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Attitude and Heading Reference System for Aerospace Application

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***Abstract*—** Many experiments have been conducted for attitude estimation with low cost micro electro-mechanical system (MEMS), even though it was of low cost and less weight it causes certain noise and errors over time. The main objective of the paper is to introduce accelerometer portion of basic attitude and heading reference system for aerospace application using Internet of Things (IoT) which can be used to find the optimal weight value such error of the Attitude and Heading Reference (AHRS) is minimised. The proposed system also assures the body rate by using 2 axis gyro and it provides distance rate measurement and angular rotation. This system consumes low power and easy to handle.

***Keywords*—ArdiunoUno, Accelerometer, Gyroscope, Magnetometer.**

I. Introduction

An Attitude and Heading Reference System (AHRS) provides orientation information by fusing sensor data from a magnetic and inertial measurement unit (MIMU). A MIMU is comprised of three components: Gyroscope, Accelerometer and Magnetometer. Gyroscope is to measure angular momentum changes Accelerometer detects the orientation of the object, Magnetometer detects magnetic field strength. A basic AHRS approach fuses two complementary components together using a weighted approach. The first component estimates the relative orientation from the gyroscope, and the second component provides the absolute orientation from the accelerometer and the magnetometer. However, the weighting of these two components is critical to obtain the best orientation information. In order to find the optimal weight a genetic algorithm is used for the optimization task. Results obtained via ground-truth simulated MIMU signals with real noise content reveal that the RMSE orientation error (root means squared error) of the Euler angles in degrees can be reduced by a factor.

In the design of an attitude estimator, various solutions can be found due to different representations of attitude. The Euler angles, the quaternion, and the direction cosine matrix (DCM) are commonly used. Besides, vector-based filters have also received attention in recent years. Actually, all the attitude estimating algorithms in 9-DOF AHRS are based on the following two vectors and their characteristics:
1) The gravity vector **g**: It is always vertical downward, and can be used to determine the tilt angles (i.e. pitch and roll). It can be measured by a accelerometer under static condition.
2) The geomagnetic vector **h**: The direction of its horizontal component is defined as the magnetic north, which can help to find the geographic north if the magnetic declination is known. This vector can be measured by a magnetometer.

The attitude and heading information (i.e. the angles of heading, pitch, and roll) can be theoretically determined according to the above two vectors. Thus, it seems that the combination of a magnetometer andaccelerometer is sufficient for AHRS. The accelerometer is sensitive to both the gravitational acceleration and the motional acceleration (also referred to as 'external acceleration' in the literature) of the carrier that it is attached to.The MIMU is the fusion of 3 sensor (1) Gyroscope (2) Accelerometer (3) Magnetometer. The sensor data procure from the gyroscope and the magnetometer has been used to obtain the heading.Basically, the integration of the gyroscope from a known initial orientation supplies the change in rotation. However, the gyroscope has a long-term tuft which is due to noise and bias. Thus, these errors need to be corrected. The graded magnetometer is used to minimize the drift in the horizontal orientation.

MIMUs are widely used in many applications of attitude determination such as human motion tracking, unmanned aerial vehicle (UAV), mobile navigation, etc. The gyroscope measures the angular rate of a moving object, the accelerometer measures the acceleration of a certain object, and the magnetometer measures the magnetic field. However, low-cost sensors have inherent drawbacks,such as nonlinearity, random walk, temperature drift, etc. In order to obtain a reliable attitude solution, MIMU sensor measurements have to be fused together using optimal sensor fusion algorithms.4 There are mainly two divergent fusion approaches. One category includes the complementary _alters and the other relates to Kalmanfiltering.

Despite the existing research and solutions, the problem of external acceleration in attitude estimation is far from solved. In most applications, insufficient prior knowledge of external acceleration results in the difficulty of its accurate modelling and estimation.

In the following sections, we firstly briefly review the state of the art, and then discuss the principles in design and adjustment of external acceleration estimator. After that, we suggest a concise solution for dynamic attitude estimation, and perform numerical simulations to evaluate its performance.

II. RELATED WORK

1.Research on Extended Kalman Filter and Particle Filter Combinational Algorithm in UWB and Foot-Mounted IMU Fusion Positioning. Xin Li ,1 Yan Wang ,1 and Dewey Liu2 1School of Computer Science and Technology, China University of Mining and Technology.

With the wide application find door positioning technologies in some areas such as supermarket shopping, fire emergency navigation, and hospital patient tracking, indoor positioning can be implemented through the following two approaches. One is based on the various wireless network technologies, such as WIFI (wireless fidelity) RFID (radio frequency identification) and UWB (ultra-wideband) which can be used to realize indoor positioning according to the intensity of received signals, the TOA.

Advantages:
This is a statistical technique that adequately describes the random structure of experimental measurements. This filter is able to consider quantities that are partially or completely neglected in other techniques (such as the variance of the initial estimate of the state and the variance of the model error).

