Analysis of Attitude Sensors in the Prototype String of HUNT Project

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HUNT Project

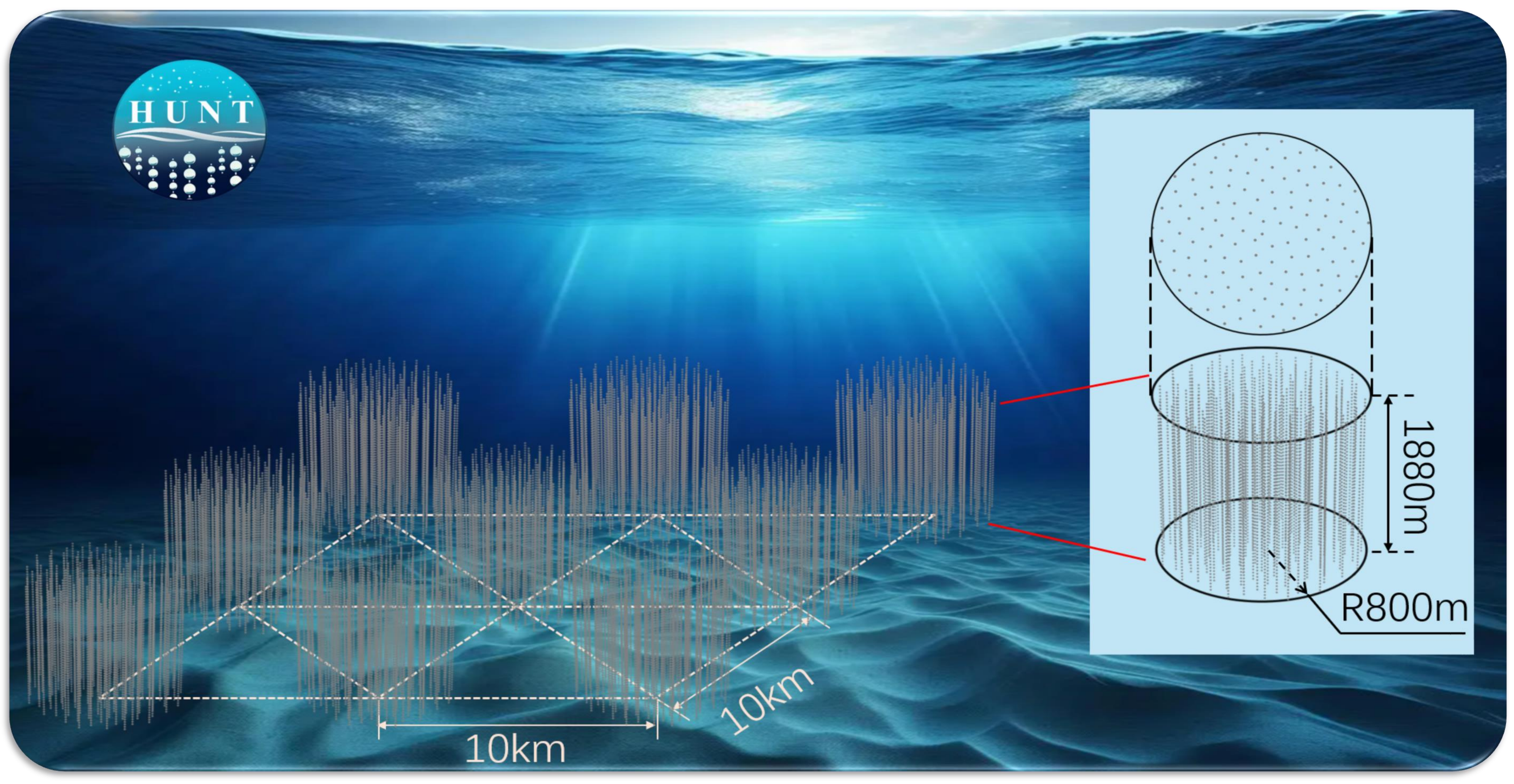


Fig.1. Schematic diagram of the HUNT

The HUNT (High-Energy Underwater Neutrino Telescope) is a next-generation neutrino telescope project. Each string in HUNT has dozens of optical modules (OMs), which house a 20-inch photomultiplier tubes (PMT) within 23-inch glass spheres. The deployed volume of this telescope will be approximately 30 km³, with a total of about 55000 OMs arranged on roughly 1152 detection strings(Fig 1). Each detection string has a length of about 1880 meters, with a horizontal spacing of about 130 m between adjacent strings, which can significantly improve the directional accuracy and event reconstruction capability for neutrinos in the TeV to PeV energy range.

Prototype String of HUNT

