Key technologies of junction boxes for Chinese experimental ocean observatory networks

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***Abstract*—Ocean observatory networks have been investigated and developed and are receiving considerable attention in the 21st century. As intermediate processing nodes, junction boxes (JBs) are essential sections of ocean observatory networks. This paper explored the key technologies of JBs for Chinese experimental seafloor observatory networks, including industrial control, Ethernet communication, and time synchronization technologies. Specific functional verifications of each section were conducted in the laboratory prior to sea trials. The JBs were packaged in a frame and were deployed in the East and South China Sea. Results of the laboratory and sea trial experiments demonstrated that the examined technologies were effective and could provide valid guarantee to the long operation of the JBs.**

Keywords—Ocean observatory network, junction boxes, industrial control, Ethernet communication, time synchronization

I. Introduction

The oceans cover more than 70% of the Earth's surface and comprise over 95% of the living space. This body of water is the dynamic engine of Earth, driving energy transport and elemental cycles of the globe [1]. Marine observation is important to mankind, mainly for discovering biogenesis, maintaining the benign development of the ecosystem, predicting earthquake and tsunami, and exploring oceanic resources. Ocean observatory networks that can provide long-term, in-situ, real-time, and continuous observations to submarines have been investigated and developed and are receiving considerable attention in the new century [2]. The experimental ocean observatory network systems deployed in the sea near Zhairuo Shan Island (Zhou Shan, China) and South China Sea represent the attempt and effort to establish regional cabled observatory networks in China.

Junction boxes (JBs) are the nodes of power conversion and distribution, signal processing and data communication, and time synchronization between shore station (SS) and submarine terminal scientific instruments (SIs). The effectiveness and reliability of the JBs are significant because JBs are core and indispensable parts of ocean observatory networks. In this paper, we present our latest considerable research on key technologies of the JBs [3–5].

II. System Structure

The structure of the JBs is shown in Fig. 1. The control system that is composed of an embedded processor and relevant peripheral circuits executes instructions received from the upper computers on the SS and monitors the working status and environmental parameters of JBs during its operation. The optical transponders, optical amplifiers, and Ethernet switches exchange data passing through the JBs and make up the communication system together with the other switching equipment on the SS. The slave clock synchronizes its local clock by exchanging time messages with the grandmaster clock installed on the SS. It also provides precise timing service for the JBs and SIs in the form of pulse per second (PPS).

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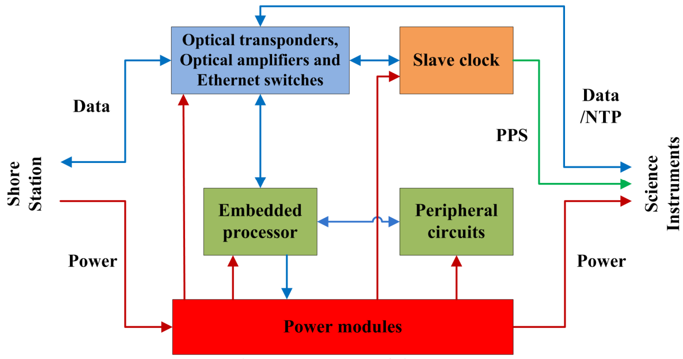

Fig. 1. Structure of the JBs

III. Key Technologies of the System

A. Conrol System

The control system of the JBs is based on industrial control technology adopted in many situations that require high reliability [6]. The embedded processor with the performances of reliable control, good stability, easy development, and longevity of service is adopted as the controller of the system. A few peripheral circuits with multiple functions are connected to the processor directly or indirectly. The functions of these circuits mainly contain two sections: control and monitoring. The switching control of the power supply for the next level equipment is realized through a method that uses a metal–oxide–semiconductor field-effect transistor and a mechanical relay in series. Once a fault occurs in the back-end, such as overcurrent or short circuit, the aforementioned functional circuit will cut off the power output automatically and protect the system reliably. Among all the failures for the ocean observatory network, grounding fault is the one most expected to occur. The grounding fault detection circuit can diagnose the grounding resistance between the power supply lines and the seawater ground. Periodic automatic detection can be set via the upper computer software. Once the actual resistance value detected is less than a previously set threshold value, an alert will be generated to the user. The voltages and currents of all output ports are monitored by the control system and the environmental parameters in the vessel, such as temperature, humidity, and water leakage signals. An alarm will be generated and relevant responses will be triggered to maintain the normal operation of the system if the detection value exceeds a specific threshold [7–9].

