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AN AUTONOMOUS EXPENDABLE CONDUCTIVITY, TEMPERATURE, DEPTH PROFILER FOR OCEAN DATA COLLECTION

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Abstract - An Autonomous Expendable Conductivity-Temperature-Depth Profiler (AXCTD) for profiling temperature, conductivity, pressure, and other parameters in remote oceanic regions is described. The AXCTD is a microcomputer-controlled sensor package that can be deployed by unskilled operators from ships or aircraft. It records two CTD profiles (one during descent and another during ascent) and CTD times series while on the bottom and adrift at the surface. Recorded data are transmitted to an ARGOS satellite with ground-positioning capabilities. The AXCTD can provide "sea truth" for remote sensing, perform environmental and military surveillance missions, and acquire time-series and synoptic data for computer models.

1. INTRODUCTION

A microcomputer-controlled conductivity, temperature, and depth profiler was developed to meet the growing need for accurate, low-cost oceanographic data. It is called the AXCTD (Autonomous Expendable Conductivity Temperature Depth Profiler). The AXCTD is programmable, has ARGOS satellite data-telemetry and ground-positioning capabilities, and can be deployed from aircraft or ships by unskilled operators. Although the prototype used for proof-of-concept tests was equipped with conductivity, temperature, and pressure sensors, other sensors could be added to measure optical, chemical, flow, or acoustic parameters. This paper describes major AXCTD components and their operation and reports the results of prototype tests conducted off San Diego, California and in the Strait of Juan de Fuca, Washington.

2. AXCTD OPERATION

The AXCTD records two CTD profiles (one during descent and another during ascent) and time-series data while on the bottom and adrift at the surface (Fig. 1). Recorded data are retrieved via Service ARGOS (Section 2.D.) Once deployed, the AXCTD 1) descends to the bottom recording conductivity, temperature, and pressure, according to a sampling program stored in RAM; 2) records data on the bottom until a programmed time interval elapses or an "event" occurs (warmer/colder, or fresher/saltier water is sensed, or some parameter exceeds a set point) and then releases its anchor and floats to the surface and continues recording data; and 3) transmits recorded data to an ARGOS satellite and drifts with surface currents, continuing to record and transmit data, until battery power is expended.

A. Sensors and Electronics

The sensors and control system used in the prototype AXCTD are a modified version of the OS100 CTD, manufactured by Ocean Sensors, Inc., of San Diego, California [1]. The general arrangement of components is shown in Fig. 2. The conductivity temperature (CT) sensor is integrally fabricated on the same substrate for close thermal tracking and fast response. Conductivity is sensed by four platinum electrodes. An encapsulated thermistor bead is used to measure temperature. The pressure transducer is a strain-gage bridge diffused onto a silicon diaphragm that measures absolute pressure. It is coupled by oil to a stainless steel diaphragm in contact with sea water. The temperature of the