Since March 2024, HUNT has deployed a total of 2 prototype strings in Lake Baikal (Fig2). These strings are mainly composed of OMs, Acoustic Positioning Systems (APSs), LED modules, String Modules (SMs), as well as anchoring and floating devices. APS is used to measure the displacement of the string underwater. The LED modules is used to calibrate the status of the OMs. A White Rabbit switch is placed inside the SM, which is used for clock synchronization and data collection.

In Figure 2, both orange and blue circles represent OMs, with a spacing of 30 meters each adjacent OM. The orange ones have electronics board installed inside, which are used to digitize the signals from the PMTs within the OMs. The blue OMs transmit PMT signals via coaxial cables to the nearest orange OM for measurement.

To measure the attitude and position information of each OM in real time, an attitude sensor is installed inside each OM. The attitude sensor is an inertial measurement unit (IMU) with the model LSM9DS1, which can measure acceleration, magnetic field, and temperature data.

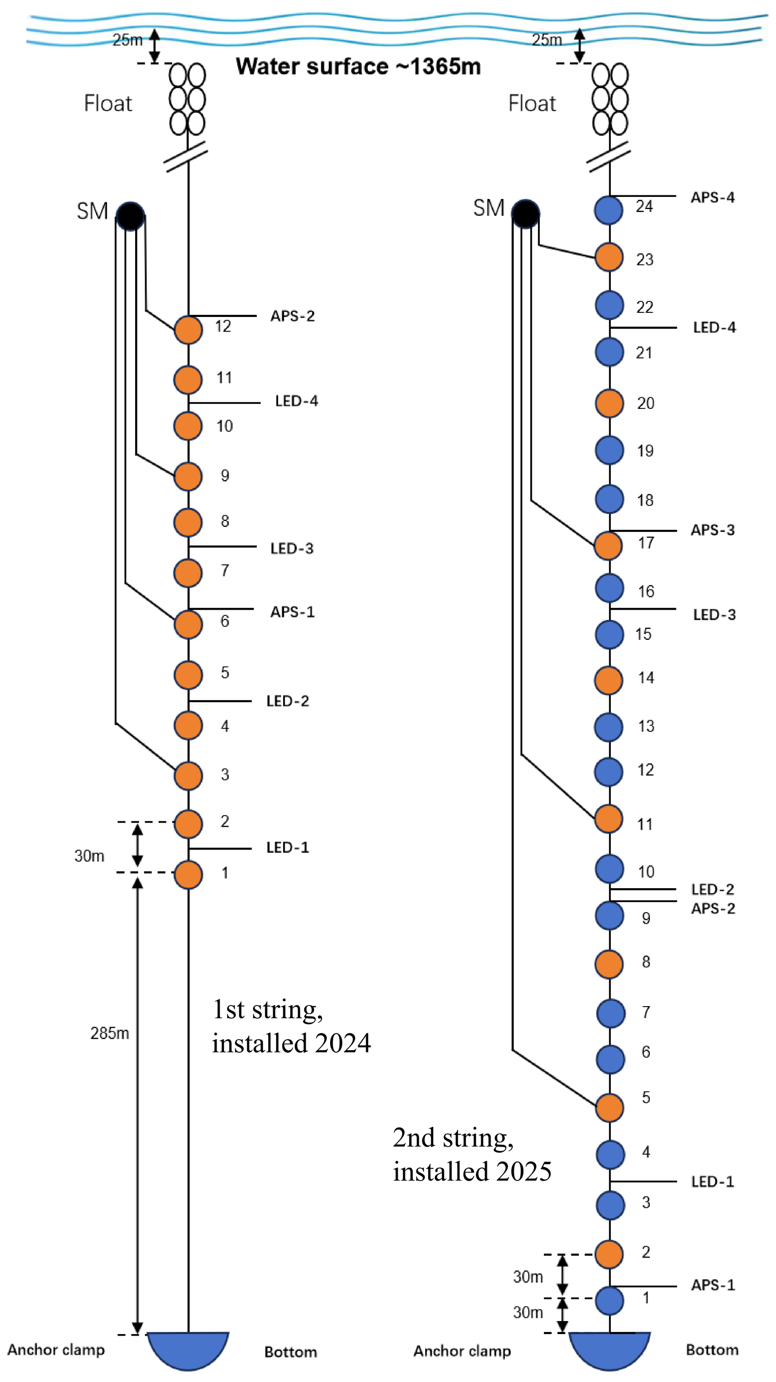
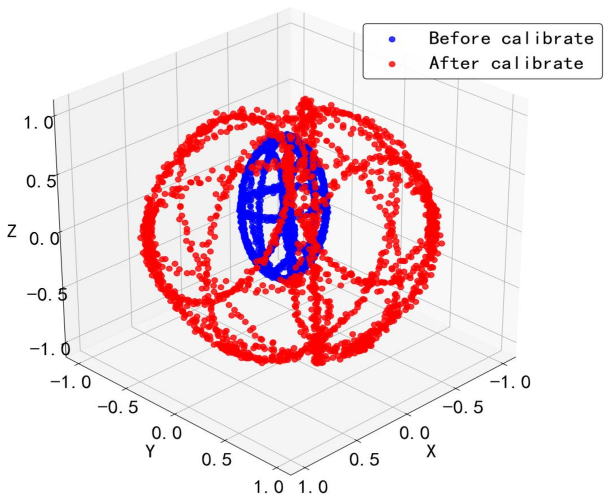


