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. Subsurface mooring system is less likely to be damaged after deployment than surface system. However, 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). TCBS is usually integrated in the main float and the designated data is downloaded from the control system. After data retrieval, 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 system is widely used for ocean observation, such as regular long-time serial environmental parameters measurement, internal wave observation, mixing of ocean research [1] and so on. However, 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 invented for scientific investigation. One of comprehensive methods is to use underwater inductive modem [3]. Data is transmitted to surface buoy using the inductivity modules before being transmitted to receivers via satellite. A special designed mooring cable (plastic-jacketed galvanized steel wire rope) is needed in typical inductive mooring configuration. Transmission rate of inductivity module is limited to 120 bytes/sec, and an individual inductive module must be used for each instruments integrated on 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 programmable schedule [4]. However, a sizeable mechanism 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 system and refined modification, a timed-communication buoy system (TCBS) is designed and evaluated (*Fig.1*). During the subsurface mooring system deployment, TCBS collect the designated sensors' data with programmable time interval and storage the data in its internal data 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 Iridium satellite communication modem. ACF is 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 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 during it 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

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TCBS design and test procedure are introduced in section II and section III.

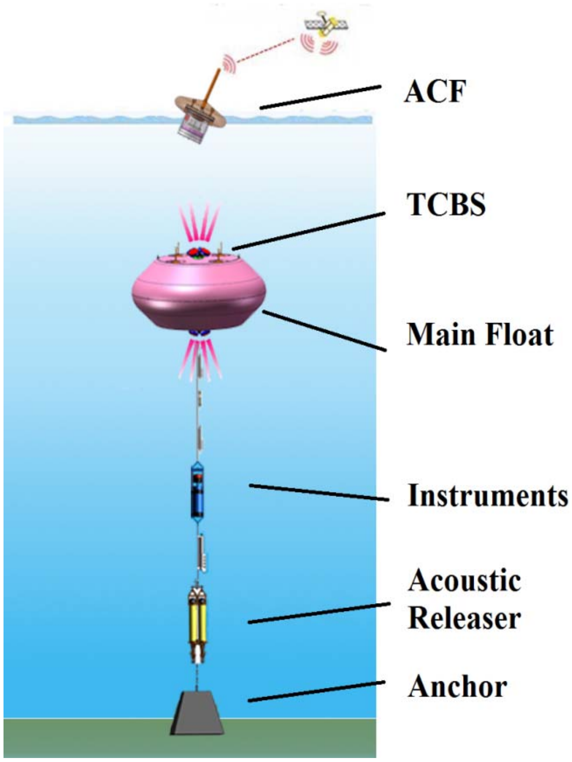

Fig.1. Subsurface mooring system with TCBS

II. CURRENT SYSTEM DESIGN

Main float is the core of the whole subsurface system. Typically the deployment depth rating is about 300 m to 500 m, and can effectively obtain the ocean current and thermocline data with ADCPs, CTDs 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 rating by horizontal flow effect on the main float, a streamlined hull is applied to main float design. In addition, a frame construction mechanical design is applied in the main float design to increase endurance to high strength and high pressure when main float is deployed underwater.

TCBS (*Fig.3*) is usually assembled into the main float for communication with main 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 floating material. Usually four TCBS is symmetrically loaded ballast into the main float to avoid the imbalance (*Fig.2)*. When one of TCBS is released from the main float, a counterweight in the bottom of TCBS will be dumped to balance the whole system.

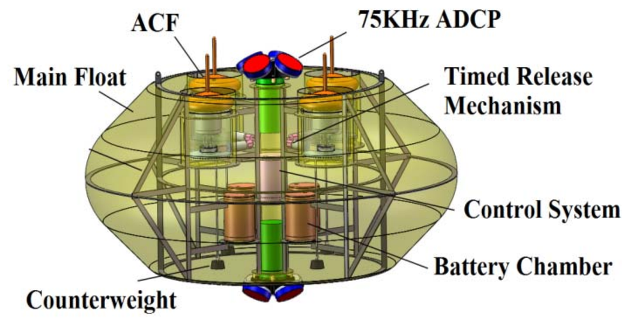

Fig.2. Main float configuration and construction

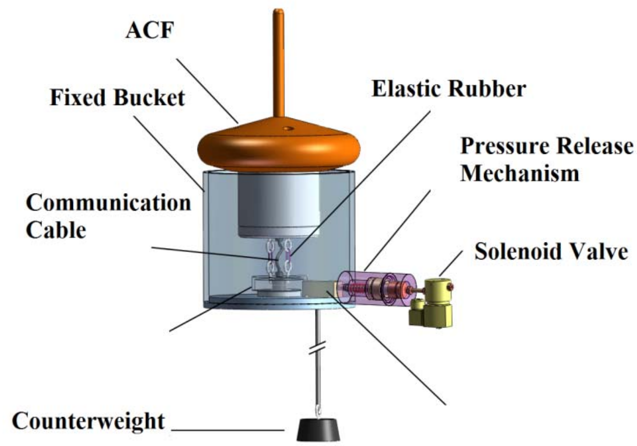

Fig.3. Timed-release real-time communication buoy system (TCBS)