B. Data Communication System

The data communication system is designed to allow observatory users easy access to the instruments and acquire the data onshore [1]. A simple tree-topology, Gigabit-Ethernet-TCP/IP based data management system (DMS) is composed of two local area networks (LAN), one onshore linking DMS, and one underwater LAN connecting the SIs [9]. The underwater LAN is made up of high-quality commercial off-the-shelf optical transponders, erbium-doped fiber amplifiers (EDFAs), and layer 2/3 Ethernet switches. The acceptable range of input optical power of the EDFAs is from -6 dBm to 3 dBm, and the output optical power is 22 dBm. The small form-factor pluggable (SFP) transceivers that provide electrical–optical conversions and the acceptable optical power ranging from -31 dBm to -8 dBm were adopted. The optical fiber of the backbone cable is single mode, the wavelength is 1550 nm, and through an actual test the light attenuation is found to be 0.185 dBm/km. The structure of onshore LAN is similar to that of the offshore. The EDFAs on the SS provide the pre-amplification for each downward channel. Series data collected by the submarine equipment are transmitted to the onshore DMS and instructions are delivered to underwater DMS to execute relevant tasks through this data communication system. The communication distance of this network is no less than 250 km because of the attenuations of light when passing through the fibers and connectors, the pre-amplification of the EDFAs, and the acceptable optical power range of the SFP transceivers. A pair of backup optical fibers is used to enhance the redundancy and reliability of the communication system. Except for transmitting to the SS, the data communication system allows the data exchange between the nodes and SIs. A total of four to eight underwater watertight cables that connect SIs can be attached to the JBs. Each cable is terminated with a wet-mateable connector that provides four pins for 10/100Base-T Ethernet [10].

C. Time Synchronization System

At present, many systems, such as testing and measuring systems, power systems, and industrial automation and distributed systems, cannot be separated from the concept of time synchronization. Given the multitude of transmission equipment, long transmission distance, large amount of information, the synchronism of signal acquisition as well as transmission of the JBs and terminal instruments are difficult to guarantee. Time synchronization thus becomes an important issue for the ocean observatory network system. Long-time-series collection of multiple variables across a breadth of environments acquired by the submarine SIs must be time-stamped for analysis and correlation with other events [11–12]. The effectiveness, accuracy, and reliability of data are guaranteed by using a unified and recognized time reference. Millisecond timing accuracy is adequate for the majority of observations, whereas microsecond timing accuracy is necessary for other observations, e.g., acoustic signal detection.

The network time protocol (NTP) is used to synchronize underwater lower computers with clock sources, such as timeserver, quartz chronometer, and global positioning system (GPS), on the SS. The client/server work pattern is generally adopted; the offset between master and slave clock and network transmission delay is confirmed by the NTP messages that commute between client and server [13]. The transmission period of the NTP messages can be set. The IEEE 1588 standard or the precision timing protocol (PTP) specifies a precision clock synchronization protocol for networked measurement and control systems. The PTP synchronization method that exhibits good robustness, excellent openness, strong interoperability, and high accuracy is adopted in the present study to provide microsecond accuracy time for the system [14]. All the multiple switching equipment on the communication link are required to support the IEEE 1588 standard when applying the PTP synchronization method.

Through the combined application of NTP and PTP time synchronization, the grandmaster clock onshore can provide microsecond-level-precision timing service for the underwater network system by receiving GPS/BeiDou signals. Among these signals, NTP timing signals provide the year, month, day, hour, minute, second, and millisecond time information; PTP timing signals provide the microsecond time information for the system. The data communication and time synchronization system is shown in Fig. 2.

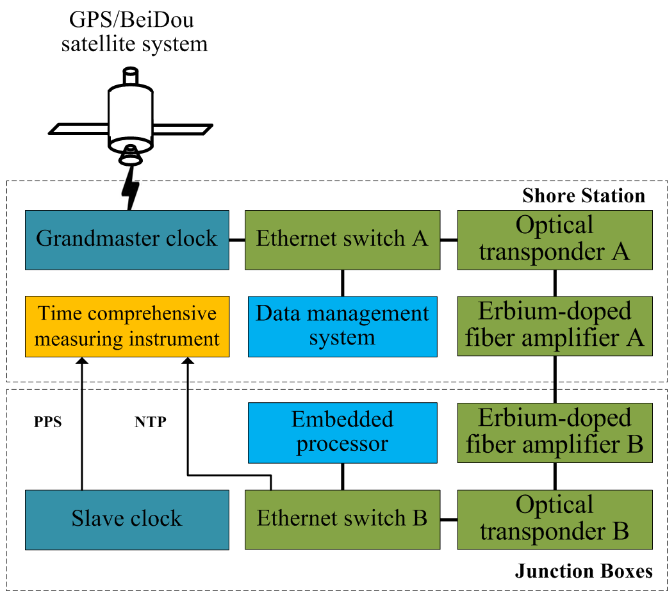

Fig. 2. Communication and time synchronizaiton system

IV. Experiments in Laboratory and Sea Trials

A prototype of the JBs was built in a laboratory, and a thorough functional verification of the system was conducted in the laboratory to guarantee its validity and reliability before being deployed on the seafloor. The main characters of the key technologies of the JBs were validated. After these laboratorial tests, the JBs were deployed successfully in the sea near Zhairuo Shan Island (Zhou Shan, China) and South China Sea.