Fig. 2. The prototype string of HUNT

Attitude Sensor Calibration

The calibration platform is made of non-magnetic copper-aluminum alloy. It provides stable and rigid support through a triangular frame structure, as shown in Fig.3. The OM is fixed at the center of the platform via a dedicated fixture. By rotating each rotation axis of the platform, the OM can be positioned in various attitudes, so as to obtain the calibration parameters of the attitude sensor.

Fig. 3 . The Attitude Sensor Calibration Platform



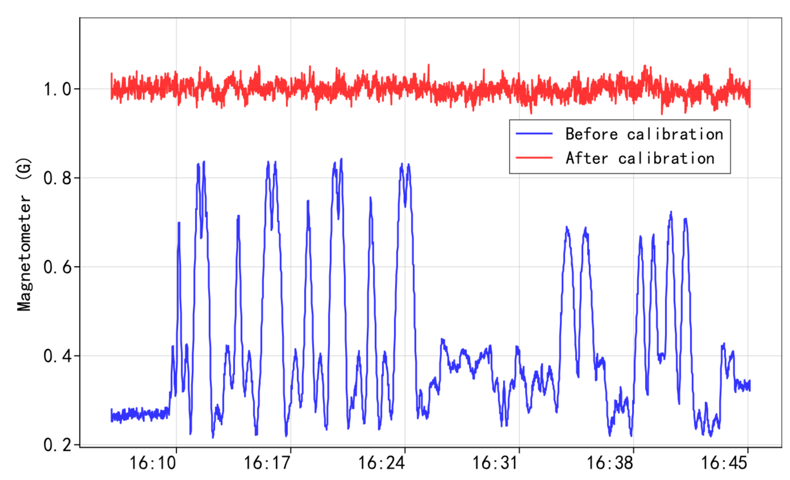


Fig. 4 Left: Distribution diagram of data points of OM before and after calibration. Affected by the magnetic substances inside the OM, the graph of the XYZ three components measured by the magnetometer presents an ellipsoid. The figure on the right shows the distribution of magnetic field strength before and after calibration. It can be observed that after calibration, the magnetic field strength measured by the attitude sensor became relatively consistent.

