction, relative humidity, dew point, barometric pressure and air temperature can be obtained. In addition, the buoy is equipped with a CTD to measure the sea temperature and salinity of the sea surface. The data transmission module uses an iridium satellite communication terminal (A3LA-RG) to transmit the observation data to the shore-based control center in Short burst data (SBD). A3LA-RG supports the standard RS232 protocol with a baud rate of 19200bps. The buoy is equipped with a wind-solar complementary system, which consists of a wind turbine, a solar array and batteries. The solar array consists of eight modules of 550 mm x 1200 mm and each rated at 100 W. The wind turbine is rated at 300 W at a wind speed of 12 m/s. The wind turbine and the solar array provide the battery with a 24V power supply. Through the DC-DC converter, the battery provides 12 VDC for the buoy and 375 VDC for the seafloor observation node.

2.2. Design of the seafloor observation node

The seafloor observation node is responsible for the sampling and transmission of seafloor environmental information. It is equipped with a variety of sensors, including Conductivity-Temperature-Depth (CTD), Acoustic Doppler Current Profilers (ADCP) and underwater cameras for biological data acquisition. The CTD is used to measure the salinity, temperature and pressure of the seafloor. Moreover, the ADCP is used to detect the flow rate and the direction of the water flow to obtain the dynamic parameters. The underwater camera monitors the ecological environment of the seafloor in real time so as to study the seafloor ecosystem and biodiversity in the future. Table 1 lists all available sensors.

Table 1. Types of sensors installed on the seafloor observation node

Sensors	Main Measurement Parameters	Sample rate (s)
ADCP	depth, current velocity and direction	10
CTD	temperature, salinity, depth	10
Camera	Seafloor environment and organisms	60

The seafloor junction box is the main component of the seafloor observation node and the design of the seafloor junction box is shown in figure 2. The working depth of the junction box is 200 meters below the sea level and the total weight is less than 300kg. The junction box can provide 12 VDC, 24 VDC and 48VDC for the seafloor sensors through the DC-DC converter.

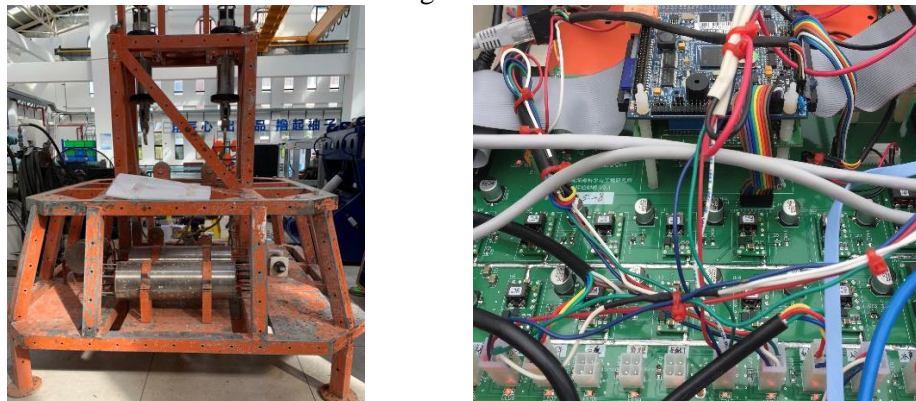


Figure 2. The junction box design.

As shown in Figure 3, the control system of the seafloor junction box relies on a 32-bit microcontroller (Cortex-M4) and an ARM controller (AT91SAM9263) to manage the information flow through the CAN bus protocol. The former is responsible for sampling and converting the input signals of various sensors, while the latter is responsible for centralized management of all data and monitoring of the status of the seafloor observation node in real-time.

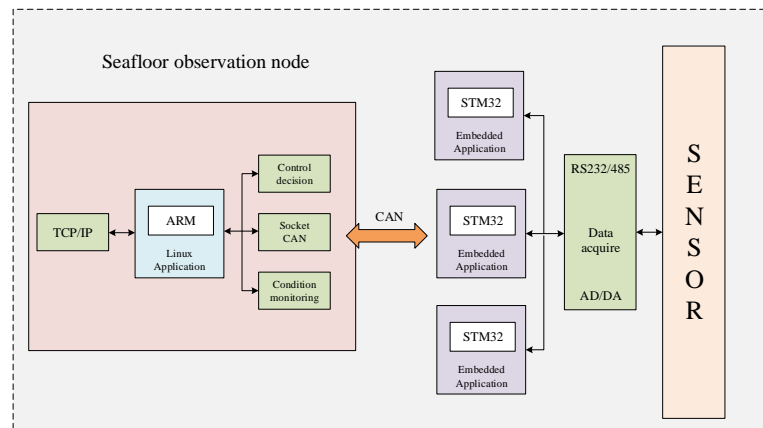


Figure 3. Software architecture of the seafloor observation node

In addition, in order to satisfy the different scientific observation requirements in the future, extended interfaces that can adapt to different types of observation instruments are reserved. The interface includes an RS232 interface, an RS485 interface, an RS422 interface and a network port.

