COMPUTER-AIDED DESIGN SYSTEMS

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DEVELOPMENT OF A LABORATORY STAND FOR SIMULATION OF UAV FLIGHT AND TRAINING OF A VISUAL NAVIGATION SYSTEM BASED ON A CONVOLUTIONAL NEURAL NETWORK

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Abstract—Simulated flight stand of Unmanned aerial vehicle for visual navigation system. The structure of the imitation stand is determined, and the principle of operation. The basic algorithms of work of the stand are given.

Index terms—Unmanned aerial vehicle; visual navigation system, servo motors, step motors computer vision, primary frame, secondary frame, driver, microcontroller.

I. INTRODUCTION

The visual navigation system is an important navigation module of the UAV. To determine the efficiency of its operation, to exclude design errors and to select the optimal computational algorithms, it is necessary to conduct numerous laboratory tests that are not dependent on weather conditions and long preparations for flights. The aim of the work is the development of an imitation test flight of UAVs for conducting tests of the visual navigation system. The paper presents the main design solutions for the hardware and electronic parts of the stand.

II. PROBLEM STATEMENT

To simulate the flight of a UAV, it is necessary to create three axial changes in the position of the camera along the roll, pitch and heading, and also have the possibility of two coordinate linear movements along the X and Y axes, along the relief map. The general concept of the stand is presented below in the form of a structural diagram. The stand consists of the following parts.

1) Primary frame is an autopilot unit which includes an inertial system for estimating the position of the visual navigation system in space, driven by servo motors and a wide-angle camera.

2) Secondary frame – fixation for the primary frame and a system of linear two axial movement of the stand consisting of four stepper motors, four drivers controlled by the microcontroller and changes in the angular position of the camera with servo motors.

3) A relief map of the earth's surface above which imitation of flight and training of a neural network is carried out by movement over it of primary and secondary frames.

General requirements for the stand are: the use of non-magnetic and public materials, ease of manufacture.

III. DEVELOPMENT OF AN IMITATION STAND OF THE VISUAL NAVIGATION SYSTEM

The primary frame should create three axial changes in the angular position of the camera, with a sufficient viewing angle of the ground relief. Among the possible variants of the design of (Imitation Stand for Visual Navigation System) ISVNS, coaxial primary square frames were chosen as gyroscopes, driven by servo-mounted motors, on the basis of which the autopilot and the camera were placed. And also a secondary platform to which the primary platform is mounted and driven by four stepping motors for linear movement of the stand in two planes. This design is easier to manufacture in comparison with gyro stabilization platforms and has more degrees of freedom of movement in space. The last element is the underlying surface in the form of a relief map.

IV. STRUCTURAL SCHEME OF THE PRIMARY FRAMEWORK OF THE IMITATION STAND

This scheme assumes the availability of three servo motors, which provide three axial positioning of the platform in three planes (Fig. 1). To determine the angular position of the platform with the camera, an inertial navigation system is necessary, which includes: a 3-axis gyroscope, a 3-axis accelerometer and a 3-axis compass. As an IMU, [2] a real autopilot with this module in its composition was selected, as well as typical UAV control commands for maximum realistic simulation.
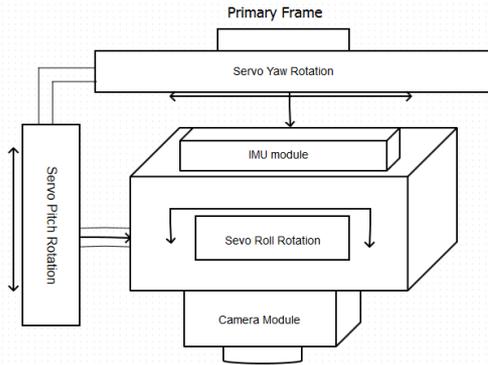
Fig. 1. Primary frame of the imitation stand

The interface of the camera data exchange of the visual navigation system of the simulation stand with an external stationary PC is USB. And from the on-board microcomputer or laboratory PC to the autopilot, data transmission is carried out through the usual serial interface USART / SPI, for feedback and adjustment of the position of the UAV in space. To simplify the design of the frame and get rid of rotating contacts, a radio module is installed on the primary frame next to the autopilot. In this case, the data is transmitted via a conventional radio channel.

The angular position of the camera module is controlled via this automatic communication channel of the autopilot, whose outputs are connected to the servo motors and a template script for changing pilot flying angles is launched.

