Design and implementation of a new low-cost subsurface mooring system for efficient data recovery

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Abstract—**Mooring systems are the most effective method for making sustained time series observations in the oceans. Generally there are two types of ocean mooring systems: surface and subsurface. A subsurface mooring system is less likely to be damaged after deployment than a surface system. However, a subsurface system usually needs to be retrieved from the ocean for data recovery. This paper describes the design and implementation of a new low-cost subsurface mooring system for efficient data recovery: Timed Communication Buoy System (TCBS). The TCBS is usually integrated in the main float and the designated data is downloaded from the control system. After data retrieval, the TCBS will separate from main float, rise up to the sea surface, and transmit data by satellite communication.**

Keywords— Mooring systems; Subsurface mooring system; data recovery; Timed Communication Buoy System; satellite communication

I. INTRODUCTION

Subsurface mooring systems are widely used for ocean observation, such as regular long-time serial environmental parameter measurements, internal wave observation, mixing of ocean research [1] and so on. However, a subsurface mooring system usually needs to be retrieved from the ocean for data recovery. For other purposes, like tsunami or telemetry reporting [2], oceanographers need an efficient method to recover data from subsurface moorings. Several methods have been developed for scientific investigation. One method is to use an underwater inductive modem [3]. Data is transmitted to a surface buoy using the inductive modem before being transmitted to the receivers via satellite. A specially designed mooring cable (plastic-jacketed galvanized steel wire rope) is needed in a typical inductive modem mooring configuration. Transmission rate of the inductive modem is limited to 120 bytes/sec, and an individual inductive modem must be used for each of the instruments integrated on the mooring chain. Another method is to control a communication float with an underwater winch. The communication profiler will rise up to the surface for data transmission based on a programmable schedule [4]. However, a sizeable a mechanical float is necessary because of the large mechanical platform.

The purpose of this paper is to describe a new method to obtain data from an in-situ subsurface mooring system. Based on existing deep-sea subsurface mooring systems and refined modifications, a timed-communication buoy system (TCBS) is designed and evaluated (*Fig.1*). During the subsurface mooring system deployment, the TCBS collect the designated sensors' data with a programmable time interval and stores the data in its internal memory.

Triggered by pre-defined events, an autonomous communication float (ACF) will separate from TCBS and float up to sea-surface before transmitting collected data via an Iridium satellite communication modem. The ACF is a one-time use float; it becomes a drifter after data is sent back to the terminal. In order to maximize its utilization, several measurement sensors are added in the ACF: temperature sensor, pressure sensor, attitude sensor and GPS receiver. As a result, seawater temperature profile and sea-surface temperature (SST) data will be collected while its floating up and drifting on the sea-surface. The sea-surface velocity can also be obtained using the GPS system.

The prototype was evaluated extensively in the lab to verify the functionality and performance of its main components (including time-releases, satellite communication efficiency, and real-time clock) under different sea conditions. The details of the design and test procedure of the TCBS are introduced in section II and section III.

