MEMS technology quality requirements as applied to multibeam echosounder

Jerzy DEMKOWICZ, Krzysztof BIKONIS

Gdansk University of Technology
Gdansk, Narutowicza str. 11/12, Poland
demjot@eti.pg.gda.pl

Small, lightweight, power-efficient, and low-cost microelectromechanical system (MEMS) inertial sensors and microcontrollers, available in the market today, help reduce the instability of Multibeam Sonars. Current MEMS inertial measurement units (IMUs) come in many shapes, sizes, and costs — depending on the application and performance required. Although MEMS inertial sensors offer affordable, appropriately scaled units, they are not currently capable of meeting all requirements for accurate and precise attitudes, due to their inherent measurement noise. The article presents the comparison of different MEMS technologies, and their parameters regarding to the main application; namely, Multibeam Echo Sounders (MBES). The MEMS parameters' quality are crucial for further MBES record- processing, the article presents the results of undertaken researches in that area, and the results are relatively positive for low-cost MEMS.

Keywords: MEMS, IMU, Multibeam Sonar

1. Introduction

Low-cost microelectromechanical system (MEMS) inertial sensors and microcontrollers, available in the market today, help reduce the instability of Multibeam Sonar measurements. Over the past decades MEMS researchers have demonstrated a number of microsensors for almost every possible sensing modality, including attitudes. Current MEMS inertial measurement units (IMUs) come in many shapes, sizes, and costs — depending on the application, and performance required. MEMS sensors have proved and demonstrated performances exceeding those of their macroscale counterpart sensors [9]. Obviously, the MEMS parameters quality is crucial for further MBES record-processing, especially in the context of attitudes, therefore we present the results of undertaken researches in that area.

2. High precision IMU requirements

High precision IMU requirements, as applied to MBES, are very demanding. Fig. 1a presents an MBES scanning acquisition process, and wreck 3D data visualization (Fig. 1b) of 10cm resolution. High resolution accuracy depends on IMU resolution and stability. An angular error of 0.1 degree, at 10 meters of depth, results in a near 2 cm linear horizontal error at the bottom; and of course, at 100 meters of depth, that error gives a 20 cm error, which is in many applications, not currently acceptable.

a) b)

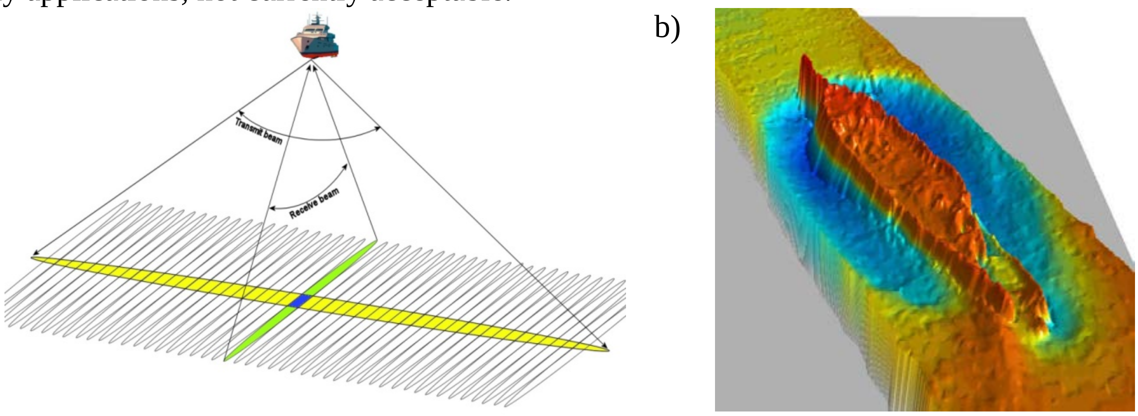

Fig. 1. Multibeam sonar system a) data acquisition b) data visualization.

