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ALGORITHMS AND SOFTWARE FOR UAV FLIGHT PLANNING FOR MONITORING THE STRESS CONDITIONS OF PLANTATIONS

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Abstract. *Remote monitoring technology is a mandatory component of the crop management concept. The available solutions allow determining the presence of plant stress but not identifying its causes. A particular danger is presented by stresses of a technological nature, and chemical poisoning of plants due to the aftereffect of herbicides, compaction of the subsoil, and the like. Plant stresses of a technological nature lead to a decrease in plant immunity and, accordingly, special measures are needed to restore their productivity. Laboratory methods for analyzing stress, in particular, chemical poisoning of plants, are technologically complex and expensive, which prevents their widespread use. Remote sensing technologies are capable of identifying areas with manifestations of technological stresses since such stresses have characteristic features. As our studies have shown, a promising method for identifying plant areas with signs of technological stress is the method of leaf diagnostics. For such areas, it is necessary to carry out monitoring with the highest image resolution, it is assumed in the UAV flight program. Taking into account the above, the aim of the work was to develop an algorithm and software for its implementation of UAV flight planning for the identification of plant stresses of a technological nature. The software was developed in the cross-platform programming language Python, and it allowed processing maps of the distribution of vegetation indices (for experimental studies, maps were used that were created using the Slantrange spectral sensor system). The use of the algorithm, implemented in the cross-platform programming language Python, made it possible to identify the paths of movement of technological equipment, the contours of areas with close values of the vegetation index, and the main features of areas with plant stress of a technological nature. The accuracy of identifying areas with technological stresses has been confirmed by ground surveys in production fields.*

Keywords: *technological stresses, UAV, flight program*

Introduction. Remote monitoring technology is a mandatory component of the crop management concept. This combines the data obtained from the use of sensor equipment and network services, including meteorological indicators (determined using both climatic stations and specialized satellite systems). This is demonstrated in the work of Mauro E. Holzman et all (2018) [1], where the state of water stress was calculated with sufficient accuracy based on the use of data from the MODIS satellite system. However, satellite technologies have significant limitations: for example, Toshihiro Sakamoto (2020) [2] showed that highly reliable data for maize can be obtained only during a few days of the growing season, which is realized only in the absence of clouds.

Climatic satellite data can be effectively supplemented with information from specialized agricultural observation points. So the experience of working on the above is presented in the work of Vladimir A. Romanenkov et all (2020) [3]. In the USA there is a network of commercial stations of the WeatherBug company, which is indicated in the work of Sarah Johnson et all (2020) [4].

Despite significant advances, Steffen Fritz et all (2019) [5] in a survey on crop forecasting [5] shows that processing large amounts of information in complex climate models poses major challenges. So the need for personal sources of information for farms is relevant. In addition, in addition to traditional stress factors of influence on crops, there are stresses of a technological nature, such as the aftereffect of herbicides that were introduced for the predecessor, soil compaction with machinery, and the like. So in the work of M. Dolia et all (2019) [6], the influence of the aftereffect of herbicides on the crops of winter rape was shown, which occurred as a result of its incorrect dosage in the event of equipment breakdown. In contrast to the stresses caused by unfavorable meteorological conditions or lack of nutrients, the identification of herbicides or their decay products in plant samples is associated with a high complexity of research and their high cost. This is shown in the work of Galina Gayda et all (2019) [7]. As noted, subsurface soil compaction affects crop yield. This is described in the works of Ihor Savchyn et all (2020) [8] and Teodoro Lasanta et all (2019) [9].

That is, crops are simultaneously affected by several different stress factors, it is extremely problematic to diagnose for an individual plant. This issue was considered in the work of N. Pasichnyk et all (2020) [10], where it is shown that the nature of stress can be identified by the nature of the distribution of stress areas on the map of vegetation indices. Considering the above, it is advisable to analyze in more detail the limiting values of the zones of distribution of vegetation indices and take this into account when planning the UAV flight (presented in the work of Yu-Hsuan Tu et all (2020) [11]).

There are no ready-made software solutions for analyzing the distribution of stress areas on the field map for identifying the nature of stress. Given the urgency of the problem for promising technologies of precision farming, the purpose of the work was to develop an algorithm and software for UAV flight planning for identifying technological stress.

