Evaluation of The Use of Inertial Navigation Systems to Improve The Accuracy of Object Navigation

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Summary

The article discusses the dead reckoning of the traveled path based on the analysis of the video data stream coming from the optoelectronic surveillance devices; the use of relief data makes it possible to partially compensate for the shortcomings of the first method. Using the overlap of the photo-video data stream, the terrain is restored. Comparison with a digital terrain model allows the location of the aircraft to be determined; the use of digital images of the terrain also allows you to determine the coordinates of the location and orientation by comparing the current view information. This method provides high accuracy in determining the absolute coordinates even in the absence of relief. It also allows you to find the absolute position of the camera, even when its approximate coordinates are not known at all.

Key words:
reference image, geometric invariants, selective images, decision function.

1. Introduction

Currently existing autonomous navigation systems for aircraft are inertial navigation systems. They have a progressive error and high cost with high accuracy. These problems are solved by using additional satellite navigation systems. This increases the accuracy of navigation systems, but leads to the loss of their autonomy and noise immunity. That is, methods that lead to an improvement in navigation accuracy simultaneously lead to a loss of autonomy and noise immunity by the system. This contradiction is resolved by the introduction of video navigation. In this case, an image of the terrain is obtained by a camera, which is then analyzed by the on-board computer and, based on this analysis, the coordinates and orientation of the aircraft are found. To create a video navigation system, it is planned to develop three modules for video navigation, which are subdivided according to the completeness of using additional information about the terrain (except for the current video shooting), obtained in advance and stored in memory [1-4].

1) A module that works on current images without involving additional information. In the first frame of the video stream, it finds characteristic points and then tracks their movement in the frame. By the nature of the movement, the program determines how the position and orientation of the camera itself changes. The program finds hundreds and thousands of characteristic points in each frame, which ensures high navigation accuracy.

2) The module for precise location on the relief according to the stereo effect that occurs when the camera moves, the relief is restored, it is compared with the data stored in the memory, in the case of "recognition" the exact coordinates and orientation are determined.

3) Module for precise positioning based on reference photos, video frames are compared with stored images of route sections, in case of "recognition" exact coordinates and orientation are determined [5-8].

2. Theoretical Consideration

Manuscript received March 5, 2021
Manuscript revised March 20, 2021
https://doi.org/10.22937/IJCSNS.2021.21.3.10

Currently, the basis of navigation systems for unmanned aerial vehicles are receivers of global satellite navigation systems, compensated with a block of inertial sensors of spatial orientation. Such a system provides a fairly accurate determination of the location of unmanned aerial vehicles and the parameters of its movement (up to 15 m) in the presence of an uncomplicated reception of signals from global satellite navigation systems. When integrated with satellite navigation, it is possible to use low-current, inexpensive inertial systems equipped with micromechanical motion sensors (accelerometers and gyroscopes). The cost of such a system is from 5 to 15 thousand US dollars, depending on the accuracy of the sensors. It should be noted that the inertial system of such a price range is not able to carry out autonomous dead reckoning of the distance traveled due to the high drift speeds of the gyroscopic sensors. The best samples are able to maintain accuracy for several minutes (no more than 10) of no signal at the level of 100-150 m. In this case, as a rule, it is required to maintain a straight-line motion mode without acceleration.

The use of high-precision inertial navigation systems also does not completely solve the problem for the following reasons:

1) such systems are expensive (from 30-50 thousand dollars);

2) the mass of the inertial system of "medium accuracy" on laser or fiber-optic gyroscopes is from 8 kg, which makes it problematic to use them on unmanned aerial vehicles of short and even medium range;

3) the fundamental limitation is the growth of the error in determining the coordinates over time of autonomous operation. The accuracy of the autonomous reckoning of coordinates for modern ones is about 1 nautical mile per hour of flight (for high-precision systems), which does not allow for high-precision determination of target coordinates.

Thus, we have a typical contradiction described by TRIZ: methods that lead to an improvement in navigation accuracy simultaneously lead to a loss of autonomy and noise immunity by the system. This contradiction is resolved by introducing video navigation [2-4, 16].

