

REVIEW

from

Prof. Eng. Boris Georgiev Borisov, PhD

of the dissertation developed by

mag. Eng. ASPARUKH IVANOV ATANASOV

on the subject:

"RESEARCHING THE APPLICABILITY AND EFFICIENCY OF SENSOR SYSTEMS IN
PRECISION AGRICULTURE"

for awarding the educational and scientific degree "DOCTOR"
by professional direction 5.1. "MECHANICAL ENGINEERING"
and PhD program "APPLIED MECHANICS",
according to order N:874 of 12.12. 2023 of the Rector of TU-Varna

1. General characteristics of the dissertation work

The presented dissertation work is developed in an appropriate structure of an introduction, five chapters with separate conclusions to them, general conclusions, a list of contributions, a conclusion, a statement of originality and credibility, a list of the literature used and 5 appendices. The total volume is 151 pages, which include 89 figures, 35 tables, 29 formulas and dependencies, a list of used symbols and abbreviations, and a bibliographic reference from 227 literary sources, including in Latin 211 and 16 from Internet sites, the majority of which are from the last 10 years.

In the first chapter, a detailed and precise overview and analysis of the types of sensors that are suitable for use in agriculture is made, such as: mechanical sensors for soil density; GPS positioning sensors; sensors for measuring speed and displacements; acoustic and pneumatic sensors for soil density; electrical and electromagnetic; optical and radiometric; spectral sensors for remote sensing by color separation; multi-sensor devices for weather stations, all with the possibility of application in the field of precision agriculture. The chapter ends with 5 conclusions related to the topicality of the topic under consideration. *The purpose and tasks of the study are appropriately and correctly formulated, namely:* To establish the applicability and effectiveness of various sensor systems in their use in precision agriculture, by means of a methodology for non-destructive control of the properties of the studied biological objects, by means of photogrammetry. A modern method for remote multispectral monitoring of agricultural crops from the air by means of unmanned aerial vehicle (UAV) imaging is proposed. To achieve this goal, 6 tasks have been defined, by solving which it is necessary to establish whether there is a correlation dependence between the spectral data of the reflection from agricultural crops and the phenological, biometric and physiological indicators, which is of decisive importance for the applicability and effectiveness of the sensor remote monitoring system.

The second chapter examines the methodology for processing the data obtained by remote monitoring of agricultural crops with UAVs. Modern methods and tools were used, such as dispersion analysis, the MatLab platform and specialized Pix4D software. *The object and the subject of the research were correctly selected and defined*, such as agricultural crops in the region of Dobruja - Northeastern Bulgaria. Modern sensor systems used in UAVs, with the possibility of application in precision agriculture, were selected as the subject of the study. A methodology for obtaining the characteristic vegetation indices is presented. The chapter ends with 7 summary conclusions.

The third chapter covers the theoretical and field studies in the laboratory-experimental fields of DTK-Dobrich and DZI-Gen. Toshevo, for a four-year period of time, on various cereal crops, such as wheat, triticale, etc. in order to determine the vegetation indices. Research has been extended to sunflower and corn crops. A remote non-destructive methodology is presented for recording the reflection of solar radiation on agricultural crops, using a small UAV equipped with an RGB and RGN camera. The assessment was made in three consecutive years (2019-2022) throughout the growing season of agricultural crops.

185 UAV shots and 93,500 photos of the observed areas were taken. During the period of experimental research, 400 hours of field work and 2000 hours of computer processing of the

experimental results were carried out. The observations were realized through sensors from a distance, and photographic material was obtained, processed in the software platform MatLab, which is a convenient tool for calculating the vegetation indices for the different crops. The data obtained allow the use of a set of indicators to give a certain idea about the development of the genotype. This shows that the developed methodology can find practical application in the selection and improvement work of cereal crops, as well as in agricultural production, to establish certain trends for a given region of the country. The results of the experimental studies are presented in tables, graphs, histograms and are shown in 10 summary conclusions.

In the fourth chapter, through mathematical modelling and statistical processing of the data with the method of regression analysis, adequate mathematical models were obtained, reflecting the drying of the areas and the development of agricultural crops under the different conditions of their cultivation. Descriptive analysis was used for the results obtained in the study of fields sown with corn in 2021. comparative studies of different corn fields were also carried out. Correlational dependencies between the generated indices and environmental conditions were also established. Using images from a small UAV, it was found that a farmer could track and analyse crop data without relying on satellite imagery. An objective picture of the weak and strong areas in the field can be obtained without the need to go through the crop. The trends of change of a total of 8 indices and their applicability in estimating plant mass and forecasting corn yields in two fields were compared. At the end, the chapter ends with a summary in 6 conclusions.

