QUALIFICATION PROCESS FOR MEMS GYROSCOPES FOR THE USE IN NAVIGATION SYSTEMS

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ABSTRACT:

Navigation systems of the future will be integrated in a complex network of driver assistance systems, providing navigation data to several active and passive systems. With respect to this development, requirements concerning navigation accuracy and reliability grow rapidly; especially in urban areas with difficult navigation conditions navigation errors should be avoided carefully. Hence, systems utilize additional sensors for a reliable determination of the travelled trajectory. A qualification process for each type of sensor has to be performed before using it in navigation systems. This paper focuses on the qualification process for MEMS Gyroscopes. The market provides various rate sensors with great differences in cost and quality. It is difficult to compare the sensors only with respect to the information in the manufacturers' data sheet because the relevant sensor parameters are differently defined and the conditions under which the parameters are valid are not necessarily equal. In order to make different sensors comparable, they have to be qualified using unified test series, exposing the sensors to realistic kinematic and environmental working conditions. Sensor errors and behaviour, potential disturbance sources and calibration procedures are discussed, and suitable test series and processing methods are presented. Main investigations focus on bias stability (zero point output, ZPO), scale factor stability, temperature influences and g-sensitivity, with tests performed on a 3 axes turn table and on a single axis turn table with climate chamber.

1 INTRODUCTION

The development of automotive navigation systems started in the late 70's of the last century. 1981 Honda launched the world's first navigation system, the *Electro Gyrocator* (Honda, 2006). The first commercial navigation systems using digital maps were introduced in the mid-80's in Europe (Blaupunkt TravelPilot IDS) and the US (ETAK Navigator). However, these systems could not fulfil expectations due to incomplete digital map data and insufficient mass storage.

Based on the availability of digital vector data covering great parts of Europe, America and Japan and of appropriate mass storage (CD, DVD), automotive navigation had a breakthrough within the 90's.

The implementation of GPS into the sensor assembly, especially after deactivation of Selective Availability (SA) made an increasing accurate determination of the vehicle's position and a more reliable *Map Matching* possible. Signal reception problems especially in urban areas (Shadowing, Multipath) justify the further use of the classic navigation sensors gyroscope and odometer. Optimised navigation results are gained by mutual sensor monitoring and calibration.

2 NAVIGATION – QUO VADIS?

Nowadays car navigation systems are more than simple positioning systems. The fusion of dynamic positioning with comprehensive road- and POI- databases makes a safe and reliable navigation within complex road networks possible and shows a lot of mobile GIS characteristics. Automotive navigation systems increasingly become an interface between driver and car, supporting the driver with his decision-making by consideration of the particular traffic, weather and road situation.

This development shows, that car navigation systems do not simply support the driver, they actively contribute to accident prevention by providing safety relevant information and warnings. Therefore automotive navigation systems move continuously deeper into the field of driver assistance.

Driver assistance systems are divided in *informative*, *Low Response* and *High Response* systems. Car navigation, as well as electronic parking aids, night vision systems or brake force displays belong to the pure informative systems, which do not intervene in the driving dynamics. Systems intervening immediately in dangerous situations, like ABS, DSC or emergency braking systems, belong to the field of *High Response*. *Low Response* systems intervene with slow reaction into car guidance, e.g. cruise control systems, they are described as informative warning systems. (Freymann, 2004)

The different assistance systems are increasingly interconnected. Combined processing of all relevant sensor data, as well as an interoperability of different systems without mutual disturbance increases the overall system performance and the driving safety more than if each system worked autonomously. BMW presented the concept *ConnectedDrive* in 2000, which allows, by combining the individual systems into one unit, an optimized adaption to the driver, the car and the environment (Bachmann, Bujnoch, 2001). Future systems are conceivable, that, based on navigation, weather and driving dynamics data, engage warnings, if the driver approaches a sharp curve too fast, or that even intervene with a breaking assistant into the situation.

