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ACOUSTICAL LOCATING SYSTEM FOR DUMAND-II

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ABSTRACT

The DUMAND-II astrophysical neutrino detector is under construction, and deployment of the main first-phase components is planned for late 1993. Reconstruction of muon track direction with <1° precision on the celestial sphere will require determination of PMT locations to better than 10 cm. Monitoring of relative positions of PMTs will be performed using specially developed techniques and equipment to be described. A site-marking transponder net has been deployed and surveyed relative to geographic coordinates using GPS satellite navigation. The survey operation provided an in-situ test of the planned locating techniques.

INTRODUCTION

DUMAND-II is a water Cerenkov detector for high energy astrophysical neutrinos. The physics goals of the project have been described in detail elsewhere[1]. Nine vertical strings each carry 24 hemispherical photomultiplier tubes, for a total complement of 216 Optical Modules, or OMs (PMTs and associated fast electronics in glass pressure housings). The ocean bottom array is sited approximately 30 km west of Keahole Point on the Island of Hawaii, at a depth of 4.7 km. The site places no significant constraints on future expansion of the system. A cable to shore, terminating in the Junction Box (JB) to which the strings are connected, provides power and fiber optic data communications.

The strings are located at the corners of an equilateral octagon with 40m sides, with the ninth string anchored by the JB at its center. The active length of each string is 230 m, with 10 m spacing between OMs and the lowest module 100 m above the ocean floor. Muons will be detected with high efficiency and reconstructed in direction with a median accuracy of about 1°. The scattering angle between the incident neutrino and the resulting muon will be within this error for neutrino energies above about 1 TeV. In order to achieve this pointing accuracy, it will be necessary to determine OM coordinates to better than 10 cm, and to relate site coordinates to celestial (i.e., absolute geographical) coordinates to better than 1°. This will be accomplished using an acoustical locating ("positioning") system with several novel features.

POSITIONING SYSTEM

During detector operation, OM positions will be determined at frequent intervals (up to 1 Hz) using sets of 5 hydrophones spaced along each string. Simultaneous range measurements to a set of five acoustical projectors at surveyed locations will determine hydrophone coordinates, and the hydrophone positions will be fitted to an appropriate catenary function to interpolate individual OM coordinates. Conventional transponder ranging systems are not suitable for several reasons. Battery lifetime would be insufficient for the 10 year anticipated life of the experiment, requiring periodic replacement and resurvey. Moreover, a transponder useful for site survey purposes at 5000m depth would be limited to frequencies on the order of 10 KHz, while positioning to a few cm would require >50 kHz using conventional techniques. The presence of the shore cable supplying power and high-rate data communications makes a different approach practical. We have developed, tested, and confirmed the performance of a positioning system based on a set of responders (hardwired, computer commanded projector/hydrophone units) moored at a radius of about 300m from the DUMAND array. Fig. 1 shows a schematic view of the initial 3-string deployment, showing responder locations. Additional hydrophones, as well as transducers required to monitor sound speed parameters -- ocean currents, temperature, pressure, and conductivity (salinity) -- will be moored to the Junction Box.

Hydrophone signals are digitized with 125 kHz sampling and sent to shore for analysis. The signals used are chirps (frequency modulated pings) which provide positioning accuracy better than 1 cm, and extremely high signal extraction capability in the presence of noise[2], by cross-correlating the raw data with a replica of the pure signal (in effect, a matched-filter technique). Results indicating <1 cm positioning accuracy over ranges of ~300m have been confirmed by tests in Lake Washington.

DUMAND deployment will proceed in several stages. In the first step, completed in October, 1992, the site location was defined and site coordinates related to celestial coordinates by deploying a set of conventional transponders, laid around the selected site center at ~1.5 km radius and surveyed to about 5m accuracy from a surface vessel using GPS navigation. Next, the first string of OMs will be deployed, with the JB as its anchor, and the electro-optical cable will be laid to shore. This operation is currently planned for October, 1993. Two additional strings will then be deployed, and connected to the JB using a manned or remotely operated submersible. At the same time, five responder units, similarly equipped with cable spools, will be deployed at 300m radius from the string array; each consists of anchor, flotation and transducers, hardwired into the JB electronics can. After test operation of the three string configuration (Phase I), a second deployment operation about one year later will install the remaining six strings of optical modules. The expendable transponders, needed only for the initial survey and deployment operations, can then be related to the coordinates of the responders, which serve as permanent fiducials. The responders will also be ranged relative to one another and to the JB transducers, providing internal local sound speed determination independent of estimates from environmental parameters.

The October, 1992 acoustical survey of the site-marking transponder network provided a realistic test of the acoustical data acquisition system components. Although the commercial transponders deployed produced conventional pings rather than chirps, the survey range data were acquired and analyzed using the same hardware and software to be used for precision location of string hydrophones. Fig. 2 shows a block diagram of the "UW Deck Box" used to perform ranging measurements. A Sun IPX workstation was used to command the deck box 68000 CPU, and to log data.