A. *Laboratory Test*

Specific tests were conducted in the laboratory to verify the performances of each section, including the power management and protection of short circuit and overcurrent, surge current suppression, and grounding fault detection of the control system; the packet loss rate, throughput, and latency of the data communication system; and the timing accuracy of NTP and PTP time synchronization for the system. The laboratory test of the prototype system is shown in Fig. 3. The test results of data communication system and time synchronization system are presented below.

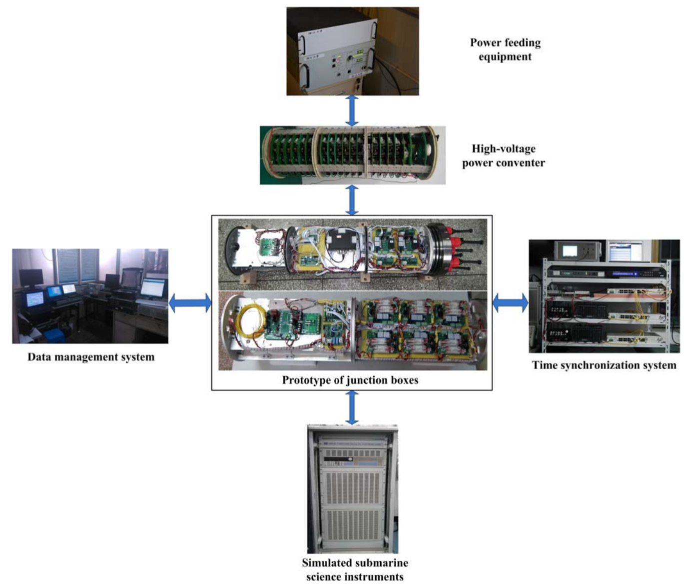

Fig. 3. Laboratory test of the prototype system

Experiments that test the throughput, packet loss rate, and latency of the network at different frame sizes and loads were performed. Table. I shows the results of the experiments. The phenomenon of packet loss was highly unlikely to occur and the latency of the network was less than 800 µs when the network load was less than 70%. Small frame size packets, such as 64/128 bytes, took more responsibilities for the network burden. The relevant latency and packet loss rate were greater when the network load was more than 80%. The network throughput decreased with the decreasing in data frame size.

TABLE I. Service Performance Test of the Communication Network

Packet Loss Rate (%)/Latency (µs)		**Loads (%)**				**Throughput (%)**
		70	***80***	***90***	***100***	
Frame size (bytes)	64	0/749.848	0.938/1334.349	11.944/1368.627	-[a]/-	76.248
	128	0/750.929	3.259/750.927	12.933/1665.725	-/-	83.432
	256	0/755.638	-/752.976	7.375/752.977	-/1596.044	89.410
	512	0/759.294	-/757.070	3.964/757.073	-/1506.444	94.178
	1024	0/764.974	-/765.268	2.057/765.272	-/1479.066	97.912
	1280	0/768.256	-/769.362	1.657/769.361	-/1474.105	98.102
	1518	0/773.216	-/773.217	1.404/773.216	-/1463.195	98.102

a. nontested

Tests were conducted to compare the synchronous precision between NTP and PTP time synchronization under no traffic condition. The NTP and PPS signals were extracted from the underwater Ethernet switch and slave clock respectively. These signals were then measured by a time comprehensive measuring instrument with a time error within 50 ns of the universal time coordinated. The results are shown in Figs. 4 and 5. The NTP timing accuracy for the system is shown in Fig. 4. The results indicate that the time deviation ranges from -100 µs to 50 µs with a mean time deviation of -11.8 µs. The PPS timing accuracy for the system is shown in Fig. 5. The results indicate that the time deviation ranges from -72 ns to 68 ns with a mean time deviation of 8.7 ns.