Temperature Effects Test

Fig. 5 OM in the temperature-controlled chamber.

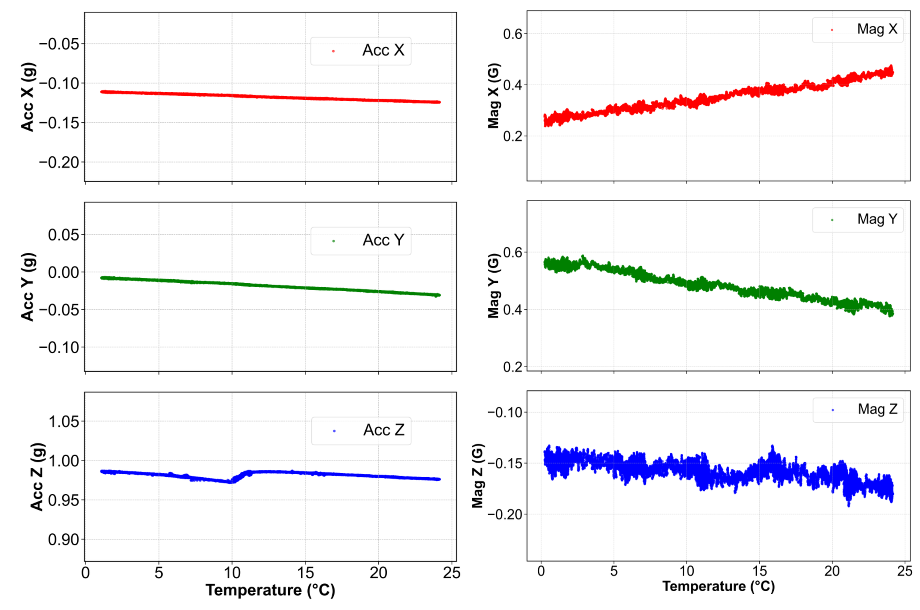


Fig. 6 Left: Variation of the accelerometer with temperature; Right: Variation of the magnetometer with temperature.

To measures the temperature effect of the attitude sensor after the packaged, an OM is placed in a temperature-controlled chamber. A temperature gradient of 5°C is set, and each gradient is maintained for 2 hours, with the temperature gradually increasing from 0°C to 25°C. Fig. 6 shows the curves of the measured values of the X, Y, Z axes of the accelerometer or the magnetometer varying with increasing temperature. Table 1 presents the results of relevant parameters of the accelerometer and magnetometer varying with temperature.

Table 1: Temperature-induced sensor parameter variations

Accelerometer parameters	Overall variation (g)	Variation g / °C	Magnetometer parameters	Overall variation (G)	Variation G / °C
Acc_X	-0.0162	-0.0006	Mag_X	0.0636	0.0023
Acc_Y	-0.0286	-0.0010	Mag_Y	-0.0582	-0.0021
Acc_Z	-0.0130	-0.0005	Mag_Z	-0.0248	-0.0009

On-site Calibration

After the prototype string was installed on-site in Lake Baikal, it was horizontally rotated before touching the lake bottom for on-site calibration. The entire prototype string is first rotated clockwise for one full circle, then rotated in the opposite direction (counterclockwise) for two full circles. Fig. 7 shows the obtained curves of azimuth angle variation for each OM. The calibration parameters of the on-site magnetometer for each OM are obtained by rotating the entire prototype string.