Research methods. ***State of the issue.*** Information Support. Information on the distribution of stressful areas of crops in the field can be obtained using satellite platforms and UAVs. In this case, various geodata storage formats can be used such as kmz, geotiff, and the like.

A special feature of remote sensing is the orientation of data on the convenience of their perception by farmers, which is achieved by using specialized palettes. This approach is inconvenient in terms of computer processing of information since manufacturers of specialized equipment and software do not have a unified approach to coding information. For computer recognition of images of the objects under study, raster data formats are convenient, presented in the work of V. Lysenko et all (2020) [12]. S. Shvorov et all (2020) [13] present a method for converting stress index maps from Slantrange from a color GeoTiff image to the numerical values of vegetation indices available in the Slantview software.

Identification of directions of movement of technological equipment. Stressful conditions of crops of a technological nature are caused by human actions, which are realized using ground technological equipment. The identification of the directions of movement of equipment was considered in the works of Junfeng Gao et all (2018) [14] on the identification of weeds on the crops of row crops, where all plants between the rows of crops were considered weeds. Carlos Henrique Wachholz de Souza et al (2017) [15] identified sugarcane rows to estimate row gaps. In both cases, the arrangement of plants in a row was considered under the rows, since this is how the ground equipment moves. However, in agricultural practices, the direction of the movement of ground equipment must change from year to year, and accordingly, the distribution of stressful areas may differ from the direction of crops. According to the identification of stresses, it can be based on the assessment of the contour of the stress area; for stresses of a technological nature, it must have the correct geometric shape inherent exclusively to artificial objects. In particular, when crops are poisoned with chemicals, the border between the affected and healthy crops will be directly linear.

Choice of the software environment. Assessment of the nature of crop stress is an urgent task to be solved both by agronomists directly in the fields and by relevant specialists using cloud services. We consider it advisable to recommend the use of the cross-platform programming language Python, which is adapted for processing large data arrays and machine learning.

Emad Ebeid et all (2018) [16], devoted to an overview of flight controllers and UAV flight control, emphasized the perspective of the Python language for implementing these tasks.

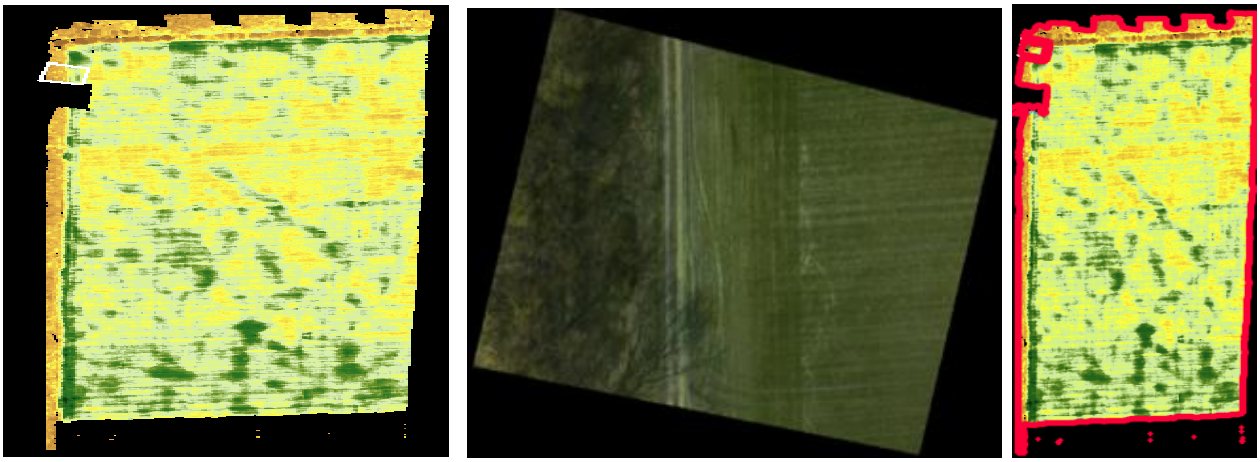
Organization of experimental research. Experimental studies of the impact of technological stresses on winter crops using the example of wheat and rapeseed were carried out during 2018-2020 on production fields located in the village of Gorodishche, Boryspil district, Kyiv region (coordinates 50º16 'N, 30º58'E). Photographing was carried out using a Slantrange 3p multispectral system installed on a DJI Matrice 600 hexacopter. Various manifestations of technological stresses were considered, namely: the aftereffect of herbicides on crops from the predecessor crop, soil compaction (subsurface soil compaction), and exceeding the seeding rate of grain. The meteorological conditions for winter wheat and rapeseed were standard for the region. Statistical data on meteorological parameters (temperature, precipitation can be obtained on the website https://rp5.ua/ for the Kyiv region, Borispol (airport). The distance between the designated meteorological station and the fields where the research was carried out does not exceed 16 km.

