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AUTOMATIC DEFINITION THE FIELD OF VIEW OF CAMERA OF UNMANNED AERIAL VEHICLE

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In the last time more and more people use light unmanned aerial vehicles for solving tasks of research a territory. The main criterion is the task of exact linking received data to the location data. In the article offered the method of determining the coordinates of the field of vision of camera, which was based on the determine communication between the coordinates of corresponding points of area and snapshot. The aim is to develop an algorithm of determining the coordinates of the field of vision of camera and to carry out its testing on data of aerial photography. In the paper used the methods of geometry, projective geometry, computer graphics and digital imaging, military topography, that used to work with a digital camera and a digital snapshot. Designed the method and algorithm based on it for the automated determining the coordinates of the field of vision of camera. It was tested on real data. The results can be used to further development of software for tracking objects with drones, the preparation photomap, cards of heights and for stereo unmanned aerial vehicle orientation in space without using of global navigation systems.

Keywords: aerial photography, elements of the exterior orientation, remote sensing, determination of the coordinates, field of view, unmanned aerial vehicle.

Сьогодні дедалі більше застосовують легкі безпілотні літальні апарати для вирішення завдань дослідження території. Головним критерієм виконання завдання є точна прив'язка отриманих даних до місця знаходження. В статті запропоновано метод визначення координат зони бачення камери, основою для якого стало визначення зв'язку між координатами відповідних точок місцевості і знімку. Метою є розробка алгоритму визначення координат зони бачення камери та його тестування, на даних аерофотозйомки. У статті розглянуто методи стереометрії, проекційної геометрії, комп'ютерної графіки та цифрової обробки зображення, військової топографії, що використовують для роботи із цифровою камерою та цифровим фотознімком. Розроблено метод та алгоритм на його основі для автоматизованого визначення координат зони бачення камери безпілотного літального апарату. Проведено тестування на реальних даних. Отримані результати можуть мати подальше використання при розробленні програмного забезпечення для стеження за об'єктами з безпілотних літальних апаратів, складання фотопланів, карти висот, а також для стереоорієнтування безпілотного літального апарату у просторі без використання глобальних систем навігації.

Ключові слова: елементи зовнішнього орієнтування, дистанційне зондування, аерофотозйомка, визначення координат, область бачення, безпілотний літальний апарат.

Introduction

The technological development improved methods of intelligence, in particular with unmanned aerial vehicle (UAV), this allows you to safely monitor the location and movement of enemy, collect information of them. Human losses reduced when use observations with UAV, but it create new tasks: processing digital images and video in on-line, creating secure channel, creating system of object recognition and watch for them. The result of digital aerial photography is digital terrain picture, and elements of the exterior orientation in the moment when photo was taken: coordinates UAV and (ψ,ϕ,θ) — angles relative to the axes [1].

The UAV operation feature is the need to collecting large amounts of data and them processing in real time. The important is the improvement of data processing and management in ground station and airborne computing systems.

The need for data processing in real time, ensure reliability and multifunctionality, make it difficult to build high-performance processing systems.

Because the known approaches are algorithmically complex, it causes additional calculation time and needs more powerful hardware. It is recommended that digital image processing system was integrated into complex control UAV.

A key component of any system of collection and processing of data must be subsystem of determine the coordinates of objects that was got from the camera UAV. Need is the development of information technology, which allow definition field of camera view in real time and system was integrated into complex control UAV, for solving operational analysis.

Analysis of researches and publications

The research in the field of processing of aerial photographs devoted the works of scientists such as Minko V., Lobanov A., Gordon P., Protsenko M., Glotov A., Sechin A. and Nazarov A. [1–8] and others. However, in most of the articles the authors consider the scope of post processing image using ground control stations, indicating insufficient research into the problems of image processing on board UAVs in real time.

About 20 countries are developing UAV such as the US (RQ-1 Predator, RO-4 Global Hawk, and others), UK (Phoenix), France (532 UL Cougar Mki), Italy (SIVA), Israel (Heron), and other NATO members [3]. The information does not apply in the open access for obvious reasons.