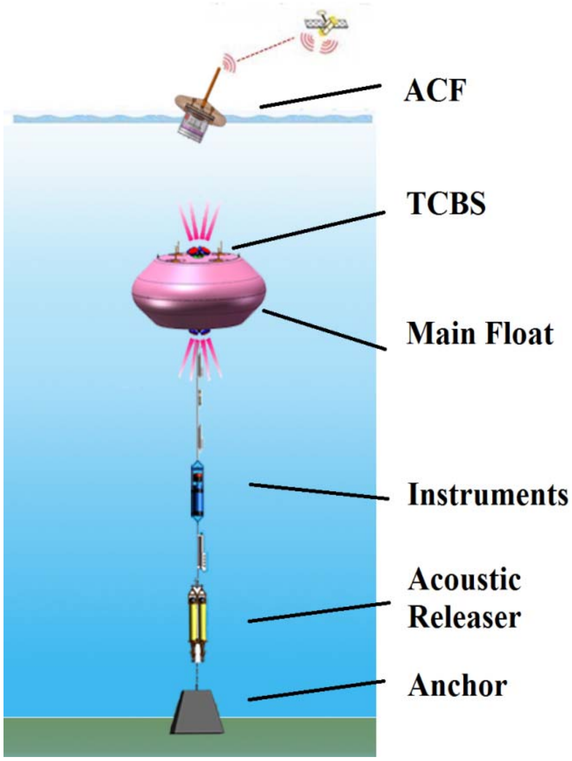

Fig.1. Subsurface mooring system with TCBS

II. CURRENT SYSTEM DESIGN

The main float is the core of the whole subsurface system. Typically the deployment depth rating is about 300 m to 500 m. The main float can effectively obtain the ocean current and thermocline data with Acoustic Doppler Current Profilers (ADCPs), Conductivity, Temperature, and Depth (CTDs) sensors and temperature chains. The main float (*Fig.2*) integrates two 75 kHz ADCPs, six CTDs, several battery chambers, control system, and four TCBSs. To reduce water drag and falling rate by horizontal flow effects on the main float, a streamlined hull is applied to the main float design. In addition, a structural frame is incorporated in the main float design to increase the endurance to high pressures when the main float is deployed underwater.

TCBS (*Fig.3*) is usually assembled into the main float for communication with the main data acquisition (DAQ) and control system for data download and executed commands. The TCBS is about 360 mm in diameter and 520 mm in height, and made of a floating material. Usually four TCBS are symmetrically loaded into the main float to avoid the imbalance (*Fig.2)*. When one of the TCBS is released from the main float, a counterweight in the bottom of the TCBS will be dumped to balance the whole system.

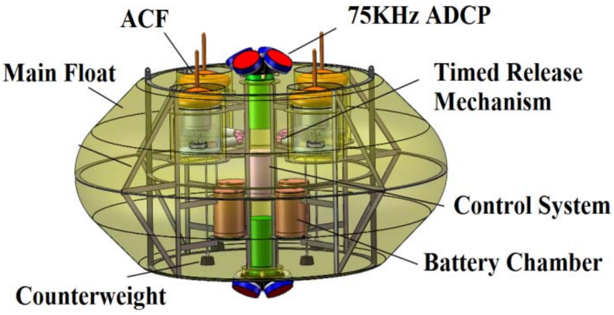

Fig.2. Main float configuration and construction

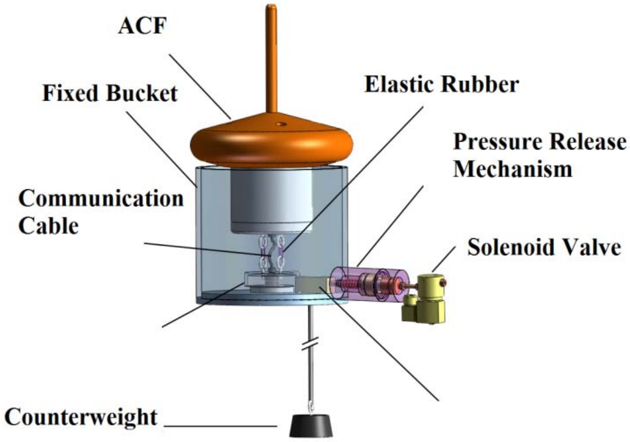

Fig.3. Timed-release real-time communication buoy system (TCBS)

For ensuring reliability each TCBS performs under its own control system and executes all instructions by its internal microcontroller, communicates with the main float, controls instruments' data collection, initiates data transmission and updates the preprogrammed time interval to determine release time. A TCBS consists of an ACF module with an electronic system, a release mechanism module, a fixed bucket, a underwater connector/cable, and a counterweight.

A. Autonomous Communication Float

The ACF includes a waterproof housing, an electronics board, battery packages, a satellite communication module and underwater antenna (*Fig.4*). The ACF can separate from the TCBS when pre-defined events are triggered. An ACF determined by the main float control system will rise up to the sea-surface and create the communication link with a satellite before transmitting the data collected by the main float.