Fig. 2 presents the overall context of IMU applications. The most important are accelerometer and gyroscope sensors. In the wider perspective, Inertial Navigational Systems utilize them, and it is well-known what a challenge is it [7], [8]: but even in this narrowed IMU context, these sensor errors are still a serious issue, see Tab. 1, as a reference, where bias error possesses the most important impact. For the experiment a motion reference unit (MRU) from Kongsberg was chosen, and selected IMU systems with parameters similar to MRU. The most important parameters in the context of attitudes of selected systems are shown in Tab. 2.

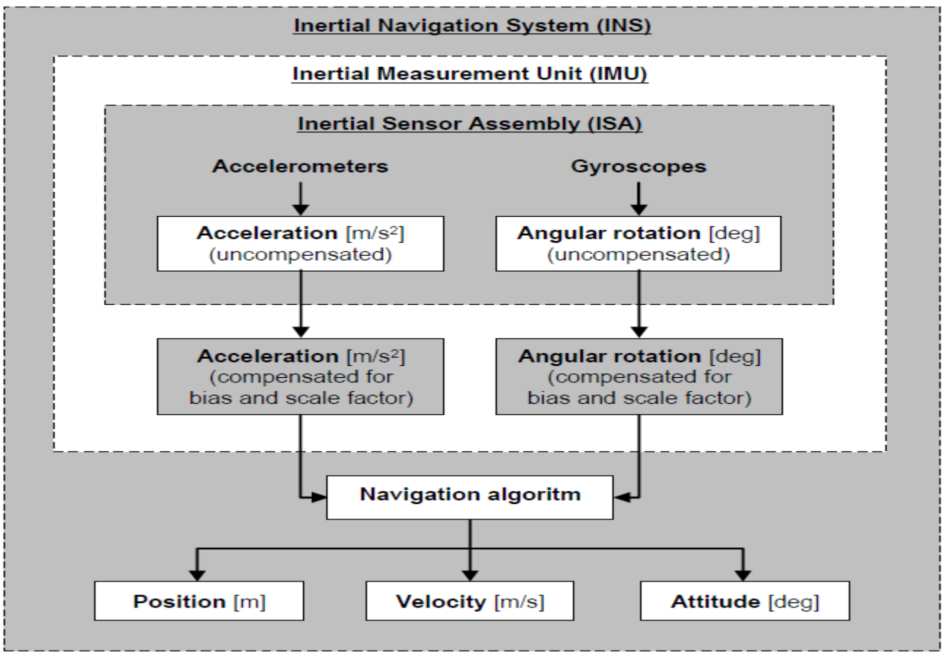

Fig. 2. Classification of inertial systems.

Therefore, usually a Kalman estimator reads in the sensor data, and in turn output, the Euler angles and the bias of the gyros as presented in Fig. 3. The Kalman filter uses knowledge of the deterministic and statistical properties of the system parameters, and the measurements, to obtain estimates which are optimal. It is an example of a Bayesian estimation technique. It is supplied with initial estimates, usually a one dimension matrix, and then operates recursively

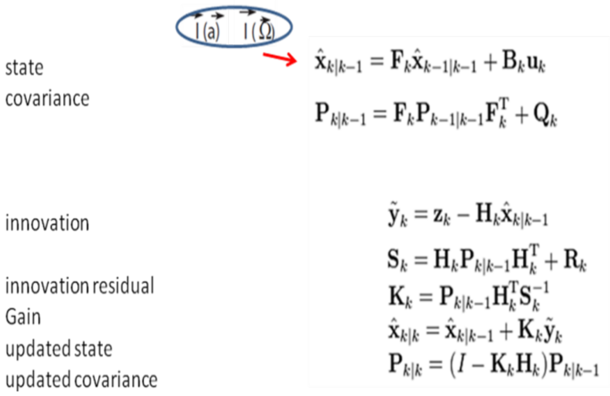

Fig. 3. Kalman filtering algorithm.

updating its working estimates with an optimal weighted average of their previous values, and new values derived from innovation measurement. In Fig.3, $\hat{x}_k$ stands for matrix state estimation, which consists of linear acceleration from accelerometers *I(a)*, angular velocities from gyroscopes *I(Ω)* and attitudes, P_k stands for process covariance, y_k – innovation, z_k – current measurement, K_k – Kalman gain, H_k – measurement matrix, R_k – measurement error variance, Q_k – model variance and F_k stands for process model. B_k may be interpreted as a control matrix; however, it was not used in the model.