The question of the using digital processing of video and photo data in the equipment UAV dedicated a few domestic publications at present time [5], for example, [7] described methods and algorithms for digital processing in optoelectronic devices; [8] described direction ensure the monitoring of areas promising equipment of UAV.

The topical task is developing algorithms and methods for implementation at Ukrainian UAV production.

Statement of the problem

Let the received data in a form:

$$\left(\text{photo}, X_{UAV}, Y_{UAV}, Z_{UAV}, \psi, \phi, \theta\right),$$

where photo — digital image, $[\![(X]\!]_{UAV}, Y_{UAV}, Z_{UAV})$ — coordinates UAV in system CK-63; (ψ,ϕ,θ) — angles relative to the axes in the moment when photo was taken.

Must to do:

– suggest a method based on the analysis of know methods, if will be need they will improved for definition the field of view of camera;

– develop an algorithm for determining the coordinates of the field of vision of camera and conducting test on data aerial photography.

Presentation of basic material

We introduce a three-dimensional right-coordinate system, it determined the position of the UAV (Fig. 1) the beginning of the coordinate system is at the center of mass of the aircraft [9]:

- an axis *Z*, or a yaw axis — directed from top to bottom, and perpendicular to the other two axes;
- an axis *Y*, or a pitch axis — aims from pilot left to right in piloted aircraft, and parallel wings winged aircraft;
- an axis *X*, or a roll axis — directed from tail to nose in the north direction of flight.

In this coordinate system, the angular position of the aircraft is uniquely defined by three angles: (ψ,θ,γ). Positive direction corners showed in the Fig. 2.

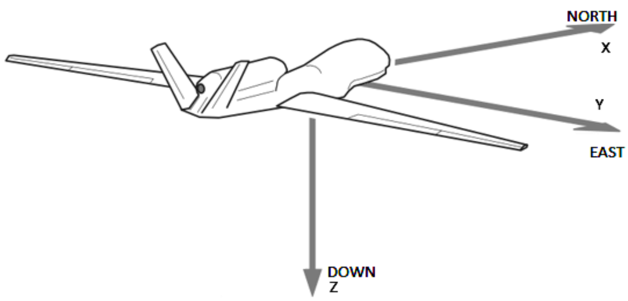

Fig. 1. The coordinate system of UAV

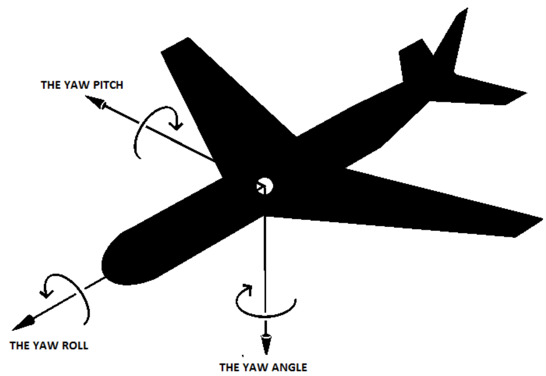

Fig. 2. An angles of turn of a UAV

It is well known that the rotation of three-dimensional point around an arbitrary axis is given matrices[1]:

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\theta) & -\sin(\theta) \\ 0 & \sin(\theta) & \cos(\theta) \end{bmatrix};$$

$$R_y = \begin{bmatrix} \cos(\gamma) & 0 & -\sin(\gamma) \\ 0 & 1 & 0 \\ \sin(\gamma) & 0 & \cos(\gamma) \end{bmatrix};$$

$$R_z = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix}. \quad (1)$$

Since the operation of matrix multiplication on the vector is not commutative, the order of multiplication will affect on the final result. Given the order of matrix multiplication of turn corners of UAV (1), we give the following formula for finding the coordinates of the point after rotation:

$$R = R_y R_x R_z. \quad (2)$$

Let we have arbitrary point P with coordinates (x, y, z). Substituting it into the formula (3), we get the point with coordinates

$$(x', y', z') = (x, y, z)R \quad (3)$$

we get the point P' with coordinates (x', y', z').