The fifth chapter presents experimental research on the design, development, and creation of a prototype version of a soil moisture sensor. The developed test prototype is presented and tested in real field conditions. The created sensor for determining soil moisture is an original and reliable solution for use by farmers in practice. It provides continuous observations of changes in soil moisture in agricultural holdings and can be used as an effective alternative to professional weather stations. The created sensor is powered by solar energy and contributes to environmental protection. Experiments show that the sensor is applicable and effective for agrometeorological and climatic features in the region of South Dobrudzha.

2. Timeliness of the problem

The dissertation work is dedicated to current interdisciplinary research from different fields of knowledge, aimed at improving intelligent human-machine interfaces, as well as technologies related to them. Technological advances in computing have permeated every industry in the world, and agriculture is no exception. The introduction of artificial intelligence into the design of user interfaces facilitates human-computer interaction. Nowadays, this technology significantly helps farmers in several ways, including accurate forecasting and decision-making based on forecast data and signalling in the execution of important agrotechnical activities. The spread of Internet technology offers farmers easy access to valuable resources and modern tools. The present development is an experimental study of a methodology for non-destructive control in determining the properties of biological objects, in particular agricultural crops, and soil, by means of remote spectral analysis. The possibility of obtaining information about test subjects by means of unmanned aerial vehicles (UAVs) and a multispectral camera without direct sampling of agricultural crops was implemented. Various sensors have been investigated for measuring agriculturally important quantities in order to manage and implement useful practices under variable field conditions. A methodology has been developed for tracking and monitoring vegetation processes in South Dobrudzha, by means of remote monitoring of changes during vegetation based on RGB and NIR images by means of photogrammetry. Direct observation of the development of wheat varieties in an experimental field was carried out, which provides important information about the state of the crop. An analysis is made of the possibilities of scanning the areas by flying over with unmanned aerial vehicles (UAVs). Modern research methods were used such as: comparative analysis of existing solutions; creation and research of specific solutions by using the capabilities of remotely controlled small-sized unmanned aerial vehicles for working with various sensors for remote monitoring, (statistical processing of the results); computer processing of the received primary digital information; creation of vegetation index databases.

All these findings undoubtedly and unequivocally determine the relevance of the subject of the dissertation work. With a thorough and critical use of a significant number of literary sources, the mathematical apparatus and instrumentation, innovative technical means for the experiments, the doctoral student *accurately and correctly identified* the unresolved case studies on the problem and,

taking a reasoned scientific position, *clearly and convincingly formulated the relevance, purpose and tasks* of his research.

3. Degree of knowledge of the state of the problem and creative interpretation of the literary material.

In this dissertation, a detailed literature review of many literary sources is made. The state and achievements of modern systems based on intelligent solutions are examined, as well as the methods and means used in their implementation. An analysis of the current state and topicality of the subject is offered. The formulated tasks fully ensure the set goal. *The object and subject of research are convincingly and correctly defined.* The general methodology of the research was chosen appropriately, *modern methods were used*, such as: mathematical modelling, systemic and cybernetic approach, correlation and regression analysis, mathematical statistics, and optimization. An opportunity has been realized to study the processes in laboratory and production conditions, under different regimes and working conditions, using innovative and intelligent technical solutions. Modern equipment was used to measure the values of the main indicators characterizing the processes. The good interpretation of the literary material, the in-depth analysis and the conclusions drawn in the individual chapters of the dissertation prove *a high degree of knowledge of the state of the problem on the part of the doctoral student.* As a result, the purpose of the dissertation work and the specific research tasks are correctly defined.

All this undoubtedly determines *the high scientific value of the dissertation work*, as well as the educational and scientific level of the doctoral student Eng. Asparuh Atanasov, who knows scientific achievements very well.