2.3. Shore-based control center

Figure 4 shows the monitoring visualization interface of the shore-based control center. It can be seen that the shore-based control center can receive the seafloor observation data in real time and display it. All collected time series data are stored independently on each platform for remote access. From the perspective of security, the data transmission between ASOS and the shore-based station is not suitable for transparent transmission. Therefore, this paper adopts a simple data encoding method to process the original data. The encoded data has time series information, and each data contains the date (yy/ mm/ dd) and time (hh: mm: ss). The followings are important components of the shore-based control center:

- Server running Windows operating system: data decoding, storage and display;
- Iridium satellite terminal: iridium satellite data receiving;
- SQL Server database: seafloor observation data storage;
- User interface: real-time display of the seafloor observation data and remote control of ASOS.



Figure 4. User interface of the shore-based control center

3. Experimental results and system verification

3.1. Field test

The purpose of ASOS research is to make real-time, continuous and long-term observations of the seafloor dynamic parameters, physical parameters and the seafloor ecosystem in the deep sea, so as to increase our understanding of the environmental changes of the deep seafloor.

During 2019.03.10-2019.04.10, we carry out the test in the South China Sea (N18.285°, E108.993°) near Sanya, China. The purpose of this test is to verify the capability of long-term observation and the reliability of remote real-time data transmission. Figure 5 (a) indicates the deployment of ASOS. Figure 5 (b) shows the sea surface buoy after successful deployment when the seafloor observation node is located at the seafloor. Seafloor observation data are transmitted in real time through the satellite communication system, and the shore-based control center receives data through the iridium satellite terminal. Finally, the seafloor observation data is stored in the SQL Server database, which can be accessed and inquired in real time through the network.

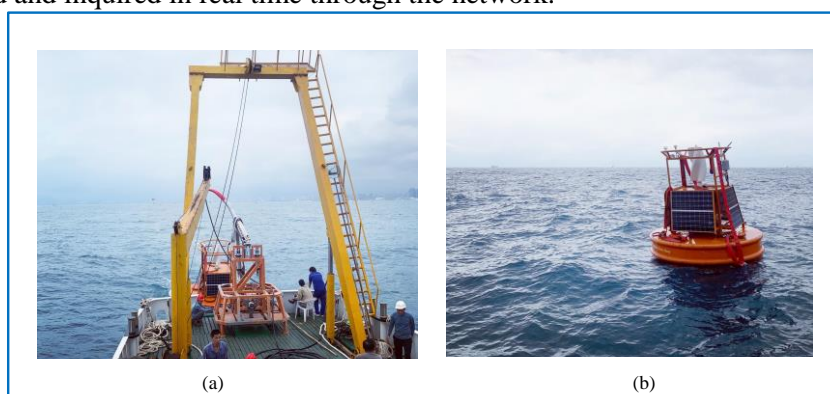


Figure 5. Field test and real-time monitoring of the ASOS.

(a) system deployment; (b) the sea surface buoy after successful deployment, when the seafloor observation node is located at the seafloor.

3.2. CTD data

In the experiment, the dynamic parameters, physical parameters and ecological environment of the seafloor were observed in a long-term, continuous and real-time manner. Figure 6 is an example of CTD observation data over a period of 20 days from March 11, 2019 to March 31, 2019. The CTD data reflects the changing trend of seafloor temperature, conductivity and depth in the target sea area during the observation period, and the salinity is calculated through the conductivity. During this period, the salinity ranges from 32.43‰ to 33.48‰ at the depth of 25 meters in the observed sea area, with an average of about 32.93‰. As can be seen from Figure 6, the measured depth of the same CTD changes periodically with time, and the change period of depth is 1 day. This may be caused mainly by tides and undercurrents.