We need to know the parameters of the camera and the UAV location to solve the problem of determining the coordinates of corner points of the frame. The input date are:

- the angle of vision of the camera ϕ;
- the focal length of the camera f;
- the matrix size of the camera *hh*, *ww*;
- a coordinate of the UAV in a system SC-63 point ;
- the altitude of the UAV Z_{BLA};
- an external orientation angles (ψ, θ, γ).

Find the coordinates of the corner points of field vision of camera when the orientation angles are zero (Fig. 3):

$$O'B = \Delta x = \frac{Z_{BLA}\, ww}{2f};$$

$$O'A = \Delta y = \frac{Z_{BLA}\, hh}{2f}. \quad (4)$$

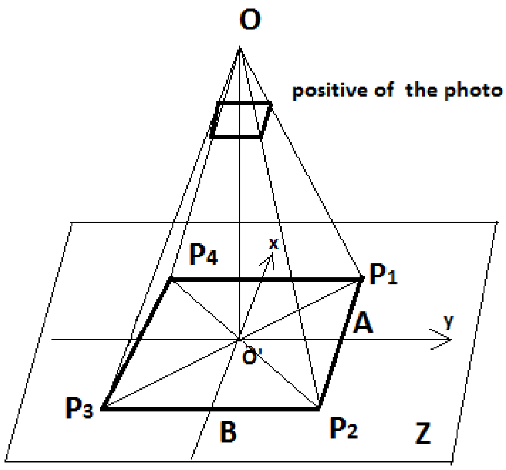

Fig. 3. The field of view of camera when $\psi = \phi = \theta = 0$

We get the point:

$$P_1(\Delta x; \Delta y; Z_{BLA}), P_2(-\Delta x; \Delta y; Z_{BLA});$$

$$P_3(-\Delta x; -\Delta y; Z_{BLA}), P_4(\Delta x; -\Delta y; Z_{BLA}). \quad (5)$$

We add the coordinates of points (5) coordinates of the UAV and we will get geographical coordinates of corner points of field vision camera provided the orientation angles are equal to zero:

$$P_1(\Delta x + X_{BLA}; \Delta y + Y_{BLA}; Z_{BLA});$$

$$P_2(-\Delta x + X_{BLA}; \Delta y + Y_{BLA}; Z_{BLA});$$

$$P_3(-\Delta x + X_{BLA}; -\Delta y + Y_{BLA}; Z_{BLA});$$

$$P_4(\Delta x + X_{BLA}; -\Delta y + Y_{BLA}; Z_{BLA}).$$

The coordinates of boundary points field of vision camera, when angles of inclination of the UAV are not zero, find when we substitute (5) in the right part of (3).We note that after the multiplication by the rotation matrix *P*, according to (3), for points P_1, P_2, P_3, P_4 value for Z coordinates is nor equal to Z_{BLA}, which means that the projection of the frame does not lie on the ground. So to get projection at sea level (which is need to determine of the real coordinates in this study) we should solve the task of crossing straight $0P_1, 0P_2, 0P_3, 0P_4$ with a plane Z. Plane equation is as follows:

$$0 \cdot X + 0 \cdot Y + Z = Z_{BLA}.$$

Lines defined as the following:

$$\frac{x}{-x_{P_i}} = \frac{y}{-y_{P_i}} = \frac{z}{-z_{P_i}}, \; i = 1, 2, 3, 4.$$

Conversion is defined system of equations:

$$\frac{x}{-x_{P_i}} = \frac{e}{-y_{P_i}} = \frac{z}{-z_{P_i}} = t_i, \; i = 1, 2, 3, 4;$$

$$z = t_i, i = 1, 2, 3, 4;$$

$$t_i = -\frac{Z_{BLA}}{-z_{P_i}}; \; i = 1, 2, 3, 4;$$

$$x'_{P_i} = -t_i\, x_{P_i}; \; y'_{P_i} = -t_i\, y_{P_i};$$

$$z'_{P_i} = -t_i\, z_{P_i}; i = 1, 2, 3, 4. \quad (6)$$

When we solving systems (6) get coordinates that define the spatial location of coordinate of field of vision of the camera:

