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THE APPLICATION OF MEMS TECHNOLOGY TO DETERMINE AN AIRCRAFT ORIENTATION

ПРИМЕНЕНИЕ ТЕХНОЛОГИИ MEMS ДЛЯ ОПРЕДЕЛЕНИЯ ОРИЕНТАЦИИ ВОЗДУШНОГО СУДНА

ӘУЕ КЕМЕСІНІҢ БАҒЫТЫН АНЫҚТАУ ҮШІН MEMS ТЕХНОЛОГИЯСЫН ҚОЛДАНУ

Isgandarov İ.A., cand. of ph.-math. sc., ass. pr..
Bakhshiyev H.E., Master degree
National Aviation Academy, Baku, Azerbaijan

Abstract

This paper analyzes the features of MEMS and the possibility of their use to build AHRS with flexible parameters, with the aim of using them on unmanned aerial vehicles. It is shown that the correct use of newer versions of modern MEMS, which have 3-axis gyroscopes, accelerometers and magnetometers, can provide complete and accurate information about the orientation of the UAV in space.

Key words: *MEMS applications, magnetometer unit, inertial measurement unit (IMU), attitude and heading reference system (AHRS).*

Аңдатпа

Мақалада MEMS ерекшеліктері мен оларды пилотсыз ұшу аппараттарында пайдалану үшін икемді параметрлері бар AHRS құру үшін пайдалану мүмкіндігі талданады. 3 осьті гироскоптар, акселерометрлер мен магнитометрлерге ие қазіргі заманғы MEMS жаңа нұсқаларын дұрыс қолдану кеңістіктегі ұшқышсыз ұшу аппараттарының бағдары туралы толық және дәл ақпарат бере алатындығы көрсетілген.

Түйін сөздер: *MEMS қосымшалары, магнитометриялық блок, инерциялық өлшеу блогы (ИӨБ), бағдарлау және курс жүйесі (БКЖ).*

Аннотация

В статье анализируются особенности МЭМС и возможность их использования для построения AHRS с гибкими параметрами, с целью использования их на беспилотных летательных аппаратах. Показано, что правильное использование более новых версий современных MEMS, которые имеют 3-осевые гироскопы, акселерометры и магнитометры, может дать полную и точную информацию об ориентации БПЛА в пространстве.

Ключевые слова: *МЭМС-приложения, магнитометрический блок, инерциальный измерительный блок (ИИБ), система ориентации и курса (СОК).*

İntrudoction

Advanced Navigation is a leading developer of high accuracy navigation technologies for Commercial and Defense applications. MEMS and FOG (Fiber Optic Gyro) based navigation products are ideal for a wide range of UAV (unmanned aerial vehicle), UGV (unmanned ground vehicle) and AUV (autonomous underwater vehicle) applications.

MEMS are very small devices or groups of devices that can integrate both mechanical and electrical components. MEMS can be constructed on one chip that contains one or more micro-components and the electrical circuitry for inputs and outputs of the components. The components include different types of sensors, transducers, actuators, electronics and structures (e.g., gears, sliding mirrors, diaphragms). Each type of component is designed to interface with an input such as light, gas molecules, and a specific type of radiation, pressure, temperature, or biomolecules.

INS are navigational systems capable of calculating position, either relative to some reference system or to absolute coordinates (via three gyros and three accelerometers) [1].

When cost or weight is an issue, inertial navigation using very accurate inertial sensors has been excluded. Instead, low-cost systems using inertial sensors based on MEMS have been widely used. For safe and reliable flight of UAV, an accurate AHRS is a key component and can give information about the UAV’s orientation in three-dimensional spaces [2].

An AHRS typically includes a 3-axis gyroscope, a accelerometer, and a magnetometer to determine an estimate of a system’s orientation. Each of these sensors contribute different measurements to the combined system and each exhibit unique limitations.

Analyzing errors which affects to AHRS measurements based on MEMS.

An accelerometer supplies an AHRS with a measure of the system’s acceleration and is assumed to be measuring gravity alone. This assumption allows the accelerometer to calculate the pitch and roll angles from the direction of the gravity vector (see **Fig. 1,a)** .

However, any biases or other errors in the accelerometer measurements cause errors in the calculation of the pitch and roll angles. In addition, since the accelerometer is assumed to be measuring gravity alone, any added dynamic motion also causes an error in the calculation of the system’s pitch & roll.

Since the accelerometer can only measure pitch & roll, a magnetometer provides an AHRS with a measurement yaw by comparing the measurement of the magnetic field surrounding the system to Earth’s magnetic field, just like a traditional magnetic compass.