Tab.1. Gyroscope error sources.

Error Type	Description	Result of Integration
Bias	A constant bias ϵ	A steadily growing angular error $\theta(t) = \epsilon \cdot t$
White Noise	White noise with some standard deviation σ	An angle random walk, whose standard deviation $\sigma_\theta(t) = \sigma \cdot \sqrt{\delta t \cdot t}$ grows with the square root of time
Temperature Effects	Temperature dependent residual bias	Any residual bias is integrated into the orientation, causing an orientation error which grows linearly with time
Calibration	Deterministic errors in scale factors, alignments and gyro linearities	Orientation drift proportional to the rate and duration of motion
Bias Instability	Bias fluctuations, usually modelled as a bias random walk	A second-order random walk

Tab. 2. Selected IMU parameter comparison.

	MRU (EM3002)	3DM-GX3-25	MTi-G700	MTi-G
Static Accuracy				
Roll and Pitch [deg]	0.04	0.5	0.2	0.5
Dynamic Accuracy				
Roll and Pitch [deg]	0.05	2	0.3	1
Gyroscope				
Full Scale [deg/s]	±100	±300	±450	±300
Bias [deg/s]	0.1	0.25	0.2	1
In-run Bias Stability [deg/h]	-	18	10	20
Non-linearity [% FS]	0.2	0.1	0.01	0.1
Accelerometer				
Full Scale [g]	±3	±5	±5	±5
Bias [g]	0.001	0.002	0.003	0.01
In-run Bias Stability [mg]	0.2	0.04	0.04	2
Non-linearity [% FS]	0.02	0.03	0.03	0.2

3. Operational Tests and Results

Operational measurements for the following IMU devices were carried out simultaneously, as presented in Fig. 4. MRU from Kongsberg is specially designed for high precision motion measurements in marine applications, and for users requiring high accuracy roll, pitch, and heave measurements. The MRU provides high performance motion data for various marine applications ranging from small underwater vehicles, to large ship motion control. Very high reliability is achieved by using solid state sensors, with no moving parts, and a proven MRU electrical and mechanical construction.

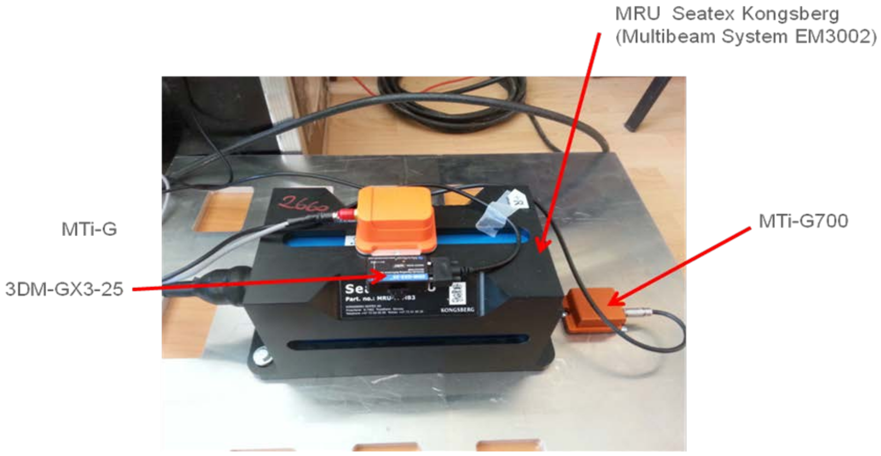

Fig. 4. Operational measurements carried out simultaneously for various devices.

The 3DM-GX3-25 is a high-performance, miniature Attitude Heading Reference System (AHRS), utilizing MEMS sensor technology. It combines a triaxial accelerometer, triaxial gyro, triaxial magnetometer, temperature sensors, and an on-board processor running a sophisticated sensor fusion algorithm, to provide static and dynamic orientation, and inertial measurements.