Algorithm for identification of technological stresses, its software mplementation, and the results of experimental data processing

Selecting the format of the output data. To process spectral monitoring data, the Slantrange sensor system has its own Slantview software, which allows you to save the received maps in several data formats, namely Shapefile, KMZ, GeoTiff. The shape format contains attribute information of geometric objects and is designed primarily for creating tasks for the operation of ground equipment for processing crops. KMZ files are 3D data in Google Earth and represent vegetation index map overlays on satellite imagery. According to the results of experimental studies on the recognition of the values of vegetation indices, it was found that when the images were overlaid, data distortions took place - the colors were recorded were absent in the palette for the indicated vegetation indices. A likely explanation for this lies in the correction of the image when superimposed on the satellite image for easier visual perception by the user. As a result of the data for the points of the distribution map from the working window of the Slantview program, it was found that for the GeoTiff format there is no distortion of colors and, accordingly, the values of vegetation indices. Unlike the KMZ format, the file does not contain positioning labels, however, when saving the map, the program retains the scaling and, accordingly, when using

landmarks, positioning calculation is quite possible. Considering the above, the GeoTiff format was adopted for the analysis.

Determination of the contours of the field in the map picture. To solve this problem, a modern Slantrange sensor complex was used. The OpenCV library, which is supported in Python, contains ready-made routines for finding the outlines of graphical objects that can be used in this case. The results of map processing are shown in Fig. 1.



a b c

Fig. 1 Map of the distribution of the Green Chlorophyll index (a) for wheat crops affected by the aftereffect of herbicides, (b) - a photograph in pseudo-flowers of the areas highlighted by a square on the map, and the results of searching for the field contour using the proposed software tools (c).

A feature of plant growing in the steppe zone of Ukraine is powerful forest belts, the leaves of which are also fixed by a sensor complex, due to which significant errors are possible (provided that the contours of crops are automatically determined). Since the field limits are stable, therefore, in order to analyze the presence of stresses of a technological nature on the maps of the distribution of vegetation indices stored in the GeoTiff format, it is advisable to enter the field limits manually using control points.

Assessment of the location of sites with technological stresses. When identifying the rows of crops described by Junfeng Gao et all (2018) [14] and Carlos Henrique Wachholz de Souza et al (2017) [15], the direction of plant rows in the field was the only one, but this is not a prerequisite for technological stresses. So in fig. 1 (a) shows the presence of a green band on the left and top, which for the Green Chlorophyll index corresponds to healthier crops than those that are yellow. This condition may be due to the better state of mineral nutrition at the borders of the field, since it is there that the equipment slows down and turns around, without stopping the fertilization. The width of such a strip usually does not exceed the turning radius of the ground equipment. This can be taken into account when analyzing the location of stress areas. In fig. 2 shows a map with stressful areas of winter wheat sowing, where soil compaction and non-compliance with grain seeding rates were recorded.