4. Correspondence of the chosen research methodology and the set goal and tasks of the dissertation work

The results presented in the dissertation were obtained based on a thorough theoretical analysis of intelligent human-machine interfaces. The logical sequence in the presentation, construction and illustration of this part presents the doctoral student as relatively well informed and with a clear vision of the tasks he has set himself. The obtained results are presented in good style, logical sequence, interpretation, and correctness. All of them are illustrated with tables, figures, graphs and photos, including and with colourful images. The credibility of the material on which the doctoral student draws his conclusions and claims contributions is based on his overall correct research approach and the developed methodologies for conducting the experiments. The obtained information is processed with modern instrumentation and the methods of mathematical statistics, regression analysis and the theory of random processes, which are applied precisely, and the analysis of the results is correct.

The presented abstract was developed and shaped according to the requirements of the Technical University-Varna, it contains and objectively reflects the main points and contributions of the dissertation work.

5. Contributions to the dissertation work

I appreciate the contributions in the dissertation work positively, as they are related to obtaining new and confirmatory scientific facts with new and existing modern means. Their importance can be useful in the use of new principles and technologies in precision agriculture, as well as for effective technical solutions in the optimization of some agrotechnical processes in agriculture.

The present dissertation work represents a completed stage of theoretical-experimental interdisciplinary research, by means of a non-contact non-destructive method for control of the development of the cultivation of agricultural crops by UAV and NIR camera, on the basis of which the following contributions can be formulated:

Scientific and applied contributions:

- A methodology has been developed for researching a sensor system using a non-destructive method for remote monitoring of UAV overflights, including planning, and conducting field campaigns depending on weather conditions.

- A database has been created for changes in the vegetation indices, through which the development of a given genotype can be monitored, and the developed methodology can be useful in the selection and improvement work in the cultivation of cereal crops in a given area.
- It has been established that there is a correlation dependence between the spectral data of the reflectance of agricultural crops and the phenological, biometric and physiological indicators, which is of decisive importance for the applicability and effectiveness of the remote sensing sensor system.
- Based on the data obtained through remote monitoring with a UAV, the range of changes of the vegetation index NDVI for wheat was established within the range of -1 to 0.5 for the region of South Dobrudzha.
- Through the methods of statistics and regression analysis, with a multifactorial experiment, the factors that have the greatest importance on the NDWI moisture index have been established, such as: first, the relative humidity of the air, followed by the air temperature and the weakest solar radiation.

Applied Contributions:

- An approach is proposed to extract the necessary information in order to track plant vegetation, using the data from the pixel matrices that digital technologies create for each image. The method is suitable for small areas during selection activity.
- An original prototype of a WiFi sensor for determining soil moisture and air temperature was designed and created, which is self-powered and is an effective analogue of professional weather stations.
- Through comparative studies, similarity between the calculated NDVI values obtained from UAV flyover data and from satellite observation data has been established. It has been argued that UAV data are more easily applicable and effective for precision agriculture purposes. By registering the reflection from specific spectral areas, phenological data have been obtained (i.e. the possibility to calculate vegetation indices), which can be useful for the practice of predicting the biomass content and the potential of the studied plants.

6. Assessment of the degree of personal involvement of the doctoral student

I believe that the doctoral student has, to a significant extent, fully participated in the implementation of the individual stages of the research in the dissertation work. The presented scientific-applied and applied contributions are the personal work of Eng. Asparukh Atanasov, under the scientific and methodical guidance of his scientific supervisors. Proof of this is the publications of the doctoral student and his participation in scientific forums in the country and abroad and in various research projects.

7. Assessment of dissertation publications

The results obtained by the author from the dissertation research are published in the presented 10 scientific articles. He is the independent author of one, published abroad, and the first author of 6. He has participated in scientific conferences with publications in Italy, Ukraine, Moldova. In Bulgaria, there are publications in the scientific magazine "Mechanics of Machines" and in collections of scientific works of TU-Varna, SUB-Varna, Ruse University and Veliko Tarnovo University. The publications were made in the period 2019-2022 and cover the subject of the presented dissertation work, reflecting the main achieved results and contributions. One of the presented publications of the PhD student is in publications that are referenced and indexed in world-renowned databases of scientific information. There are also publications that are also visible *in the international indexed database Scopus*. The obtained experimental results have been presented and published in international scientific conferences and magazines in the country and abroad.

I assess the publication activity of the doctoral student as very good, and I believe that the results of the work on the dissertation work have become sufficiently available to the Bulgarian and international scientific community. The publications on the dissertation in quantitative and qualitative terms *fully satisfy the requirements for obtaining the educational and scientific degree "Doctor"*.