The Earth's magnetic field is weak, so large metal structures, high power cables, or any other magnetic disturbances can distort Earth's magnetic field and cause errors in the estimated heading angle. Advanced filtering techniques can be used to mitigate the impact of external disturbances in the environment, but their effectiveness varies by manufacturer and application. Additionally, the magnetic North pole of the Earth is not in the same location as True North or the geographic North pole of the Earth. If the heading angle with respect to True North is desired, the declination angle between these two poles must be factored into the heading determination. Another challenge faced when using a magnetometer is that the sensor is often oriented in such a way that the pitch and roll angles are non-zero (in contrast to the use of a handheld magnetic compass). This requires the AHRS to utilize a technique known as tilt-compensation of the magnetometer measurements, in which the estimated pitch and roll angles are used to remove the impact of the vertical component of Earth's magnetic field [3].

In an AHRS, the measurements from the gyroscope, accelerometer, and magnetometer are combined to provide an estimate of a system’s orientation, often using a Kalman filter. This estimation technique uses these raw measurements to derive an optimized estimate of the attitude, given the assumptions outlined for each individual sensor. The Kalman filter estimates the gyro bias, or drift error of the gyroscope, in addition to the attitude. The gyro bias can then be used to compensate the raw gyroscope measurements and aid in preventing the drift of the gyroscope over time. By combining the data from each of these sensors into a Kalman filter, a drift-free, high-rate orientation solution for the system can be obtained.

Sustained dynamic accelerations can cause a problem in the estimation of the pitch and roll angles as the assumption that the accelerometer is measuring gravity alone is constantly being violated. The most common case where this becomes a significant problem for an AHRS is when an aircraft is operating in a banked turn. When this occurs, the accelerometer measures gravity plus a long-term acceleration due to the centripetal force created by traveling along a curved path. This results in a measurement vector that acts perpendicular to the wings of the aircraft and cause the AHRS to estimate a roll angle of zero while the aircraft is in fact in a banked turn and thus has significant roll relative to the horizon, as shown in **Fig. 1,b**.

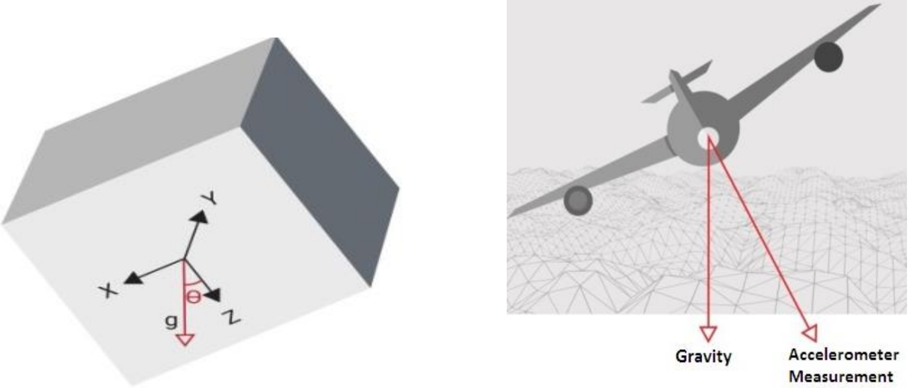


Figure 1. a) Accelerometer Pitch and Roll; b) Measured Acceleration in a Coordinated Turn

Magnetic disturbances, which can be internal or external to the system, also pose a problem to an AHRS and cause the magnetometer to measure a biased and distorted magnetic field. They can be non-variable disturbances, such as a steel plate, or variable disturbances, such as motors or multi-rotors. External magnetic disturbances are caused by anything in the environment surrounding the system such as batteries, electronics, cars, rebar in concrete, and other ferrous materials. To account for any non-variable magnetic disturbances internal to a system, a hard and soft iron (HSI) calibration can be preformed on the system.

Errors that exist in the accelerometer and magnetometer attitude solution, either due to sensor biases or to violations of the operating assumptions for each, cannot be avoided in the AHRS solution over longer periods of time. In fact, those errors can cause bounded drifting of what is otherwise considered a "drift-free" attitude solution from the AHRS. One simple illustration of this can be revealed through a static-dynamic-static test. This test is broken up into three parts in which the system is stationary during the first part of the test, experiences dynamic motion during a short second part, and finally returns to a stationary state in the third part of the test. An example of a static-dynamic-static test is shown in **Fig. 2**, in which the yaw measurements are tracked as a vehicle proceeds through a turn. In this scenario, the magnetic signature of the vehicle has not been compensated using an HSI calibration, so the magnetic heading measurements are inaccurate throughout the test.

