# USING OF ORIENTATION SENZOR CHR6-DM IN SECURITY TECHNOLOGIES

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## KEYWORDS

CHR6-DM, gyroscope, accelerometer, magnetometer.

## ABSTRACT

This article presents the possibilities offered by exploiting CHR 6-DM Orientation Sensors in Security Technologies. It also addresses hardware resources suitable for the inertial navigation of RC models used in Security Technologies. The basis of the CHR 6-DM sensor is a gyroscope that is further complemented by an accelerometer and a magnetometer. In order to use orientation sensor security technology, suitable software was developed that can be used for the autonomous implementation of autonomous RC models suitable for use in Security Technology applications.

## INTRODUCTION

Inertial Navigation Systems (further only INS) are used for navigation, i.e. they are mainly used to measure the instantaneous geographic coordinates of a mobile device. The main significance of inertial navigation lies in its autonomy, i.e. its independence from external sources of information. Studies on inertial navigation go back to long before the advent of Micro-Electro-Mechanical System (further only MEMS) technology. The first inertial navigation device was developed and tested by rocket makers like Robert Goddard and Werner Von Braun in the early nineteen-thirties. Later, the inertial technology was further improved by institutions like Drapers Labs - which created the first INS. Inertial navigation enabled further great air accomplishments; e.g. the Apollo rocket and the space program.

Prior to the advent of MEMS technology, precision mechanical gyroscopes and accelerometers had been used. Their high cost however, limited the individual applications to a very great extent.

## MEMS

An MEMS micro-system is generally defined as a miniature, intelligent sensing system associating the scanning of information, signal processing and the execution of special functions on the output. Micro-systems usually combine the properties of two or more of the following six basic energy domains - electrical, mechanical, optical, biochemical, magnetic and thermal. They are usually designed and integrated on a single chip - possibly in a multi-chip hybrid design. Exo-system components have structures with micron (µm) dimensions whose technical features are conditioned by the shape of the microstructure. Micro-systems combine several micro components with two or more functions, optimized in the internal system - in many cases using microelectronic structures and functions.

Prior to the advent of MEMS technology, precise mechanical gyroscopes and accelerometers were used. Further development/evolution of MEMS technology enabled the production of sensors, which – while not attaining the performance of conventional mechanical sensors – but, which dramatically reduced the price, size and weight/mass.

Inertial Measurement Unit (further only IMU/s) micromechanical sensors, have only recently begun to appear on the market cheap, modern and effective alternatives to existing inertial sensors. Many of today´s - contemporary, inertial sensors can now be found in military, automobile, industrial, and the pharmaceutical industries - for instance.

## INERTIAL UNITS

Inertial navigation represents a navigational technique – where measurement is actualised/implemented using accelerometers and gyroscope. They (are/can be) used for following or tracking positions and for the orientation of objects relative to (their) known starting point, orientation and rapidity.

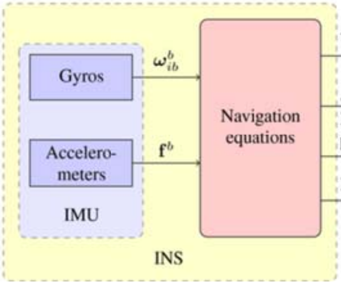

Figure 1: An Inertial Navigation System [1]

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An INS typically contains three orthogonally located gyroscopes and three orthogonal accelerometers, which measure declination speed and linear acceleration.

The processing of such signals from these devices means the possibility of such devices being used to acquire the location and orientation of objects.

Inertial Navigation is based upon the application of Newton´s Laws on Motion. The Second Newton Law is used to discover acceleration – according to the following equation:

$$a = \frac{F}{m} \tag{1}$$

where: *a* is the acceleration of the body, *F* is the force influencing that body, and *m* is the body´s mass.

A. A Stable Platform System

A Stable Platform System is assembled using inertial sensors, sited upon a platform that is isolated from any form of external rotation.