For ensuring reliability during the system in-suit period, TCBS performs under its own control system and executes all instructions by its internal microcontroller, communicate with main float, instruments' data collection, data transmission and updates preprogrammed time interval to determine release time. TCBS consists of autonomous communication float (ACF) module with electronic system, release mechanism module, fixed bucket, underwater connector/cable, and a counterweight.

A. Autonomous Communication Float

The ACF includes waterproof housing, electronic board, battery packages, satellite communication module and underwater antenna. *Fig.4* shows the basic system components and diagram of ACF.

ACF can separate from TCBS when pre-defined events are triggered. An ACF determined by the main float control system will be rise up to the sea surface and create the communication link with satellite before transmitting the data collected by the main float.

Mechanical design of the ACF has been improved following several rounds of tank tests: 1) We found that lowering the barycenter of the ACF can decrease the ACF body's swing, and the frequency of ACF body's swing is related to the quality of satellite communication (discussing 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.

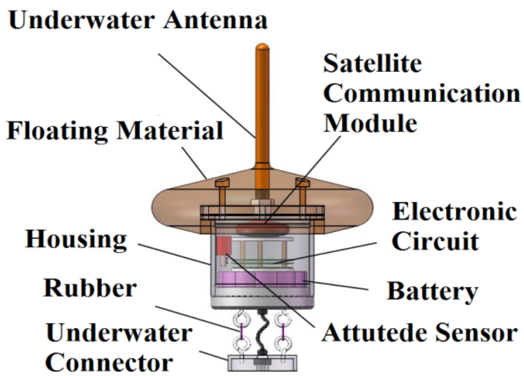

Fig.4. Basic components and diagram of the autonomous communication float

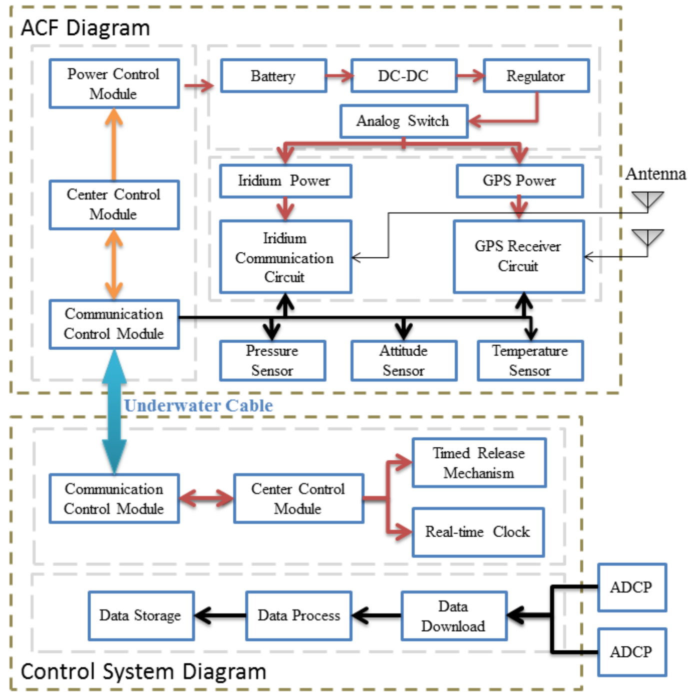

Fig.5. Diagram of ACF and Main control system

B. Internal Electronic System

ACF internal electronic system performs data communication, stores the designated data from control system, triggers the release mechanism by accurate real-time clock, parameter measurement, and transmits data via satellite modem. The linkage between ACF and control is shown in *Fig.5*.

DC power converter provides 12V and 5V for the whole system. 16GB SD card is used for instruments data storage and a 16-bit MSP430 Microcontroller can automatically detect if new measurement data is valid for downloading from control system.

A real-time clock (RTC) with pre-programmed time events will output an interrupt signal from interior system to notify microcontroller when to active the release mechanism accurately. 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 within +/- 32s offset in one year with temperature range from 0 ° to 40°C.

Iridium satellite modem 9523 is used in the prototype of TCBS for large packets data transmit. 9523 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]. Underwater antenna, combined with Iridium and GPS, is able to withstand high pressure (10,000 psi about 6890 m depth rating). Additional sensors DAQ circuit boards for temperature, pressure and attitude measurement are also available.