Upon receipt of a command to obtain a range measurement to a specific transponder (each having unique interrogate or reply frequency in the range 8.5--14.5 kHz) the deck box generated a signal emulating those produced by a commercial control unit, which was amplified to 400W power level and transmitted by a pinger suspended from the ship. The transponder's reply was detected by a hydrophone located near the pinger. The hydrophone signal was digitized and correlated with a model of the expected reply by a DSP board. Peaks in the output of the DSP, representing detection of the expected signal in the noisy hydrophone signal stream, were detected by an analog threshold circuit, stopping the range-timing clock. Both the pinger and the hydrophone were prototypes of those to be used in the DUMAND array. The Sun workstation logged transit time measured, along with the ship's GPS position at transmission and receipt. The data were analyzed offline, and the resulting fitted coordinates for the transponders had errors equivalent to the GPS positioning accuracy of a few meters.

CONCLUSION

The DUMAND acoustical locating system has been tested under realistic conditions and anticipated performance confirmed. As a byproduct of the positioning requirements for astrophysical neutrino track reconstruction, the acoustical system will provide additional oceanographic data of interest, such as long-term measurement of currents and other physical parameters, and information on bioluminescence (seasonal fluctuations, diurnal variation, spatial correlations, etc.) reflected in OM backgrounds. Correlations between environmental observations in different modes (acoustical, physical and optical) may provide exciting new insight into the abyssal environment. For example, it may be possible to use DUMAND string shape data as a sensitive measure of low velocity currents over a long time period, and to use the hydrophone network as a system for acoustical detection of high energy cascades[3].

REFERENCES

* For a full list of DUMAND Collaboration participants, see ref. 1.

1) The DUMAND Collaboration, "Update on the Status of DUMAND", this Conference; V.Z. Peterson, et al., Proc. OCEANS-91 (1992).
2) T. Aoki, et al., Proc. XXII ICRC, 4:666 (1991).
3) See J. Learned and R. J. Wilkes, "Acoustical Detection of Cascades in DUMAND", this conference.

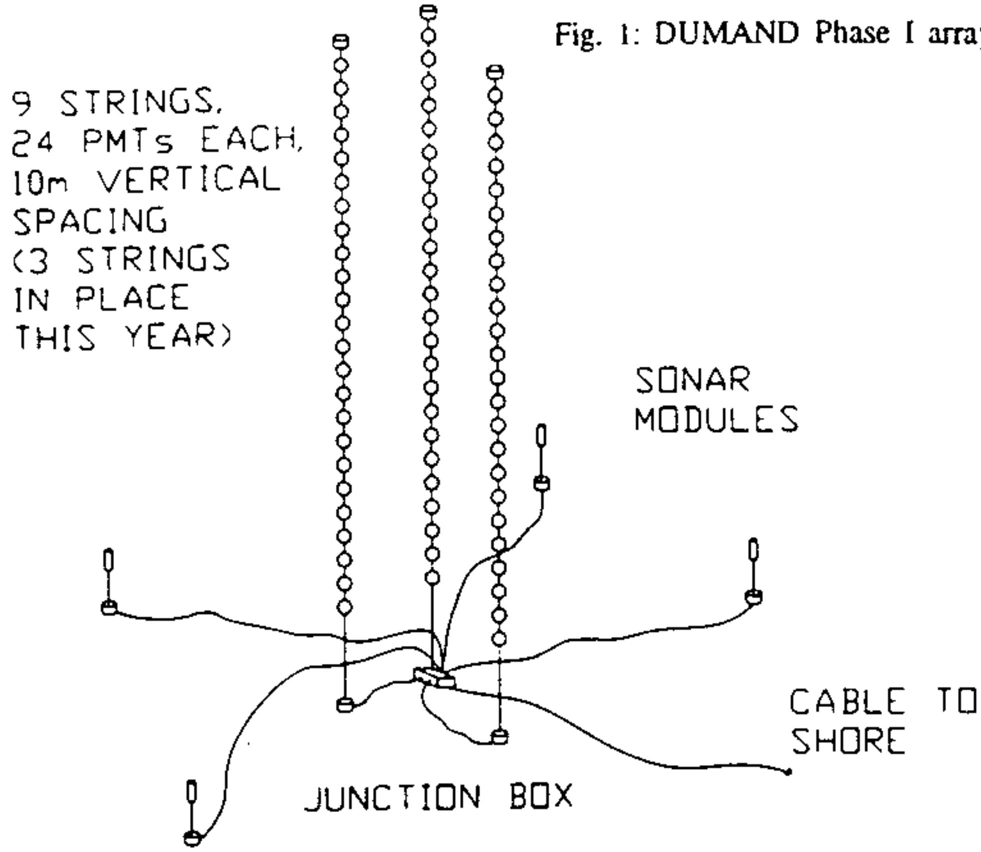

Fig. 1: DUMAND Phase I array.

Fig. 2: UW acoustical data system for transponder survey.