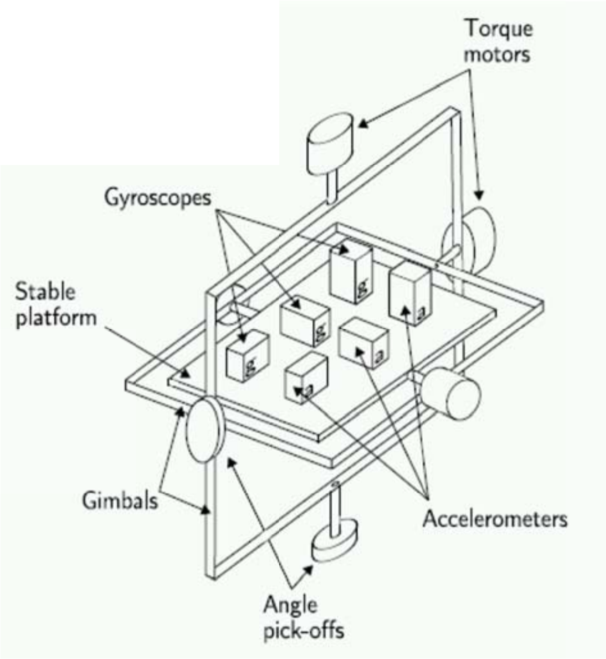


Figure 2: A Stable Platform [2]

B. A “Strapdown” System

In Strapdown systems, inertial sensors are solidly mounted to the device; thus, the output is measured in bodily geometric sets. The integrated output from the gyroscope used for tracking movements is a triad of signals from the accelerometer (which are) transformed into global coordinates. The acceleration signals in global coordinates are then integrated in the same way as in a stable platform algorithm.

Stable platforms and Strapdown systems are based on the same principles. Strapdown systems have reduced mechanical complicatedness – and are physically smaller. These advantages are achieved at the cost of increasing the computational complicatedness, while the costs for such computational units are reduced. Strapdown systems have become a dominant type of INS.

## A TYPICAL SENSOR MODEL

Each MEMS sensor can be described by a linear model.

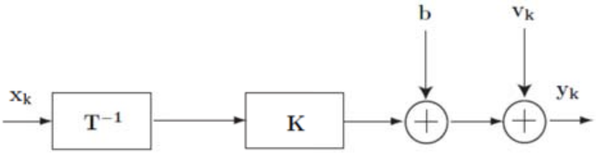


Figure 3: An Inertial Sensor Block Diagram [3]

In Figure 3 is $x_k$ is the value of the physical quantity, $T^{1}$ is the inverse matrix of the deviated axis, *K* is the scale, *b* is bias, $v_k$ is the measurement interference, and $y_k$ is the output of the inertial sensor.

$$b = \begin{bmatrix} b_x & b_y & b_z \end{bmatrix}^T \tag{2}$$

$$K = \begin{pmatrix} k_x & 0 & 0 \\ 0 & k_y & 0 \\ 0 & 0 & k_z \end{pmatrix} \tag{3}$$

Since the error of a deviated axis typically attains several tenths of a degree, one can use the following equation:

$$T_a^p = \begin{pmatrix} 1 & -a_{yz} & -a_{zy} \\ a_{xz} & 1 & -a_{zx} \\ -a_{xy} & a_{yx} & 1 \end{pmatrix} \tag{4}$$

The measured output can then be modelled as follows:

$$y_k = K\left(T_a^p\right)^{-1} x_k + b + v_k \tag{5}$$

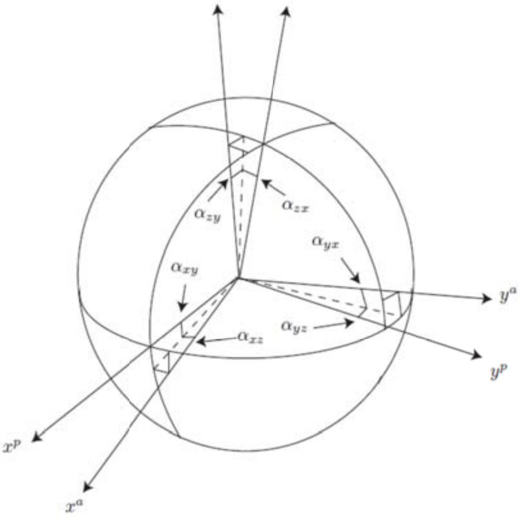


Figure 4: An Axis Deviation Error [3]

## INERTIAL SENSOR QUALITY

All types of accelerometers and gyroscopes demonstrate bias, scale errors, errors in the inclination of the scale axis, or random interference. The size of these errors depends upon the type of sensor.