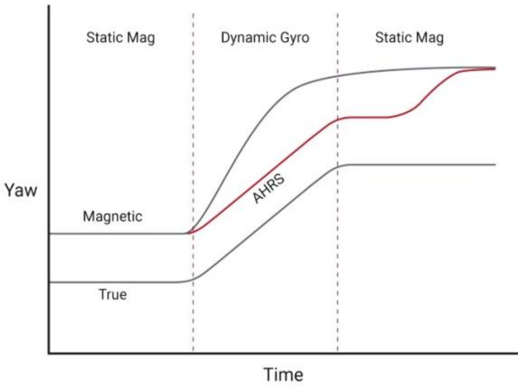


Figure 2. Static-Dynamic-Static Response.

Mathematical calculating of aircarft orientation.

The Euler angles describe the body-axis orientation of UAV body coordinate frame (frame) in North, East, and Up navigation coordinates frame (frame). Here, is the yaw angle, is the pitch angle, and is the roll angle, as illustrated in **Figure 3**. The initial attitude and heading of the UAV are needed to initialize the AHRS. When UAV is stationary, Initial attitude and heading of UAV are computed by accelerators and digital compass. The calculation formulas are described as follows:

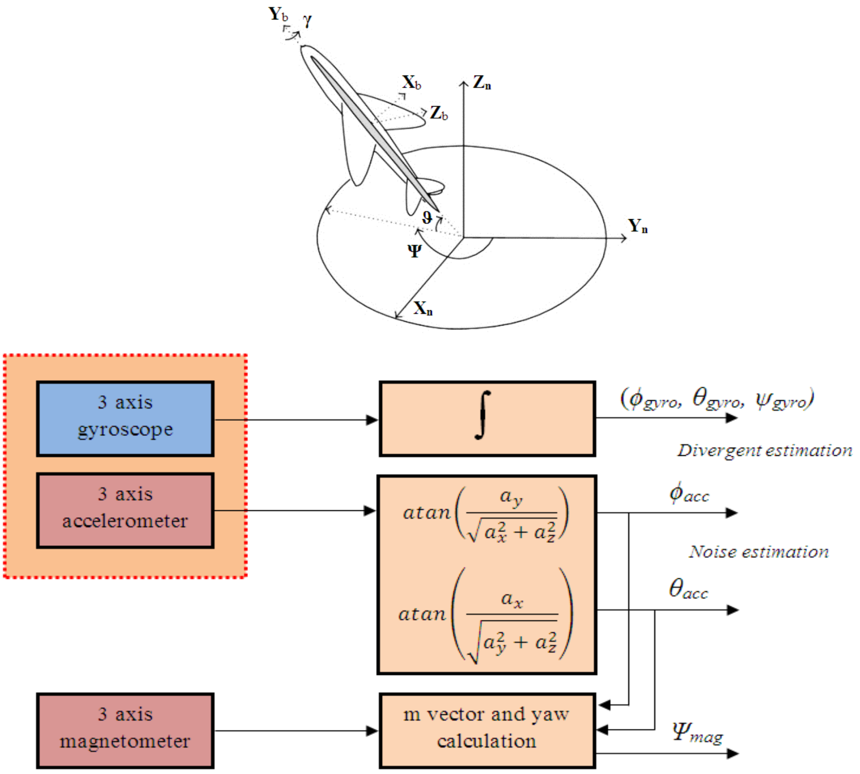
$$\gamma = \tan^{-1}\left(\frac{f_x^b}{(-f_z^b)}\right)$$

$$\theta = \tan^{-1}\left(\frac{f_y^b}{\sqrt{f_x^{b^2} + f_z^{b^2}}}\right)$$

$$\bar{\psi}_m = \tan^{-1}\left(\frac{m_x^b \cos\bar{\gamma} + m_z^b \sin\bar{\gamma}}{m_x^b \sin\bar{\gamma}\sin\bar{\vartheta} + m_y^b \cos\bar{\vartheta} - m_z^b \cos\bar{\gamma}\sin\bar{\vartheta}}\right)$$

(1)

