APPLICATION NOTE

North Finding

North finding is critical for tactical navigation and target localization. It is used in both fixed static observation systems and handheld portable devices. The present application note focuses on the military domain, primarily in scouting operations.
Common north-finding modules integrate a 3-axis magnetometer. Such a sensor measures the angle between the system's pointing direction and the Earth's magnetic field. Magnetometers are inexpensive and compact; however, they exhibit several limitations. First and foremost, this type of sensor measures magnetic north, requiring declination correction to obtain true north. Secondly, their accuracy is significantly degraded when the sensor is surrounded by magnetic materials or disturbances.

Advanced north-finding modules use a gyroscopic compass instead of a magnetometer. Gyroscopes measure angular velocity relative to an inertial frame. A 2-axis gyroscope can determine north, while a 3-axis gyroscope can estimate the Earth's rotation axis.
There are several types of gyroscopes based on different operating principles:

Classic Mechanical - Spinning wheel mounted on a gimbal
Optical – Fiber optic gyros (FOG) and Ring Laser Gyro (RLG), based on the Sagnac effect
Vibrating – Coriolis effect – Hemispheric Resonating Gyros (HRG), Micromechanical Gyros (MEMS)

The gyroscopes measure true north and are not affected by external magnetic fields or surrounding metals but they are affected by Bias drift

Accelerometer Function in System

Accelerometers are combined with gyroscopes in north-finding systems for three main reasons. First, these systems are often exposed to continuous error sources such as temperature drift, vibration, bias offset, and aging. Over long measurement periods (typically more than one hour), accuracy tends to degrade. Therefore, accelerometers are commonly used as auxiliary sensors to compensate for gyroscope errors. The accelerometer measures specific force, and its output is used within a Kalman filter to help correct and recalibrate gyroscope drift.
Another advantage of using accelerometers arises when a system is rotating without translating, such as a platform at sea. In such conditions, the gyroscope cannot distinguish between the system's own rotation and the Earth's rotation; both contributions are combined into a single measured angular rate vector.

Figure 1: The STERNA Family Safran Vectronix SA

The angular velocity of the platform is calculated using the accelerometer, and a derivative electronic circuit. Once obtained, the angular velocity is subtracted from the gyroscope's output to acquire the Earth's rotation axis and north direction.

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A third way of exploiting the potential of an accelerometer is to obtain the inclination of the system. Inclinometers are also embedded in north finding devices in order to read the vertical angle between the horizon and the target. For a low range inclinometer, the acceleration is directly related to the angle, by the following formula:

$$a = g \times \sin \varphi$$

Where $\boldsymbol{a}$ is the acceleration, g the gravity on Earth, and $\boldsymbol{\varphi}$ the angle between the horizontal and the cantilever. If the angle is small:

$$a = g \times \varphi = 9.81 \times \varphi$$

Accelerometer Performance Grades

The embedded accelerometers must not only respect high safety standards, by measuring reliable data over long periods of time, but also have a small size and low power consumption. Accelerometers differ in performance classes based on manufacturing technology and performance. Here are the four main grades distinguishing accelerometer performances:

- High End motion control Grade
- Tactical Grade
- Navigation Grade
- Strategic Grade

The following table sums up the specifications[1]:

Class	Accelerometer Technology	Global Bias Accelerometer Accuracy	Corresponding Gyro Technology
Static Grade	Quartz Servo accelerometer	< 30 µg	ESG, RLG
Navigation Grade	Quartz Servo accelerometer, Vibrating Beam	50-100 µg	RLG, FOG, HRG
Tactical Grade	Quartz Servo accelerometer, Vibrating Beam, MEMS	1 – 10 mg	RLG, FOG, HRG, Quartz MEMS
High Performance (motion control)	MEMS	10-100 mg	CVG, MEMS
Industrial instrumentation	MEMS	1 g	MEMS

[1] Source from http://www.navlab.net/Publications/Introduction_to_Inertial_Navigation.pdf , slide 10

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MS1000 – an optimal MEMS accelerometer for North Finding

Fig.2: MS1000 Accelerometer

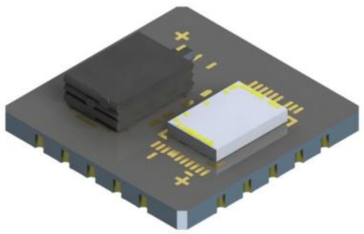

Fig. 3: MS1000 Architecture

As shown in the previous table, quartz servo accelerometers are high-performance sensors that meet strategic, navigation-grade performance levels. North-finding applications require tactical-grade performance, as well as compact integrated components and very low power consumption. A measurement range of ±2 g and ±5 g is suitable for north-finding, as it helps prevent most saturation events during measurements.

A good example of tactical-grade performance MEMS sensor is the new open-loop MEMS accelerometer MS1000, designed by Safran for advanced inertial applications. Its initial bias residual modelling error over the temperature range of −40 to +85 °C is less than 140 µg. The long-term bias repeatability is better than 240 µg, and the in-run bias stability (Allan variance) is better than 3 µg (all values are typical and given for the ±2 g range).
In north-finding systems, during the alignment phase, the turn-on-to-turn-on bias repeatability of the sensor plays a critical role. The MS1000 exhibits a turn-on-to-turn-on bias repeatability of 15 µg over the ±2 g range.

MEMS capacitive accelerometers operate using two electrodes and a proof mass that deflects in response to changes in acceleration. This motion induces a capacitance variation, which is converted into a voltage proportional to the applied acceleration.
MEMS sensors are known for their low mass and low power consumption, as well as their good reliability and durability.The MS1000 accelerometer consumes only 2.5 mA and offers shock resistance up to 1,500 g and vibration resistance > 20 g RMS. The sensor is hermetically sealed, enabling reliable operation in harsh environments. A temperature sensor is also integrated to enable system-level drift compensation.
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Glossary:

- CVG: Coriolis vibratory gyroscope
- DC: Direct current
- ESG: Electrostatic gyroscope
- FOG Fiber optic gyroscope
- GPS: Global positioning system
- HRG: Hemispherical resonating gyroscope
- IMU: Inertial measurement unit
- MEMS: Microelectromechanical systems
- RLG: Ring laser gyroscope

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