$$P_1(\dot{x}_{P_1}; \dot{y}_{P_1}, \dot{z}_{P_1});$$

$$P_2(\dot{x}_{P_2}; \dot{y}_{P_2}, \dot{z}_{P_2});$$

$$P_3(\dot{x}_{P_3}; \dot{y}_{P_3}, \dot{z}_{P_3});$$

$$P_4(\dot{x}_{P_4}; \dot{y}_{P_4}, \dot{z}_{P_4}). \quad (7)$$

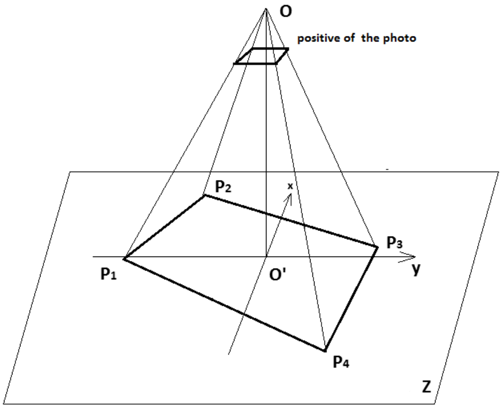

Fig. 4.The field of view of camera when $\psi \neq \phi \neq \theta \neq 0$

Add to (7) coordinates of the UAV and get the geographical coordinates of boundary points of the field of vision of camera arbitrary conditions:

$$P_1'\left(\dot{x}_{P_1} + X_{BLA}; \dot{y}_{P_1} + Y_{BLA}; Z_{BLA}\right);$$

$$P_2'\left(\dot{x}_{P_2} + X_{BLA}; \dot{y}_{P_2} + Y_{BLA}; Z_{BLA}\right);$$

$$P_3'\left(\dot{x}_{P_3} + X_{BLA}; \dot{y}_{P_3} + Y_{BLA}; Z_{BLA}\right);$$

$$P_4'\left(\dot{x}_{P_4} + X_{BLA}; \dot{y}_{P_4} + Y_{BLA}; Z_{BLA}\right).$$

We have next algorithm determining the coordinates of corner points of field of vision the camera:

Step one. Enter the camera settings such as a matrix size and a focal length. If necessary, translate them up to meters.

Step two. Enter your location UAV at the time of image fixing, there are: the geographic coordinates of UAV format SC-63, the orientation angles in degrees, if coordinates does not enter in the system SC-63 transfer them to the SC-63.

Step three. Calculate the rotation matrix *R* by formula (2).

Step four. Calculate the coordinates of the boundary points of field of vision of camera formulas (4) and (5).

Step five. The resulting coordinates of the substituted into the formula (3) to determine the space coordinates of where $\psi \neq \phi \neq \theta \neq 0$.

Step six. The coordinates of points convert by formula (6).

Step seven. Add the coordinates of the boundary points of field of vision of camera and coordinates of the UAV, and result of this is space coordinates of field of vision of camera of the UAV.

System testing

The method has been implemented in test software developed in Object Pascal in an environment Borland Delphi 7.1., for testing and evaluating of error determination of coordinates.

Testing was on data obtained from the UAV in flight over v Motyzhyn, Makarov district, Kiev region. Specifications of the cameras set on the UAV: the camera angle $f = 35$ mm, matrix size of the camera

8176×6132*p*(*hh* = 49 mm; *ww* = 36.75 mm).

Flight data of the UAV there are: the average altitude was 984.1 m, external orientation angles $\psi \neq \phi \neq \theta \neq 0$. Shown an example received digital images from cameras of the UAV in Fig. 5 *a*), and in Fig. 5 *b*) shown the field of vision of a camera on the digital map [10].

a

b

Fig. 5. An example of the information system:
a — digital images from cameras of the UAV; *b* — the field of vision of a camera on the digital map

Conclusions

The paper presents an algorithm for determining the field of vision of the camera, and provides data on testing his.

The results can be used to further development of software for tracking objects with drones, the preparation photomap, cards of heights and for stereo unmanned aerial vehicle orientation in space without using of global navigation systems.

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