Especially in recent years mobile navigation systems, solely GPS-based and *not* fixed to the car, established themselves successfully on the market, providing modular navigation in the car, on the bike or on foot, addressing a large target group.

In addition, a demand for indoor personal navigation is getting more and more relevant. PDA-based systems, acquiring the position and attitude of a person within buildings, could be used e.g. as museum guides, providing information about exhibits in the person's vicinity, displaying escape routes or providing product information in malls and supermarkets. Such systems often utilize a combination of GPS, MEMS inertial sensors and indoor location techniques based on infrared, radio (e.g. WLAN) or ultrasonic.

3 QUALIFICATION PROCESS

In consideration of the progressive interconnectedness of different Assistance Systems, demands on product quality grow rapidly. Although data from different sensors is mutually plausibility checked, quality deficiencies can directly affect driving safety and the overall system performance. Therefore, and due to economic and reputation reasons, a comprehensive quality control is mandatory, before a product is delivered to the customer.

This quality assurance process relates to all components of a navigation system, the navigation sensors, the data base, the software and the electronic components to be used. For the verification, if a component fulfils the requirements for quality, which have been defined for automotive navigation, a comprehensive qualification process has to be conducted for each component (ISO 9000). This paper will intensively discuss the qualification process for angular rate sensors (gyroscopes). This encompasses the acquisition of test data and the analysis of sensor parameters, characteristics and performance, the discussion of potential error sources that occur during normal navigation practice and driving dynamics, as well as economic aspects.

The market is overloaded with a wide range of different sensors from different manufacturers. Especially in the field of inertial sensors there are huge prize and quality spans, from which suitable sensors are to be chosen, that fulfil the technical and economical requirements.

A sensor selection can not be made simply with respect to the information in the manufacturers' data sheet, because the relevant sensor parameters are on the one hand abstract and not necessarily navigation practice-related, on the other hand merely valid under laboratory conditions. In addition to this the relevant sensor parameters are differently defined and the conditions under which the parameters are valid are not necessarily equal. Therefore, comprehensive sensor tests are necessary, using unified test series, exposing the sensors to realistic kinematic and environmental working conditions.

For this purpose, specific test procedures and scenarios are to be utilized, by which different sensors can be tested and directly compared to each other. For sensor qualification a number of unified test series is needed to acquire and describe every relevant sensor parameter. Additionally, boundaries are to be defined for each parameter, which relate to sensor requirements in automotive navigation. If sensor characteristics exceed these boundaries, the tested sensor is not suitable for navigation.

4 ANGULAR RATE SENSORS / GYROSCOPES

Oscillating or rotating masses tend to maintain their oscillation plane resp. rotation axis constant in inertial space. If they are located in a rotating frame, they experience a change in oscillation plane / rotation axis which is analog to the angular rate of the rotating frame or its effective component. This is based on Coriolis force, a pseudo force that is only present in rotating frames and serves as the basis for mechanical angular rate measurement. Consequently, the Foucault Pendulum in 1851 was already an angular rate sensor, measuring the effective component of the earth's rotation.

Besides oscillating or rotating masses today several methods for angular rate measurement are commonly used. Optical Gyroscopes (*Fibre Optic Gyroscope* (FOG), *Ring Laser Gyroscope* (RLG)) are based on the *Sagnac-Effect* (Sagnac, 1913a, 1913b), acting on opposing electromagnetic waves due to a rotation. Vibratory gyroscopes utilize vibrating structures, whose vibration behaviour changes due to Coriolis effect in consequence of a rotation.

Optical gyroscopes, as commonly used in modern strap down inertial navigation, are featuring long-term stability, low drift and excellent performance. They are discussed extensively e.g. in (Garus, 1995) and (Lefèvre, 1993). Due to constant sensor calibration during the *Map Matching* process, a long-term stability is not relevant for automotive navigation; low cost sensors are used. Today vibratory gyroscopes are standard, due to their low prize, their small size and their still satisfactory performance. Therefore, their working principle is described in detail below.

