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Research and calculate flight navigation parameters using data from the angular speed sensor and long acceleration sensor

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Abstract
Today, along with the development of science and technology, inertial navigation systems are applied with precision sensors and high-speed specialized digital computers. With the advantages of compactness and ease of integration and installation on aircraft, this type of navigation system is effectively applied to small and medium-sized unmanned aerial vehicles. When combined with other systems of the same function, such as satellite navigation systems, radio altimeter systems, barometric altimeter systems, etc., this system allows for the provision of angle and position information with high precision. In this paper, the Inertial Labs INS-P Professional Single Antenna GPS-Aided Inertial Navigation System was selected by the authors to improve the aircraft navigation system.

Keywords: Navigation system, unmanned aerial vehicles, angular speed sensor, long acceleration sensor

1. Introduction
The basic content of the improvement is to partially replace the old-style flight parameter indicator on the aircraft with a multi-function indicator display with a digital computer, combining the INS-P system and some new sensors. The purpose of the improvement is to increase reliability, increase information redundancy, and solve a number of other problems in ensure materials, exploit and use aircraft. To serve the improved mission, the INS-P system will provide information about the angle and position of the aircraft in space. The system also provides information about the angular velocity and long acceleration values of the aircraft.
From the above characteristics, it is important to use information sources such as angular speed and long acceleration received from INS-P to study and calculate navigation parameters. To accomplish the above content, it is necessary to study in detail the principles of building an inertial navigation system in order to deeply understand the algorithm for calculating navigation parameters as a basis for building, selecting, and performing the algorithm.

Fig 1: INS-P system

2. Research and selection of algorithms for calculating the aircraft flight navigation parameters

Research on the principle of building an inertial navigation system can be divided into two parts: The first part is to calculate the orientation parameters of rotation; the focus is on calculating the orientation matrix. The second part is the calculation of the translational motion parameter in space.

On the basis of studying the parameter calculation algorithms of the inertial navigation system, each algorithm has advantages and limitations related to the number of calculations, the number of equations, and the errors in the algorithm. Therefore, it is necessary to study some characteristics when building an inertial navigation system with the use of different algorithms in order to clarify the nature of each algorithm and thereby select the appropriate algorithm [1-3]. In this paper, the author focuses on detailed research on algorithms for inertial navigation systems using Rodriga-Hamilton parameters with quaternion vectors to clarify some problems in setting input and correction for quaternion vectors [4, 5].

Set the values $\lambda_0, \lambda_1, \lambda_2, \lambda_3$ as Rodriga-Hamilton parameters of quaternion Λ with the characteristic of continuous transformation of the geographic coordinate system $OX_gY_gZ_g$ to the linked coordinate system OXYZ.

Set the values $\lambda_{0n}, \lambda_{1n}, \lambda_{2n}, \lambda_{3n}$ as Rodriga-Hamilton parameters of quaternion M with the characteristic of continuous transformation of the inertial coordinate system $OX_uY_uZ_u$ to the linked coordinate system OXYZ.

Set the values $\mu_0, \mu_1, \mu_2, \mu_3$ as Rodriga-Hamilton parameters of quaternion K with the characteristic of continuous transformation of the inertial coordinate system $OX_uY_uZ_u$ to the linked coordinate system $OX_gY_gZ_g$.

To determine the parameters during flight, the digital computer will solve the following systems of differential equations:

$$\begin{cases} \dot{\lambda}_{on} = \dfrac{1}{2}(-\lambda_{1n}\omega_x - \lambda_{2n}\omega_y - \lambda_{3k}\omega_z) \\ \dot{\lambda}_{1n} = \dfrac{1}{2}(\lambda_{0n}\omega_x - \lambda_{3n}\omega_y + \lambda_{2n}\omega_z) \\ \dot{\lambda}_{2n} = \dfrac{1}{2}(\lambda_{3n}\omega_x + \lambda_{0n}\omega_y - \lambda_{1n}\omega_z) \\ \dot{\lambda}_{3n} = \dfrac{1}{2}(-\lambda_{2n}\omega_x + \lambda_{1n}\omega_y + \lambda_{0n}\omega_z) \end{cases} \tag{1}$$