Every source of systematic errors has four components: fixed contributions, temperature deviations, run-to-run deviations, and in-run deviations. Fixed contributions are permanently present on a sensor and the INS processor unit is corrected with the aid of data measured in a laboratory. As regards Run-to-run, the error size changes over time on the sensor – but remains constant for any run. The in-run contribution deviations change slowly in the course of the activity. Theoretically, it is possible to correct this error through the addition of more sensors; but, practically speaking, this is very difficult to attain.

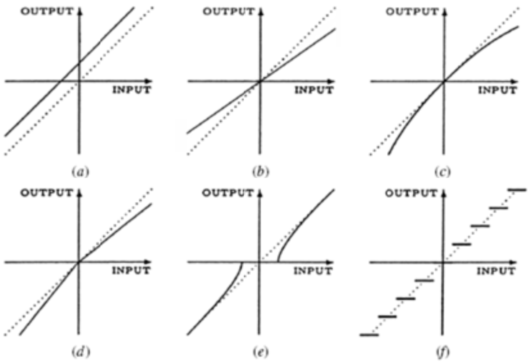
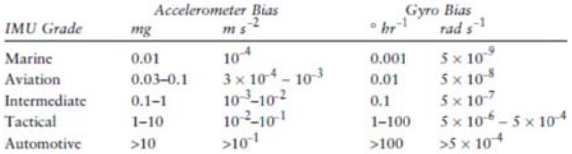


Figure 5: Typical Inertial Navigation Errors: (a) Bias, (b) Scale Errors, (c) Non-linearity Errors, (d) Asymmetrical Errors, (e) Dead-zone Errors, (g) Quantificational Errors [4]

### A. Bias

Bias is a constant error that occurs in all accelerometers and gyroscopes. In many cases, bias is a dominant error in inertial sensors.

Table1. Bias Error Levels for IMU Degrees [5]



| | Accelerometer Bias | | Gyro Bias | |
|---|---|---|---|---|
| IMU Grade | mg | $m\ s^{-2}$ | $°\ hr^{-1}$ | $rad\ s^{-1}$ |
| Marine | 0.01 | $10^{-4}$ | 0.001 | $5 \times 10^{-9}$ |
| Aviation | 0.03–0.1 | $3 \times 10^{-4} - 10^{-3}$ | 0.01 | $5 \times 10^{-8}$ |
| Intermediate | 0.1–1 | $10^{-3}$–$10^{-2}$ | 0.1 | $5 \times 10^{-7}$ |
| Tactical | 1–10 | $10^{-2}$–$10^{-1}$ | 1–100 | $5 \times 10^{-6} - 5 \times 10^{-4}$ |
| Automotive | >10 | $>10^{-1}$ | >100 | $>5 \times 10^{-4}$ |

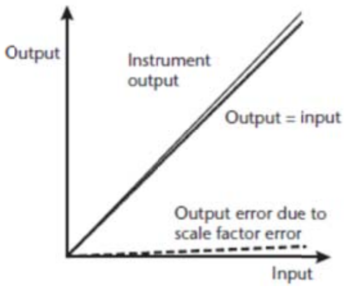


Figure 6: Scale Error [6]

### B. Scale Errors

A scale error is a deviation in the input-output inclination. Accelerometer output error is dependent upon the size of the acceleration force acting upon the axis. For gyroscopes – this is on the size of angle velocity.

### C. Deviated Axis Errors

Deviated axis errors occur in all types of INS. This error is the consequence of technological restrictions on production.

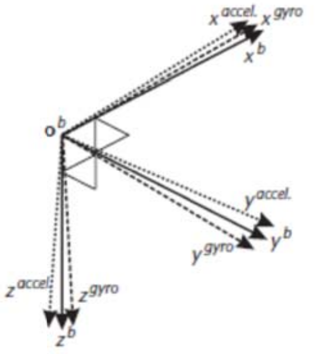


Figure 7: Deviated Axes of Accelerometers and Gyroscopes [6]

### D. Non-linearity

Non-linearity represents the precision of real calibration curves with the ideal static transmission characteristics (i.e. straight line). It expresses in percent the upper border of the scale´s extent and provides the maximum deviation of any calibration point whatsoever from the corresponding point on the ideal characteristic. Sensor linearity error (i.e. Non-linearity), is defined as follows:

$$L_e = \frac{\Delta y_{\max}}{Full\ scale} \qquad (6)$$

## INERTIAL NAVIGATION HARDWARE RESOURCES

### A. STEVAL-MKI02V2

The STEVAL-MKI02V2 kit is a development kit from STMicroelectronics.