The MTi-G is an integrated GPS and MEMS Inertial Measurement Unit with a Navigation and Attitude and Heading Reference System processor. The internal low-power signal processor runs a real-time Xsens Kalman Filter (XKF), providing inertial enhanced 3D position and velocity estimates. The MTi-G also provides drift-free, GPS enhanced, 3D orientation estimates, as well as calibrated 3D acceleration, 3D rate of turn, 3D earth - magnetic field data, and static pressure (barometer). The MTi-G is an excellent measurement unit for navigation and control of vehicles and other objects.

Results for static tests were presented in Fig. 5, for static Roll measurements. Measurements and results for Roll at different attitudes, and for various IMU units, were performed as well, but are similar and have been omitted in the article. Fig. 6 summarizes some of the obtained results.

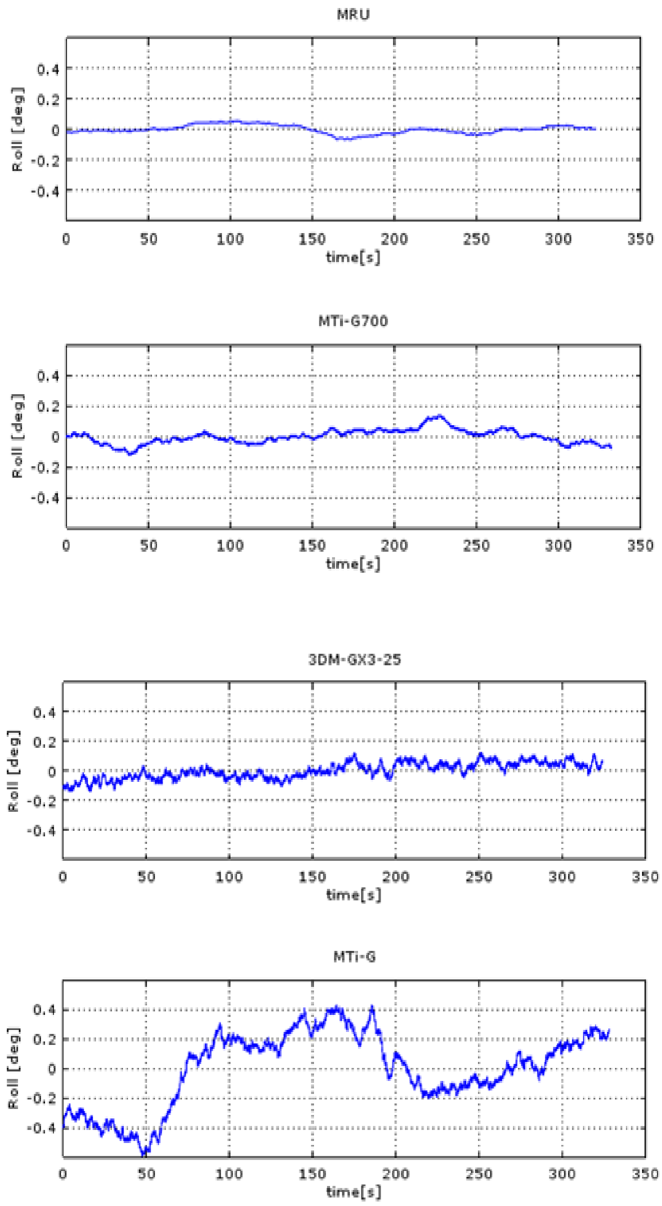

Fig. 5. Measurement results for static tests Roll

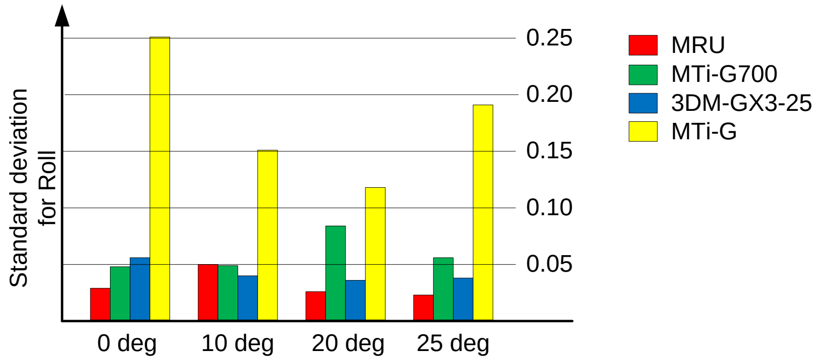

Fig. 6. Standard deviation for static Roll measurements.