C. Release Mechanism

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

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

D. Sensor Measurement Module

Sensor measurement module includes high accuracy temperature sensor, pressure sensor and an attitude sensor. Temperature parameter of the seawater can be collected during ACF 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 it drift on surface. The sensor will be sampled at 4Hz when the satellite communication is established, internal microcontroller will calculate swing angle and swing frequency of ACF, and also compare with the preprogrammed threshold value. In extremely adverse sea conditions, the satellite communication will be cancelled or suspended when the measurement value exceed to threshold value.

ACF can also integrate other sensors for different applications.

III. Experiments And Analysis

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

A. Experiment of TCBS

Timed-release experiment is conducted in lab's tank (*Fig.6)*. The tank is 4 m wide, 10 m long and 3 m depth. Time interval is set 30 minutes for triggering the release mechanism. Also in order to simulate in real condition, the entire system will be submerged in a visual pressure chamber for future research and analysis with various difference status and attitude. Numerous test trials have been done with 100% success rate in the lab.

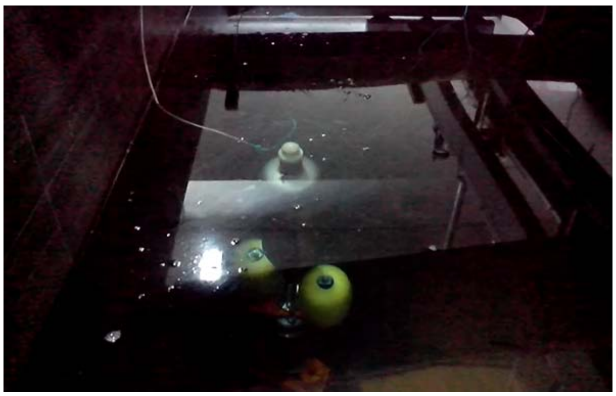

Fig.6. Timed-release experiment is being conducted in a water tank

B. Effects of ACF Attitude on Data Communication

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 angle and frequency.

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 result is illustrated in *Fig.7*.

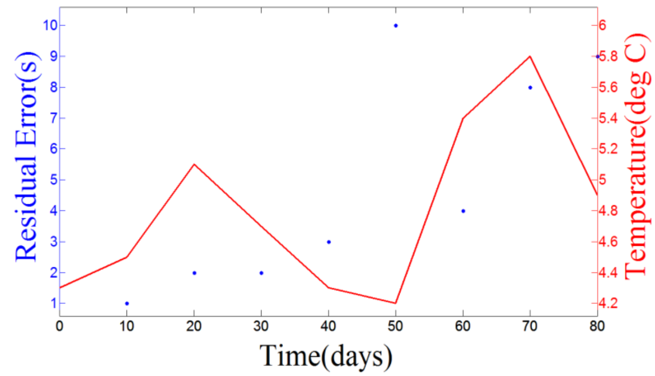

Fig.7. RTC residual error variation with time and ambient temperature

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 subsurface mooring system

Sea field experiment will be carried out in this summer to evaluate the function repeatability and long-term stability of the TCBS. Additional functionality may also be incorporate to the TCBS to further improve its robustness and flexibility.

Acknowledgment

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References

[1] Dalei Song, Jingjing Sun, Bingxue, Chuan Tian, "The Fixed-point Ocean Turbulence Observation based on Submerged Buoy," Intelligent Control, Automatic Detection and High-End Equipment (ICADE), 2012 IEEE International Conference, pp. 72-77.

[2] Meinig, C., S.E. Stalin, A.I. Nakamura, H.B. Milburn (2005), Real-Time Deep-Ocean Tsunami Measuring, Monitoring, and Reporting System: The NOAA DART II Description and Disclosure.

[3] Real-Time Oceanography with Inductive Moorings, Sea-Bird Electronics, Inc. 13431 NE 20th Street, Bellevue, Washington 98005, USA, TEL: (+1) 425-643-9866 Fax: (+1) 425-643-9954; http://www.seabird.com

[4] SeaCycler Sub-surface moored profiler with two-way satellite communication, ODIM ASA and ODIM Inc., 461 Windmill Road,Dartmouth, Nova Scotia,Canada B3A 1J9, TEL: (+1) 902-468-2928 Fax: (+1) 902-468-1388; http://www.brooke-ocean.com/index.html

[5] http://www.iridium.com/products/Iridium-Core-9523.aspx?productCategoryID=2

[6] Iridium communication test, Datawell BV. Zomerluststraat 4, 2012 LM Haarlem, Netherlands, TEL: (+31) 23-531-4159 Fax: (+31) 23-531-1986; http://www.datawell.nl/Home.aspx