$$\begin{cases} \dot{\mu}_0 = \dfrac{1}{2}(-\mu_1\omega_{xg} - \mu_2\omega_{yg} - \mu_3\omega_{zg}) \\ \dot{\mu}_1 = \dfrac{1}{2}(-\mu_0\omega_{xg} - \mu_3\omega_{yg} + \mu_2\omega_{zg}) \\ \dot{\mu}_2 = \dfrac{1}{2}(\mu_3\omega_{xg} + \mu_0\omega_{yg} - \mu_1\omega_{zg}) \\ \dot{\mu}_3 = \dfrac{1}{2}(-\mu_2\omega_{xg} + \mu_1\omega_{yg} + \mu_0\omega_{zg}) \end{cases} \tag{2}$$

In which ω_x, ω_y and ω_z are continuously updated from the corresponding sensors according to the axes of the linked coordinate system ω_{xg}, ω_{yg} and ω_{zg} are the apparent angular Velocities on the geographic coordinate system calculated according to the algorithm's cycle.

An important feature is that the numerical program that solves the system of differential equations (1) needs to include the initial data. For this algorithm, the first thing is to calculate the initial values to include in the calculation. The solution is to use the initial orientation angles $\vartheta_0, \gamma_0, \psi_0$ and then the values $\lambda_{0n0}, \lambda_{1n0}, \lambda_{2n0}, \lambda_{3n0}$ are calculated according to (3).

$$\begin{aligned} \lambda_{0n0} &= \cos\frac{\psi_0}{2}\cos\frac{\vartheta_0}{2}\cos\frac{\gamma_0}{2} - \sin\frac{\psi_0}{2}\sin\frac{\vartheta_0}{2}\sin\frac{\gamma_0}{2}; \\ \lambda_{1n0} &= \cos\frac{\psi_0}{2}\cos\frac{\vartheta_0}{2}\sin\frac{\gamma_0}{2} + \sin\frac{\psi_0}{2}\sin\frac{\vartheta_0}{2}\cos\frac{\gamma_0}{2}; \\ \lambda_{2n0} &= \sin\frac{\psi_0}{2}\cos\frac{\vartheta_0}{2}\cos\frac{\gamma_0}{2} + \cos\frac{\psi_0}{2}\sin\frac{\vartheta_0}{2}\cos\frac{\gamma_0}{2}; \\ \lambda_{3n0} &= \cos\frac{\psi_0}{2}\sin\frac{\vartheta_0}{2}\cos\frac{\gamma_0}{2} - \sin\frac{\psi_0}{2}\cos\frac{\vartheta_0}{2}\sin\frac{\gamma_0}{2}. \end{aligned} \tag{3}$$

When using this algorithm with the Rodriga-Hamiltonian parametric method, the quaternion components Λ will be calculated, which is typical for the transformation from the linked coordinate system to the geographic coordinate system. From there, it is possible to calculate the components of the absolute angular velocity vector and the absolute acceleration of the geographic coordinate system ω_g, a_g. Thus, N_g is the displacement of the absolute acceleration component from the coordinate system associated with the geographic coordinate system (N is the matrix of calculated values of the absolute acceleration when projecting onto the OXYZ axis system). Then calculate the accelerations n_{xg}, n_{yg}, n_{zg} on the geographic coordinate system, and the relationship between Λ, Ng and N is shown as follows [5]:

$$N_g = \Lambda . N . \bar{\Lambda} \tag{4}$$

Synthesizing the research process for the orientation algorithm and the algorithm to calculate the translational motion parameters, the author builds a complete algorithm to calculate the flight navigation parameters using the Rodriga-Hamilton parameter. The structure diagram is as shown in Figure 2.