V. STRUCTURAL SCHEME OF THE SECONDARY FRAMEWORK OF THE IMITATION STAND

This frame is the main bearing structure whose base consists of beams, as well as four grooves along which the frame of the secondary frame moves in wheels in the planes *Ox* and *Oy*. The drive circuit generating the two axial movement consists of 4 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 (Fig. 2).
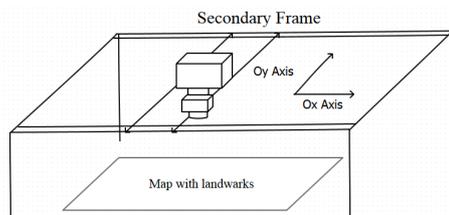

Fig. 2. Secondary frame of the imitation stand

Control is carried out using four drivers DRV8834 and the central microcontroller STM32f103C8.

The electrical wiring diagram has the form (Fig. 3).

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.
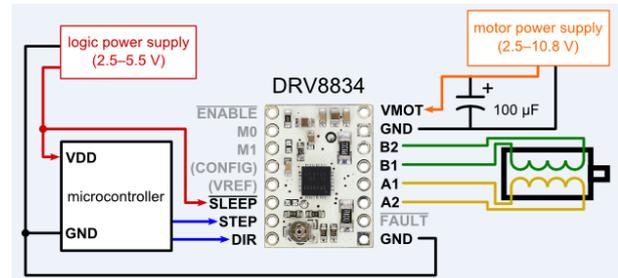

Fig. 3. The electrical wiring diagram

As a result of the connection of the primary and secondary frames, we obtain an imitation stand of five degrees of freedom, which have the form (Fig. 4).
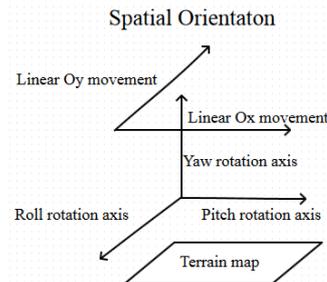

Fig. 4. Spatial movement of the stand

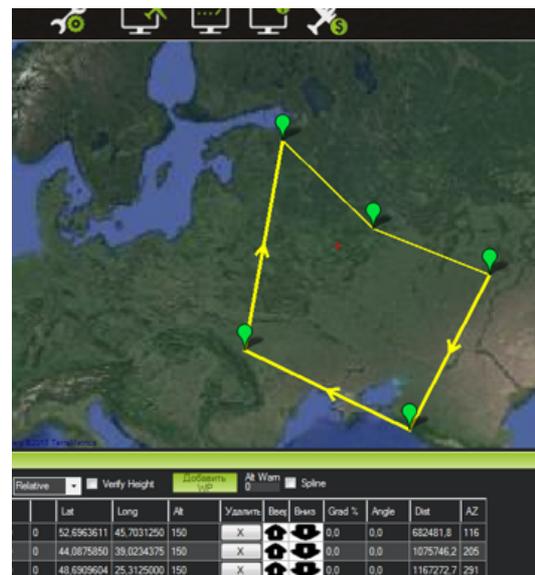An example of the construction of a real UAV flight plan is shown in Fig. 5.

Fig. 5. Example of constructing a flight plan

In addition to the passage of [1], [2] the map with all possible geometric trajectories, simulated by a secondary frame, the primary frame simulates the angles of roll, pitch and heading. These angles can be unloaded from the memory of the autopilot of the real UAV after the completion of the auto mission, and loaded into the autopilot installed on the simulation stand. After that, all real maneuvers will be repeated or you can create and upload your flight plan.

VI. Calculation of the Scale of the Earth Surface Card for the Imitation Stand

For space digital images, the notion of "ground-based distance" (GSD) is used. This concept should also be used for on-board digital cameras. Variants for shooting cameras with different matrix sizes are shown in Fig. 6.
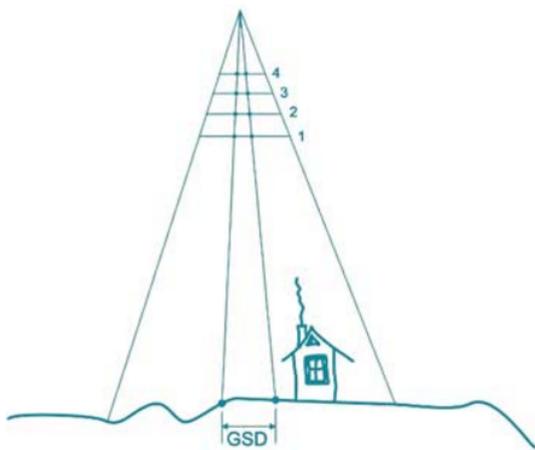

Fig. 6. An example of shooting cameras with different sizes of matrices and GSD

The figure shows that the scale of the shooting, for all cameras is different. If the focal length in pixels is not specified in the digital camera's passport, it is easy to calculate by dividing the focal length in millimeters by the physical pixel size of the camera matrix. When working in the digital still camera with the images obtained by it, it is quite natural to measure all the values in pixels. The physical size of the pixel of the matrix determines its photosensitivity. The larger the size of the cell, the more photons get to the matrix (when using one lens), which allows you to shoot at slower shutter speeds or in poorer lighting conditions.

