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UAV Navigation and Management System Based on the Spectral Portrait of Terrain

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***Abstract*—The paper is devoted to research on unmanned aerial vehicle navigation using spatial-spectral portraits of the terrain. Such navigation is relevant in the event of failure of global positioning system receivers and other navigation equipment, but its implementation requires the solution of a number of methodological issues. In particular, the effect of illumination changes on the spectral characteristics of objects should be taken into account. The borrowing of satellite solutions using optical patterns is inadequate for low-flying unmanned aerial vehicles and it is more promising to use the service data from the meter display of the spectral sensory equipment of the unmanned aerial vehicle. In this research, an existing method for correction of illumination changes based on the value of LightValue for different cameras in laboratory and field conditions is considered. It has been experimentally established that the dependencies between LightValue and the intensities of color constituents in different cameras are individual in nature. For the correction due to changes in natural light, it is suggested to use experimentally obtained dependences for specific brands of the sensory equipment. When organizing navigation systems for spectral portraits of the terrain, it is recommended to use objects with the most stable optical changes in terms of illumination.**

***Keywords*—unmanned aerial vehicle, spectral portraits, correction of illumination**

I. Introduction

The emergence of widespread access to robotized unmanned aerial vehicles (UAVs) creates fundamentally new challenges for the failure of navigation equipment. The cost of sufficiently advanced copters, capable of flying a few kilometers to the destination, is at least 3–4 times smaller than that of manned military vehicles. The above gives the opportunity to organize a terrorist group even an effective cyber attack on the navigation and control system of several UAVs. In addition, available solutions for managing the UAV flight by the operator over the radio channel can be relatively easily blocked by electronic warfare (EW) by organizing electromagnetic interference to the control channel. The use of satellite positioning devices such as global positioning system (GPS) or global navigation satellite system (GNSS) to navigate the UAV is more secure. However, in the event of an attack on small objects, problems with accuracy of positioning may be encountered. In addition, when constructing satellite navigation systems, designers introduced the possibility of introducing errors for civilian ranges. In addition, the means of the EW can distort the signals of the satellite navigation system – GPS spoofing. Since these technologies are widely available, counterfeit strategies are being developed to neutralize them, namely, the search for counteraction strategies in [1] and in [2], fixing the start of the cyber attack in [3] and so on. However, in the case of terrorist acts, it is quite probable that the power and purpose of the EW will lead to a deviation of several dozens or even hundreds of meters, which eliminates the benefits of UAVs before the manned vehicle.

A possible solution to protect against terrorist groups is to use navigation on the basis of spatial-spectral portraits of the terrain when the UAV focuses on preloaded landmark libraries on the terrain. In the case of using a small number of reference points or landmarks, they can be falsified or destroyed, but when using a large number of objects, taking into account only their geometry, and their spectral portrait, their falsification is essentially complicated. For this reason, spatial-spectral navigation is one of the priority areas for the development of UAV control in the event of failure of navigation equipment and the use of EW equipment by terrorist groups.

When using the most widespread and cheap spectral sensors in the optical range, the effect of the illumination state on the spectral indices of the objects should be taken into account. Based on these considerations, the purpose of the research is to develop a methodological approach for correction for illumination to determine the optical range of spectral portraits of objects.

II. Problem Statement

Traditionally, measurements of spectral indicators of objects in conditions of variable illumination can be arranged with the use of artificial illumination. In article [4] describes the successful experience of using the Raptor ACS-225LR Active Spectral Sensor installed on a light-jet airplane that illuminated terrestrial objects with powerful light diodes. Taking into account the significant limitations on power and carrying capacity of non-specialized and most widespread UAVs, the expediency of using additional light sources on them today is of little promise.