It can be seen clearly from Fig. 6 that MRU is distinctly the best IMU. Results for dynamic tests give rather opposite results in some situations. In that case the significant difference can be observed for new generation MTi-G700, 3DM-GX3-25, and for MTi-G, but the MTi satisfies the requirements, see Fig. 7. That is true for frequencies <1Hz.

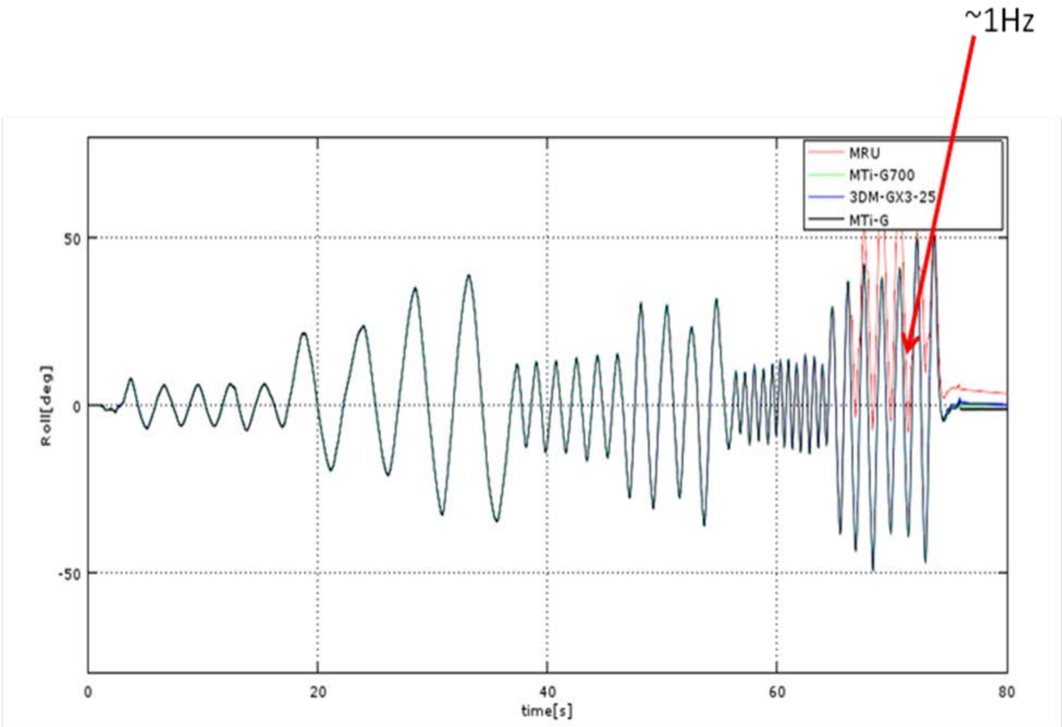

Fig. 7. Dynamic IMU tests for all IMU units.