Coriolis Vibratory Gyroscopes (CVG) belong to the mechanical gyroscopes, because all of them base on Coriolis effect. They consist of a solid structure, in which vibrations are induced (primary mode). If the structure is rotating along its sensitive axis, its vibration behaviour changes because of Coriolis acceleration proportional to the applied angular rate (secondary mode). Vibration induction is mostly done piezoelectric, electromagnetic or electrostatic, the measurement piezoelectric, piezoresistive or capacitive (Paoletti et al., 1996).

The path of a pendulum in a frame {O,x,y,z}, rotating by the Z-Axis, in the X-Y-plane, is described in (Billep, 1999) by:

$$x = a\cos(\omega_0 t)\cos(\Omega t) + b\sin(\omega_0 t)\sin(\Omega t) \tag{1}$$

$$y = -a\cos(\omega_0 t)\sin(\Omega t) + b\sin(\omega_0 t)\cos(\Omega t) \tag{2}$$

$$b = a\frac{\Omega}{\omega_0} \tag{3}$$

With: a: amplitude
ω_0: pendulum frequency
Ω: rotation frequency of {O,x,y,z}

Normally is $\omega_0 >> \Omega$, whereby b tends to zero. Consequently, (1) and (2) simplify to:

$$x' = a\cos(\omega_0 t)\cos(\Omega) \tag{4}$$

$$y' = -a\cos(\omega_0 t)\sin(\Omega) \tag{5}$$

These equations, assigned analog to vibrating structures, are the basis for development and use of vibratory gyroscopes.

Vibrating Structure Gyroscopes (VSG) mostly use cylindric or ring-shaped probe masses, in which vibrations are induced. The vibration of this shell resonator is characterized by four knots on the circumference of the structure, in which the vibration cannot be detected. These knots are shifted by 45° to the points, in which the vibration is induced (Figure 1). Detector elements are located in these knots. If a rotation around the symmetry axis of the structure is applied, the knots do not stay fixed; they move along the circumference proportionally to the applied angular rate in opposite direction. As a result, the detector elements will measure an amplitude and give an output voltage. (Geiger, 2002; Czommer, 2000) This application of a shell resonator, whose plane of vibration changes due to an applied rotation, reminds strongly of the Foucault pendulum.

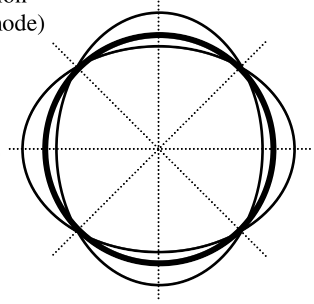

Figure 1. Vibrating Structure Gyroscope

Gyroscopes utilizing the bending vibration principle (Figure 2) consist of a structure, in which vibration is induced along one axis (primary mode). The probe masses are usually tuning fork-shaped, or bar-shaped with square, triangle or circular outline. A rotation along its sensitive axis will induce a second vibration mode rectangular to the primary mode due to the Coriolis effect. The amplitude measured is proportional to the applied angular rate.

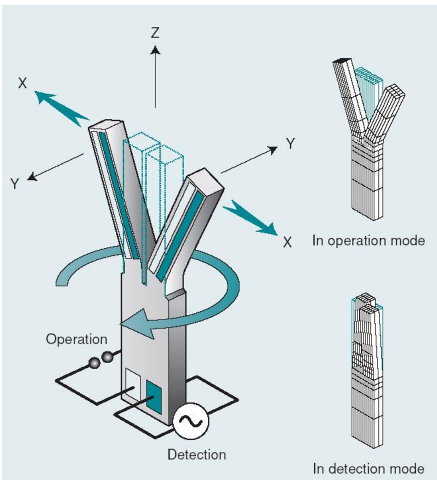

Figure 2. Tuning Fork Gyro (Fujitsu Ltd., 2004)

Besides the presented gyroscope types based on shell resonator principle and on bending vibrations there are a couple of further sensor models, using linear and torsional vibrations. Basically, their working principles, based on Coriolis effect, are very similar to the presented sensors; there are merely differences in the probe mass, the actuation and in the type of vibration.