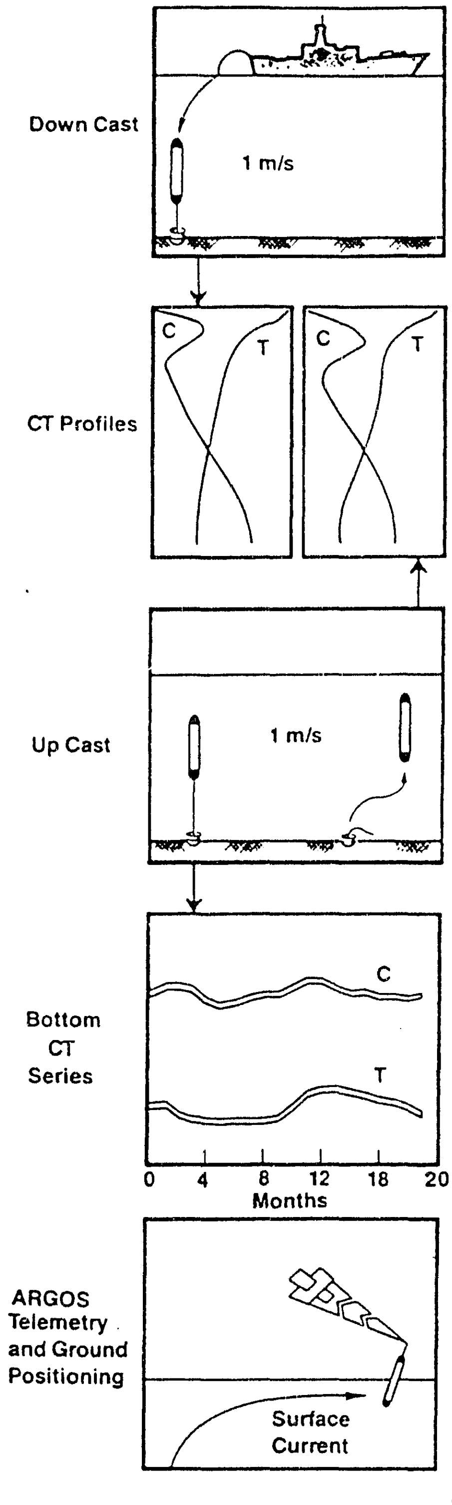

Fig. 1. AXCTD Operation

pressure transducer is monitored with one arm of the bridge that is relatively insensitive to pressure but has a large temperature coefficient. The transducer temperature and the temperature of the offset/gain digital-to-analog converter are used to compensate for temperature errors in the system. Specifications of the sensors are given in Table 1. These specifications apply when the sensors are operated with OS100 analog interface and digital electronics.

B. Signal Conditioning and Sampling

Each sensor is part of an analog circuit that converts sensor resistance to voltage. The pressure transducer is excited with constant-current; the thermistor is in the feedback loop of an operational amplifier; and the conductivity sensor is a constant voltage device. Voltage outputs from the sensors are multiplexed with analog switches and connected to a digitally controlled gain-and-offset circuit. The output is subsequently input to an analog-to-digital converter that produces a 14-bit binary number equivalent to the ratio of sensor voltage and a precision reference voltage. The sensor bridge voltages are sampled this way 99 times per scan and averaged for noise reduction. This sampling scheme adds 2 bits to the system resolution.

TABLE 1. AXCTD SPECIFICATIONS

Sensor	Range	Accuracy
Pressure[1]	10,000 dBar	0.5%
Conductivity	10 to 70 $mS \cdot cm^{-1}$	0.02 $mS \cdot cm^{-1}$
Temperature	-2 to 30° C	0.02° C
Service Depth[1]	6,000 m	
Fall/Rise Velocity	1.5 $m \cdot s^{-1}$	
Response Time	20ms	
Spatial Resolution (at 1.5 $m \cdot s^{-1}$)	1 cm	
Data Capacity[1]	6,000 scans of CTD	
Maximum Deployment[1]	24 Months	
Current Demand		
Standby	200 μA	
Profiling	70 mA	
PTT Transmitting	130 mA	

1. These specifications were not implemented in the prototype AXCTD.

C. Control and Data Logging

The controller is a 80C88 microprocessor-based system with an RS-232 serial communication port and 128K bytes of RAM for storing programs and CTD data (about 6,500 CTD scans). The serial port allows the user to enter sampling and control instructions, check the system status, and retrieve data interactively with a PC. Programs to control sampling, anchor release, and other switching functions are written by the user with a set of six BASIC-like statements that are loaded in the AXCTD RAM via the serial port. Control programs have a loop format and use WAIT statements for timing sampling and switching operations. The power requirements for the electronics depend on the system state. While sampling, the AXCTD draws 70 mA from a 6-V battery; when in standby mode it draws 200 μA.

D. Argos Data Telemetry

Satellite data telemetry and ground-positioning capabilities were implemented with the Telonics ST-5 platform transmitter terminal (PTT), an ARGOS-certified RF transmitter with a carrier frequency of 401.650 mHz. The ST-5 was selected because it is compatible with most microprocessors and the AXCTD mechanical design. In addition, it has an asynchronous serial port and a high-quality oscillator for ground-positioning to ±500 m [2]. The AXCTD microcomputer controls the PTT by sending 8-bit commands via the serial port with ACK/NAK hand shaking. Software to control the PTT is recorded on an EPROM contained in the AXCTD. The ST-5 draws 750 mA at 5-V while transmitting.

ARGOS data collection and location systems are carried aboard the NOAA-10, -11, and -12 TIROS-N satellites in sun-synchronous, polar orbits that provide PTT visibility at the same local time about 10 to 42 times per day at the equator and poles, respectively. Each period when the PTT is visible from the satellite lasts 10 to 13 minutes. Messages containing identification and format information, and up to 256 bits of data can be transmitted at a repetition interval of 40 to 200 s. The received signal is Doppler shifted by the relative speed between the PTT and the satellite. This Doppler shift is detected and converted to a line of position (LOP) and used with other LOPs to compute the ground position of the PTT. Data from PTTs serviced by ARGOS satellites are transmitted to four ground stations and can be obtained from Service ARGOS in a variety of ways. We chose to retrieve our data electronically by telephone modem [3].

