GSN Network Operator
Sensor Orientation Best Practices

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Introduction

As the GSN concludes its deployment phase and keener attention is paid to overall station performance and data quality, the network operators are devoting time to re-examining the methods they have used to orient sensors at GSN stations. These procedures have evolved with the experience of our staffs and with the introduction of new technology. On January 15th, the two groups met by telephone and agreed to settle on the procedures below to address current and future orientation questions.

The procedure to orient a sensor involves the following three steps:

1. Determining True North

Methods used by the GSN network operators include:

a. Gyroscopic theodolites. IRIS has supplied to each operator a Sokkia GP1-2A gyro-theodolite to better orient GSN instruments.

   Usage: Both above and below ground.
   Advantages: Highly accurate (Stated accuracy is 20 seconds in the hands of a good operator), can be used at any site.
   Disadvantages: Expensive (> $30K) and difficult to operate properly.

   The USArrray TA uses a Fiber Optic Gyroscope (FOG) instrument manufactured by Ixsea to accomplish the same task. The Ixsea Octans is much easier to use than the Sokkia model (and much more expensive), but restrictive export license requirements render it impractical for international use.

b. Astronomical ("Sunshot") methods. Using inexpensive surveying equipment, the position of the Sun or Moon at precisely known times is measured. The direction of true North is then derived from these data. ASL has considerable experience using this technique.

   Usage: Above ground only.
   Advantages: Very accurate (most Theodolites in our use have a stated accuracy of 2 and 5 seconds. The sun azimuth calculators we use are accurate to 1 second below 72 degrees latitude), moderately inexpensive

($6-8k).
Disadvantages: Fails when skies are overcast.

c. Differential GPS methods. GPS-based survey equipment is used to establish the orientation of a line connecting two surveyed points. IDA has used the Magellan GPS NAV 1000 Pro model successfully since the early 1990s. The NAV 1000 Pro claims an uncertainty of 3m rms horizontally. ASL has used Trimble Geo Explorer system utilizing a base and rover receiver to record data at the same time. Post-processing software gives an azimuth accuracy to/or from the 2 receivers of 6 minutes. Both the IDA and ASL equipment dates to early 1990's and are no longer supported by the manufacturers. The ASL system is not operational.

Usage: Above ground only.
Advantages: Very accurate (6 minutes on a 300 m baseline), less expensive than gyro-theodolite.
Disadvantages: Limited to above ground usage. Difficult to learn.

d. "Shadow tip" method. This astronomical-based orientation technique can be used to find an East-West line using shadow tips cast by the sun, taken in equal times before and after Celestial Noon.

Usage: Above ground only.
Advantages: Moderately accurate and inexpensive. Very easy to learn. Good emergency method when your other orientation equipment failed to arrive.
Disadvantages: This method can take considerable time and must have a suitable flat and level surface to see the shadow tips. Fails if the sun is blocked or obscured.

e. Magnetic field methods. A Brunton compass or fluxgate magnetometer is used to determine the declination of the local magnetic field.

Usage: Both above and below ground.
Advantages: Well understood method.
Disadvantages: Subject to error sources from local geology or local ferrous objects. Lack of good repeatability.

Although some techniques are limited to above ground use, it is possible to translate the lines to a vault using a theodolite.

The consensus reached during the 1/15/2009 teleconference was that both groups would restrict themselves to using methods a-c, although method d is a good emergency fallback. It should be noted that the uncertainty of true North may be the single greatest source of error in GSN orientation metadata. At the majority of stations, ***GSN installation teams relied upon pre-existing fiducial lines established either by the WWSSN or by the host institution and did not***

verify the accuracy of this information. Our goal is to correct this deficiency in the course of future routine maintenance.

2. Translating True North to a fiducial line

Both groups have unique procedures for projecting True North onto a fiducial line. These are being documented and will be added as an appendix to this outline.

