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Improving transmission reliability of inductive coupling temperature-salinity-depth mooring cable system

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ABSTRACT

Inductive coupling temperature-salinity-depth mooring cable is an important instrument for measuring deep sea environment. However, the channel characteristics change depending on the load and marine environment, and these characteristics affect the signal transmission reliability. In this paper, an inductive coupling temperature-salinity-depth communication system is developed and channel characteristics are derived theoretically. The amplitude-frequency and phase-frequency characteristics in seawater and freshwater environments are measured using the frequency-sweep method in laboratory. The measured results are compared with the theoretical results. The accuracy of the results is verified by recovering a square-wave using the measured amplitude-frequency and phase-frequency characteristics. Next, amplitude shift keying modulation is used to test the signal transmission reliability and the results show that the error rates are high due to the influence of noise. Finally, to improve the signal transmission reliability, a concatenated code comprising of Reed-Solomon and convolution code is used. The concatenated code can make the error rate less than 1.906% and 6.502% in sea water and fresh water, respectively. The study provides an important experimental evidence for understanding the channel characteristics and improving signal transmission reliability of inductive coupling temperature-salinity-depth mooring cable.

1. Introduction

Covering approximately 71% of the Earth's surface and representing 90% of the Earth's biosphere, oceans play a major role in the world (Charette and Smith, 2010). The mooring buoys and submersible buoys are the most widely used ocean monitoring platforms for fixed-point monitoring of the marine environment. The inductive coupling temperature-salinity-depth mooring cable comprises of a vertical structure with many underwater sensor nodes. Each sensor node acts as a port for data acquisition and transmission. Using these sensor nodes, the dynamic marine parameters and environmental data can be collected. The collected data, including information about salinity, depth, temperature, chlorophyll, ocean current etc., is transferred to overwater buoy system and sent to the coastal control center. The control center can provide fast response in real-time (Tomisa et al., 2008a). For the case of wired cable transmission, it is necessary to solve the problems related to the water tightness of the cable, the reliability of multi-node communication and the winding of cable and anchor. In the wireless transmission mode, the distance of optical transmission is limited (Chen et al., 2017). The acoustic transmission has the problems of high cost, low reliability and the poor synchronization (Stojanovic and Preisig, 2009). The transmission using inductive coupling temperature-salinity-depth mooring cable (Kojiya et al., 2005; Yoshioka et al., 2007)is based on the principle of inductive coupling. The transmission uses the mooring cable as a transmission medium and the anchor system as a part of the transmission link to achieve wireless transmission (Xiu et al., 2012). The transmission using mooring cable provides a robust real-time long-distance communication suitable for acquiring marine environmental observation data.

As the detection depth is increasing, more underwater sensor nodes are required. Namely, the systems of different detection depths require sensors of different number. This leads to the fact that the transmission channels of different detection depths are different. The change of the ocean environment influences the impedance parameters of the channel and the amplitude of the signal will be attenuated after passing through the channel. Therefore, the channel has fading characteristics and it is time-varying. Due to the influence of the marine environment, the signal is susceptible to various kinds of burst noise and random noise in the transmission process. Therefore, the signal to noise ratio (SNR) of the

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transmitted signal is low and this results in a low reliability of signal transmission (Tomisa et al., 2008b; Zheng et al., 2016). The method of establishing the circuit model of transmission channel is often used to analyze the transmission channel characteristics of the inductive coupling transmission system (Wu et al., 2016). However, the previous works overlooked many uncertain channel impedance parameters, which leads to a certain difference between the channel characteristics derived from theoretical circuit model and the actual signal transmission.

In order to improve the reliability of data transmission over inductive coupling temperature-salinity-depth mooring cable, the method presented in this paper is as follows: firstly, an inductive coupling temperature-salinity-depth communication system is developed in laboratory. Secondly, the amplitude-frequency and phase-frequency characteristics of the seawater and freshwater systems are measured by using the frequency-sweep method (Chen and Latchman, 1995; Chen and Niculescu, 2004). The measured results are compared with the results of the theoretical circuit model. The accuracy of measured results is verified by recovering a square-wave signal passed through the system using the measured amplitude-frequency and phase-frequency characteristics. Thirdly, the error rates (the ratio of the number of erroneously received symbols to the total number of transmitted symbols) of the system in seawater and freshwater environment are tested using the amplitude shift keying modulation technique. The measurement results show that the error rates are high because of the influence of the noise. To improve the reliability of transmission channel, a concatenated Reed-Solomon and convolution code is used. In this paper, the transmission characteristics of the inductive coupling channel are described more accurately compared with the theoretical circuit model. Further, high reliability of the transmission signal is achieved using the frequency-sweep method and the concatenated Reed-Solomon and convolution code.

