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ACOUSTICAL POSITIONING SYSTEM FOR DUMAND-II

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ABSTRACT: The DUMAND-II astrophysical neutrino detector is under construction, and deployment of the first components is planned for late 1992. Reconstruction of muon track direction with 1° precision on the celestial sphere will require determination of PMT locations to within about 10 cm. Survey of the array relative to geographic coordinates will be performed using GPS satellite navigation in conjunction with conventional acoustical positioning techniques. Monitoring of relative positions of PMTs will be performed using a network of acoustical responders; DUMAND has the unique advantage of a high rate fiber-optic data link to shore, permitting sophisticated realtime analysis of acoustical signals. Techniques and equipment to be used will be described.

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 to which the strings are connected, provides power and fiber optic data communications. The DUMAND-I experiment[2] operated a short prototype string near this site, and confirmed the ability of the planned system to detect and reconstruct muon tracks.

The strings are located at the corners of an equilateral octagon, with the ninth string at its center. The active volume of the array will have a height of 230 m and a diameter of 105 m, with the lowest module 100 m above the ocean floor. Horizontal and vertical spacings between the modules are 40 m and 10 m, respectively. Array geometry has been optimized for the detection of high energy (>25 GeV) muons from neutrino interactions, as well as contained neutrino induced cascades. 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 positioning system with several novel features.

POSITIONING SYSTEM. During detector operation, OM positions will be determined at frequent intervals using sets of 5 hydrophones spaced along each string. Simultaneous range measurements to a set of acoustical projectors at surveyed locations will determine hydrophone coordinates, and the hydrophone positions will be fitted to a suitable catenary function to interpolate individual OM coordinates. Conventional transponder ranging systems are not suitable because battery lifetime would be insufficient for the needs of the experiment, requiring periodic replacement and resurvey. Moreover, a transponder suitable 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 will deploy a set of responders (hardwired, computer commanded projector/hydrophone units) at a range of about 300m from the DUMAND array (Fig. 1). Additional hydrophones, as well as transducers required to monitor sound speed parameters -- temperature, pressure, and conductivity (salinity) -- will be moored to the Junction Box.

Hydrophone signals will be digitized with 100 kHz sampling and sent to shore for analysis. Thus we are not limited to the simple threshold detection methods used in conventional transponders, but can employ more complex numerical procedures to obtain enhanced positioning precision. The chirping (frequency modulated pinging) technique we plan to use provides positioning accuracy on the order of 1 cm, and extremely high signal extraction capability in the presence of noise[3]. Figure 2 shows a simulated chirp (10--30 kHz sweep), and Fig. 3 shows the same pulse with gaussian noise superimposed at a signal/noise ratio of 1:1. While signal extraction with simple threshold logic would be difficult, Figure 4 shows the results of cross-correlating the raw data with a replica of the pure signal (in effect, a matched-filter technique). Notice the extremely sharp resolution of the correlogram (peak located within 0.015 msec, corresponding to 2 cm), which shows how this technique can extract clean timing information from data with a very poor S/N ratio. A prototype chirping system has been constructed and tested. Fig. 4 shows data logged from a test in which projector and hydrophone were separated by 100 m in fresh water. Our results indicate that the spacing could be determined to ~1 cm precision over this range. Further calibration, over longer ranges and in seawater, is underway.

DEPLOYMENT. DUMAND deployment will proceed in several stages. First, the site location will be defined and site coordinates related to celestial coordinates by deploying a set of conventional transponders, laid on a 1 km baseline and located to about 10m accuracy from a surface vessel using GPS navigation. Next, the electro-optical shore cable will be laid, and its terminating Junction Box deployed from the cable ship at the DUMAND-II site. After a period of test operation of the JB and associated equipment, the first three strings of Optical Modules will be positioned using the transponders, anchored on the ocean bottom, and connected to the JB using a manned submersible. Each string will be equipped with a cable spool and appropriate length of single fiber electro-optical cable. The individual string cables will be joined to the electro-optical shore cable using wet-mateable connectors inserted into the JB by the submersible. At the same time, four 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, 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.

CONCLUSION. As a byproduct of the positioning requirements for astrophysical neutrino track reconstruction, the DUMAND 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.