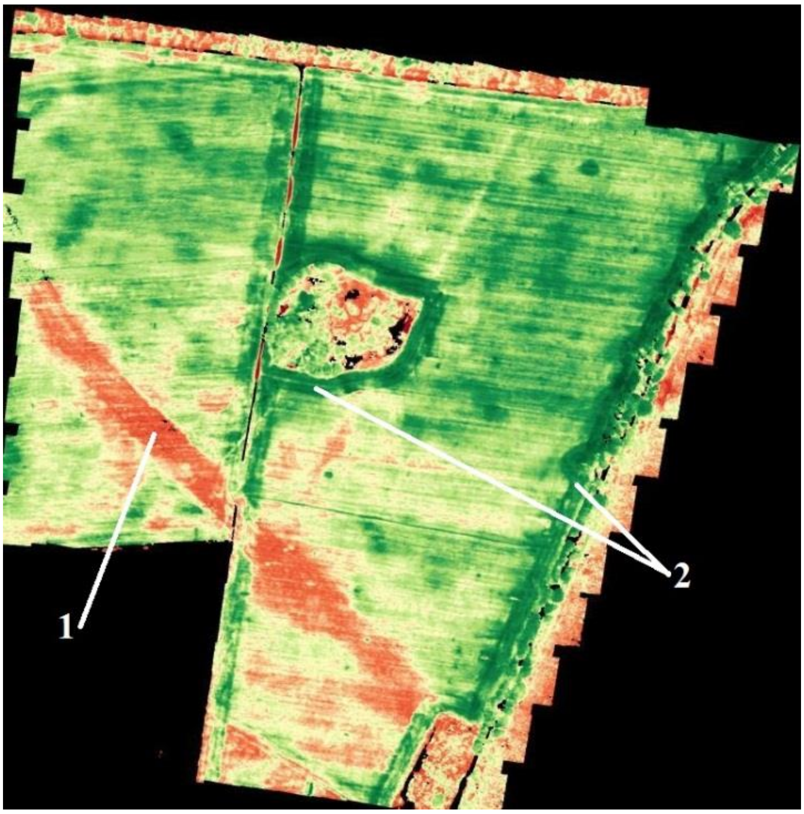


Fig. 2. Map of the distribution of stress areas for the NDVI index for winter wheat crops dated 05/11/2020, where 1 - soil compaction (remnants of the road created by the Wehrmacht during World War II), 2 - double sowing.

The stripe width of healthier plants in Fig. 2 exceeds the width of the stripes in Fig. 1a, which is explained by the repeated sowing of grain along the road. This led to the lodging of plants and, accordingly, loss of yield in these areas in early July 2020. Based on the data presented, it can be concluded that there is a possibility of the simultaneous presence of several non-parallel bands of stress areas of a technological nature; it is necessary to take into account when analyzing the maps of vegetation indices to identify the causes of stress.

On the basis of the material presented, an algorithm was proposed for identifying stresses of a technological nature and the results of processing a field map with the indicated stress (Fig. 3).

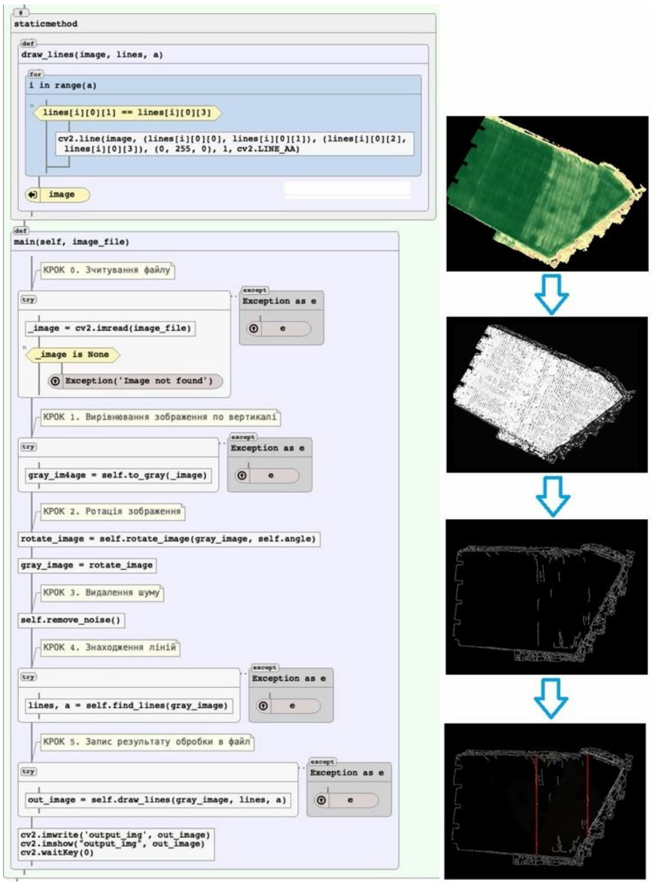


Fig. 3. Diagram of the software algorithm for recognizing stress areas on the stress index map in GeoTiff format, and the result of processing the RedNDVI vegetation index map for rape crops affected by the aftereffect of herbicides.