The mechanical design of the ACF has been improved following several rounds of tank tests: 1) lowering the barycenter of the ACF can decrease the ACF body's swing, and the quality of satellite communication is related to the frequency of the ACF body's swing (discussed in Section III). 2) To reduce ACF rise up time and prevent unexpected horizontal water drag, a special slender solid of revolution is applied. 3) Reduced size and weight is critical for subsurface mooring system configuration.

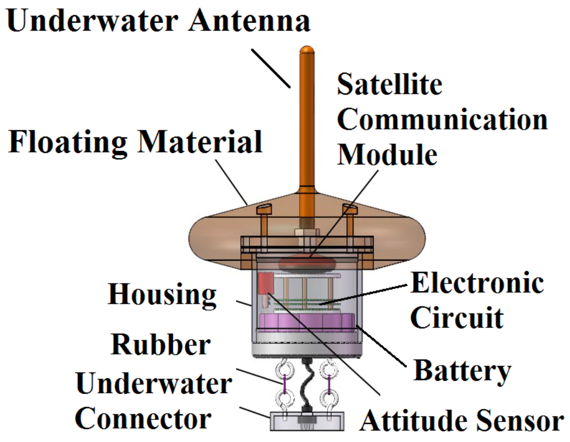

Fig.4. Basic components and diagram of the autonomous communication float

B. *Internal Electronic System*

The internal electronic system of the ACF performs data communication, stores the designated data from the control system, triggers the release mechanism by using an accurate real-time clock, and transmits data via satellite modem (*Fig.5*).

A DC power converter provides 12V and 5V for the entire system. A 16GB SD card is used for the instruments' data storage and a 16-bit MSP430F169 Microcontroller (Texas Instrument) can automatically detect if new measurement data is valid for downloading from the control system.

A real-time clock (RTC) with pre-programmed time events will output an interrupt signal from the interior system to notify the microcontroller when to activate the release mechanism accurately. The RTC component is driven by an ultra-stable temperature-compensation oscillator which addresses applications requiring better timekeeping accuracy. This design can significantly improve the RTC performance to within +/- 32s offset in one year with temperature range from 0 ° to 40°C.

An Iridium satellite modem 9523 is used in the prototype of TCBS for transmissions of large packets of data. The Iridium modem is designed to support all data services (dial-up, direct Internet, RUDICS, SBD and SMS) and the nominal bandwidth for the iridium network is 2.4kbits/s [5]. An underwater antenna, combined with the Iridium and GPS, is able to withstand high pressure (10,000 psi, which is about a 6890 m depth rating). In addition, several acquisition circuit boards for temperature, pressure and attitude measurement are integrated in the system.

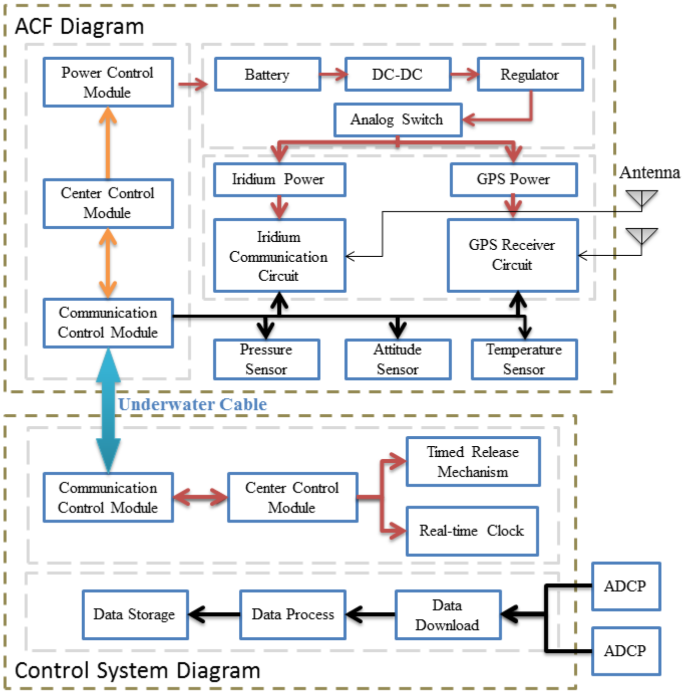

Fig.5. Diagram of ACF and Main control system

C. *Release Mechanism*

The control system is connected with an external solenoid valve to complete the release task. When the solenoid valve is opened, a hook-release mechanism will release the hook between the ACF and TCBS by using the external water pressure.