5 CHARACTERISTICS AND MODELLING

For evaluating different gyroscope types with respect to their suitability for a particular application, they have to be describable by means of various parameters in their behaviour, their accuracy, their dynamic range, etc. Although there is a wide range of gyroscopes available, ranging from high-end to low-cost sensors, they usually can be described by the same parameters and are subjected to very similar error sources and similar behaviour. Respectively general mathematic modelling can be conducted.

For the allocation of an output voltage U with an input angular rate ω initially the basic sensor-specific parameters are necessary. This is the scale factor resp. the *Sensitivity* S (in V/°/s), connecting the input range with the output range, as well as the bias, or *Zero Point Output* (ZPO), which is the output voltage for the angular rate zero. With these parameters the angular rate can be calculated from a measured voltage by:

$$\omega = \frac{U - ZPO}{S} \tag{6}$$

Ideally, the sensitivity of a sensor remains constant over the whole dynamic range; then the sensor's idealized transfer function $T(U)$ is a straight line. In practice a straight line transfer function is never exactly realised. The real transfer function $T'(U)$ deviates, which leads to measurement errors $D_{Lin}(U) = T'(U) - T(U)$. The measurement error due to nonlinearity depends on the output voltage U and is ideally constant zero. Hence, for gyroscope characterisation detailed information regarding nonlinearity behaviour over the entire dynamic range is necessary. Furthermore, for correct angular rate calculation, the mathematic model is extended:

$$\omega = \frac{U - ZPO - D_{Lin}(U)}{S} \tag{7}$$

These parameters and characteristics do not remain constant. The drift is the central problem in gyroscope technology.

The main reason for sensor drifts are temperature variations, which cause gyroscope components to contract or expand in different ways. As a result friction forces, tensions, deformations, etc. arise, acting on probe masses, rotors, signal detectors, causing the sensor output to drift away from the measured value. This is temperature dependent drift $D(T)$, causing predominantly systematic errors.

Little imperfections in sensor production, like an irregular mass distribution in the rotor or the probe mass, or material impurity can cause drifts, dependant of operation time. Time dependant drift causes predominantly random errors, which are not predictable or computable. Such drift behaviour will normally not occur, resp. occur in a negligible way, within a reasonable period of time (up to ca. 30 min). Excessive strong drift errors within such a short period of time are an indication for a faulty sensor.

In vibratory gyroscopes Zero Point Output and Sensitivity change due to drift (ZPO-drift, Sensitivity-drift). The ZPO-drift $D_{ZPO}(T,t)$ affects the measurement by shifting the entire output range (constant error for each angular rate), Sensitivity drift $D_S(T,t)$ affects the measurement by an angular rate-dependant error. In addition, linearity behaviour may change dependant on temperature, whereby $D_{Lin}(U)$ is extended by the temperature influence to $D_{Lin}(U,T)$. It is obvious, that a simple parameter is insufficient for a reliable gyroscope characterization. Parameter curves, which describe the different parameters temperature-dependently, are needed. Including temperature-dependant drifts the gyroscope model is extended to:

$$\omega = \frac{U - ZPO - D_{Lin}(U,T) - D_{ZPO}(T)}{S - D_S(T)} \tag{8}$$

Another important aspect is the repeatability of parameter curves. Reliable statements regarding a gyroscope are only possible, if it is known, how far a gyroscope behaves identically, when it is exposed to identical conditions several times. Thus, drift curves acquired from two independent test runs should ideally be identical. Only if this condition meets, correction parameters D_i can be applied effectively to a measurement.

For evaluation of sensor resolution, it is important to have information about sensor noise. Noise is a part of the signal, which does not depend on the measurand, but exclusively on statistic laws. A distinction is made between *inherent noise*, which emerges from within the electric circuit, and *transmitted noise*, which emerges from outer influences, like e.g. electric fields or vibrations (Fraden, 1996). For sensor comparism, the noise equivalent rate is a propriate parameter.