For spectral monitoring, the focus on purely sunny illumination has been worked out for satellite platforms

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since the 70's. In article [5] proposed a radio frequency correction method based on the use of reference standards for terrestrial objects with known and stable parameters, such as deep water bodies. In article [6] show the creation of a network of ground stations for measurements, on the basis of which it is possible to calibrate satellite data for spectral monitoring. Similar decisions on the use of optical patterns have been proposed for UAVs. In article [7] demonstrate high accuracy of measurements and reproducibility of results when using 3 artificial patterns. In article [8] 6 colored patterns that were made of tarpaulin were used to improve accuracy. In this case, to ensure sufficient accuracy of measurements from the side of the airplane (hang glider), the dimensions of the patterns were several meters. Despite the sufficient accuracy and reproducibility of the results, the presence of a sufficient number of natural or artificial spectral patterns in real conditions is doubtful.

The possible fixation of the illumination change for the UAV is the use of an additional anti-aircraft sensor, such as the LightSensor for the MicaSenseRedEdge camera, presented in [9] and in [10]. Hardware fixation of illumination will not require terrain patterns, but will increase the cost of UAV. In addition, such an approach will be relevant only in conditions of uniform illumination. However, in the presence of clouds, unacceptably significant errors are possible. An alternative to a specialized sensor is the ability to calibrate the data from the built-in exposure meter of the main touch-sensitive equipment proposed in [11]. The technique for using the standard digital camera exposure meter was developed in [12] for the Canon A460 camera with regard to white balance adjustment options for field surveying. Mathematical equations for light variations were presented in [13], where the calculation of the intensity of the color component was based on the LightValue value for the DJIPhantom 3PHANTOM VISIONFC200 UAV Native Camera. The authors experimentally established the linear nature of the dependence of the intensity of color components on the value of LightValue for a certain range. However, it is unclear whether such a pattern of dependence is maintained for other camera models. That is, taking into account the illumination changes directly in the field by using the official data of the digital camera exposure meter is possible, however, it needs to be checked or adapted to other sensory equipment models.

III. Methods of Experimental Study and Results Obtained

The research was carried out in laboratory conditions and directly at the experimental field station. In laboratories, along with digital cameras, developed for the UAV (FC200), smartphones (AppleiPhone 5s and Lenovo s660) were also observed. The choice of smartphones for research is due to the fact that in [14], [15], the possibility of using such equipment as a control module in the manufacture of assembly of the UAV, even in living conditions, is shown.

Studies on determining the dependence of component color intensity on LightValue were conducted on a gray color pattern example (69% saturation), printed by a laser printer on white office paper and wheat samples placed on the pattern (Fig. 1).

Camera setup options: "white balance"– clear weather. The change in LightValue value was made by correction of exposure in the range ev = -2.0 ... 2.0. The processing of the results was carried out using the software environment provided in [16]. The obtained results are shown in Fig. 2.

According to the results of experimental data processing, it was found that the nature of the dependence on the cameras is uneven. For a sample of gray, the determination coefficient (R2) for the iPhone 5s, FC200, and s660 cameras was 0.957, 0.931, and 0.989 respectively, when linearly approximating. For exponential dependence – 0.989, 0.996 and 0.996, respectively. For maize, by analogy, the linear dependence of R2 was 0.993, 0.989 and 0.989, respectively, for the exponential one – 0.92, 0.991 and 0.986 respectively.

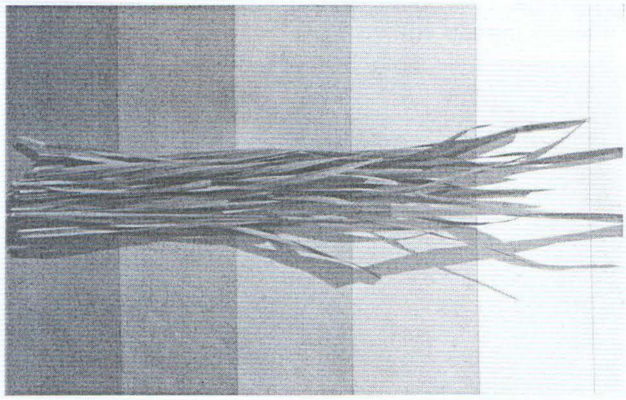

Fig. 1. A sample of an optical pattern with a wheat.

