CAN measuring unit for mobile machines

Micro-electro-mechanical system (Mems) inertial sensors are commonly used for orientation, pose estimation, and tracking. Due to their size and cost, they are used in automotive and industrial applications. Gemac introduces its point of view.

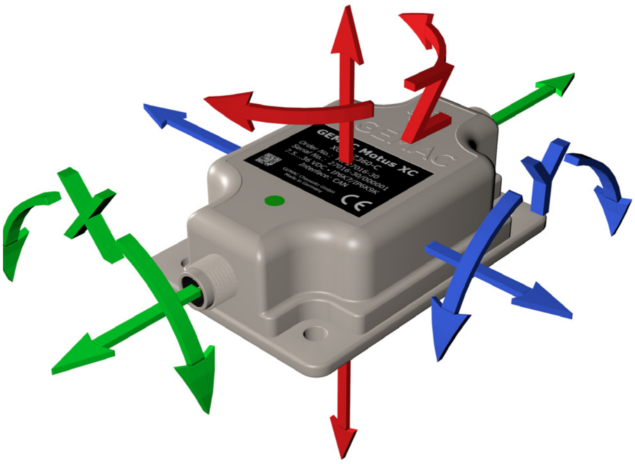

Figure 1: Gemac Motus is a 6 degrees-of-freedom inertial measurement unit with a 3-axis accelerometer and a 3-axis gyroscope (Source: Gemac Chemnitz)

With Gemac Motus, a configurable sensor measuring unit was designed for the most varied fields of application to perform 6-axis motion acquisition on mobile machines, such as construction vehicles, agricultural machines, forestry machinery, cranes and hoisting equipment, as well as vessels.

The sensor consists of a 3-axis accelerometer measuring the external forces acting on the sensor in all three spatial directions, including gravity. This makes the accelerometer the perfect choice for measuring the orientation or inclination of the device for static cases which means, without the influence of external forces besides gravity. The 3-axis gyroscope allows the measurement of the turn rate as angular velocity around the three sensor axes.

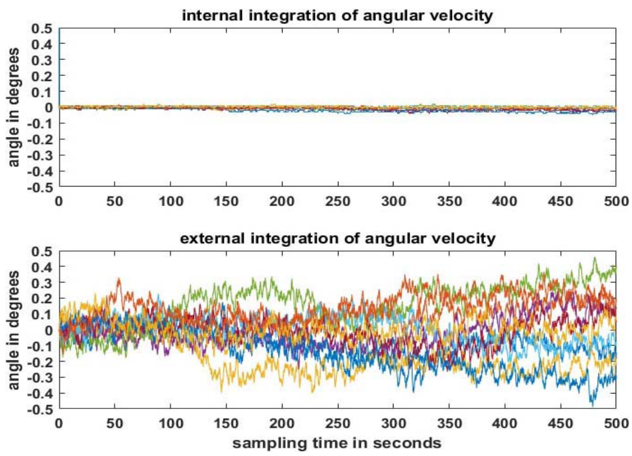

Figure 2: Comparison of the integration of gyroscope data by the sensor itself (top) and by an external control unit (bottom). The integrated data processing leads to a lower standard deviation of the signal and thus to more precise data (Source: Gemac Chemnitz)

The orientation can also be calculated from the gyroscope data by integrating the turn rate over time. The advantage of the measurements from the gyroscope is that it is not affected by external accelerations, which makes it suitable for dynamic applications. By combining the accelerometer and gyroscope data using a so-called sensor fusion filter, the sensor can provide precise orientation information in static and dynamic applications, making the sensor fusion technology crucial for mobile machines.

Integrated calculations for precision

Traditional IMU's (inertial measurement unit) only provide the raw data for acceleration and angular rate to a controller unit, where further calculations, like integrating the signals, are performed. This brings potential inaccuracies, resulting from signal delays, different time stamps, or rounding of the numbers. Gemac Motus includes calculations in the measurement unit, like, for example, the integration of the angular rate to angle values using internal high precision timestamps. With the internal calculation, the stability of the gyroscope output data can be im-proved essentially (see Figure 2). The already preprocessed data can then be output on the CAN network, thus saving computation time and memory in the controller unit.