In some cases the sensitive axis of a gyroscope is not located parallel to the rotation axis of the rotating system (vehicle); as a result, only a component of rotation resp. angular rate is being measured. For detecting the entire angular rate, the model is extended by the influence of the tilt angle α:

$$\omega = \frac{U - ZPO - D_{Lin}(U,T) - D_{ZPO}(T)}{(S - D_S(T)) * \cos(\alpha)} \tag{9}$$

Besides the systematic influences that have been considered, especially regarding the parameter curves, there are further influences, which affect an angular rate measurement erroneous. These are in the field of automotive navigation especially the g-sensitivity, as well as influences induced by vibrations, voltage variations or magnetic fields. Because neither the influences itself, nor their effect on an angular rate measurement can be modelled in a reliable way, they will not be implemented into the mathematic gyroscope model. By means of test results a decision can be found, whether the resulting measurement errors are acceptable or not.

6 GYROSCOPE QUALIFICATION FOR NAVIGATION SYSTEMS

Gyro manufacturers conduct several intensive test series, from which they derive their gyroscope specifications. The decision-making, whether an angular rate sensor is suitable for automotive navigation, cannot be done solely based on the information in the data sheet because of lacking application-related information. Comprehensive test series are to be conducted, that characterize the sensor behaviour in various working conditions reliably. Especially a complete determination of the parameter curves is necessary, covering the entire temperature range the sensor will be exposed to in navigation practice.

6.1 Parameter Curve Determination

A detailed determination of the parameter curves is essential for the qualification process. The sensor temperature of a navigation system can raise within a few minutes from -20°C up to +60°C or even more when operated in winter. This warming-up process is one of the most critical aspects of a gyroscope operation in navigation practice.

For determination of parameter curves different angular rates have to be generated with high accuracy for a comparison to the sensor output. Furthermore, temperatures ranging from -40°C to +80°C are to be generated. This is done ideally using a precision rate table, which turntable is located inside a climate chamber. A few companies are specialized on test equipment for inertial sensors, offering a range of precision rate tables with one up to three free axes, that are, combined with a climate chamber, very suitable for gyroscope qualification.

Tests for a parameter curve determination cover the required angular rate spectrum and the operation temperature range in a stepwise test routine. As a result, there should be at least two independent measurements covering each tested angular rate (e.g. in 10°/s intervals) at each realized temperature (e.g. in 10°C intervals). Based upon this test data, temperature dependant ZPO- and Sensitivity drift, as well as linearity behaviour for each temperature can be constructed. Time dependant drift can be revealed by implementing waiting time between two test runs at each temperature. Multiple independent test runs make an analysis of parameter curve repeatability possible.

A continuous determination of temperature dependant ZPO drift is done by a further test, in which the sensor is heated up and afterwards cooled down, covering the entire operation temperature range. The result are two curves (output voltage on temperature), which can be compared directly. In addition this test allows an examination of an eventual influence of the temperature gradient, because the gradient in this test is obviously higher than in the stepwise tests.

6.2 Voltage Variations

The supply voltage will not stay constant during gyro operation. This is due to other power consumers and oscillations in the power regulator itself. Respective tests for an examination of an impact on ZPO due to supply current variations are recommended. On the one hand voltage jumps with different magnitude should be realised, on the other hand oscillations with different frequency and amplitude are overlaid on supply voltage (ripple). Especially due to frequency responses with mechanical gyro components, ripple on supply voltage can cause ZPO variations with great magnitude.

6.3 Vibrations

Automotive vibrations depend among others on driving speed, road conditions, engine revolutions and vehicle load, covering a wide frequency range. The relevant frequency range is between 50 and 2000 Hz, in which the car body and passenger cell are subjected to several resonance vibrations (DeJong, 1985).

Frequencies below 50 Hz should also be tested; they can result e.g. from slow driving on cobblestone. Therefore, tests should cover the frequency range from 10-2000 Hz, accelerating by 2-4g.

