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PREFACE

After the four successful International Symposiums on Agricultural Engineering – ISAE, that were held in Belgrade at the Faculty of Agriculture, thanks to our colleagues we are organizing The Fifth International Symposium on Agricultural Engineering – ISAE 2021. Together with the University of Basilicata, School for Agricultural, Forestry, Food and Environmental, Sciences (Potenza, Italy), University of Sarajevo, Faculty of Agricultural and Food Sciences (Sarajevo, Bosnia and Herzegovina), Aristotle University of Thessaloniki Faculty of Agriculture, Thessaloniki (Greece), University of Belgrade, Faculty of Mechanical Engineering, Department of Agricultural Engineering, Belgrade (Serbia), Vinča Institute for Nuclear Science, Belgrade, Serbia, and thanks to the Ministry of Education, Science and Technological Development, Republic of Serbia, support of the AMAPSEEC, RebResNet and BENA, and sponsor and donors, we have managed to organize the presentations of the 29 papers that were submitted to the Scientific Committee of the ISAE 2021 Symposium. We have arranged them in to four sections and categorized them as Original scientific papers, Scientific review papers, Firs (short) communications, Case studies, Professional (Expert paper) and Popular papers. All papers within the Proceedings of the ISAE 2021 were reviewed by the members of the Scientific Committee and kind assistance of some members of other Conference bodies.

The Proceedings of the ISAE 2021 International Symposium is organized in four thematic sections. Section I – Sustainable agriculture and biosystems engineering; Section II – Soil tillage and agroecosystems protection; Section III – Energy and energy efficiency in agriculture and Section IV – Economics in agricultural engineering.

We wish to thank to all the authors for their contribution to the ISAE 2021 Symposium and to the all the Institutions, Associations, Universities, Sponsors and Donors for the contribution in ISAE 2021 Symposium organization.

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ISAE 2021

The 5th International Symposium on Agricultural Engineering, 30[rd] Sep – 2[nd] Oct 2021, Belgrade–Zemun, Serbia

TECHNICAL RESOURCES FOR SPECTRAL CROP SCOUTING – CURRENT STATE AND PROSPECTS

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INVITED PLENARY LECTURE

Abstract: *From planting to harvest, the primary aim of agricultural producers is associated with monitoring cultivated plant species (arable crops or fruit plantations) in arable field areas during the vegetation period in order to make timely and appropriate decisions regarding the implementation of adequate agricultural measures to provide optimal plant development and to maximize the yield. Information about the current state and recent changes in crop sets over the vegetation period represents an important basis for reaching more precise decisions in the spheres of agronomy, economics, and environmental protection. By analyzing large amounts of interdisciplinary spatial data over longer periods of time, key information becomes available, facilitating monitoring crops in larger land areas, and providing the definite picture of changes in arable plots and ecosystems. Spectrometry is the most widespread method of scouting crops. Indirect analysis of the data obtained this way can help determine nutritional deficiencies of crops, as well as defective states caused by diseases, weeds, or pests. Consequently, it is possible to ensure the distribution and administration of optimal doses of appropriate fertilizers and pesticides subsequent to or concurrent with monitoring within the optimal agricultural frame and/or with changeable dosage norms. This review covers various technological processes for spectral crop scouting contingent on various technical resources and sensors. At the end of the paper, advantages and disadvantages of each resource are given, and the key comparisons are made in terms of the efficacy and precision of these resources.*

Keywords: *crop scouting, spectral sensors, sensor carriers, tractors, unmanned aerial vehicles, satellites*

1. INTRODUCTION

From planting to harvest or picking, the primary aim of agricultural producers is associated with monitoring cultivated plant species in arable field areas during the vegetation period in order to make timely and appropriate decisions regarding the implementation of adequate agricultural measures to provide optimal plant development and to maximize the yield. Information about the current state and recent changes in crop sets over the vegetation period represents an important basis for reaching more precise decisions in the spheres of agronomy, economics, and environmental protection. By analyzing large amounts of interdisciplinary spatial data over longer periods of time, key information becomes available, facilitating monitoring crops in larger land areas, and providing the definite picture of changes in arable plots and ecosystems. Therefore, crop scouting involves an analytical process whose aim is to discover spaciotemporal changes in crops from planting to harvest [1].

Incentives to embrace crop scouting techniques include a possibility of yield increase, better fertilizer utilization, and/or pesticide cost reduction. Field specofocity determines whether location-specific approach is profitable or not. However, field experiments that compare uniform rate application (URA) with variable rate application (VRA) show unstable advantages in yield and profit [2-7], and just a few agricultural producers have so far adopted precision agriculture technologies, such as implementation of variable rate application based on crop scouting sensor readings. It should be borne in mind that the main motive of agricultural producers to accept innovations involving crop scouting sensors is their interest in technology [8-12]. They actively use the collected data, frequently comparing them from one season to the next, discovering variations in the biomass change. Still, this group comprises little more than 5% of agricultural producers in Denmark, for example, one of the most developed countries in Europe.