Besides the acceleration and angular rate in all three directions, Motus provides the output of inclination values in the format of quaternion, Euler angles, or perpendicular ▷

Figure 3: Example application with different mounting positions (Source: Gemac Chemnitz)

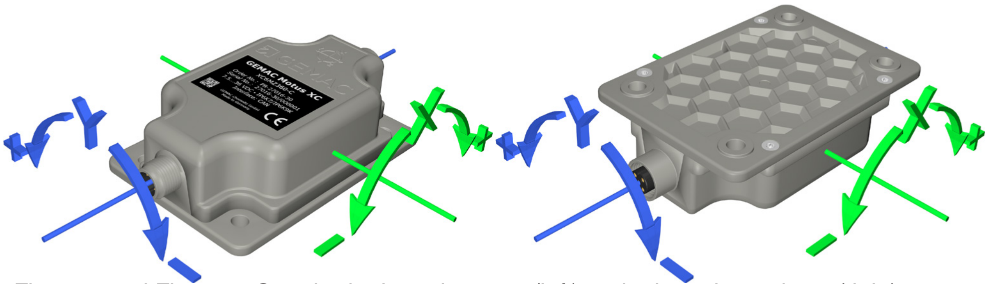

Figure 4 and Figure 5: Standard orientation z-up (left) and orientation z-down (right) (Source: Gemac Chemnitz)

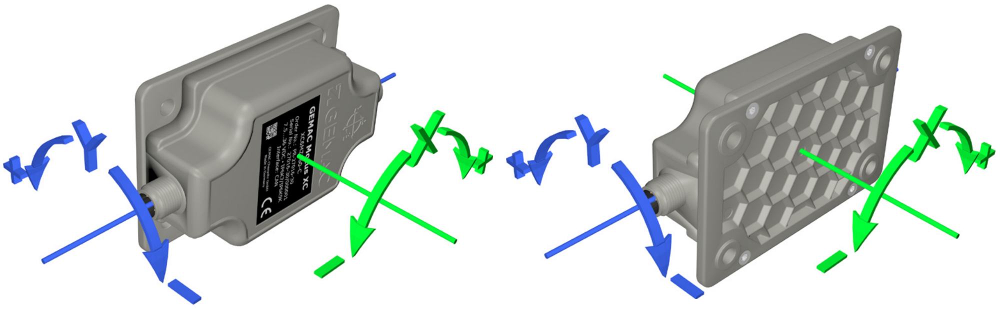

Figure 6 and Figure 7: Orientation y-up (left) and orientation y-down (right) (Source: Gemac Chemnitz)

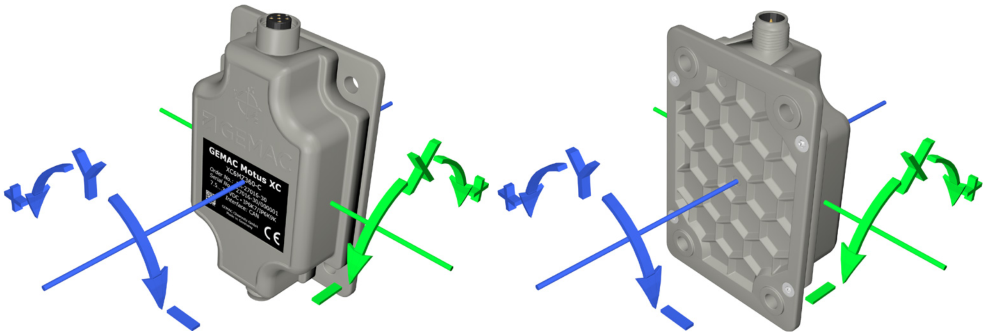

Figure 8 and Figure 9: Orientation x-up (left) and orientation x-down (right) (Source: Gemac Chemnitz)

angles. Both angle formats can be output with or without sensor fusion, covering both static and dynamic applications.

The CANopen version implements the CiA 301 (version 4.2.0) CANopen application layer and communication profile. The CANopen device profile for inclinometers (CiA 410 version 2.0.0) is supported for the inclinometer function. The output signals can be mapped to up to four TPDOs (Transmit Process Data Objects). The J1939 version provides several standardized Parameter Groups like slope sensor information - Parameter Group Number (PGN) 61481, acceleration sensor (PGN 61485), and angular rate information (PGN 61482). Further, a set of proprietary messages is available, allowing flexible and user-specific mapping of the required output signals.

Motus provides 360-degree orientation estimation independent from the mounting position of the sensor. The user can define the measurement axes by selecting one of six possible device orientations. Furthermore, the sensor can determine its mounting position by user command and automatically transform its internal coordinate system to best match the device orientation. Additionally, the user can enter an offset to both axes for inclination measurement without restricting the sensor's measurementrange. Thus, the sensor can be adapted to every possible measure-ment scenario.