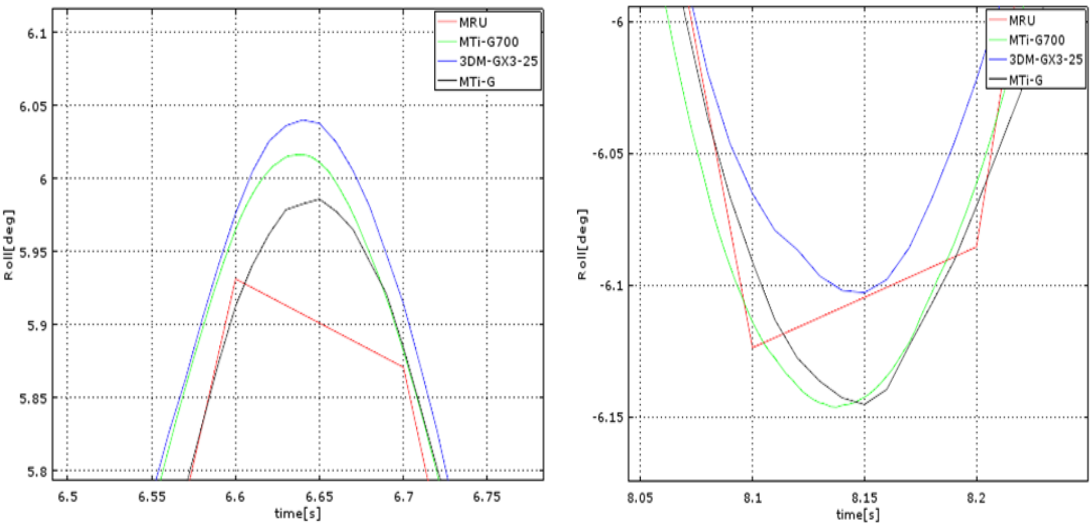

Fig. 8. Dynamic IMU tests for all IMU units, enlarged for some seconds.

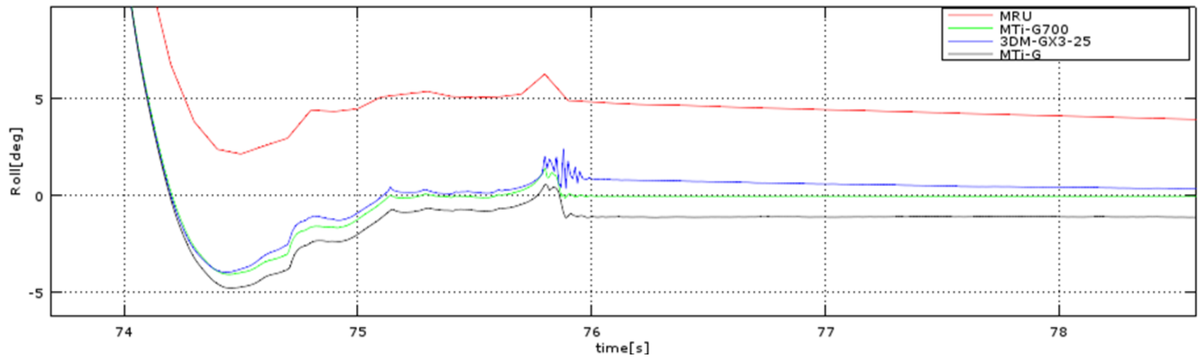

Fig. 9. Dynamic IMU measurements for seconds 74-78 [s].

For frequencies close to 1Hz and greater, MRU is very unstable and returns to a stable state after over 16 minutes. The records from MTi-G700, 3DM-GX3-25 and for MTi-G are much better, and the stable state return period lasts over 10 seconds.

4. Conclusions

An exceptional possibility of SOEST (*Seatex MRU Calibration Certificate*) certified device comparison was presented. Operational tests were carried out for Kongsberg MRU-M-MB3 – SOEST certificated, Xsens MTi-G700, Xsens MTi-G-28 A53 G35, MicroStrain 3DM-GX3-25. The tests consisted of static operational test comparisons, and dynamic tests for frequencies < 1Hz and greater. It turned out that dynamic tests >1Hz are a very demanding case for all tested IMUs, but especially for MRU. In the last case, the test procedure was carried out very carefully and repeated. The results for dynamic tests > 1Hz resemble low pass filter with a long time constant applied.

MEMS inertial sensors, which are not SOEST certified, offer affordable, appropriately scaled, units, that are currently capable of meeting all requirements for accurate and precise attitudes, due to inherent measurement noise merely acceptable. Nevertheless, MRU offers the best standard variance of 0.01 deg in Roll and Pitch, new generation MTi-G700 offers comparable performance with low noise.

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