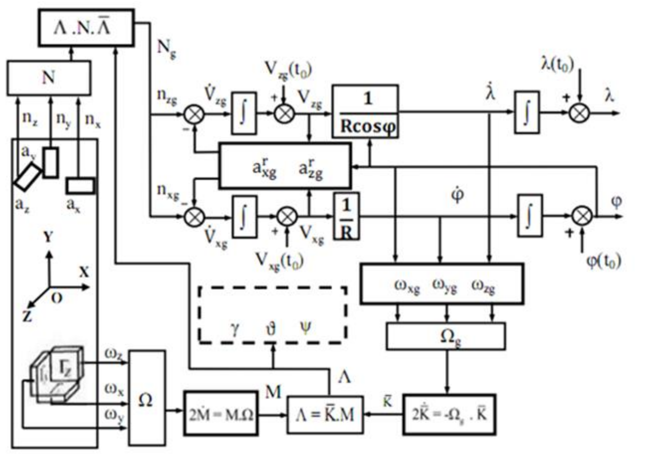


Fig 2: Structure diagram of the algorithm using Rodriga-Hamilton parameters

3. Implement a flight-navigation parameters calculation algorithm

This navigation system's algorithm for calculating flight-navigation parameters includes a complex calculation process with systems of differential equations, and the information is interleaved. The most difficult tasks of implementing the algorithm are the analysis, the selection of calculation methods to solve the system of differential equations, and the calculation of the orientation parameters. The calculation methods applied to calculate the parameters for this inertial navigation system are diverse and complex. For example, the Runge-Kutta method, Picard approximation method, critical rotation method, Taylor method, and average speed method. Each of the above methods, when applied to each type of equation for each parameter, has different characteristics with different levels of complexity and depends on many factors, such as sensor sampling time, the calculation cycle of the calculator, the number of equations to solve, and the accuracy level.

The author chooses the method of average speed [5, 6], to perform the algorithm to calculate the flight-navigation parameters. The author uses the algorithm shown in Figure 3 to calculate the parameters of the inertial navigation system. The average speed method is used to solve the system of differential equations (1), (2). From there, calculate the orientation parameters: direction angle, angle of inclination, and angle of attack.

Next, using the orientation matrix allows for the calculation of the acceleration values n_{xg}, n_{yg}, n_{zg} and the velocity values V_{xg}, V_{yg}, V_{zg}, longitude λ and latitude φ, ω_{xg}, ω_{yg}, ω_{zg}. The algorithm is executed sequentially, and the values calculated at time k are the input data for the next calculation (k+1). The calculation step is $h = t_{k+1} - t_k$.

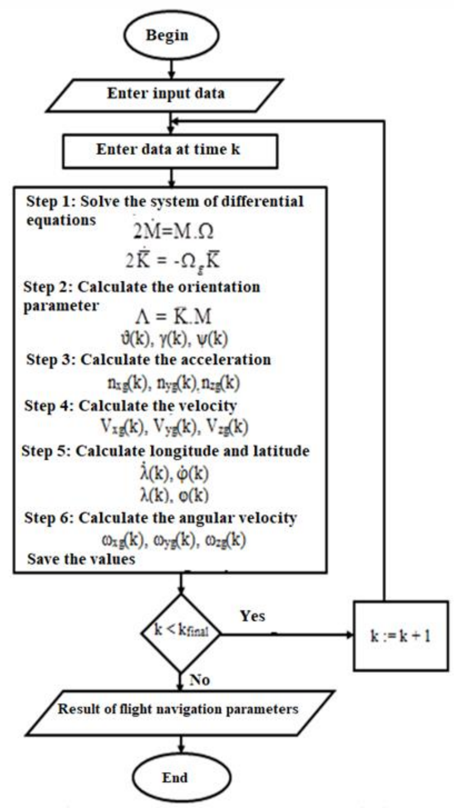


Fig 3: Flowchart of the algorithm for calculating the flight-navigation parameter using the Rodriga-Hamilton parameter

Thus, the implementation of the algorithm for calculating flight-navigation parameters is fully demonstrated through six steps according to the complete algorithm structure diagram in Figure 3. Each calculation step is performed very specifically and in detail with corresponding input values, allowing programming to be performed in discrete form.

