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Random misalignment and lever arm vector online estimation in shipborne aircraft transfer alignment ☆

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ABSTRACT

Shipborne aircrafts normally do not have regular position on the carrier. This would lead to large misalignment between the master strapdown inertial navigation system (M-SINS) and slave strapdown inertial navigation system (S-SINS) as well as random lever arm vector. It is critical for the accuracy of the transfer alignment. The large attitude error will make the linear alignment algorithm invalid. And the lever arm vector caused by the location difference will lead to the lever arm effect which is sensed by the accelerometers in the S-SINS. Therefore it is necessary for the shipborne aircraft to estimate the lever arm vector and misalignment before the transfer alignment takes place. In this paper, a new misalignment and lever arm vector online estimation method based on gyroscope, accelerometer measurement and filtering is presented. Sensor measurements of M-SINS and S-SINS will be recorded for a few seconds. Misalignment and the lever arm vector will be calculated from these measurements directly. The values will be filtered according to the chosen threshold of the error gain. Then a second stage estimation based on least square estimation will be applied to acquire a better result. Simulation results demonstrate the effectiveness of the estimation algorithm in the situation when both large misalignment and random lever arm vector exist.

1. Introduction

Shipborne aircrafts are playing an important role in modern combat. The SINS of the aircraft ensures the initialization accuracy of the airborne weapon navigation systems. The initialization of the aircraft SINS is critical for tactical mission. There are two fundamental types of alignment process: self-alignment, using gyrocompassing techniques, and the transfer alignment (TA) [1]. Self-alignment takes normally longer time to achieve an acceptable accuracy. The sea state and motion of the carrier will affect the alignment performance significantly.

Transfer alignment is the process of aligning the slave system with respect to a master reference. Some current shipborne aircrafts perform transfer alignment on the launch position of the catapult, because the aircraft has known position and attitude there. But this will delay the takeoff. Accuracy and speed are both critical for the aircrafts SINS alignment. High accuracy strapdown inertial navigation systems based on mature ring laser gyroscope (RLG) and electrostatic suspended gyroscope (ESG) are installed on board naval vessels nowadays. The systems combined with multi-antenna GNSS receiver and celestial navigation system could offer precise attitude, velocity and position. However, both GNSS and celestial navigation system are not always available. But once the M-SINS is corrected, it could keep the accuracy for a relative long period until next correction. This offers an opportunity to

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estimate the misalignment and random lever arm vector of the aircrafts.

Methods have been developed to offer rapid and accurate alignment [2,3]. Misalignment and lever arm vector estimation are the critical issues for the alignment accuracy [4–7]. The major static part of the misalignment and lever arm vector for shipborne weapon, such as missiles, and torpedoes will be generally fixed after assembling and calibration. And the ship and weapon manufacturing and assembly tolerances will bring extra errors. The dynamic parts mainly come from long-term events such as thermal flexure as well as short-term events like sea state and vibration [8]. For the applications, such as shipborne aircraft (Fig. 1), UAV (unmanned aerial vehicle), and AUV (autonomous underwater vehicle), there is normally no regular position on the carrier. This will probably lead to the large misalignment of the S-SINS and the random lever arm vector.

Different methods are applied to acquire the misalignment and lever arm vector:

(1) Calculation from the carrier schematic and direct optical measurement

Weapon systems, such as missiles and torpedoes, normally have fixed positions when the design of the carrier is released. The nominal relative position and attitude could be calculated from the schematic of the carrier. If there is a light transmission path between the M-SINS and the S-SINS, optical equipments like laser range finder and the total station could be used to acquire very accurate measurements [9,10].

But for the shipborne aircraft, the position and attitude are random, and could not be calculated in advance. And there is normally no free light transmission path between the M-SINS and S-SINS.

(2) GPS assisted lever arm estimation [11]

A carrier-phase measurement based GPS receiver has a high position and velocity accuracy. It is normally difficult for the GPS receiver to measure the location of the M-SINS because of the carbine shield of the radio signal. But if combined with the M-SINS strapdown calculation, lever arm velocity could be estimated with the Kalman filter transfer alignment algorithm. The implementation of this method is restricted by in-cabin applications when GPS signal is shielded by the metal structure. Besides, the GPS receiver is highly electro-magnetic environment dependent.

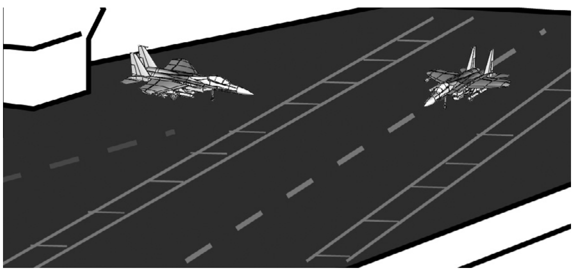

Fig. 1. Random position and attitude of shipborne aircraft.

(2) Non-linear Kalman filter estimation [12–16]

The attitude error and lever arm error vector could be added to the state vector of the Kalman filter. During filter iterations, the velocity and attitude error observation will update the estimation. If the misalignment is large or the lever arm vector is random, non-linear Kalman filter should be applied.

These methods are normally designed to estimate the lever arm vector residual, which means the nominal value of the lever arm vector must be known. And the calculation time will be significantly increased compared with the linear transfer alignment algorithm. The misalignment and lever arm vector are crossed over the whole state vector before the filter converges.

Thus, it is necessary to develop a method adaptive to both random location and attitude of the S-SINS. And the method could be quickly and easily implemented to existing systems.

A new misalignment and lever arm vector online estimation method based on sensor measurements direct calculation and data filtering is presented in this paper. A second stage lever arm vector estimation based on least square algorithm is also applied to achieve a better accuracy. It offers a possibility for the aircrafts to minimize the misalignment and lever arm effect independently of the GNSS not only in the fixed position and attitude. It could also reduce the takeoff preparation time. The effectiveness of the method is demonstrated by simulation results.

2. Misalignment estimation using linear algebraic equations solving

The gyroscope output curves of the M-SINS and S-SINS should be consistent if the bounding between the M-SINS

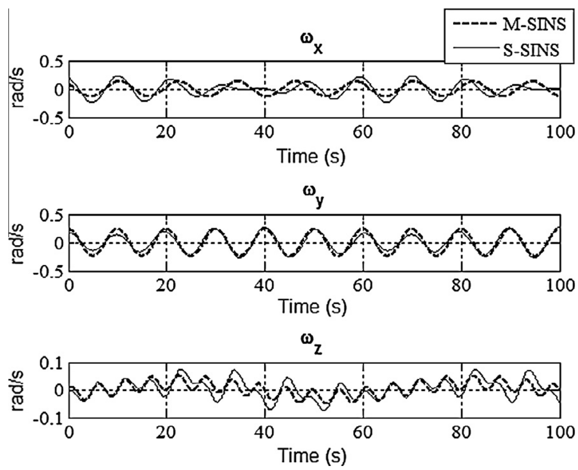

Fig. 2. Simulated M-SINS and S-SINS gyroscope output difference caused by misalignment. Simulated according to motion condition 1 (listed in Table 1), local vibration condition 1 (listed in Table 7) and preset values listed in Table 8 in Section 4.