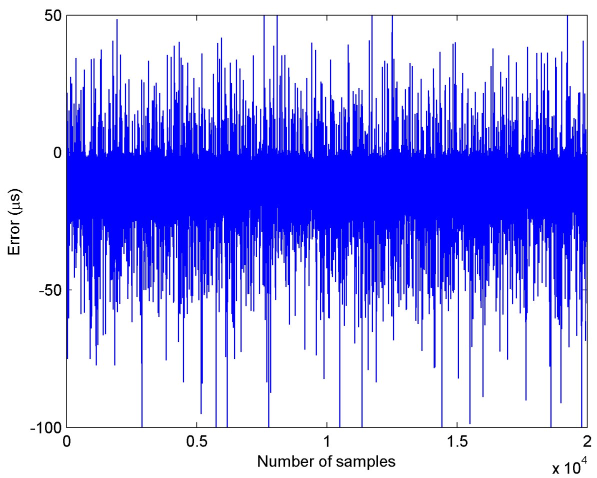

Fig. 4. NTP timing accuracy test

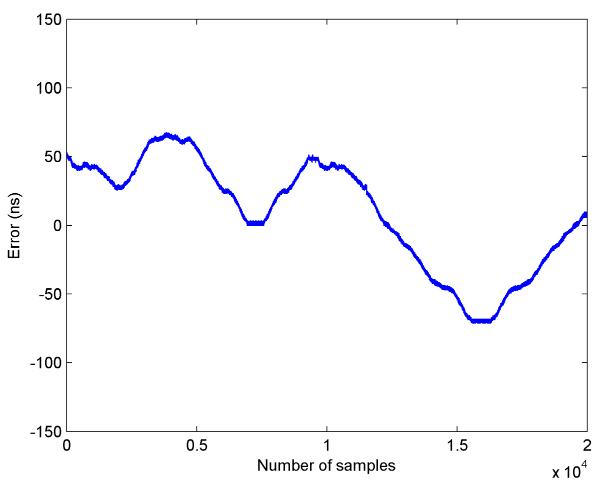

Fig. 5. PPS timing accuracy test

B. Sea Trials

For the application in shallow sea, a cabled ocean observatory system called Zhejiang University-ZRS Experimental Research Observatory (Z_2ERO) was successfully deployed in the East China Sea near Zhairuo Shan Island (Zhou Shan, China) in October 2014 (Fig. 6). Z_2ERO is a single-node network system, and the only JB was deployed 1 km offshore at a depth of approximately 20 m. The -10 Kv high voltage power and 1 gigabit high bandwidth communication were transmitted via a 1.5 km optical-electrical backbone cable between SS and underwater system. Two output channels of the JB were connected to two scientific instrument interface modules (SIIMs) via two sections of 500 m-long optical-electrical cables. Before the connections, the electric signals of communication were converted to optical signals to guarantee more than 100 m communication distance. Numerous instruments, such as conductivity-temperature-depth system and acoustic Doppler current profiler, were connected to the SIIMs through dry-mateable watertight cables. In this sea trial, time series data collected by physical, chemical, and biological instruments were obtained. The system had operated normally and non-continuously for about one year since its deployment in the seabed.

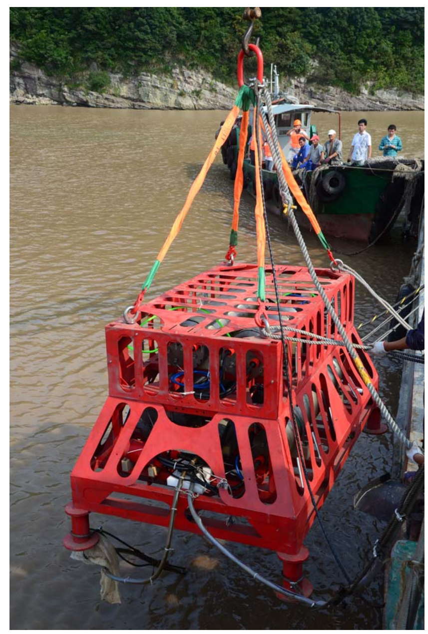

Fig. 6. Deployment of the experimental assembly system in East China Sea

For the ultimate application on the deep seafloor, a sea trial was successfully conducted in the South China Sea in August 2015 (Fig. 7). A simple tree-topology experimental seafloor observatory network with two nodes and several branching units was deployed. The two JBs were deployed 75 km offshore at a depth of 200 m, and 150 km offshore at a depth of approximately 2000 m. High-voltage power and high-bandwidth communication were normally transmitted to the system through a 150 km optical-electrical backbone cable between the SS installed near the beach with power and global Internet available and submarine system. The grandmaster clock installed on the SS received the satellite timing signals via the GPS/BeiDou antennas, and provided NTP and PTP timing signals for the underwater network system. The secondary JBs were connected to the primary JBs through 50 m cables with an ROV wet-mateable plug connector. Various instruments, such as geophysical, oceanographic chemistry, and ocean dynamics, were deployed beside the JBs. The PJBs were a separate structure. The core cavities and outer frame could be connected and separated via high voltage and optical fiber wet-mateable plug connectors.

Fig. 7. Deployment of the experimental assembly system in South China Sea

V. CONCLUSIONS AND FUTURE WORK

The JBs for Chinese experimental seafloor observatory networks were investigated and developed. Based on industrial control, Ethernet communication, and NTP and PTP time synchronization technologies, the key technologies of JBs were examined and validated with respect to their functional aspects. Future work will focus on optimization and perfection of DMS and on improving the stability and reliability of JBs in long-term operations.

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