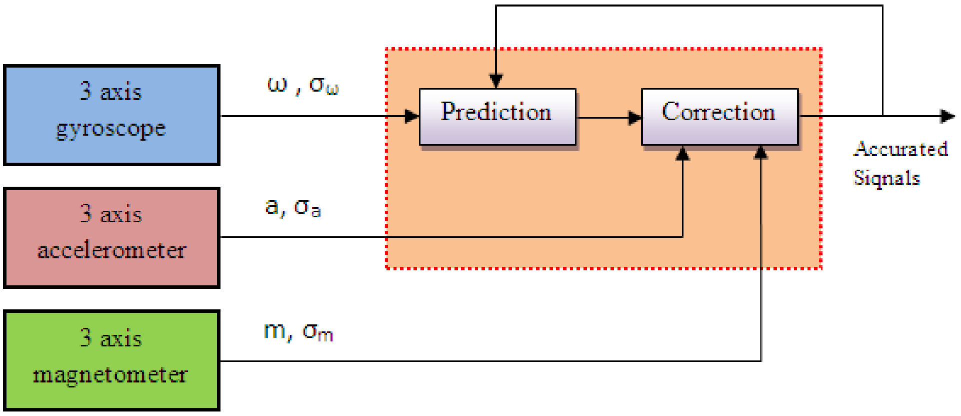
where, f_x^b, f_y^b, and f_z^b are the specific force of the accelerometers in body coordinate frame (b frame). m_x^b, m_y^b, and m_z^b and are the components of the magnetic field strength in body coordinate frame [4].



Euler angles: ϕ – *roll*, θ – *pitch*, ψ – *yaw*.

Figure 3. b frame, n frame, and Euler angles.

However, stationary UAV is difficult owing to wind and engine vibration in actual test, the initial attitude and heading are seriously influenced by high-frequency noise when the initial attitude and heading are computed by using (1). However, the error of attitude and heading computed from the gyroscopes output is large since it is easily influenced by drift of the gyroscope. The block diagram of the orientation estimating using correction is shown in **Fig. 4.**



L_ω = argular velocity vector in the local frame; L_a = acceleration vector in the local frame;
L_m = magnetic field vector in the local frame; b = sensor bias; v = sensor noise.

Figure 4. Design of the orientation estimating block.

The sensor can be connected to an external GNSS receiver to improve its performance. Indeed, GPS-aided AHRS delivers additional navigation [5].

INS are composed of an IMU and additionally embed a GPS/GNSS receiver (**Figure 5**). An INS fuses inertial, navigation, and aiding data (odometer, DVL, etc.) thanks to the Extended Kalman Filter.

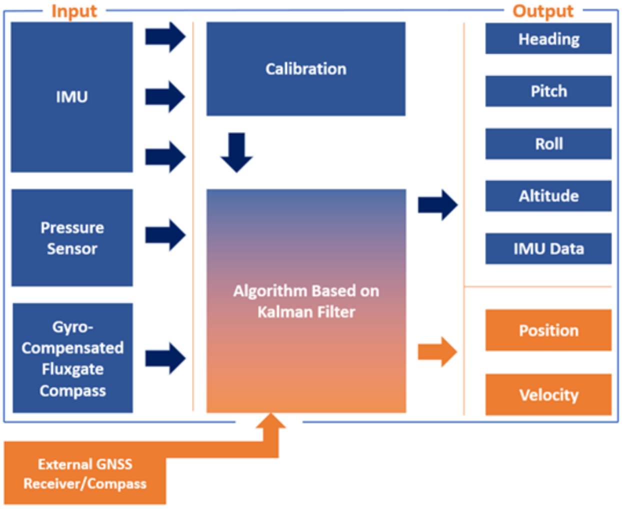


Figure 5. Functional Diagram of the reference system

Conclusion

The creation of compact and relatively inexpensive heading and attitude determination systems (AHRS) became possible with the introduction of MEMS components based on new generation microelectromechanical technologies.

MEMS-based AHRS are of low cost, light weight, and consume little power. However, the advantages of inexpensive MEMS sensors are coupled with the drawback of having greater potential error in reported roll, pitch, and yaw due to increased sensor noise and drift.

High performance integrated MEMS sensor technology provide direct and computed AHRS outputs in a small package.

Every inertial sensor can be calibrated in temperature from -40 to 85°C, ensuring a consistent behavior in all environments.

Calibration greatly improves sensor quality: Gain and bias temperature compensation for accelerometers and gyroscopes; Gain temperature compensation for magnetometers; Cross-axis and misalignment effects compensation for accelerometers, gyroscopes and magnetometers; Non linearity correction for gyroscopes and Gyro-G effect compensation for gyroscopes.

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