The value of GSD, which ultimately determines the accuracy of the results of further processing, is calculated by the equation:

$$GSD = H/F$$

where is the height H measured in centimeters, and the focal length F in pixels.

The value of GSD determines the order of accuracy of the results in the plan, the real accuracy can be slightly better when using marked points and automatic measurement procedures and worse if there are systematic errors, poor calibration of the camera. To obtain the accuracy of the results for height, you should divide the value of GSD by B/H, this is the ratio of the survey base to its height. Since 60% overlap is required to equalize the block of images, B/H is easy to calculate.

In the case of the use of automatic measurements (correlator), the accuracy of the measurement in height will be determined by the equation:

$$dZ = c \, (GSD/(B/H)),$$

where c is the "quality" of the image. On the indirect grounds (errors of mutual orientation, accuracy of free triangulation models) for some digital cameras, the value of c can reach up to 0.1.

One of the passport characteristics of digital cameras is the number of frames per second – FPS.

The FPS limits the minimum shooting height (minimum GSD value). The fact is that [4] the aircraft on which the camera is installed can not have a speed less than a certain one. For photogrammetric processing of the aerial survey block, overlapping of adjacent images in the route is required to be not less than 60%. Therefore, the speed of UAV(V), the height H and FPS are related by the equation:

$$V = H \, (FPS \, (0.4 \, (S/F))) = 0.4 \, (\, FPS \, (\, S \, (\, GSD))),$$

where S is the frame size in pixels along the flight axis (usually the smaller side of the frame).

If an IMU system is installed with the GPS receiver on board the aircraft, then after processing the GPS / IMU data, you can get external orientation elements for each picture. With sufficient accuracy of these elements, the equalization can be eliminated from the data processing process on the DSC and the so-called direct geo-positioning can be used. A very rough estimate of the required accuracy of the IMU system is the angular size of the pixel $\Delta\varphi = 1/F$, where F this is the focal length of the camera in pixels. For the digital cameras under consideration, this value is approximately 0.006°. Manufacturers of IMU systems produce devices of different accuracy class. So, from devices Applanix company can not use the most expensive POS AVI series 410–510.

If an additional laser scanner is installed on board the aircraft, which allows receiving a cloud of points in flight, the photogrammetric processing of the images is further simplified, since after the post-processing of the scanner data for the construction of orthophoto planes, a terrain model will already be

available. To use the technology of laser scanning, GPS/IMU-systems of a class not lower (and sometimes even higher) than for digital cameras are required.

Direct geodetic technologies using GPS/IMU-systems and obtaining terrain with the help of laser scanning are increasingly used in the implementation of production projects.

The camera selected for installation on the UAV flight simulator has the following specifications:

- Module Size: 38mm * 38mm 32mm * 32mm.
- Temperature (Operation): -20degree to 70 degree.
- Temperature (Stable Image): 0 degree to 60°degree.
- Camera Board Assembly technique: SMT (ROSH).
- Focus: Manual.
- Object distance: 5CM-100M.
- Resolution: 3264(H) X 2448(V) 8Megapixel.
- Interface: USB 2.0 High Speed.
- Protocol: USB Video Class(UVC).
- Operating system request: Win XP\Win7\Win8\Linux.
- Certifications: FCC and CE.
- Sensor Type: Sony (1/3.2").
- Active Array Size: 3264X2448.
- Minimal illumination : 0.5 Lux.
- 3264X2448 MJPG 15fps YUY2 2fps.
- Dynamic Range: 83.5 dB.
- Focal Length: 3.6 mm.
- FOV: 75 degree.
- IR Filter: 650 ± 10 nm.
- Maximum Image Transfer Rate:
  - 3264X2448 MJPG 15fps YUY2 2fps;
  - 2592X1944 MJPG 15fps YUY2 3fps;
  - 2048X1536 MJPG 20fps YUY2 3fps;
  - 1600X1200 MJPG 20fps YUY2 10fps;
  - 1280X960 MJPG 20fps YUY2 10fps;
  - 1024X768 MJPG 30fps YUY2 10fps;
  - 800X600 MJPG 30fps YUY2 30fps;
  - 640X480 MJPG 30fps YUY2 30fps.

VII. Remedial Distortion of the Camera

The selected camera is wide-angle (FOV:75deg) that allows you to capture the maximum area of the earth's surface. However, this causes radial distortion of the so-called "Fish eye". Consider the methods of software image preprocessing to eliminate this defect.

The camera is calibrated to find out the internal parameters of the camera, namely the camera matrix and distortion coefficients (Fig. 7).