Manufacturers of unmanned systems in the United States and Israel are conducting research and development aimed at ensuring the autonomy of the use of unmanned aerial vehicles in the absence of satellite navigation signals based on alternative data sources. Such data include: first of all, species information coming from on-board photo and video cameras of daytime and infrared ranges, synthesized radar image, digital terrain data, satellite images, as well as so-called "signals of natural origin":
the vector of gravity, the magnetic field of the Earth, the position of the stars. The development and miniaturization of computer systems, systems for collecting and processing species information made it possible to implement such a system as part of the navigation and control hardware of an unmanned aerial vehicle[9-11].
In particular, the Rockwell-Collins company, which produces navigation and flight control equipment for unmanned aerial vehicles of various types, announced the completion of the development of the Vision Augmented Inertial Navigation System (VAINS), which provides correction of the inertial system in terms of speed and coordinates from a video camera in the absence of signals.
At present, the mathematical foundations for determining the location of the aircraft by species information have been developed, computer modeling has been carried out and the requirements for the hardware of the integrated navigation system for unmanned medium and short-range aircraft have been substantiated.

The principle is based on 3 basic methods [1-3,12-15]:

1) Dead reckoning based on the analysis of the video data stream coming from optoelectronic surveillance devices. Dozens of characteristic points are automatically found in each frame. Analysis of their movement from frame to frame gives information about the movement of the object. A large number of such points guarantees the accuracy of the determination displacement, course and orientation angles. The main limitation of the method is the possibility of only relative determination of coordinates and orientation, which can lead to an increase in the navigation error over time. Its other disadvantage is incompleteness - all distances are found accurate to an arbitrary constant. There may also be reasons leading to the inability to find the corresponding pairs of points in the images: insufficient illumination, inability to use in case of cloudiness, inability to use over a smooth surface without characteristic special points (flat, uniformly illuminated water surface "without ripples" and waves; homogeneous and even sandy desert without vegetation).

2) The use of relief data allows to partially compensate for the shortcomings of the first method. Using the overlap of the photo-video data stream, the terrain is restored. Comparison with a digital terrain model allows the location of the aircraft to be determined. Unlike Method 1, when using a scanning laser altimeter, it is possible to determine the location in the absence of daylight, however, similarly to Method 1, the approach under consideration does not work over a water or sandy surface and gives a

significant error in the absence of a pronounced relief. The main advantage over the previous method is the ability to find not only the relative, but also the absolute position of the camera, since knowledge of the map binds the camera to specific points on the terrain with known absolute coordinates. This leads to the navigation error not increasing over time. The main disadvantage of the method is its sensitivity to too large errors in the initial coordinates of the camera obtained from inertial navigation devices, which the method must then refine [12].

3) The use of digital images of the terrain also allows you to determine the coordinates of the location and orientation by comparing the current view information. This method provides high accuracy in determining the absolute coordinates, even in the absence of relief. It also allows you to find the absolute position of the camera, even when its approximate coordinates are not known at all. This is achieved by scanning the entire database of terrain images and comparing them with the current image. In addition, having a "tethered" image, it is possible to determine with high accuracy the coordinates of ground objects detected by optoelectronic equipment. It is important to note that the development of the mathematical foundations of all these methods has already been carried out, and their feasibility has been mathematically substantiated and proven. This is evidenced by the links of the world scientific press. Preliminary estimates and computer modeling show that the use of methods for determining the coordinates of an object using species information and digital geodata allows determining the location coordinates with an error of no more than 30 m, regardless of time.
Inertial system of unmanned aerial vehicles.