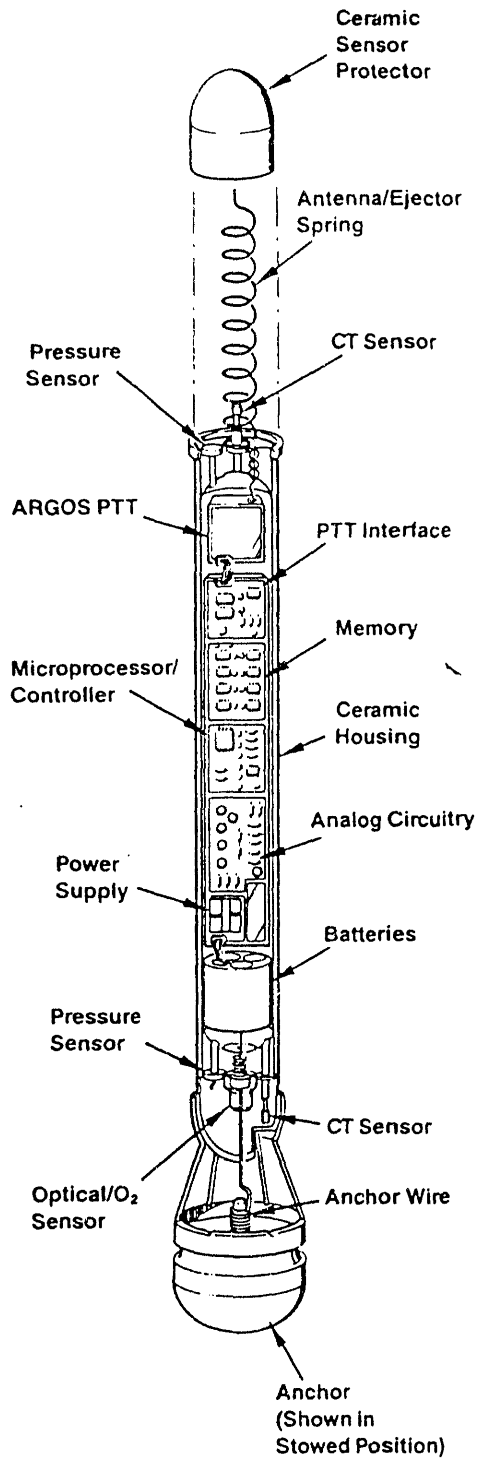

Fig. 2. Sensor Package

Because of the limited baud rate of the uplink and the need for adequate data to resolve CTD profiles at full-ocean depth, eight ID codes, with

256 bits of data per code, were used for our prototype. The PTT receives, buffers, and transmits each ID code at a repetition interval of 90 s. With eight ID codes, the maximum daily throughput is 262,143 bits, which is equivalent to 6,240 scans of conductivity, temperature, and depth. This estimate of throughput assumes that the AXCTD is at 45° latitude, the PTT is visible about 192 minutes per day, and each ID code is transmitted only once. The battery capacity required for this transmission schedule is 0.36 Ah per day.

3. MECHANICAL COMPONENTS

A. Pressure Housing

The prototype electronics are contained in a 577- by 76-mm acrylic tube (6.4-mm wall thickness) with Delrin end caps sealed by o-rings. The prototype package is 1,035 mm long, including the PTT antenna. The CT and pressure sensors are mounted in the top end cap with the PTT antenna. The anchor-wire and serial-port connectors are mounted in the bottom end cap. Rounded fairings on the end caps enhance hydrodynamic stability during descent and ascent.

B. Deployment Container

A container was designed for the prototype sensor package so that it could be shipped and deployed by unskilled operators. The container protects the AXCTD from shock loads and puncture damage during shipment, storage, and deployment, and maintains the sensor in a vertical position prior to release. The design criteria were as follows: 1) the outside diameter must be compatible with launchers for Type-A sonobuoy equipment (124-mm); 2) acceleration of the sensor package must not exceed 50 g during water entry; 3) the container must float in a stable, upright, anchor-down position prior to releasing the sensor package; 4) the release mechanism must be sea-water actuated.

The prototype deployment container consists of a rigid-aluminum cylindrical shell, split in half longitudinally, hinged at the top, and lined with polyethylene foam. Water-soluble paper tape holds the container closed and compresses the foam liner around the sensor package and anchor. A ribbed collar on the anchor prevents the sensor package and anchor from sliding out of the container on impact with the water. The container and payload float vertically, with the anchor down, until the water-soluble adhesive dissolves and releases the sensor package. This method proved to be a simple and reliable way to launch the AXCTD.