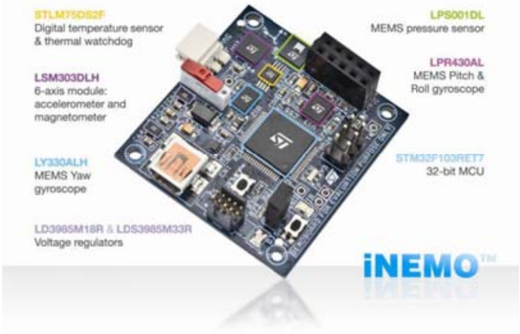


Figure 8: The STEVAL_MKI02V2 Development Kit [7]

- Two possible ways of charging: A charging connector or a USB connector
- STM32F103RE: High-density performance line, ARM-based 32-bit MCU with 256 to 512 kB Flash, USB, CAM, 11 timers, 3 ADC and 13 communication interfaces
- LPR430AL: 2-axis gyroscope (roll, pitch), 300°/s full extent with an analogue output and settable additional filters
- LSM303DLH[7]: 6-axis geomagnetic module: ±2 g/ ± 4 g/ ± 8 g acceleration range, configurable magnetic field ±1,2 do 8,1 Gauss (max), I2C Bus-box
- LPS001DL: Pressure sensor range: 300-1100 mbar with an I2C Bus-box
- STLM75: Temperature sensor range: -55 to +125°C and an I2C Bus-box

### B. CH Robotics 6DM

The CH Robotics CHR-6DM AHRS contains an IMU complemented by a triple-axis magnetometer. Data from all of the sensors are collated by a 64 MHz ARM Cortex M3 processor with an Expanded Kalman Filter (EKF). The EKF combines data from the accelerometer, gyroscope and magnetometer with estimates of yaw, pitch, and roll angles. The output is presented in Euler Degrees via a UART Bus-box with speeds up to 300 Hz.

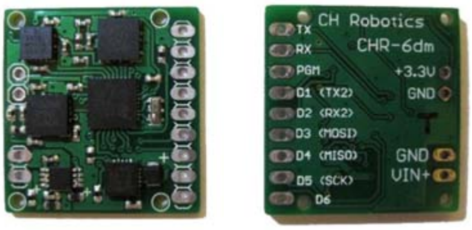


Figure 9: CH Robotics CHR-6DM AHRS Developer Kit [8]

Main components:

- STMicroelectornics LPR510AL – pitch a roll gyroscope: ±100°/C, with analogue output
- STMicroelectornics LY510LH – yaw gyroscope
- Analogue Device: ADXL335[8] – tri-axial accelerometer
- Honeywell HMC5843 – tri-axial digital magnetic compass

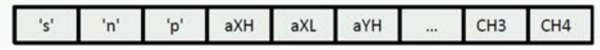
Functions:

- EKF estimation of yaw, pitch and roll angles
- Adjustable output speeds: (20 Hz – 300 Hz)
- Motherboard with a 3.3V regulator
- +3.3 output, with an ability of up to 400mA for recharging other peripherals (e.g. GPS)
- Two UARTs and an SPI Bus-box

## A SOFTWARE DESIGN FOR THE CHR6-DM SENSOR

In order to be able to track all of the measured quantities from the sensors on-line, a user-program was written using the C# language. The program communicates with the measurement system across a UART or RS232 interface.

Communication between the measurement system and the user-program takes place across a UART interface with a transmission speed of 115200, 8 bits, without parity, with a single stop bit. For data transmission purposes, a data packet was created whose length is 41 bits.