Drawbacks:
1.It was assumed that the accurate models and prior distribution of noise first. but in real application, sometimes it was unrealistic.
2.The basic assumption of noise is that the state belief is Gaussian distributed. In rapid change situation, sometimes Kalman filter has a slow reaction speed. It also mentions that there are solutions based on colored noise.

2.Attitude and velocity estimation of a projectile using low cost magnetometers and accelerometers. ChristopheCombeites GNC department French-German Research Institute of Saint-Louis (ISL) Saint-Louis, Francechristophe.combettes@isl.eu. SébastienChangey GNC department French-German Research Institute of Saint-Louis (ISL) Saint-Louis, France sebastien.changey@isl.eu.
A guided and controlled ammunition requires a performing navigation system. In this paper, an attitude and velocities estimation process are presented. It is based on a 3-axis magnetometer and 2 axis accelerometers. The estimation process is divided into 3 successive observers. Each observer is validated on simulations. Then the complete process is tested on free flight measurements. The results show that low cost sensors combined with a simplified 6 degrees of freedom projectile model are sufficient to estimate angular velocities without using the gyroscopes. The military domain needs to improve the accuracy of their weapons in order to avoid the collateral damages and to precisely target the objectives. To meet this requirement, a guided and controlled system is needed. To design guided ammunition, estimations of attitude, velocities and ideally projectile position are critical.

Advantages:
A prior information given by the complete modelling of the ballistic behaviour (trajectory, attitude) of the projectile is simplified to give a pertinent reduced evolution model. An algorithm based on extended Kalman filters is designed to determinate.

Drawbacks:
1.The orientation estimator uses an integrated filter to combine feedback from a three-axis magnetometer, two single-axis gyros and a GPS receiver. As a new feature of this algorithm, the magnetometer feedback estimates roll angular rate of projectile.

2.The algorithm also incorporates online sensor error parameter estimation performed simultaneously with the projectile attitude estimation. The second part of the paper deals with the verification of the proposed orientation algorithm through numerical simulation and experimental tests.

3.Magnetometer bias finite-time estimation using gyroscope data Giuseppe Fedele, Member, IEEE, ORCID: https://orcid.org/0000-0003-0273-780X, Luigi Alfonzo, and Gaetano D'Aguila, Member, IEEE.

This paper deals with the problem of estimating the hard iron bias affecting the measurements provided by a tri-axial magnetometer. The estimation is carried out using measurements from a magnetometer and a gyroscope mounted on the same inertial measurement unit. The described solutions ensure finite-time estimation performance and robustness against measurements noise. The effectiveness of the proposed solutions is proved by experimental tests carried out using real inertial sensors. Magnetometers are commonly used to measure Earth's local magnetic field vector so that to obtain the orientation of a body w.r.t. the magnetic North

Advantages:
A wireless magnetometer provides a cost-effective and convenient alternative to other sensing technologies. It requires no wiring or external control box, but achieves an accurate and repeatable response.

III. METHODOLOGY

The aim of this project is to develop an engineering model for the Altitude Heading Reference System (AHRS) for aerospace application. This will involve the hardware design of the sensor assembly of AHRS, including sonar and accelerometers, preferably MEMS based sensors. For the project, 2-axis gyros have been used to provide body rates. The gyros will provide distance rate measurement and angular rotation, and accelerometers will measure the linear acceleration forces. The output of the sensors will be converted to digital signals and will be processed by a software algorithm to realize the linear and angular motions.

BLOCK DIAGRAM:

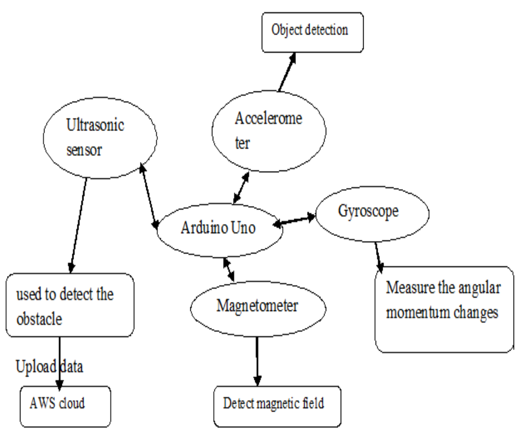

Fig 3.1BLOCK DIAGRAM OF AHRS

(a) **Arduino Uno**
The Arduino UNO is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits.[1] The board has 14 Digital pins, 6 Analog pins, and programmable with the Arduino IDE(Integrated Development Environment) via a type B USB cable

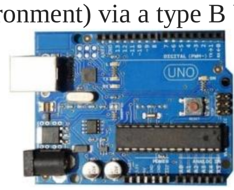

Fig 3.2.Ardunio Uno Microcontroller

(b) **Ultrasonic sensor**
As the name indicates ultrasonic sensor measure distance by using ultrasonic waves. The sensor head emits an ultrasonic wave and receives the wave reflected back from the target. Ultrasonic sensor measures the distance to the target by measuring the time between the emission and reception.

Fig 3.3.Ultrasonic Sensor

(c)Accelerometer
Accelerometers are used to detect and monitor vibration in rotating machinery. Accelerometers are used in tabletcomputers and digital cameras so that images on screens are always displayed upright. Accelerometers are used in drones for flight stabilization.

