Comparison of Attitude Determination Methodologies for Implementation with 9DOF, Low Cost Inertial Measurement Unit for Autonomous Aerial Vehicles

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ABSTRACT

The performances of three attitude determination algorithms are compared in this paper. The three methods are the Complementary Filter, a Quaternion-based Kalman Filter and a Quaternion-based Gradient Descent Algorithm. An analysis of their performance based on an experimental investigation was undertaken. This paper shows that the Complementary Filter requires the least computational power; Quaternion-based Kalman Filter has the best noise filtering ability; and the Quaternion-based Gradient Descent Algorithm produced estimates with the highest accuracy. As many attitude determination methodologies make use of the quaternion rotation representation, the attitude quaternion to Euler angle singularity property has been investigated. Experiments conducted show that when Y-rotation approach the singularity position (±90°), the X-rotation drifts away from the reference input. This paper proposes the use of an imaginary set of sensor measurements to replace the original sensor measurements as the Y-rotation approaches the singularity. The proposed methodology for overcoming the conversion singularity has been experimentally verified.

Keywords: *Attitude Determination, Autonomous Aerial Vehicles, Inertial Measurement Unit, Low Cost, Micro Electrical Mechanical System*

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INTRODUCTION

An aircraft's attitude is defined as the angular orientation of the aircraft's fixed coordinate frame with respect to the Earth fixed coordinate frame (Cook, 2007). The attitude information is important for the system parameter identification, control, and path planning for Autonomous Aerial Vehicles (AAVs) (Mohammadi, Shahri & Boroujeni, 2012). The system parameter identification relies on accurate attitude information, as the dynamic model of the AAV is developed through analysis of the aircraft's flight history. The AAVs attitude is a vital component of the flight history. The feedback control of an AAV also relies on the acquisition of accurate attitude information. This is due to the linearization of the non-linear aircraft dynamics using information of the current state of the AAV (Soloviev, 2010; Tsach, Penn, & Levy, 2002; Sidebottom, Dutta, Choi, & Shirinzadeh, 2011). Therefore, inaccuracies in attitude information severely limit the performance of a feedback controller. The attitude of an AAV must also be considered for path planning applications. This is a result of the dynamic characteristics of an aircraft, in particularly its inability to rapidly alter its heading, imposing constraints on future path generation (Soloviev, 2010).

The attitude and position of an AAV can be determined by either ground-based, or AAV-based, hardware. Laser tracking has been successfully implemented to determine the position and pose of a body in motion (Shirinzadeh, 1998; Shirinzadeh & Teoh, 2001). Information obtained in this manner can be differentiated to determine the velocity and angular rates of the body (Wang & Shirinzadeh, 2012; Zhang, Wang, & Cai, 2009). However, ground-based attitude and position determination methods impose an unavoidable constraint: the range of the AAV is limited to the line of sight. To overcome this limitation, gyroscopes have been incorporated on-board AAVs. Gyroscopes can be used to determine the angular rates of an AAV. High-grade gyroscopes, such as those used for commercial and military applications, are sufficiently accurate to allow orientation of the aircraft to be found by integrating the angular rates. However, low cost Micro Electrical Mechanical System-based (MEMS-based) gyroscopes suffer from significant drift error, bias error and noise, when compared to ring laser gyroscopes (Brown, 2005; Abdel-Hamid, 2007; Syed, 2008; Aghili & Salerno, 2013). The drifting error is due to the gyroscope's bias changing with time, resulting in decreasingly accurate attitude estimation. To compensate for these errors, accelerometers and magnetometers are implemented in addition to gyroscopes (Alandry, 2011). This combined unit is referred to as an Inertial Measurement Unit (IMU). The accelerometers are used to measure the gravitational effect along each axis of the AAV, and magnetometers are used to measure the Earths magnetic field across each axis of the AAV. Mathematical formulation can then be developed to form an estimate of the attitude of the aircraft from the information from these sensors. Thus, information obtained from the IMU can provide multiple attitude estimates. The combination of attitude estimates, resulting in a single attitude estimate with an increased accuracy, is known as sensor fusion. The algorithm and sensor array used to determine the attitude of the AAV is commonly referred to as an Attitude Heading Reference System (AHRS).

Much research has been undertaken to estimate the attitude of AAVs using on-board IMUs (Wang, Guo, & Cui, 2009). The primary aim of this paper is to compare three attitude determination algorithms in terms of their accuracy and computational burden. The first attitude determination method presented is the algorithm most commonly implemented. It is the known as the *Complimentary Filter Algorithm* (Mahony, Hamel, & Pfimlin, 2008; Euston, 2008). The algorithm has gained popularity with the rise of the small scale AAV due to its low computational burden, making it suitable for use with low power micro processing units. Another commonly implemented algorithm is known as the *Madgwick Algorithm* (Madgwick, Harrison, & Vaidyanathan, 2011), which utilises a gradient descent method to perform attitude estimation. This method involves a higher computational burden, initially hindering its rate of adoption.

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