Laboratory calibration of a MEMS rate gyro sensor

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Introduction.

In oil, gas or geological exploration borehole drilling and logging work, acquiring the direction, inclination and orientation of the drilling tool as well as the borehole is provided by surveying tools. Data from surveying tools is gathered in real-time and transmitted to surface or stored into internal tool's memory.

This information is used to the decision-making control side to adjust the action of drill bit accurately, which will efficiently improve the quality of drilling engineering or other application.

For those applications, where high accuracy or stability is required, MEMS sensors - accelerometer, magnetometer and gyroscope are used. To maximize performance, the sensors used in these applications are generally calibrated and externally temperature compensated.

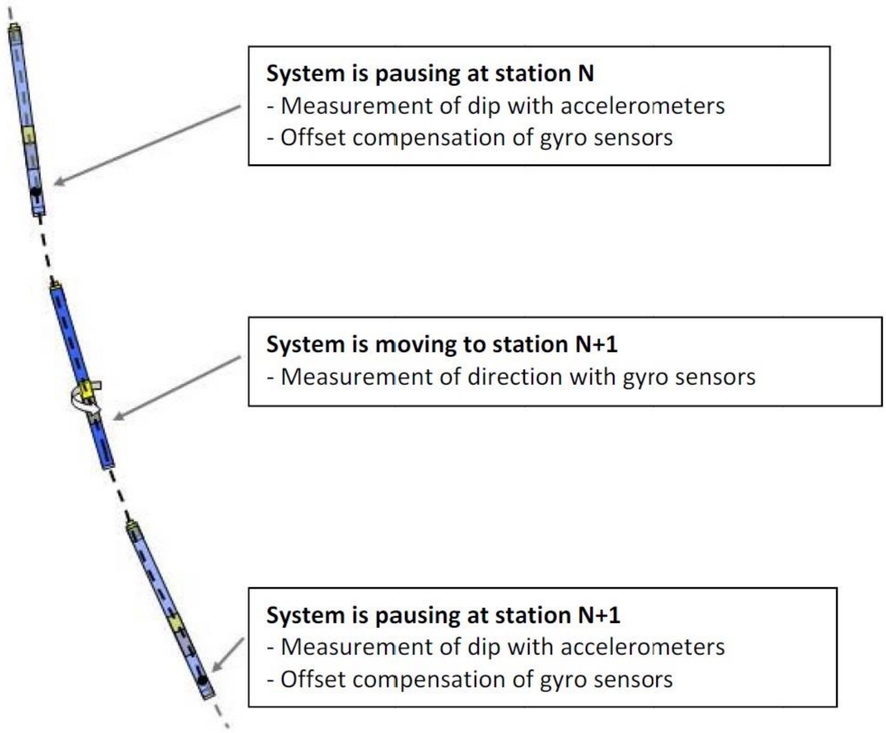

Figure 1. Borehole surveying.

Simple borehole surveying technology is shown in Figure 1. In the example accelerometers and gyro sensors are employed for precise direction (azimuth) and inclination (dip) measurement in order to determine borehole 3D coordinates.

Background.

Calibration is essential for providing the maximum of sensor specification. It includes calculation of couple parameters (constants) used to normalize measured data and most often include bias (offset), sensitivity (scale factor) and misalignment.

Here we will focus on gyroscopes calibration. 3D gyroscopes measure the angular velocity in inertial space around three perpendicular sensitivity axes. Thus it allows for the orientation of an object to be determined. In general, the orientation of a rigid body is the position of its coordinate system observed relative to a reference coordinate system with the same origin. The orientation can be described by a rotation that would move the rigid body's coordinate system, which is initially aligned with the reference coordinate system, to its new position. When working with gyroscope measurements, we consider the gyroscope as the rigid body and the inertial space coordinate system as the reference system. The measured angular velocity determines the rotation required to move the sensor to its new position.

In the real world a physical body (surveying tool with sensors) has its position and orientation expressed by the column vector Q of the real physical quantity values in the basic coordinate system of the tool expressed by:

$$Q = \begin{bmatrix} q_x \\ q_y \\ q_z \end{bmatrix} \quad (1)$$

Then the values detected (measured) by a 3D sensor along its three sensitivity axes in a column vector can be expressed by:

$$Q_s = \begin{bmatrix} q_{s,x} \\ q_{s,y} \\ q_{s,z} \end{bmatrix} \quad (2)$$

In the noiseless model, the accuracy of the measured values Eq. 2 with MEMS gyroscope depends on 1.) the zero level offset; 2.) the sensitivity, and 3.) the alignment of the three sensitivity axes of the sensor. In order to calibrate a 3D sensor we must determine the values of 12 parameters defined by the 3D sensor model, the nine elements of the calibration matrix include the sensitivities of the 3 axis and misalignment and the three elements of the zero level offset vector.

The zero level offset is the value detected by the sensor when the measured physical quantity is equal to zero. To do this, it is needed to bring the gyro sensor up to the intended operating temperature (allowing sufficient soak time) and measure the null output voltage for all axes.

The sensitivity of the sensor is equal to the ratio between the change in the detected value and the change in the real value, assuming that the sensor characteristic is full-scale linear.

Due to imprecise manufacturing, the sensor sensitivity axes can be misaligned and thus deviate from the sensor coordinate axes. We consider the orientation of each sensor sensitivity axis to be independent of the remaining two axes.

Problem Formulation.

There are several methodologies that provide solution for the problem of mutual calibration of MEMS sensors – gyroscopes. Those methods, however are quite complex and computationally expensive, require very expensive test equipment, long time for development and assume some initial calibration of the sensors.

A simple and quick solution for laboratory-based calibration is needed, that to be used as a quick calibration, followed by a high-precision calibration, which should cover the temperature and aging deviations of the calibration parameters.