(d)Gyroscope
A gyroscope is a device used for measuring or maintaining orientation and angularvelocity. It is a spinning wheel or disc in which the axis of rotation (spin axis) is free to assume any orientation by itself. When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation angularmomentum.

(e)Magnetometer
A magnetometer or magnetic sensor is an instrument that measures magnetism either the magnetization of a magnetic material like a ferromagnet, or the direction, strength, or relative change of a magneticfield at a particular location. A compass is a simple type of magnetometer, one that measures the direction of an ambient magnetic field.

FLOW CHART

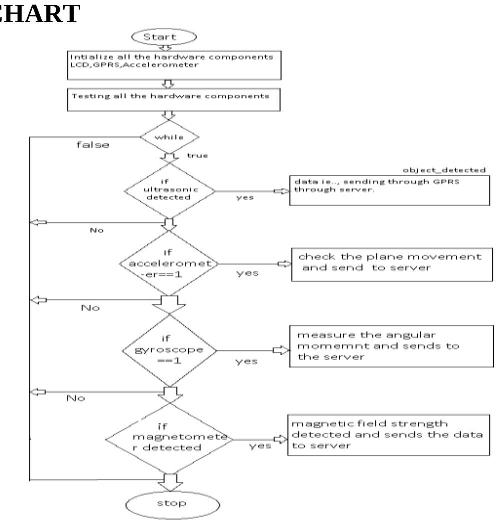

Fig 3.4 FLOW CHART

IV. RESULTS AND DISCUSSION

By making use of optimization approachoptimization task has been described, afterwards the sensor data description used for the experiments is given, and then the results of the simulation
experiments**.** MIMU contains sensor data of a straight trajectory of 1000 steps based on a human step pattern characteristic measured by a motion capture system. For our experiments, we have only used partial data of the data set. The information from the MIMU is the acceleration, turn rates from the gyroscope and the magnetic field. The data sets also include the orientation ground truth values. Simulation of experiments are discussed by using optimization task,
The AHRS are fussed together as a weighted approach.The first part estimates the relative orientation obtained by integrating the gyroscope angular rate reading from an initial orientation

$$q_g(k)^- = q_g(k-1)^+ \otimes \delta q(k) \qquad (1)$$

where, $qg(k)-$ is the quaternion orientation given by direct gyroscopic integration at sample time *k*, and $qg(k-1)+$ represents a previous initial or fused estimation. The term $\delta q(k)$ is the micro rotation given at the *kth* sample interval measured by the 3-axis gyroscope's angular rate *w* in radians per second. The term δq is computed as:

$$\delta q = [\cos(\frac{|w|dt}{2}), \sin(\frac{|w|dt}{2})\frac{w(1)}{|w|}, ..., \sin(\frac{|w|dt}{2})\frac{w(3)}{|w|}] \quad (2)$$

where $|w|$ is the norm of the gyroscope readings, and $w(1)$, $w(2)$ and $w(3)$ are the three angular rates measured at time *k*.

The next part estimates the absolute orientation from accelerometer and the magnetometer ($qa/m(k)$).The gravity vector can be identified by magnitude and orientation, which is used to derive absolute pitch and roll of MIMU.
Both components ($qg(k))-$ and $qa/m(k)$) provide independent but complementary orientation estimates and thus are fused together ($qg(k)+$) in order to benefit from each source of information as shown in Equation 3.

$$q_g(k)^+ = \gamma q_g(k)^- + (1-\gamma)q_{a/m}(k) \qquad (3)$$

The above equation 3 explains the fusion of gyro based estimation along with accelerometer and magnetometer drifts.

Here the γ value provides the weighting between the gyroscope and the accelerometer/magnetometer portions

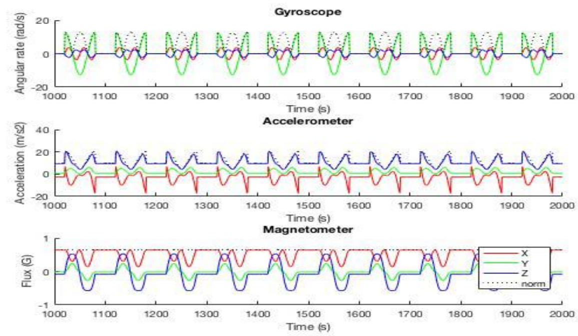

Fig 4.1 The sensor data of Gyroscope, Accelerometer and Magnetometer

V. CONCLUSION AND FUTURE SCOPE

The AHRS contains the fusion of 2 components as weighted approach, the first component is used for estimation of orientation by gyroscope and the next component provides the orientation from the accelerometer and the magnetometer. The aim was to use this motion data to estimate the Euler angles in order to find the orientation. In order to find the optimal weight optimization task is used. The results show the RMSE (root means squared error) of the Euler angles and the best value obtained was an RMSE of 2.7646 whereas the worst RMSE was 10. 0547.Thus reduction of error caused due to MEMS are overcome by making use of optimization method.

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