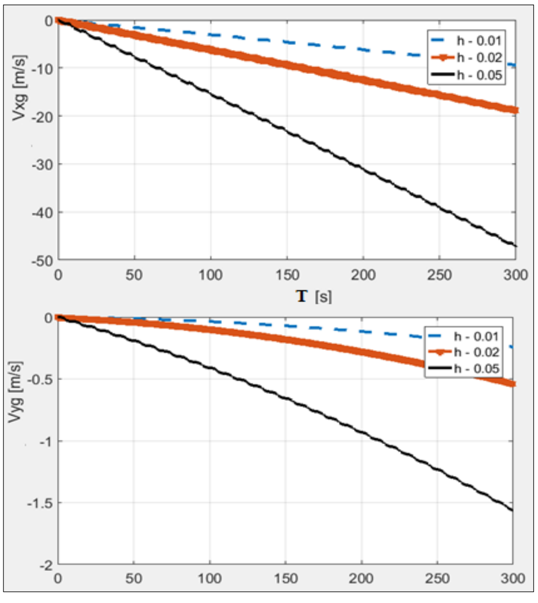
4. Evaluation of the calculation results of flight navigation parameters

To build an algorithm for calculating the complete flight navigation parameters that can be applied in practice, which requires computational steps, algorithm testing must be performed many times for many different cases. However, this is very difficult because the models and paired electronic devices, such as sensors, computer processing speed, etc., will produce many errors and many error types, leading to complexity in evaluating the results of algorithm implementation.

Therefore, the content of the article will simulate and evaluate the solution to implement the algorithm to calculate the flight navigation parameters, using the method of calculating the average speed by Matlab-Simulink software.

Run simulations and survey the system while it is in a state of local rotation. The program creates fake signals of angular velocity ω_x, ω_y, ω_z and angular acceleration a_x, a_y, a_z with initial conditions, allowing the algorithm to work in accordance with the algorithm diagram in Figure 3. The results of the algorithm implementation will provide the values of the orientation angles: angle of attack, angle of direction, and angle of inclination. These values are compared with the actual values of the pseudo-generator to obtain the angular errors. In addition, due to the survey in the local rotation condition, the calculated values of V_{xg}, V_{yg}, and V_{zg} are the velocity errors. Similarly, we have the errors of longitude and latitude, which are also easily determined when subtracting the original longitude and latitude values.

To evaluate the accuracy of the algorithm, we consider the working process of the system in time T = 300s with sampling periods $h_1 = 0.01(s)$, $h_2 = 0.02(s)$, and $h_3 = 0.05(s)$; longitude value $\varphi(t_0) = \pi/4$; latitude value $\lambda(t_0) = \pi$; input parameter values: $V_{xg0} = 0$, $V_{yg0} = 0$, $V_{zg0} = 0$, U = 7.292.10-5 (rad/s), g = 9.8(m2/s), and R = 6371110(m). Specific results are as shown in Figure 4, Figure 5, and Figure 6:



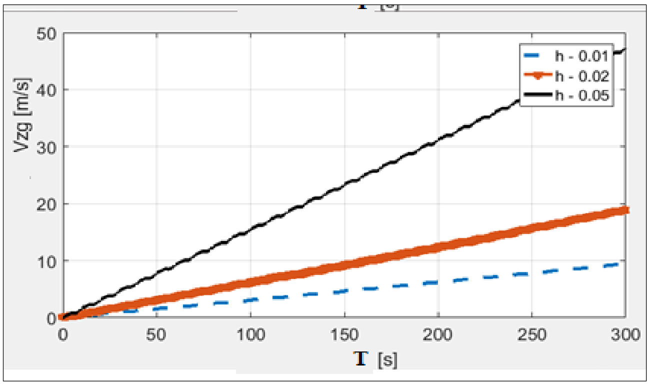


Fig 4: The velocity errors V_{xg}, V_{yg}, V_{zg} when performing the algorithm with h1=0.01, h2=0.02, h3=0.05