Four principal problems regarding crop scouting in the aforementioned period include (1) limitations that large acreage to be monitored impose; (2) the necessity of quick, effective, precise, and accurate measuring; (3) chemical instability of nitrogen as the most significant crop nutrient, because of which very dynamic changes in its content levels in the soil and plants occur, which means that for determining optimal nitrogen-based artificial fertilizer doses it is essential to measure the nitrogen levels as close as possible to the time of the fertilizer application; and finally (4) enabling mineral nutrient distribution via variable rate application represents an additional challenge.

Data collected by crop scouting represent a solid basis for geo-agronomic analyses. Nevertheless, different ways of detecting changes in crop state are not equally suitable to every analysis, so digital detection of crop changes is affected by special, atmospheric, spectral, and temporal limitations. To counter these, we have at our disposal numerous techniques for detecting changes, while opting for an appropriate method or algorithm for the desired crop scouting is key to the successful analysis of the obtained data. The diagram in Figure 1 presents the most prevalent ways (methods) and indirect means of using multispectral camera sensors for agricultural purposes in crop scouting.

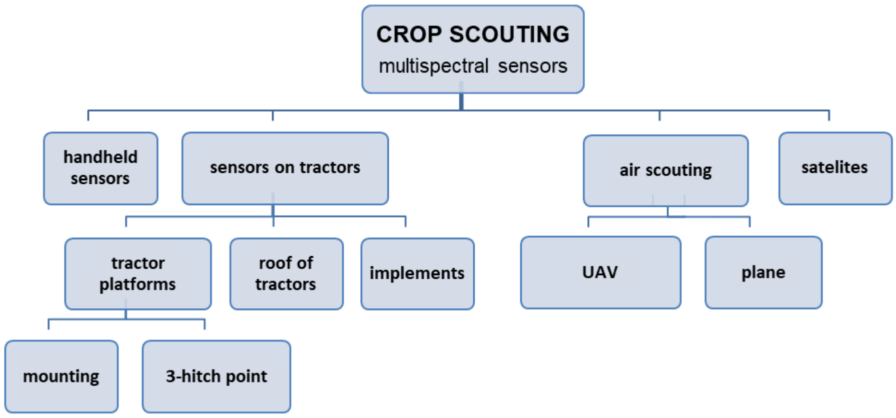

Figure 1. Ways of multispectral crop scouting and multispectral technical systems (platforms) in agriculture [1]

Each of the crop scouting ways mentioned, together with the accompanying multispectral technical system comprising a multispectral camera sensor and an adequate sensor carrier, possesses certain advantages and renders recommendations for use in line with the preferred intentions or actual conditions in crop scouting.

2. SPECTROMETRY DESIGN AND ITS APPLICABILITY IN AGRICULTURE

Remote detection represents a non-invasive method of collecting information using systems that are not in a direct, physical contact with the object or the phenomenon examined (Figure 2). Sensors are main devices in this type of investigation dedicated to discovering, registering, and measuring electromagnetic radiation emitted or reflected by the examined object. Sensors transform the registered electromagnetic energy into electric impulses, and their set-up enables them to cover a narrow or wide spectral range. To monitor fields with adequate remote sensors, of all types of electromagnetic radiation, only those types of radiation whose wavelength corresponds to that of visible light, infrared light, and microwaves are used. Field mapping is mostly done using the so-called optical RGB cameras and spectral sensors, although for agricultural purposes, in crop scouting directed at observing parameters presented in Figure 2, mechanical sensors, thermal imaging cameras, scanners, lasers, radars, and ultrasound sensors are used as well.

Main units of multispectral sensors that measure light reflectance from a certain part of the spectrum are light source, reflected light detector, control unit, and power supply unit. A schematic representation of a sensor thus defined is given in a block diagram in Figure 3.

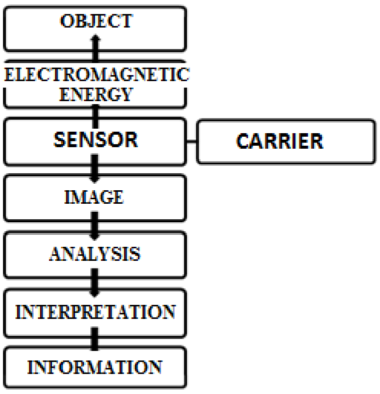

Figure 2. Remote detection principle

Since reflectance is measured in several distinct parts of light spectrum, the source must be such that it can generate light in four portions of the spectrum, that is, in the blue, green, red, and infrared spectra. In this way, calculating several reflectance indices is made possible. One light diode is used as a light source, and its chip incorporates all four light sources necessary for the described sensor function and crop scouting. The light source has the power of 3 W. The reflected light detector can be a PIN photodiode that has the ability to detect light in the range of 400—1100 nm. A PIN photodiode is a semiconductor component which converts an optical signal into a corresponding electrical signal, or charge. This semiconductor component has better dynamic characteristics and sensitivity compared with other types of photodetectors, such as phototransistors or photoresistors.