6.4 Magnetic Fields

Due to the large amount of ferromagnetic materials and the increasing number of electronic components in a vehicle it is surrounded by magnetic fields, constantly changing their direction and magnitude. However, these fields do not affect gyroscope operation in a significant way. The sensitive sensor elements are well shielded in a solid metal casing against magnetic fields; analyses regarding magnetic field influences on a gyroscope measurement therefore are not mandatory.

6.5 Noise

Noise analysis can be conducted using the drift-free ZPO signal. By picking up the maximum and minimum values within a certain period of time, maximum noise (peak to peak) or the noise equivalent rate can be derived. A harmonic analysis gathers information about eventual oscillations overlaid with the signal.

6.6 Sensor Tilt

Inclined radio shafts (up to 40°) often enforce an angular rate measurement with tilted sensor. As a result, only one component of the true angular rate is being measured. The sensitivity decreases with the cosine of the tilt angle. Some manufacturers offer gyroscopes with pre-tilted sensitive axis for compensating such effects in inclined radio shafts. Measurements with un-tilted probe mass are simply corrected by the tilt angle cosine.

For verification, whether a tilted sensor behaves in that systematic way, some test runs with different tilt angles are recommended.

6.7 G-Sensitivity

In driving dynamics not only the vector of g-force acts on a sensor, there are also inertia forces due to vehicle acceleration, deceleration and in curves acting on the sensor. In contrast to the g-force, that approximately parallels the sensitive axis and thus having no effect, acceleration and centripetal forces act perpendicular to the sensitive axis, affecting the angular rate measurement. Therefore, a sensor analysis regarding inertia forces resp. accelerations arising from driving dynamics is interesting.

Knowledge of maximum accelerations arising during normal driving is necessary. Ideal conditions assumed, these do seldom exceed 10m/s² (~1g) in acceleration/deceleration and 0,73-0,8g in curves. (Mitschke, Wallentowitz, 2004).

Accelerations due to driving dynamics seldom exceed the force of gravity, whereby it is predestined for gyroscope tests on g-sensitivity in automotive navigation applications.

Respective tests rotate the sensor, tilted by 90°, around its sensitive axis; gravity acts perpendicular on the probe mass, resulting in a sine oscillation, overlaying the measurement.

6.8 Rotation Sceneries

Besides numerous tests using constant angular rates or ZPO, a couple of rotation sceneries should be tested. These tests should be oriented upon realistic movements and encompass a wide range of angular rates and angular accelerations. Information can be gathered, how precise a sensor measures an angular rate curve, if sensor output lags behind the true rotation, or if problems occur regarding high angular accelerations. Such tests are either conducted on a suitable rate table system or in a car on a test track, using a reference gyroscope (FOG or RLG) for acquisition of pseudo-true values.

6.9 Product Diversity

Applying the presented test procedures to solely one sensor of a kind of course is not sensible. Although today gyroscopes are produced very precisely and uniform, there will be always little differences, causing different gyroscopes to behave in different ways. If a gyroscope-*type* shall be evaluated regarding its suitability for the use in several thousand navigation systems, at least a rudimentary view on product diversity is necessary. Thus, all presented tests should be run on multiple sensors at a time. The more sensors simultaneously are tested, the better the insight into product diversity. A measurement arrangement comprising of 10 sensors is, with respect to measurement and processing efforts, as well as to the limited space within a climate chamber, without any problems realisable.

7 QUALIFICATION PROCESS IN PRACTICE

This paper is based upon tests on three different gyroscope types, conducted in cooperation with Harman/Becker Automotive Systems, during the qualification process for angular rate sensors. All described test procedures have been applied and processed.

For a reliable sensor qualification the entire qualification process should be run. However, in practice it often concentrates on a sensor's ZPO-behaviour. Deeper insights, like e.g. linearity errors, g-sensitivity and several external influences are welcome, but not mandatory. Especially under time pressure the qualification process is reduced to a minimum.