The hook-release mechanism mainly consists of a upper hook and lower hook. Both hooks are normally closed and can endure a vertical pulling force. The lower hook is connected with a gearing; once the gearing is pulled by external pressure it will cause the upper hook to move to the release state and then the ACF can separate from the TCBS. After the release mechanism is completely opened, a counterweight for controlling the balance of the floating body will be released.

D. *Sensor Measurement Module*

The sensor measurement module includes a high accuracy temperature sensor, pressure sensor and an attitude sensor. The temperature of the seawater can be collected while the ACF is floating up and drifting on the sea surface. In order to improve communication efficiency and reduce power consumption an attitude sensor is added for measuring the ACF's attitude during its drift on the surface. The sensor will be sampled at 4Hz when the satellite communication is established. The internal microcontroller will calculate swing angle and swing frequency of the ACF and also compare these values with the preprogrammed threshold values. In extremely adverse sea conditions, the satellite communication will be cancelled or suspended when the measurement values exceeds the threshold values. The ACF can also integrate other sensors for different applications.

III. EXPERIMENTS AND ANALYSIS

Several experiments, including satellite communications test and timed-release tests, have been conducted to determine the relationship between different sea conditions to satellite communication efficiency.

A. Experiment of TCBS

Timed-release experiments were conducted in the lab's tank (*Fig.6)*. The tank is 4 m wide, 10 m long and 3 m depth. The time interval was set to 30 minutes for triggering the release mechanism. Numerous test trials have been done with a 100% success rate in the lab.

Fig.6. Timed-release experiment is being conducted in a water tank

B. Effects of ACF Attitude on Data Communication

The satellite communication's quality is not related to wave height but determined by buoy swing frequency and swing angle [6], so the communication efficiency was evaluated using different ACF attitudes. Table I shows the communication results for various swing angles and swing frequencies.

TABLE I. Communication tests with various swing angle and frequency

No	**Interval**	**Swing Angle**	**Swing Frequency**	**Result of Communication**
1	20s	30°	0.5Hz	OOOO
2	20s	60°	0.5Hz	OOOO
3	20s	80°	0.5Hz	OOOO
4	20s	60°	1Hz	XXXO
5	20s	30°	1Hz	OOOO

O - successful, X – failure

C. Accuracy of Real-Time Clock (RTC) in SCB

Accuracy of the RTC is critical for accurately controlling the trigger mechanism to release the ACF from the main float. With an integrated temperature-compensated component, the RTC module is rated at +/- 32s per year. A short period test was just completed and the test results are illustrated in *Fig.7*.

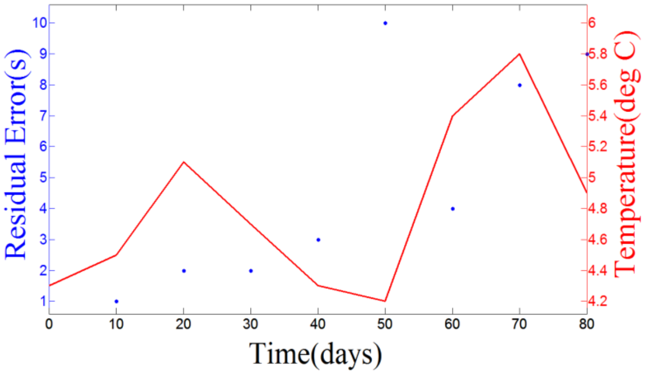

Fig.7. RTC residual error variation with time and ambient temperature

IV. CONCLUSION

TCBS is a reliable, low-cost, easy-to-deploy subsurface mooring system with low risk. It provides an effective method to obtain data in a subsurface mooring system.

Field experiments in the sea will be carried out this summer to evaluate the function repeatability and long-term stability of the TCBS. Additional functionality may also be incorporated into the TCBS to further improve its robustness and flexibility.

ACKNOWLEDGMENT

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