2. System structure and measurement principle

2.1. System structure

The inductive coupling temperature-salinity-depth mooring cable mainly consists of underwater sensor nodes, a mooring cable and overwater control unit. The transmission channel is composed of magnetic rings (including underwater magnetic rings and overwater magnetic ring), a mooring cable and water (including sea water and fresh water) (Huang et al., 2013). During the measurement, the mooring cable and water constitute a closed loop, which is equivalent to a single-turn coil. The underwater sensor nodes are used to collect data about marine information such as temperature and salinity at different depths of the ocean. The collected data is sent to the overwater control unit using the magnetic coupling technology. Fig. 1 shows an example of the mooring cable system. The circuit model and channel characteristics change with the number of underwater sensor nodes. In this paper, all the studies are carried out based on the point-to-point data transmission channel.

An inductive coupling transmission system was built in the laboratory. A cable of 10 m length is placed perpendicularly in a cylindrical bath with a diameter of 3 m and a height of 10 m. A set of magnetic rings are placed underwater and overwater along the cable. The test platform is composedoftheNI-USB6259 (NI, USA)signal collection board, the Agilent 81150 A (Agilent, USA) signal generator, and the Agilent 4249 A (Agilent, USA)impedance analyzer. TheNI-USB6259 (NI, USA) signal collection board is used to collect data. The Agilent 81150 A (Agilent, USA) signal generator is selected as the signal source and the Agilent 4249 A (Agilent, USA)impedance analyzer is used for measuring impedance parameters.

2.2. The principle of theoretical calculation and actual measurement of channel characteristics

The theoretical circuit model of the channel is established and the theoretical calculation process is shown in Fig. 2.

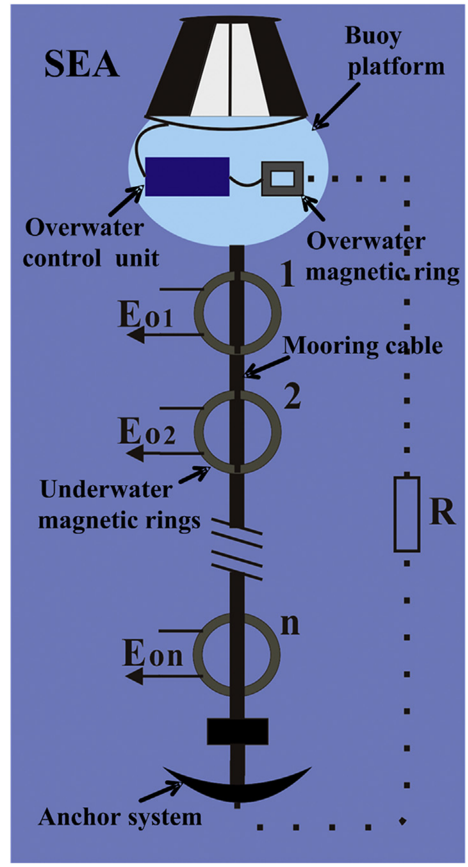

Fig. 1. The inductive coupling temperature-salinity-depth mooring cable.

As shown in Fig. 2(a),establishing the channel circuit model is important to analyze transmission channel characteristics. A voltage signal E_i is input to the underwater magnetic ring, and this induces a current in the single-turn loop consisting of a mooring cable and water. Finally, the current induces an electromotive force of E_o in the overwater magnetic ring. The calculation process based on the Kirchhoff's voltage law is as follows:

$$E_i = \dot{I}_1 \times \dot{Z}_1 + j\omega M_{1,2} \times \dot{I}_2 \tag{1}$$

$$j\omega M_{1,2} \times \dot{I}_1 + \dot{I}_2 \times \dot{Z}_2 = 0 \tag{2}$$

$$\dot{E}_o = j\omega M_{2,3} \times \dot{I}_2 \tag{3}$$

where j is the square root of-1, $\dot{Z}_1 = j\omega L_1$, $\dot{Z}_2 = R + r + j\omega(L_2 + L'_2)$, $M_{1,2} = \sqrt{L_1 L_2}$, $M_{2,3} = \sqrt{L'_2 L_3} = \sqrt{L_2 L_3}$, *Z1* is the primary winding impedance of*T1*, *Z2* is the secondary winding impedance of *T1*, *M1,2* is the mutual inductance of underwater magnetic ring and single-turn loop, *M2,3* is the mutual inductance of the single-turn loop and the underwater magnetic ring, *L1* is the primary winding inductance of *T1*, *L2* is the inductance of the single-turn loop, *L3* is the secondary winding inductance of *T2*, *R* is the resistance of water (including freshwater resistance *R1* and seawater resistance *R2*), and *r* is the resistance of the mooring cable. The derivation of output voltage E_o based on equations (1)–(3) is as follows:

$$\dot{E}_o = \frac{\sqrt{L_3}}{\sqrt{L_1}} \frac{\dot{E}_i}{\sqrt{1 + \frac{(R+r)^2}{\omega^2 L_2^2}}} e^{j \arctan\frac{R+r}{\omega L_2}} \tag{4}$$