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VISUAL NAVIGATION SYSTEM SIMULATION

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Abstract*—The paper deals with the software structure of the unmanned aerial vehicle flight simulator stand. Algorithmic support of each module is presented. Approaches to quality control of the visual navigation system are considered. The focus is on the methodology for assessing the quality of visual navigation systems, and their configuration. The article defines sets of global and local parameters of the imitation stand. The module for digitizing a terrestrial map is also considered in detail. A method for estimating errors in the operation of a visual navigation system is proposed. Using this software architecture allows creating a unmanned aerial vehicle flight simulator for checking and adjusting visual navigation systems, as well as developing a new, more advanced system.*

Index Terms—Visual navigation system; local features; global parameters; camera gimbal; gyro stabilization; autopilot; primary frame; secondary frame; microcontroller.

I. INTRODUCTION AND PROBLEM STATEMENT

The problem of high-precision navigation of aircrafts without the use of any radio signals has recently become highly relevant due to the active use of unmanned aerial vehicles (UAVs) in areas where electronic warfare facilities work and there is a probability of loss of Global Positioning System (GPS) signal, which can lead to a UAV accident.

The visual navigation system (VNS) is an important navigation module of the UAV. This system works with visual landmarks on the Earth's surface using information obtained from the camera.

The visual navigation system in case of GPS signal suppression can act as a corrector of the inertial navigation system, using only visual landmarks. Despite its shortcomings, namely: the inability to work in the case of unfavorable weather conditions (fog, precipitation), the lack of pronounced landmarks (water surface, desert), visual navigation is a promising way to solve the navigation problem. However, at the present time there are no mass-produced VNS, which is due not so much to the lack of technical means, but primarily to the difficulty of debugging and developing the mathematical software that is implemented on the on-board calculator. There are two approaches used to debug the visual navigation system.

– debugging on a real UAV with transferring controlled parameters to a radio channel to a ground station;

– debugging on an imitation stand allowing to simulate the flight of UAVs with VNS on board in real conditions; landscape, time of year, time of day, climatic conditions.

In the first case, large financial and time costs are required to develop and configure a visual navigation system. This approach is good for testing the work of an already configured system, but it requires a large number of flights, preparation time and satisfactory weather conditions.

In the second case, an imitation stand is used for system debugging, which ensures real flight conditions taking into account the time of the year, time of day and climatic conditions.

Consider methods for assessing the quality of the visual navigation system.

II. EVALUATION QUALITY OF VISUAL NAVIGATION SYSTEM

The main criteria that determine the quality of the work of the visual navigation system are the accuracy of determining the coordinates of the UAV with the help of VNS and also the time spent by the calculator to determine the current coordinates of the UAV.

The structural scheme of the simulation stand is shown in Fig. 1, and the block diagram of the software is shown in Fig. 2.

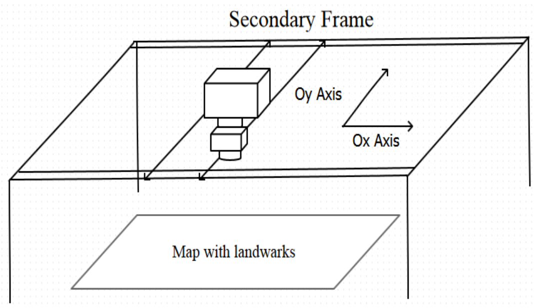

Fig. 1. Structural diagram of the stand

Consider the program modules of which the stand is designed to develop and configure visual navigation systems.

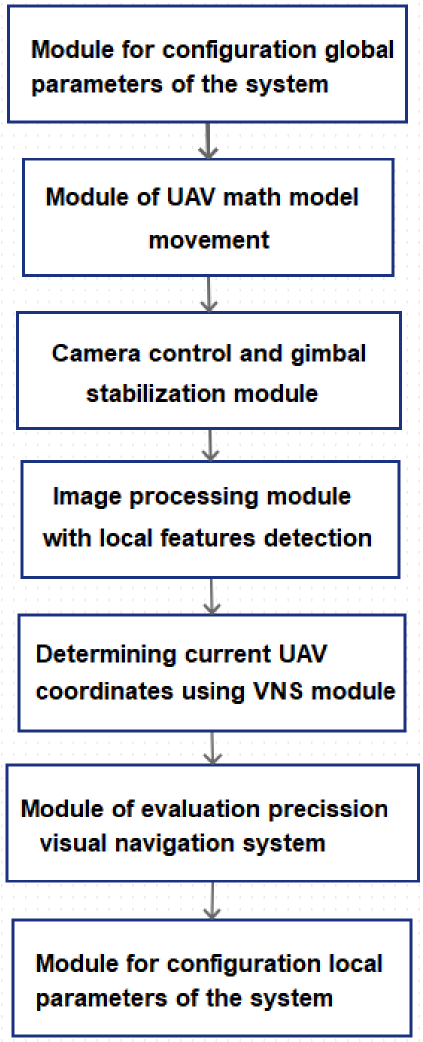

Fig. 2. Block diagram of main software structure of the visual navigation system simulation