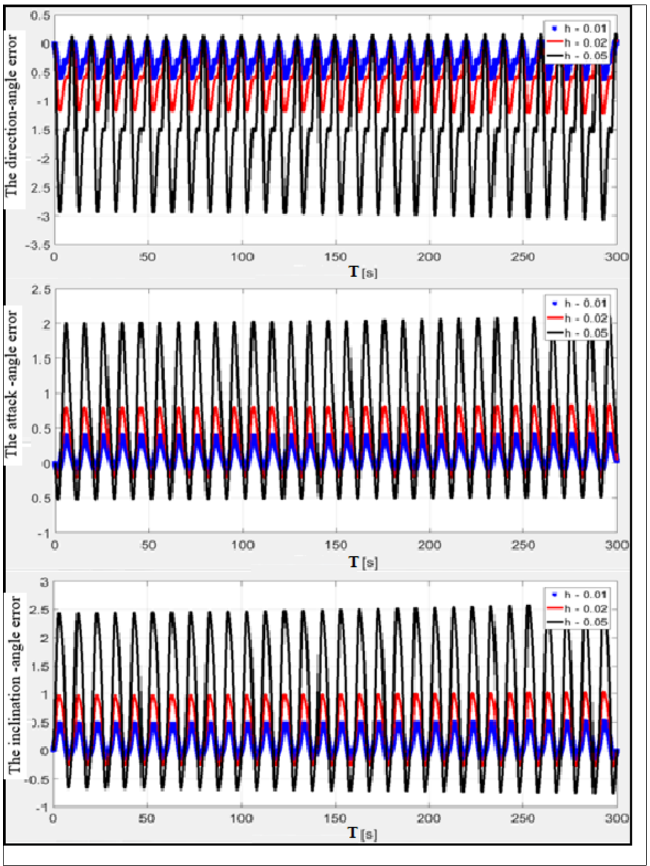


Fig 5: Error of orientation angles for algorithm implementation with h1=0.01, h2=0.02, h3=0.05

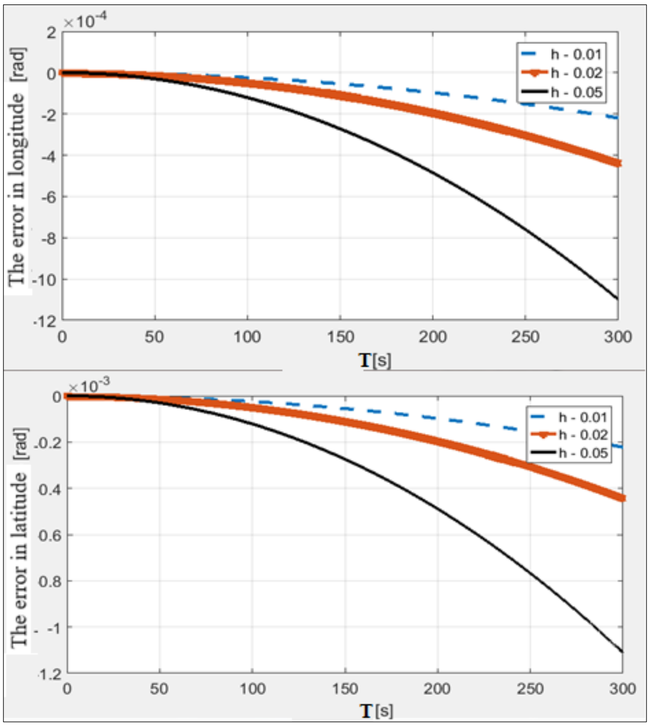


Fig 6: The latitude and longitude errors when performing the algorithm with h1=0.01, h2=0.02, h3=0.05

Figures 4 and 5 show that for each h value, the error of the velocity orientation angles V_{xg}, V_{yg}, and V_{zg} all increase with time; the error value is the smallest when h=0.01, the error value is the largest when h = 0.05. Thus, the error of orientation angles and the error of velocity depend on h. The smaller h is, the smaller the error of the orientation angles when performing the algorithm; in other words, the more accurate the calculated value of the orientation angle.

In Figure 6, it can be seen that for each h value, the error of latitude and longitude increases over time, and the error value is the smallest when h=0.01, the error value is the largest when h = 0.05. This result confirms that the latitude and longitude error depends on h; the smaller the h, the smaller the error of longitude and latitude when performing the algorithm.

5. Conclusion

With the content as presented, the author asserts that the implementation of the algorithm to calculate the flight navigation parameters is feasible. In this paper, the author has

Studied in detail the algorithm of the inertial navigation system using Rodriga-Hamilton parameters with quaternion vectors and proposed to use programming code on microprocessors or computers using a high-level language. This is an important foundation for conducting surveys, which can be expanded to include a variety of parameters or calculation methods. From there, choose the best solution for the system, ensuring high accuracy. The author also combines other devices to form a combination for calculating flight navigation parameters, which can be applied to many different types of aircraft.

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