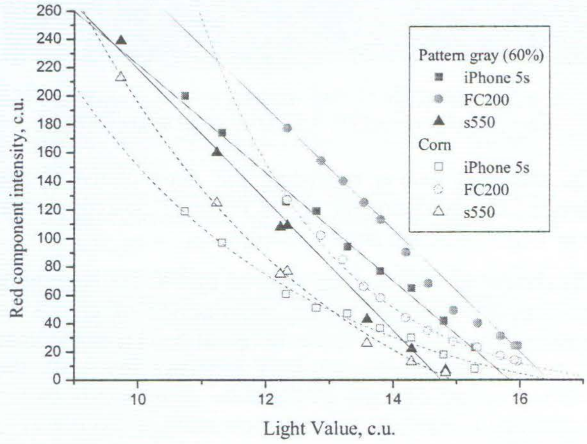

Fig. 2. Dependence of the intensity of the red color component on the value of LightValue for various models of digital cameras.

Thus, it can be proved that the nature of the dependence is to a certain extent determined by the object of monitoring. For an artificial pattern, it is more precisely described by a nonlinear dependence, which makes it difficult to calibrate in different illuminations according to the methodology proposed in [13]. It is established that the character of the above dependence will be individual for each model of the camera, which should be taken into account when used for spatial spectral navigation. It was suggested that more precise correction for illumination changes can be done for practical purposes, having obtained an experimental dependence for objects in field conditions.

Experimental research in field conditions was conducted at the experimental station of the Department of Agrochemistry and Plant Production Quality of NULES of Ukraine, where the wheat field was analyzed with sections with different mineral nutrition status and unformed road (Fig. 3). Before studies, during 3 days, there was no precipitation on the site and the road was air-dried.

Experiments were conducted on 17.05.24 from 15 to 21 o'clock. The illumination thus ranged from 41500 to 500 lux. At measurements, the luxmeter was placed horizontally without a random shadow due to the influence of clouds. In the presence of clouds during the surveying, the uniformity of the illumination of all objects in the frame was visually evaluated, uneven illumination was not allowed. As objects of research, the unformed road and two plots of winter wheat crops were on the vegetative growth stage (0 – background, 1 – a normalized dose of mineral fertilizers was artificially introduced).

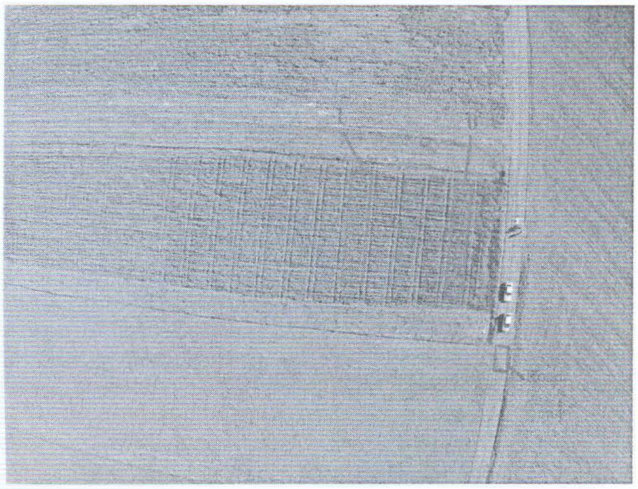

Fig. 3. Experimental station of the department of agrochemistry and quality of plant products NULES17.05.24, UAV flight height is 100 m.

The obtained results regarding the dependence of the intensity of the components of the color of objects on the value of LightValue are shown in Fig. 4.

The results of the research showed that at the beginning of the vegetative growth stage, in presence of clouds or evening light (LightValue in the range of 6–11), in the case of surveying without correction of exposure (ev = 0), the dependence of the intensity of the color components on the level of mineral nutrition (nitrogen content) of the plants is expressed maximally.