Yet gyro-measurements in navigation systems are not corrected e.g. resp. linearity or temperature dependant drift, although this was possible and would increase sensor performance significantly. Normally, an orientation on certain boundary values for several gyroscope parameters (max. linearity error, max. drift, max drift gradient, …), based upon long term experience of the developing companies and kept by them like a holy grail, is the basis of the qualification process. These boundary values embody the main conditions for gyroscope operation in automotive navigation systems.

Analyses of gyroscopes from several manufacturers have shown, that behaviour of a single sensor can be described very well. Especially linearity and drift behaviour is highly reproducible. In conjunction with a temperature sensor, temperature-dependant correction parameters can be applied, to increase stability and reliability of a gyroscope measurement significantly. However, product diversity is a problem. It is, regarding linearity and sensitivity drift, relatively small; regarding ZPO drift sensors of the same type behave seldom equal. Although they often have a similar magnitude, the ZPO drift curves of identical sensors often vary strongly. Hence for linearity behaviour and sensitivity drift a unified correction was often possible, but the resulting errors normally are small, so a correction is normally not applied in practice.

A unified drift curve for ZPO drift correction will not suffice in the majority of cases. For a significant improvement, a parameter curve determination has to be run on each sensor. The necessary effort and the resulting costs are not justifiable for a mass market. The orientation on the approved boundary values therefore is still the most efficient approach. Latest sensor developments display, that gyroscope manufacturers handle the temperature problem increasingly better; the temperature-dependant drift of recent sensors often does not exceed 1-2°/s over a temperature range from -40°C up to +80°C.

Although the gyroscope qualification process is often reduced to the bare necessities, the various potential error sources should not be disregarded. In vibration tests some sensors have proven to be very vibration-sensitive, resulting in heavy ZPO-variations, up to irreparable damage of some sensors. This proves once more, that navigation practice does not happen under laboratory conditions. Despite continuously increasing sensor performance, the range of potential suitable gyroscopes often differs seriously.

8 CONCLUSIONS

A comprehensive qualification process is essential for a correct sensor choice. The economic damage, resulting in a sensor showing unexpected serious deficiencies, released for some hundred thousand navigation systems, is easyly conceivable. Some sensor deficiencies will be balanced by additional navigation sensors (odometer, GPS) and the Map Matching process, longer GPS failure with the system running purely on dead reckoning can result in heavy navigation errors due to these sensor deficiencies. Especially with respect to the mentioned increasing implementation of automotive navigation systems into active driver assistance, requiring high system reliability, there is no space for compromise in sensor choice.

In the course of a comprehensive qualification process, angular rate sensors are described in detail, including the determination and evaluation of external influences. Concrete and precise statements regarding the suitability of a sensor for automotive navigation applications and its advantages and disadvantages can be made.

With respect to the growing market, quality assurance in the field of automotive navigation is getting more and more relevant. There are various companies already active in car navigation and multimedia branch. This competition, increased by Asian companies flooding the market with low cost products, will accumulatively enhance the meaning of the quality factor. Aspects like quality, reliability, accuracy, stability, operability, actuality and safety will be decisive factors for maintaining upper class and distinguishing from competitors.

Here, qualification of position determination sensors is one important matter. There are several changes taking place in the field of low cost inertial sensors and satellite navigation, ranging from the European satellite navigation system Galileo to new MEMS gyroscopes and accelerators, getting continuously smaller, better and more inexpensive. Constant qualification work will be necessary to have an appropriate overview of available sensors and to equip navigation systems with the ideal sensor assembly.

The field of indoor personal navigation also depends on miniaturized sensors; the use of vibratory gyroscopes for attitude determination appears as being useful. Similar qualification work will be necessary, optimized on special requirements resulting from individual personal movements and application environment (different dynamics, different error sources).

The qualification of accelerometers or other sensors for height determination like barometers will be, in addition to gyroscope qualification, focussed in future. Especially for the navigation in booming Asian metropoles, where roads often are built in several layers upon another, the aspect of height surveillance gets increasingly relevant. Respective qualification processes will be needed for this as well.

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