III. SOFTWARE MODULES OF VISUAL NAVIGATION SYSTEM

A. Module for configuration global parameters of the system

The module contains a description of the functions of the stepping motors realizing the grid in the horizon plane.

On this grid are constructed function templates of basic geometric shapes.

Combining geometric shapes describes the typical trajectories of the UAV for stepper motors.

Was added a new flight mode called "Simulator". In the new flight mode, slopes of the servo motors (roll, pitch, course) of the controlled gyro suspension are added when moving around the corners of the already described templates of the step-by-step motors of the Camera Gimbal Control module. This software is configured by global parameters, which determine the degree of flight simulation of the UAV. Such parameters are: flight speed (displacement of stepper motors).

B. Module of UAV math model movement

This module realizes the movement of the primary and secondary frames in the horizontal plane (O_x, O_y) by controlling the step motors.

This frame is the main bearing structure whose base consists of beams, as well as four grooves along which the secondary frame body moves in wheels in the planes O_x and O_y. The drive circuit generating the two axial movement consists of 4x servo motors pairwise connected to the two axes. This allows a 2-fold increase in the torque and, correspondingly, the payload of the imitation stand. Control is carried out using four drivers DRV8834 and the central microcontroller STM32f103C8.

Linear traversal of the primary frame over the relief map is carried out at the choice of one of the templates of geometric figures pre-loaded into the microcontroller: a passage through a square, a triangle, a rectangle and more complex ones. Thus, the maximum similarity to the actual loadable flight plan of the auto mission in the UAV autopilot is achieved. It is also possible to consider a real flight plan Fig. 3 and convert its trajectory into a movement of the stand.

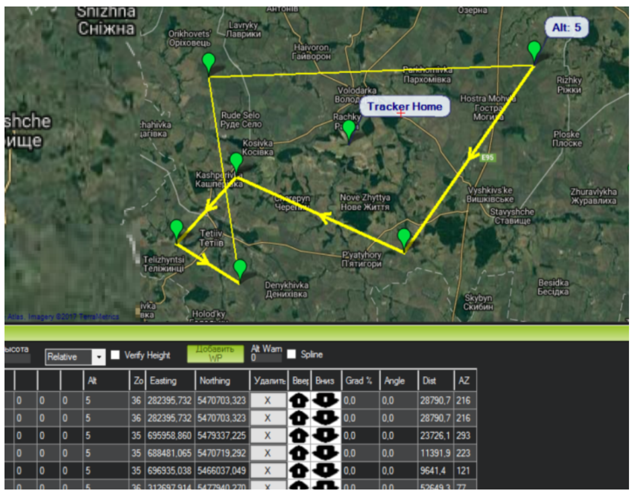

Fig. 3. Template auto mission

C. Camera control and gimbal stabilization module

The module contains previously described camera motion patterns, the tuning of the speed settings of the suspension is set in the open program Mission Planner.

Activation and selection of templates occurs by the inclusion of a new flight mode of the autopilot "Imitation".

Since real UAVs do not roll and pitch more than 45 deg during the flight, providing around 80 deg of payload inclination is more than enough.

This module works in tandem with the auto trajectory generation module, for stabilization and control of the camera this module uses the Pixhawk basic flight controller (PWM pins) simulating maneuvers on bends.

D. Image processing module with local features detection

This module is the main source of navigational data on visual landmarks. The basic stages of the search for UAV detection and finding are similar to SIFT/SURF/ RANSAC algorithms.

The algorithm of the module is presented below.

1) Generate a digital image model in the form of a pixel matrix.

2) Construction of the Gaussians pyramid and Difference of Gaussian DOGs for finding singular points.

3) Testing the suitability of the extremum point for the role of a key.

4) Finding the orientation of the singular point.

5) Construction of a descriptor for a singular point.