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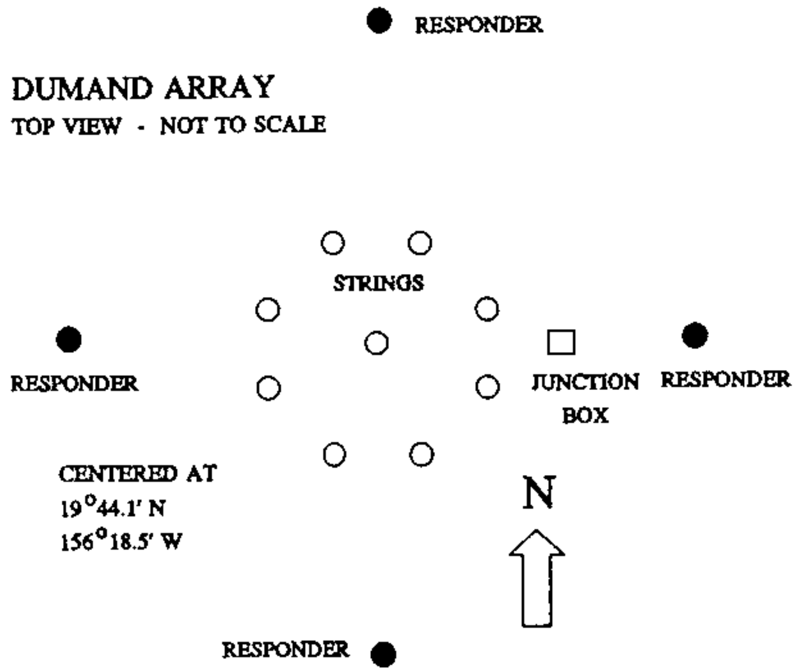

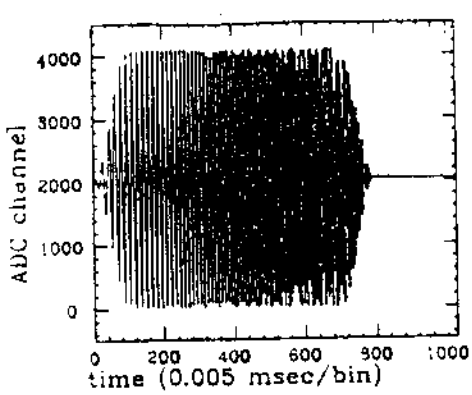

Figure 2: Simulated chirp.

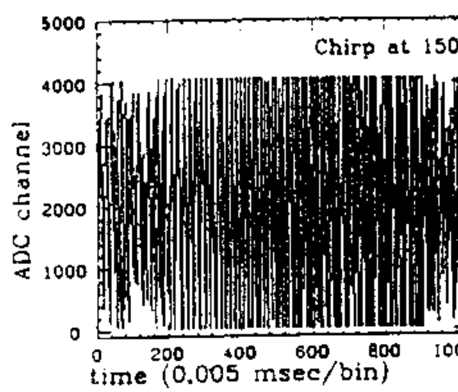

Figure 3: Chirp with noise.

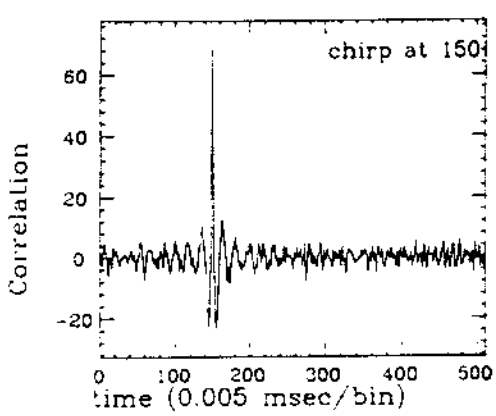

Figure 4: Chirp identified.

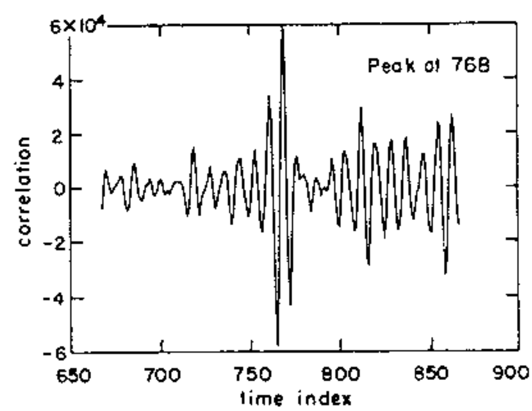

Figure 5: Field test results.