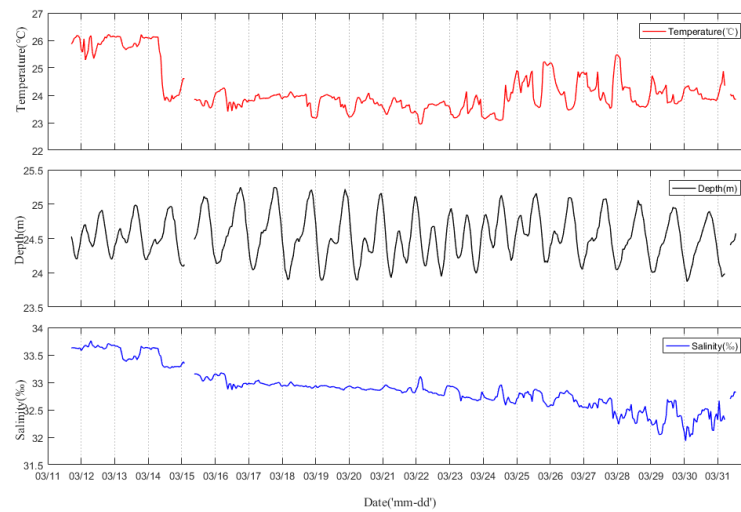


Figure 6. Example of CTD observation data over a period of 20 days from March 11, 2019 to March 31, 2019.

3.3. ADCP data

ADCP uses the Doppler effect principle to measure the flow velocity, and the measured parameters reflect the flow velocity and direction change of water flow respectively on the three-dimensional space vector. The idea of dynamic visualization analysis of ADCP data is to represent the flow velocity and direction of water flow with the vector diagram. Figure 7 shows the dynamic parameters of the seafloor measured by ADCP. Figure 7(a) represents the velocity and direction of water flow in the horizontal component synthesized by MATLAB. The maximum flow velocity measured in the horizontal component is 0.758m/s, and the direction of water flow is indicated by the direction of the arrow. Figure 7 (b) shows the flow velocity and the depth change curve of the vertical component. It can be seen from Figure 7 that there is a great coupling between the change of seafloor flow velocity and the change of water depth in the horizontal component. The maximum flow velocity occurs when the depth changes greatly, which may be caused by tides.

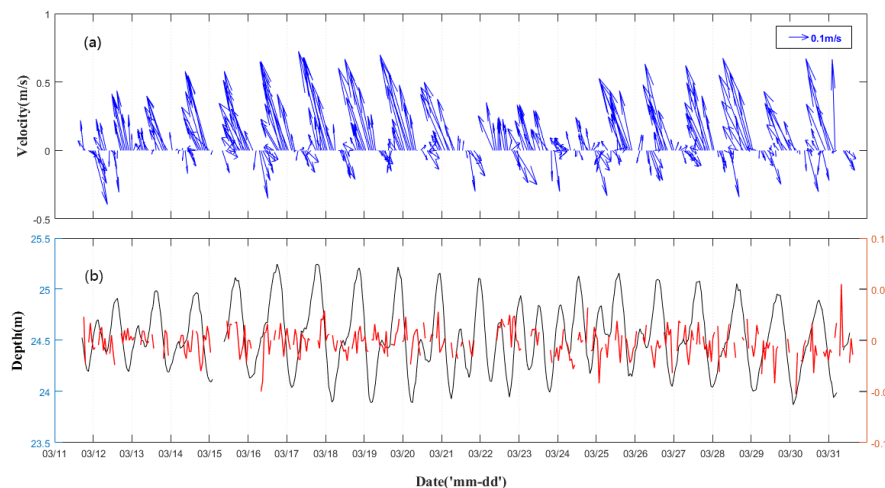


Figure 7. Vector data of water flow collected by ADCP.
(a) the velocity and direction of water flow; (b) the changing curves of velocity and depth in the vertical component.

4. Discussion and Conclusion

At present, the realization of real-time data transmission and power autonomy is still a major challenge for a long-term seafloor observation in the deep sea. In this paper, an autonomous seafloor observation prototype system is designed, which provides an opportunity for the long-term seafloor observation in the deep sea. ASOS has a lower cost of deployment and maintenance than traditional seafloor observation systems. At the same time, it has advantages in terms of the time and space scale of the observations. ASOS improves the system's long-term observation capability by collecting wind and solar energy for power supply. The combination of Ethernet communications and satellite communications technology enables ASOS to remotely transmit seafloor observation data in real time. During 2019.03.10-2019.04.10, ASOS was deployed at a depth of 25 m in the South China Sea (N18.285°, E108.993°) near Sanya, China. According to the data transmitted to the shore-based control center, 99.4% of the data were successfully received. Experimental results show that the system can satisfy the requirements of long-term observation and remote real-time data transmission, so deep sea experiments can be carried out in the next few months. In the experiment, the anchor chain and EOM cable were tied together to moor the buoy. This method is suitable for shallow water. The next step is to deploy the ASOS at a depth of 1000 meters for long-term observations, so the EOM cable has to redesign as a net buoyancy cable to moor the buoy. In addition, in order to ensure the reliability of data transmission, we plan to carry out a redundant backup of transmission and establish redundant communication links between the seafloor observation node and the shore-based control center.

Acknowledgments

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