3. Orienting sensor to fiducial line

The procedure to orient a sensor to the fiducial line depends upon the type of sensor. Both groups have developed jigs to speed the process and decrease the chance of transcriptional error. These include:

3.1 IDA STS1 laser alignment tool. This tool consists mainly of a mirror to be mounted on the frame of an STS1-H. Light from a laser aligned with a fiducial line is reflected back to the source. The orientation of the sensor is determined by measuring the position of the reflected beam relative to the source beam. See:

http://ida.ucsd.edu/pdf/IDA_STS1_alignment_tool.pdf

for details on use and proof of concept. This tool can also be used to check the orientation of sensors already in place. The jig can be made for less than $500. IDA built the first unit of this design in 2008.

3.2 ASL STS1 laser alignment tool. Like the tool described in 3.1, this makes use of a laser level to align the sensor with the fiducial line. Its compact design is ideal for ease of transport and use. It consists of a scientific grade laser module with 60 deg fan line generating optic. The website for the supplier is listed below. Preliminary sketches can be found at:

ftp://aslftp.cr.usgs.gov/pub/users/Gee/GSN_orientation/ASL_laser_fixture

The cost to build the tool will be <$1000.

3.3 ASL STS2 Sunshot tool. This specialized tool is designed to orient an STS2 using the Sunshot method described in Section 1b. Drawings of the design can be found at:

ftp://aslftp.cr.usgs.gov/pub/users/Gee/GSN_orientation/STS-1_jig

Both groups have made use of the STS2 alignment rod for orienting that sensor to a fiducial line. A similar feature of the CMG3T permits that to be aligned as well. The Episensor casing includes an arrow on the housing for alignment purposes.

Other methods used in the past include setting the NS feet of the seismometer on the fiducial line and using a right angle determine a line 90 degrees to the fiducial line to align the EW feet (in the case of an STS-1).

For cases in which a sensor of unknown orientation is down a borehole or in an underground vault with no accurate fiducial line available, a second broadband sensor may be emplaced at the surface and oriented using one of the tools mentioned previously in this section. Data from both sensors are then analyzed to determine their relative orientation.

Note: Once all procedures are finalized, we will determine a central location for long term Web access.

Verification procedures

Now that the GSN is largely installed, there is only one site where sensors remain to be set-up *ab initio*. Moving forward, the ASL and IDA groups propose leave installed sensors undisturbed and instead to determine the orientation externally using something like the ASL-developed "SensOrLoc" kits to determine both calibration and orientation. Exceptions to this rule are when the horizontal sensors are found not to be orthogonal or when the sensors need to be reinstalled for other maintenance reasons. Sensors will be considered orthogonal if their relative orientation is within 1.5 degrees of 90.

Estimation of accuracy and precision

GSN staff at IDA and ASL have developed a test plan to evaluate the accuracy and precision of their procedures. We intend to conduct these tests independently in Albuquerque and La Jolla and compare results.

1. Determine true North.

Using a subset of the methods described above, ASL and IDA field engineers will determine the orientation of a test baseline relative to true North and compare the results to a known true North line. The ASL team will use the Sokkia gyroscope, Sunshot, and Shadow tip methods; IDA will use the Sokkia gyroscope and differential GPS methods. The endpoints of the test baseline shall be 10m apart at a minimum.

For this test, three members of each group will conduct three trials for a total of nine observations for each method. All trials will be performed “outdoors”

(Essentially, this is a mock-up of a standard vault or tunnel outlined on a suitable surface like a concrete pad. The known (reference) North line should fall onto the mock up pier for comparison of results.)

2. Orient sensor

In this part of the evaluation, ASL and IDA field engineers will orient multiple sensors to a fiducial line. Each field engineer will orient 2 STS-1 horizontals and 2 STS-2s. Both STS-1 horizontals will be aligned in the same direction to permit their relative alignment to be checked using time series analysis; likewise, the STS-2s. For the STS-1s, the IDA team will use the IDA alignment tool and the ASL team will use the ASL alignment tool. The pairs of sensors will be compared for precision and with a known reference sensor for accuracy. ASL will also test the use of the reference surface sensor and azimuth software as a means to orient the sensor.