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 's' | 'n' | 'p' | aXH | aXL | aYH | ... | CH3 | CH4 |

Figure 10: Data Transmission Packet for the User-program

The meaning of the individual bytes is as follows:

- 1 to 3 – bits: 's','n','p' – form the headliner of the message
- 4 – bit: aXH [mg] – is the upper byte of acceleration on axis X, written in paired additions
- 5 – bit: aXL [mg] – is the lower byte of acceleration on axis X, written in paired additions
- 6 to 7 – bits: aYH, aYL [mg] – is the acceleration along axis Y, also written in paired additions
- 8 to 9 – bits: aZH, aZL [mg]
- 10 to 15 – bits: gXH, gXL, gYH, gYL, gZH, gZL [°/s] – are the angle speeds in individual axes, measured by the gyroscopic sensor
- 16 to 21– bits: mXH, mXL, mYH, mYL, mZH, mZL [mGauss] – are the outputs from the magnetometer in the individual axes
- 22 to 27 – bits: rollH, rollL, pitchH, pitchL, yawH, yawL [°/s] – are the rotational angles of the inertial unit

- 28 to 41 – bits: rollRateH, rollRateL, pitchRateH, pitchRateL, yawRateH and yawRateL – are the angle speed, acquired by merging the gyroscopic sensor, the accelerometer and the magnetometer.

The following figure represents an example of the depiction of the data from the gyroscope, accelerometer and magnetometer in the user-environment.

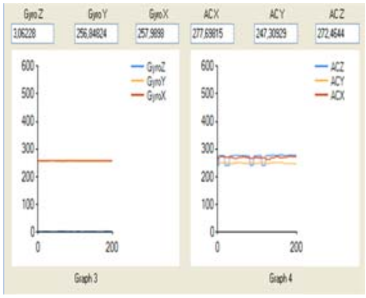

GyroZ: 3,06228
GyroY: 256,84824
GyroX: 257,9898
ACX: 277,69815
ACY: 247,30929
ACZ: 272,4644

Figure 11: Depiction of the course of the output data from the gyroscope and accelerometer

The CHR6-DM sensor was used for the analysis of the behaviour of the individual control components of the RC model. To be able to track on-line all of the measured quantities on the RC model, software was designed using C# language which communicates with the measurement system across the UART interface.

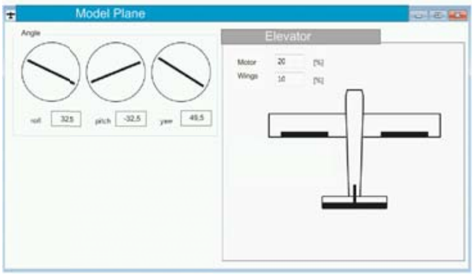

roll: 32.5
pitch: -32.5
yaw: 49.5
Motor: 20 [%]
Wings: 10 [%]

Figure 12: User-program for the depiction of the measured quantities of an RC model

The entry entitled “Acceleration” depicts the information about all of the measured quantities on the CHR 6-CD kit. The program also enables the record data to files function. Data recording is possible in two ways. The first is the recording of all of the data received by the program. The first button “Record Data” registers all the data. The second possibility is to select only a certain section of the data – where the second button “Allow Selection” serves for this function. Upon clicking this button, an index is saved of the last-received data and a second click finishes the “data collection” while the recording of this data is written in a file.

## CONCLUSION

The system suggested herein is a suitable instrument for the control of pilotless RC aircraft, which can be used in security applications. Especially, it enables the exploitation of such RC models for monitoring hard-to-access locations during floods - or, as the case may be during extensive fire outbreaks. It is becoming clear that it is appropriate to construct such pilotless RC models with inertial navigation capacities.

Contemporary technical levels already allow the development of very high-quality IRS (Inertial Reference Systems) with precise measurement of positional angles in flight of cca ±1°.

The precision and reliability of an IRS conceived in this way can be substantially improved – for instance, by the use of a minimum of three groups of inertial sensors (very cheap, light, small, and with minimum consumption).

In the case where stochastic processes breakdowns causing measurement errors are correlated, and after adding together the adequate signals, the resultant measurement errors are reduced to one third. An IRS like this, with micromechanical (MEMS) inertial sensors´ precision approaches that of an IRS, artificial horizon and gyro-magnetic compass based on classical gyroscopic technology and, in the coming decade, it can be expected that this will completely force out classical gyroscopic technologies from onboard aircraft.

## ACKNOWLEDGMENTS

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