C. Anchor and Release System

Pool tests conducted in Battelle's underwater test facility at Columbus, Ohio and calculations demonstrated that a 10-lb mushroom anchor could tow the prototype AXCTD through the water stably at 1.5 $m \cdot s^{-1}$ and hold the sensor package on the bottom in currents up to 1.0 $m \cdot s^{-1}$. An electrochemical system, easily controlled by software and having no moving parts, seemed the best way to release the prototype anchor. The release mechanism consists of a polyurethane-coated, 0.8-mm, stranded, stainless steel wire. One end of the wire is sealed and connected to the anchor with a standard crimp fitting. The other end is terminated with an underwater connector that provides electrical contact with a release circuit in the AXCTD. A 2-mm section of plastic coating is stripped from the wire to make a sea-water contact about 1-cm from the connector. To release the anchor, the AXCTD controller switches a 9-V battery to the wire, allowing current to flow to a metal contact of the underwater connector through the surrounding sea water. The resulting high current density at the stripped section corrodes the exposed wire, causing it to part and release the anchor in 3 to 6 minutes.

4. PROTOTYPE EVALUATION

The prototype AXCTD was tested in the laboratory and at sea. Laboratory tests are described briefly by DeRoos, et al. [4]. The results are summarized here.

The dynamic response of the sensor package was investigated with a 1:1-scale model in Battelle's underwater test facility at Columbus, Ohio. With a 10-lb mushroom anchor, the model accelerated to a terminal descent velocity of 1.6 $m \cdot s^{-1}$ within 2 s of release from the deployment container. With 50 g of positive buoyancy, the model ascended at 1.4 $m \cdot s^{-1}$ and floated stably with adequate freeboard for PTT transmissions.

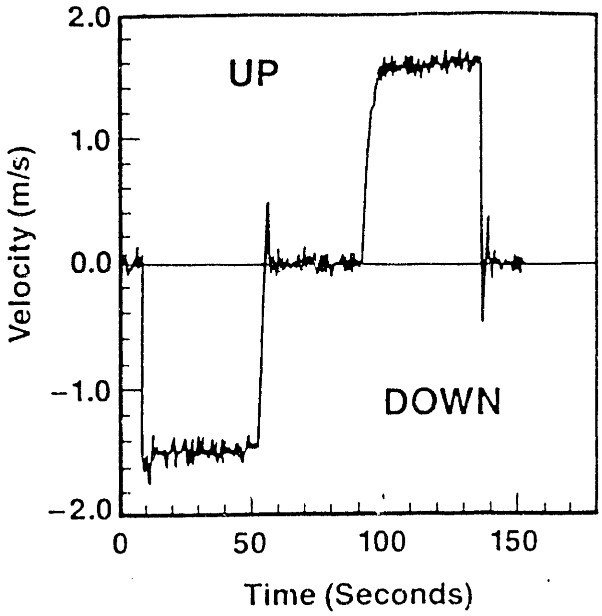

Fig. 3. Ascent and descent velocities

The AXCTD was dropped into flat water from a height of 4.6 m to determine accelerations of the sensor package during deployment. Peak accelerations are between 5 and 25 g when the AXCTD enters the water at 0 to 45° from the vertical. When it strikes the water horizontally, peak accelerations exceed 50 g. The prototype deployment container and water-soluble release system performed well in the pool tests. The sensor package released from the container in a stable vertical attitude after less than 3 minutes of immersion in water. The anchor release system also performed reliably during laboratory tests. The time to corrode and sever an 8-mm stainless steel anchor wire varied from 3 to 6 minutes.

A. Sea Tests

Sea tests were conducted in October 1989 to prove that the AXCTD concept could work. The first test was conducted off San Diego, California. The prototype AXCTD, including the sensor package with monofilament tag line, deployment container, and anchor, was deployed from a small boat in 90 m of water. During the test, the sensor package deployed normally from its container, descended to the bottom, released the anchor, returned to the surface, and recorded data as programmed. These data were successfully transmitted to Service ARGOS and recovered several hours after the experiment.

The second test was completed in the Strait of Juan de Fuca, Washington. The objectives were to 1) make multiple tests of the anchor release mechanism, 2) compare the prototype AXCTD data with a commercially available CTD (SEACAT®, Sea Bird Electronics), and 3) test the ARGOS uplink. Five anchor releases were successfully completed. The pressure data from one cast were converted to vertical velocities to verify the descent/ascent velocity specifications (Fig. 3). The sea test demonstrated that the dynamic behavior of the prototype met sys'em design requirements.