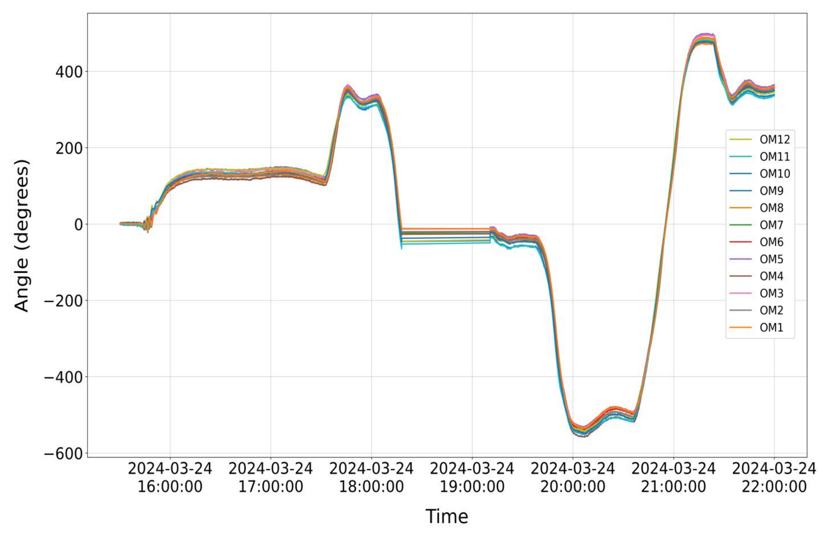


Fig. 7. Curves of azimuth angle in each OM during on-site calibration

OM Attitude Monitoring

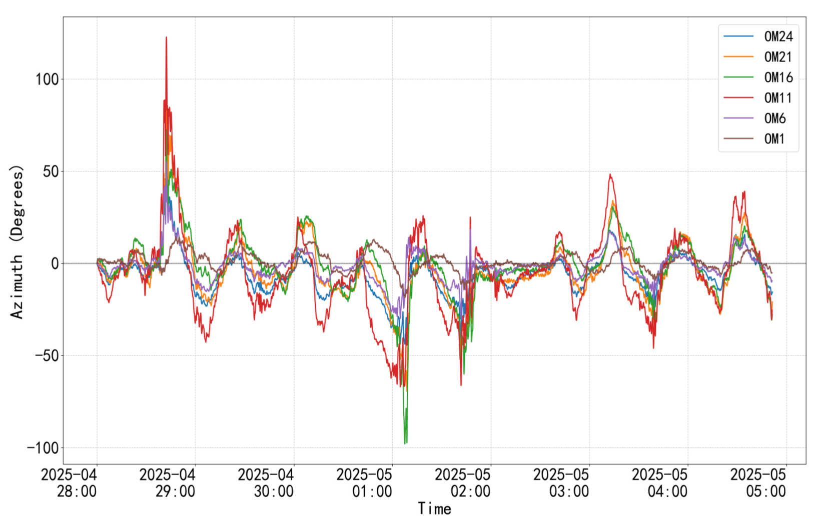


Fig. 8. Azimuth angle variation curves of 6 OMs over one week

Figure 8 shows the changes in the azimuth angles of 6 OMs on the second prototype string over approximately one week. Due to the action of water currents, the OMs on the prototype string have shifted in position and rotated and swayed around the steel cable to which the OMs are fixed. The changes in OMs at different depths vary, reflecting the complexity of water flow in Lake Baikal.

Summary

The positioning method for OM positions in the prototype string of the HUNT, which combines attitude sensors with APS data, is feasible. Calibrating the attitude sensors within the OMs to obtain more accurate accelerometer and magnetometer data constitutes a critical step in underwater OM positioning. By analyzing the temperature effects on the attitude sensors, the data variations of accelerometers and magnetometers under different temperatures can be determined. The overall rotation calibration of the prototype string underwater helps deepen our understanding of the attitude changes of OMs at different depths on the string. The position information of each OM can be accurately derived from the data of the attitude sensors. Related analytical work is still under further research.