8. Using the results obtained

For the practical implementation of the results of scientific research and development in his dissertation, the doctoral student presents two certificates and two assurances: Certificate for participation in the conference "Farm Machinery and Processes Management in Sustainable Agriculture" in Bari, Italy; Certificate for participation in the "Development through Research and Innovation - 2021" conference, Chisinau, Moldova.

Certificate from private farmer ET "LG - Galina Nikolova" for a technical defect found in the seedier by means of remote spectral research of a field sown with winter wheat; Certificate from DZI - town of G. Toshevo for early diagnosis of yellow rust on wheat, by means of remote spectral research of the experimental field.

The large number of experimental studies and their evaluation, the very large number of graphs and diagrams, through which the analyses and generalizations made as a result of the experiments are very precisely and clearly visible, is impressive. I believe that the research in the dissertation work and the achieved results can be successfully used to build intelligent applications in the field of agriculture and in particular precision agriculture, as well as for the technologies related to them.

9. Opinions, remarks, and recommendations

The dissertation work is designed *very carefully and diligently*. The high level of competence of the doctoral student is visible, his deep knowledge in the field of innovative information technologies, finding application in agriculture and more specifically in precision agriculture.

The doctoral student has achieved the set goals and objectives in the dissertation work and formulated his contributions based on them. The obtained experimental results have been presented and published in international scientific conferences and magazines in the country and abroad. Some of them are also visible *in the international indexed database Scopus*. One of the publications is in publications that are referenced and indexed in world-renowned databases with scientific information. The mentioned remarks and recommendations do not detract from the merits of the scientific work. I believe that the dissertation testifies to the *author's very good knowledge* of the subject area under consideration, presents many scientific and practical studies and provides an opportunity for future developments in the field of precision agriculture, which is relevant both in our country and abroad. My recommendations to the author of the dissertation are as follows:

- In his future research and educational activities, Eng. Asparukh Atanasov needs to show even greater precision, greater depth, and critical analysis, use modern scientific achievements and try to work in a team with specialists and from other scientific fields areas.
- To publish the results of the conducted scientific research in international scientific publications with Q rank, and some of them to be patented, to preserve their copyright.

10. Conclusion

I know mag. Eng. Asparuh Atanasov as a full-time doctoral student and assistant at DTK-Dobrich. He is distinguished by his very good theoretical training and accumulated experience in the field of agricultural technology, statistical research methods, innovative information technologies used in agriculture and the educational process. In addition, the doctoral student stands out for his hard work, precision, and sense of responsibility to his students and colleagues. I believe that he is a well-built scientific worker in the field of agriculture, capable of solving complex engineering tasks alone or in a team.

The dissertation of *mag. Eng. Asparuh Ivanov Atanasov* was developed in a wide-ranging interdisciplinary scientific field, at a high scientific level, in the necessary volume and depth. It contains significant scientific-applied and applied contributions to the field of agriculture and has a finished look. Doctoral student *Asparuh Ivanov*, thanks to his very good theoretical preparation, knows how to formulate and critically analyse, as well as independently solve complex scientific and practical tasks, using modern methods and tools for research and experimentation.

From the presented reference, it can be seen that the doctoral student covers the Minimal National requirements for the acquisition of ONS "Doctor" (MSR) for Professional Direction (PD) 5.1.

"Mechanical Engineering" with a minimum number of points of 80 for groups A and D, he collects 134 points, with a weightage of group G7 and G8.

On the basis of the defined contributions, as well as the modern research methods mastered and applied by the doctoral student, the correctly performed experiments, the generalizations and conclusions made, **I THINK** that the presented dissertation meets the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria, the Regulations for the application of the law and the relevant Regulations of the Technical University-Varna for its application, which gives me to evaluate it **POSITIVELY**.

Based on the topicality, credibility, and significance of the dissertation work for science and practice, my personal impressions of the author and his contributions, **I SUGGEST THE DEAR SCIENTIFIC JURY** to award **Eng. ASPARUKH IVANOV ATANASOV** the educational and scientific degree "**Doctor**" in professional field 5.1 "Mechanical Engineering", Doctoral Program "Applied Mechanics".

31.01.2024

Reviewer:

/Prof. Eng. B. Borisov, PhD /