Fig. 4 shows average σ_t values ($\sigma_t = [\rho_{s,t,0} - 1] \cdot 10^3$) computed from six tandem casts of the AXCTD and SEACAT in the Strait of Juan de Fuca. The shapes of the profiles are very similar; however, there is an offset of about 0.2 σ_t units between them. It was discovered after the test that an incorrect calibration factor in the AXCTD program had biased the conductivity data. We also noted large discrepancies between the two instruments at sharp salinity gradients. These

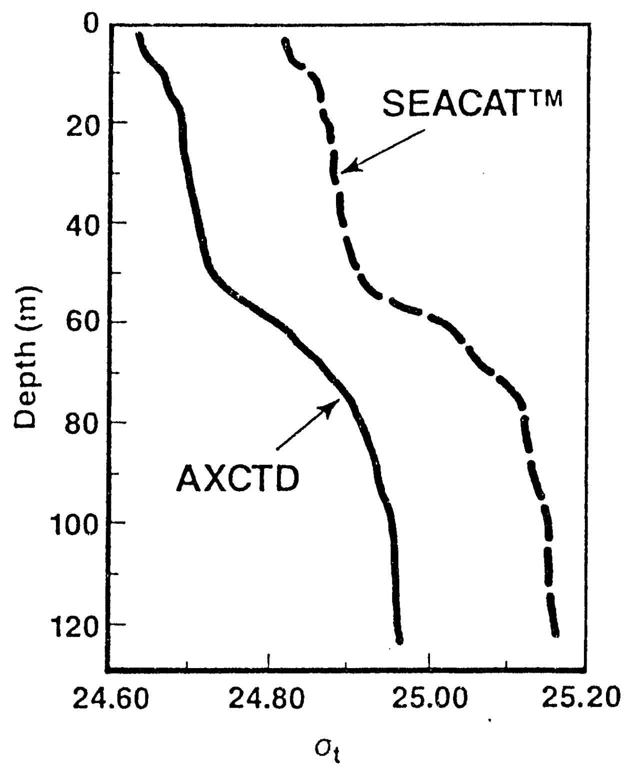

Fig. 4. AXCTD and SEACAT σ_t profiles

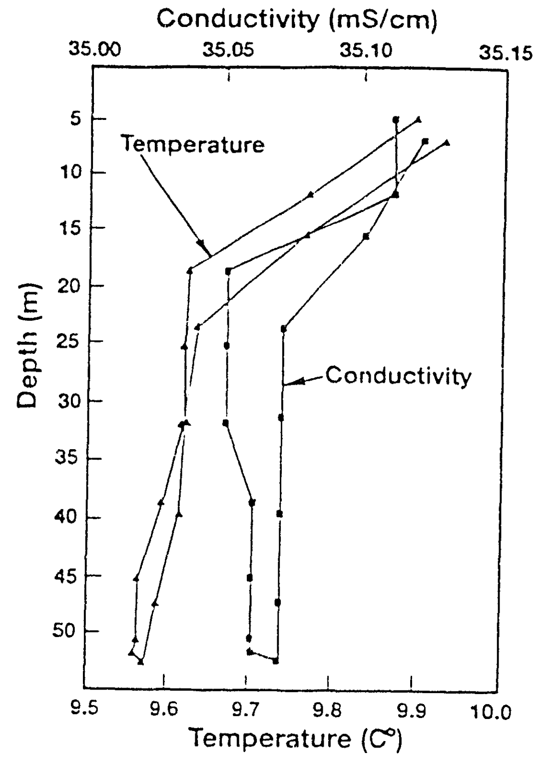

Fig. 5. Conductivity and temperature data retrieved by SERVICE ARGOS

result from differences between the response times of the instruments. It appears that the SEACAT responds slower than the AXCTD because it has a flow-through conductivity cell that takes longer to flush than the CT sensor on the AXCTD. Fig. 5 shows profiles obtained on October 27, 1989 and recovered via System ARGOS. The coarse resolution of these profiles relative to the tandem tests resulted from the use of a sampling program set up to scan the CTD at 5-m depth intervals. Although they are not very useful for oceanographic purposes, the data compared well with SEACAT profiles obtained at the same site and demonstrated the successful performance of all AXCTD functions.

5. CONCLUSIONS

Sea tests demonstrated that the AXCTD is appropriate for many applications when oceanographic and environmental data are required in remote regions where vessel operations are prohibitively expensive or when event detection is needed. These include:

- providing "sea truth" for remote sensing
- environmental and military surveillance
- obtaining time-series and synoptic data for initializing and validating computer models of ocean circulation and acoustic environments.

All of these applications depend critically on keeping the cost of producing AXCTDs low enough to be an attractive alternative to other systems. Our initial estimates of production costs suggest that this will be possible.

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