The key point in this chain is “measuring the state of the system”. That is, coordinates of location, speed, altitude, vertical speed, orientation angles, and angular velocities and accelerations. In the on-board navigation and control complex, developed and manufactured by TeKnol LLC, the function of measuring the state of the system is performed by a small-sized inertial integrated system. Having in its composition a triad of inertial sensors (micromechanical gyroscopes and accelerometers), as well as a barometric altimeter and a three-axis magnetometer, and combining the data of these sensors with the data of a GPS receiver, the system develops a complete navigation solution for coordinates and orientation angles. The small-sized inertial integrated system developed by TeKnola is a complete inertial system that implements the algorithm of a strapdown satellite navigation system integrated with the receiver. It is in this system that the "secret" of the operation of the entire control complex for unmanned aerial vehicles is contained. In fact, three navigation systems operate simultaneously in one computer using the same data. We call them "platforms". Each of the platforms implements its own principles of control, having its own "correct" frequencies (low or high). The master filter selects the optimal solution from any of the three platforms, depending on the nature of the movement. This ensures the stability of the system not only in rectilinear movement, but also during bends, uncoordinated turns, and gusty side winds. The system never loses the horizon, which ensures the correct reactions of the autopilot to external disturbances and an adequate distribution of impacts between the controls of unmanned aerial vehicles.

Figure 1. Block of inertial navigation system

Micro-BINS (FREE INERTIAL NAVIGATION SYSTEM)

New SINS of Russian design and production, intended primarily for use in military aviation, which should be able to operate even in the event of loss or suppression of GLONASS / GPS signals[8].
The ultralight module, smaller than a credit card, can be used in a wide range of products, from navigation systems of strategic bombers to aircraft missile guidance systems and miniature unmanned aerial vehicles. The micro-unit, with a volume of only 30 cubic centimeters, has best-in-class silicon-based micromechanical sensors and is a miniature inertial positioning device, or GIMU-OEM for short.

The microblock, only 14mm thick and weighing 60 grams, contains everything you need for autonomous navigation: gyroscopes, accelerometers and a high-performance core with a math coprocessor to perform accurate navigation calculations in real time with a record speed of calculating navigation parameters of 1-2 ms. This allows you to build the trajectory of the controlled object from a known point and establish a location with high accuracy. The new microblock of a full-fledged inertial navigation system is designed to solve the problem of GLONASS / GPS vulnerability at a low cost. The new

GIMU was originally designed for high G-forces and is suitable for use in high-precision weapons, including promising small bombs, missiles and kamikaze UAVs. Inertial Navigation Systems (GIMU-OEM) can also be used in advanced heavy weapons such as the BRAMOS supersonic cruise missiles with a range of more than 300 km. The INS accuracy at such a distance is lower than that of GLONASS / GPS, but modern technologies of visual target recognition can solve this problem. Of course, the new micro-SINS does not replace GLONASS / GPS, but is an addition to the existing satellite navigation system. However, GIMU-OEM can have a big impact on some aspects of military affairs. First of all, navigation will improve in difficult urban conditions, where numerous obstacles interfere with the satellite signal[4-6].

Figure 2. Strapdown inertial navigation system

The new micro-SINS, unlike the best foreign samples, is not just a sensor or a meter of primary parameters - all the necessary software for working with GLONASS, GPS, COMPAS, Galileo, and all kinds of additional sensors is already integrated in the unit. GIMU-OEM provides a minimum time for calculating a complete navigation solution of 1-2 ms, it interfaces with modern control systems using high-speed digital exchange, and can also be successfully used to modernize existing missiles and ammunition using analog control channels, for which 4 -e software-controlled high-speed analog channels. Currently, 3 types of micro-SINS are already prepared for serial delivery. Two types of products - for use in military equipment and a specialized inexpensive type of product for embedding directly into devices for satellite GLONASS / GPS monitoring of vehicles and into equipment stabilization systems.

3. Conclusions

Thus, the article considers the presence of signals from global satellite navigation systems, which are currently a necessary condition for unmanned aerial vehicles to perform their tasks. The absence or intentional suppression leads to the impossibility of accurately determining its own coordinates and, as a consequence, to fly along a given route. If an ultra-low-precision inertial system is used on unmanned aerial vehicles (especially on unmanned short-range aerial vehicles), the absence of corrective signals from global satellite navigation systems can lead to the "collapse" of the inertial system and the accident of unmanned aerial vehicles. Therefore, the suppression of global satellite navigation systems is considered as the main method of dealing with unmanned aerial vehicles.

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