Key parameters for IMU selection

Scale, offset, and alignment errors, nonlinearities: One of the main error sources of Mems-IMUs comes from misalignment of the measurement axis to the sensor housing and from gain and offset errors of the inherent sensing elements. As these types of errors tend to be stable, they can be measured and corrected during production of the sensor. At Gemac, each sensor is calibrated on a high precision rotation stage, limiting all these combined errors to an angular precision of 0,15 ° (typical 0,1 °).

Table 1: The variants NB, NC, and IB compared (Source: Gemac Chemnitz)

Variants	***NB***	***NC***	***IB***	
General parameters	Inclination		Accelerometer	Gyroscope
Measurement range	360 °/±90 °		±8 g	±250 °/s
Resolution	0,01 °		0,244 mg	0,00875 °/s
Temperature	±0,01 °/K	±0,0016 °/K	0,2 mg/K	0,005 °/s/K
Static accuracy	±0,3 °	±0,1 °		
Dynamic accuracy	±0,5 °	±0,25 °		
In run bias stability				2,5 °/h
Angle Random Walk				0,1 °/√h
Interface	U, I, CAN, CANopen, SAE J1939		CAN, CANopen, SAE J1939	

CANopen

Table 2: The variants XB and XC compared (Source: Gemac Chemnitz)

Variants	***XB***			***XC***		
General parameters	Inclination	Accelerometer	Gyroscope	Inclination	Accelerometer	Gyroscope
Measurement range	360 °	±8 g	±250 °/s	360°	±8 g	±250 °/s
Resolution	0,01°	0,244 mg	0,00875 °/s	0,01°	0,244 mg	0,00875 °/s
Temperature coefficient	±0,005 °/K	0,2 mg/K	0,005 °/s/K	±0,0016 °/K	0,02 mg/K	0,005 °/s/K
Static accuracy	±0,3 °			±0,1°		
Dynamic accuracy	±0,5 °			±0,25 °		
In run bias stability			2,5 °/h			2,5 °/h
Angle Random Walk (ARW)			0,1 °/√h			0,1 °/√h
Interface	CAN, CANopen, SAE J1939			CAN, CANopen, SAE J1939		

Temperature effects: Temperature changes in the sensor's environment result in shifts of scale factor and offset in Mems, inducing an error in orientation. Because these shifts are not linear and highly device-specific, the temperature effects cannot be foreseen. The maximum angular deviation due to temperature changes for Gemac Motus is 0,2 ° over the whole temperature range from -40 °C up to +85 °C.

Gyroscope bias stability: The offset or bias of the gyroscope output changes over time due to flicker noise in the Mems components. This noise with a 1/f spectrum is usually observed at low frequencies, leading to a long-term drift of the gyroscope data. The bias stability is typically expressed in °/h. Correcting the gyroscope bias during runtime is essential, especially when integrating the angular rate over time to calculate angle values from the gyroscope data. For example, an error of only one resolution step (0,00875 °/s for Motus) cumulates to an error of 31,5 ° during a one-hour measurement. The gyroscope bias can be ten or a hundred times higher in practice. Motus incorporates a dynamic gyroscope offset correction that adjusts the bias automatically during runtime or manually on request by the user.

Random walk: Another type of noise, the thermomechanical noise, is causing a randomly distributed error in the data, the random walk. This error can be observed for the accelerometer as velocity random walk and the gyroscope as angular random walk. Due to the noise, the integration of the signal will drift over time, where the standard deviation of the drift equals the random walk multiplied by the square root of the observation time.

Vibration rectification error: This error is also called g^2-sensitivity and causes a bias shift due to oscillatory linear accelerations. It is caused by asymmetries and nonlinearities in the sensor design and applies to both accelerometers and gyroscopes.

The IMU is available in 29 different application-related configuration options. The ISD-Control software for the IMU parameterization is available for a free download. It works with CAN adapters from various manufacturers. The units are dedicated for use in construction machinery, agricultural machinery, forest machines, cranes, lifting technology, and ships.

Depending on the customer's needs, the Motus offers different variants: Recording of inclination (Gemac Motus NB and NC), recording of acceleration and rotation rate (Gemac Motus IB), and recording of inclination, acceleration, and rotation rate (Gemac Motus XB and XC). In Table 1 and Table 2 the variants are compared. ◀

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