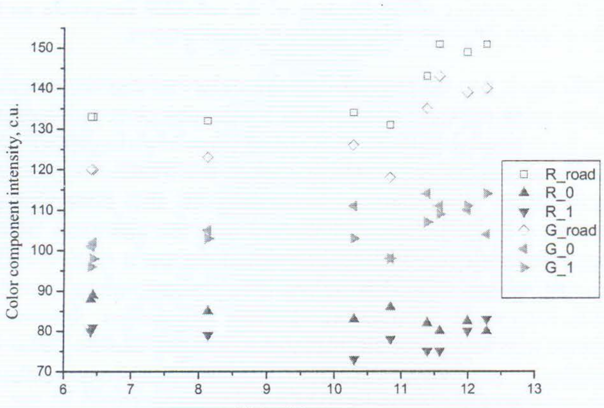

Fig. 4. Dependence of the red and green components of the color of the unformed road and winter wheat fields on the value of LightValue where: road is the unformed road; 0 is the without artificial fertilization; 1 is the normalized dose.

When using a calibration method with an additional anti-aircraft sensor, in which the luxmeter was used, the nonlinearity of the dependence is also observed. Thus, the difference in mineral nutrition has the greatest impact on the intensity of color constituents in the range of illumination of 1000–20000 lux (Fig. 5).

It was established that for the objects under consideration the smallest influence of illumination was recorded for the area of the wheat field without artificial fertilization, and the maximum for the unformed road, which is very important to consider not only for the navigation of the UAV, but also to solve problems of route planning, control and navigation of unmanned aerial vehicles combines and other unmanned vehicles using data from UAVs [17].

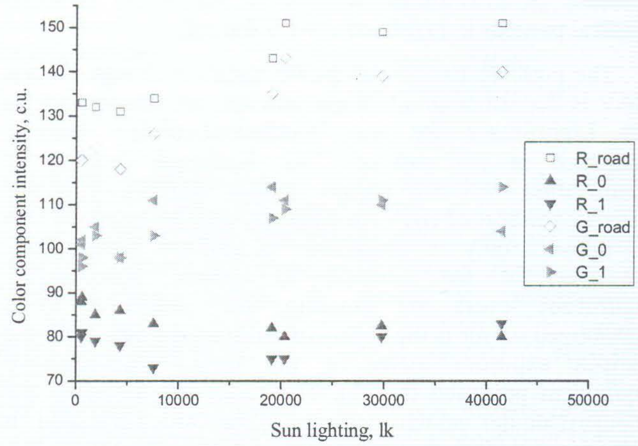

Fig. 5. Dependence of the intensity of the color components of the objects on the value of sunlight.

Thus, when constructing a navigation system based on the use of spatial-spectral portraits it is advisable to focus on objects with stable characteristics.

In general terms the method of solving the navigation problem can be divided into several stages:

1) Automated preparation of area maps with the allocation of the spatial-spectral portraits of objects: To do this UAV makes a test flight (or a series of flights) across the territory and all objects that it "sees" are stored on its map. This task involves the study of well-known algorithms of computer vision:

a) Preparing images algorithms, including algorithms that can "blur", change the contrast, brightness and other photography elements.

b) Selecting objects algorithms in a photo. From them you can take those that determine the contours in the images of spatial-spectral portraits of objects.

2) Formation of the database of objects: In this part, it is necessary to explore and implement storage algorithms for spatial-spectral portraits of objects and geodata, which are used in various geographic information systems.

3) Creating a module that generates a routing task in terms of spatial-spectral portraits of objects that stores a UAV card.

IV. Conclusion

It has been experimentally confirmed that, when changing the illumination, the calibration of spectral data based on service data from the camera can be carried out for different models of cameras.

Dependencies of component color intensity on LightValue for different cameras and monitoring objects are individual in nature. For

- practical needs of spatial-spectral navigation correction when changing illumination is expedient to carry out using experimentally obtained dependencies for a specific model of sensory equipment;
- organization of the UAV navigation system on the basis of spatial-spectral portraits, it is expedient to choose as objects of orientation those having the most stable spectral indicators.

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