A set of singular points of the current image with coordinates (X_i (t_k), Y_i (t_k)) is given; and (X_i ($t_k - 1$), Y_i ($t_k - 1$)), $i = 1 \ldots n$; $k = 1 \ldots N$ of the previous image.

It is necessary to determine the correspondence between the same singular points of one descriptor on different images.

E. Determining current UAV coordinates using VNS module

This module takes the center of the first picture at the takeoff point as the starting point of the origin. After that, the found landmarks in the image will be associated with this point and its GPS coordinates. Extrapolating the received coordinates from the pictures, and reading from the memory of the autopilot the recorded coordinates of the points of the flight plan auto mission, we obtain the coordinates of the target point and the current one. Using the formula haversine, consider the distance to the target point through the arc of a large circle by approximating the Earth with a sphere in meters.

F. Module of evaluation precision visual navigation system

We have two sets of output data. First set is etalon movement of simulation stage in horizontal plane which is expressed in steps done by step motors and converted to meters on relief map. Second set is travelled distance given by algorithms of visual navigation system with wide range of preestablished local parameters of the algorithms. Comparison these two sets give us distance error between real movement of UAV and evaluated by visual navigation system in lat/lon frame.

It is necessary to re configure parameters of visual navigation system until results of two sets will be the same.

G. Module for configuration local parameters of the system

Local system parameters are as follows:

1. The number of required singular points (nFeatures).
2. The number of octave layers (nOctavesLayers = 3 by default).
3. Brightness threshold (contrastThreshold = 0.04 by default).
4. EdgeThreshold = 10 by default.
5. Sigma = 1.6 by default.
6. The descriptor normalization factor = 0.2 by default.
7. Threshold value of Hessian.
8. The magnitude of the height scale (sigma).
9. Size and type of the filter kernel.
10. The value of the threshold for the arrival of singular points (sigma).

It is the adjustment of these parameters that requires a large amount of time and determines the quality of the visual navigation system.

III. Conclusion

The necessity of creating a laboratory simulation simulator of UAV flight is argued. The stand will make it possible to repeatedly repeat the flight experiments of those areas in which errors in the operation of the visual navigation system occur and eliminate them. A detailed implementation of an imitation stand with electronic and hardware parts is proposed. The tolerances and criteria for the scale of the earth map for studying the visual navigation system are considered. Since a fish-eye camera is chosen for maximum image capture, a calibration algorithm with elimination of radial distortion is proposed.

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В. М. Синєглазов, В. С. Іщенко. Імітація роботи системи візуальної навігації
Представлено структуру програмного забезпечення імітаційного стенду польоту безпілотного літального апарату. Представлено алгоритмічне забезпечення кожного модуля. Розглянуті підходи перевірки якості роботи системи візуальної навігації. Основна увага приділяється методології оцінки якості роботи систем візуальної навігації, і їх налаштуванню. Визначено набори глобальних і локальних параметрів імітаційного стенду. Так само детально розглянуто модуль оцифровування наземної карти. Запропоновано методику оцінювання помилок роботи системи візуальної навігації. Використання даної програмної архітектури дозволяє створити стенд симуляції польоту безпілотного літального апарату для перевірки і підстроювання систем візуальної навігації, а також розробити нову, більш досконалу систему.
Ключові слова: візуальна навігаційна система; локальні особливості; особливі точки; ортофотоплан; безпілотний літальний апарат; візуальна навігаційна система; серводвигуни; комп'ютерний зір; первинний кадр; вторинна рама; мікроконтролер.

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В. М. Синеглазов, В. С. Ищенко. Имитация работы системы визуальной навигации
Представлена структура программного обеспечения имитационного стенда полета беспилотного летательного аппарата. Представлено алгоритмическое обеспечение каждого модуля. Рассмотрены подходы проверки качества работы системы визуальной навигации. Основное внимание уделяется методологии оценки качества работы систем визуальной навигации, и их настройки. Определены наборы глобальных и локальных параметров имитационного стенда. Так же детально рассмотрен модуль оцифровки наземной карты. Предложена методика оценки ошибок работы системы визуальной навигации. Использование данной программной архитектуры позволяет создать стенд симуляции полета беспилотного летательного аппарата для проверки и подстройки систем визуальной навигации, а также разработать новую, более совершенную систему.
Ключевые слова: визуальная навигационная система; локальные особенности, особые точки, ортофотоплан, беспилотный летательный аппарат; визуальная навигационная система; серводвигатели; компьютерное зрение; первичный кадр; вторичная рама; микроконтроллер.

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