When processing the distribution map of the standard RedNDVI index, the algorithm and its software implementation made it possible to identify the interfaces characterized by a sharp change in the stress state of plants. Signs inherent in stresses of a technological nature, revealed by the proposed algorithm and software, were confirmed by ground-based studies in production fields.

So, when planning UAV flights in a flight task, it is advisable to take into account the need for a more detailed survey of just such areas using sheet diagnostic tools, and this requires the use of high-resolution images.

Direction for Further Research. Since the size of stress areas can be calculated with high accuracy, that is, the prospect, on the basis of the existing technological equipment park, to identify the type of equipment, the use of which could lead to the appearance of technological stresses.

With the accumulation of statistical information, it becomes relevant to study the issue of the influence of image resolution on the quality of the identification of the developed algorithm and its software implementation of manifestations of technological stresses.

Conclusions. For remote monitoring of technological stresses, a

UAV flight planning algorithm and its software implementation based on the use of the Python software environment have been developed. The use of the above made it possible to identify the paths of movement of technological equipment, the contours of areas with homogeneous parameters, and the main features of areas with the stress of plants of a technological nature using the maps of the distribution of stress indices.

The accuracy of identifying areas with technological stresses in the developed program was confirmed by ground-based studies in production fields.

Confirmation and thanks. Preliminary results of the study were presented in the form of abstracts 'Algorithms and software for UAV flight planning for monitoring the stress conditions of plantations" at international scientific conference 2020 IEEE 6th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC). The authors express their gratitude to the specialists of the National university of life and environmental sciences of Ukraine: Serhii Shvorov, Volodymyr Reshetiuk, Oleg Udovenko, Tetiana Knizhka and Maryna Kharinova for the provided support and equipment for flights.

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АЛГОРИТМИ ТА ПРОГРАМНЕ ЗАБЕЗПЕЧЕННЯ ПЛАНУВАННЯ ПОЛЬОТІВ БПЛА ДЛЯ МОНІТОРИНГУ СТРЕСОВИХ СТАНІВ РОСЛИННИХ НАСАДЖЕНЬ

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Анотація. *Технології дистанційного моніторингу є обов’язковою складовою концепції керування врожаєм. Наявні рішення дозволяють визначити наявність стресу рослин проте не ідентифікувати його причини. Особливу небезпеку становлять стреси технологічного характеру, а саме хімічне* *отруєння рослин в наслідок післядії гербіцидів, ущільненням підорного шару тощо. Стреси рослин технологічного характеру призводять до зниження імунітету рослин і, відповідно, потрібні особливі заходи для відновлення їх врожайності. Лабораторні методи аналізу стресів, зокрема хімічного отруєння рослин, є технологічно складними і дорогими, що перешкоджає їх масовому застосуванню. Технології дистанційного зондування здатні виявити ділянки з проявами стресів технологічного характеру, оскільки такі стреси мають характерні ознаки.*

Як показали наші дослідження, перспективним методом виявлення ділянок рослинних із ознаками технологічних стресів, є метод листової діагностики. Для таких ділянок потрібно провести моніторинг із вищою розподільчою здатністю знімків, що передбачається в програмі польоту БПЛА.

Зважаючи на означене, метою роботи стало розроблення алгоритму та програмної його реалізації планування польотів БПЛА для ідентифікації стресів рослин технологічного характеру. Програмне забезпечення розроблене на кросплатформеній мові програмування Python, дало можливість обробити карти розподілу вегетаційних індексів (для експериментальних досліджень використовували карти, створені на основі використання спектральної сенсорної системи Slantrange).

Використання алгоритму, реалізованому на кросплатформеній мові програмування Python, дозволило ідентифікувати колії пересування технологічного обладнання, контури ділянок з близькими значеннями вегетаційного індексу та основні межі ділянок зі стресом рослин технологічного характеру. Точність ідентифікації ділянок із стресами технологічного характеру була підтверджена наземними дослідженнями на виробничих полях.

Ключові слова: *технологічні стреси, БПЛА, програма польоту*