A matrix of a chamber is a matrix of the form:

$$\begin{bmatrix} f_u & 0 & c_u \\ 0 & f_v & f_c \\ 0 & 0 & 1 \end{bmatrix},$$

where (c_u, c_v) is the coordinates of the principal point (the point of intersection of the optical axis with the image plane, in the ideal chamber is exactly in the center of the image, in the real one is slightly offset from the center); f_u, f_v is the focal distance f, measured in the width and height of the pixel.
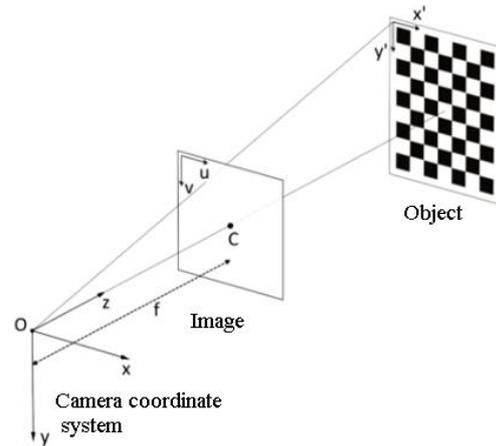

Fig. 7. Projection of the camera on the earth's surface

There is a distortion barrel-shaped and pillow-like (radial, tangential).

In our case, we have a radial distortion - distortion of the image as a result of the non-ideality of the parabolic shape of the lens. Distortions caused by radial distortion are equal to 0 in the optical center of the sensor and increase toward the edges. As a rule, radial distortion makes the greatest contribution to image distortion.

To eliminate the distortion, the pixel coordinates can be recalculated using the following equation:

$$U_{\text{corrected}} = u\left(1 + k1r^2 + k2r^4 + k3r^6\right) \\ + 2p1uv + p2\left(r^2 + 2u^2\right),$$

$$V_{\text{corrected}} = v\left(1 + k1r^2 + k2r^4 + k3r^6\right) \\ + p1\left(r^2 + 2v^2\right) + 2p2uv,$$

where (u, v) is the initial pixel location; $(U_{\text{corrected}}, V_{\text{corrected}})$ is the pixel location after geometric distortion elimination; k_1, k_2, k_3 are coefficients of radial distortion; p_1, p_2 are coefficients of tangential distortion, $r^2 = u^2 + v^2$.

The accuracy of measuring [5] the camera parameters (distortion coefficients, camera matrix) is determined by the average error of the reprojection (*ReEr, Reprojection Error*). *Reprojection Error* the distance (in pixels) between the projection *P′* on the

image plane of the point *P* on the surface of the object, and the projection P'' of the same point *P* constructed after the distortion is eliminated using camera parameters (Fig. 8).
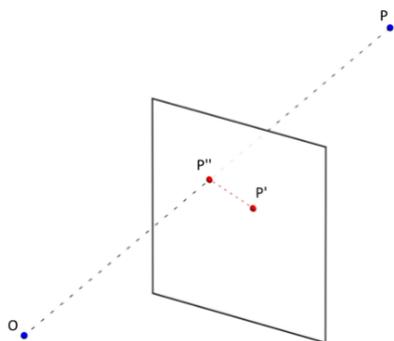

Fig. 8. Elimination of distortion using camera parameters

The standard procedure for calibrating the camera consists of the following steps.

1) Carry out 20–30 photos with different positions of the chess checkerboard object.

2) Determine the key points of the object in the image.

3) Find such distortion coefficients that minimizes *ReEr*.

For the camera of the UAV flight simulator, the average value of *ReEr* was 0.3 pixels.

VIII.   CONCLUSION

The need to create a laboratory flight 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 examined. Since a fish-eye camera is selected for maximum image capture, a calibration algorithm with elimination of radial distortion is proposed.

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В. М. Синєглазов, В. П. Іщенко. Розроблення лабораторного стенду для проведення імітації польоту БПЛА і навчання системи візуальної навігації на основі згортальної нейронної мережі
Розглянуто імітаційний стенд польоту безпілотного літального апарату для системи візуальної навігації. Визначено структуру імітаційного стенду та принцип роботи. Наведено основні алгоритми роботи стенду.
Ключові слова: безпілотний літальний апарат; інтегрований навігаційний комплекс; польотний контролер.

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В. М. Синеглазов, В. П. Ищенко. Разработка лабораторного стенда для проведения имитации полета БПЛА и обучения системы визуальной навигации на основе сверточной нейронной сети

Рассмотрен имитационный стенд полета беспилотного летательного аппарата для системы визуальной навигации. Определена структура имитационного стенда и принцип работы. Приведены основные алгоритмы работы стенда.

Ключевые слова: беспилотный летальный аппарат; интегрированный навигационный комплекс; полетный контроллер.

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