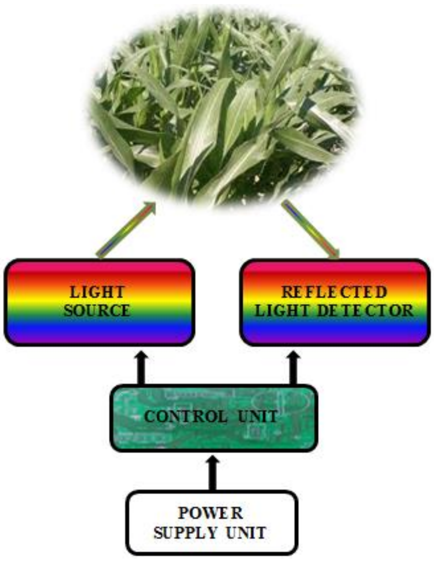

Figure 3. Block diagram of a multispectral sensor

Multispectral analysis is currently the most prevalent and the most comprehensive type of remote detection, or crop scouting in agriculture. Despite various manners, or indirect technical means for implementing multispectral sensor imaging in agriculture, what they all have in common is the multispectral camera sensors that measure plant spectral reflectance and detect the typical vegetation spectral signature.

3. ON-THE-GROUND CROP SCOUTING SYSTEMS

On-the-ground crop scouting is performed using sensors integrated in agricultural machinery, that is, machine-tractor aggregates, and is categorized under the so-called terrestrial photogrammetry. Tractor platforms can be mounted or mounted directly on the tractor by means of a special construction adapted to each tractor model individually or by means of a platform of the coupling type which enables connection to the tractor in three points in the classical way (Figure 4). The number of multispectrometic sensors on the carrier is usually two or four, although any number of sensors can be installed. In addition to special platforms, the sensors can also be mounted on the roof of the tractor or directly on the working machines, e.g. on the wings of mounted and towed sprayers or on the wings of high-clearance self-propelled sprayers. The front tractor platforms for multi-spectrometic sensors, as well as those sensors that are mounted on the roof of the tractor, can be used, although much less frequently, for exclusive crop reconnaissance without simultaneous dosing of any agent per plot and crops. In any case, the common characteristic of all variations of the above-mentioned method of crop reconnaissance is the best possible resolution and possible simultaneous reconnaissance and dosing of fertilizers and pesticides with a variable rate.

Figure 4. Typical tractor platforms for crop scouting

On market, there are comparatively few complete crop scouting tractor platforms, predominantly with a three point hitch system. Their load-bearing structure is robust, they allow hydraulic wing manipulation, and they are equipped with two laterally placed sensors. However, the leading manufacturers of agricultural GPS equipment base their business and development in the domains of sensors and electronics, meaning that they deliver autonomous systems for spectrometric crop scouting in the form of sets comprised of nothing else but electronic sensory equipment with a various number of sensors in accordance with the customers' demands, controlling module, and the accompanying cabling. Customers are completely left to their own devices when it comes to positioning these components on corresponding platforms. Agricultural sprayers have wide wings, enabling sensor installation and positioning to some extent. Still, using sensors simultaneously with fertilizing or solely for crop scouting inevitably requires a separate, specifically designed platform for sensor installation.

4. ADVANTAGES AND DISADVANTAGES OF SCOUTING SYSTEMS

Using hand-held sensors is the least effective method of crop scouting. Thus, scouting boils down to inspecting agricultural plots or fruit plantations visually, above all, and the sensor itself is used for evaluating the state of the crops using the vegetation index measured. Vegetation index measuring is done sporadically, at the discretion of the technicians doing the scouting, and less frequently according to a plan determined in advance. The location can be a *spot*, when the hand-held sensor is activated and held for several seconds above an individual plant, or a *line*, when one walks several dozen meters along a single row with the activated sensor that is directed to the crop. The number of measurements (samplings) depends on the predetermined measuring period of time and the skill of the technicians themselves, and wet or muddy terrain can be a significantly limiting factor for this manner of scouting. In addition to its price, the advantages of these devices include small dimensions and light weight, portability, as well as a very quick computation of the vegetation index (in a couple of seconds) with no need for long imaging procedures and processing. Nevertheless, these devices can most frequently determine only one vegetation index.

On-the-ground crop scouting is done using the sensors integrated in agricultural machinery, or machine-tractor aggregates (MTAs), and is categorized under the so-called terrestrial photogrammetry. This type of scouting is most profitable and most effective when it is done simultaneously with the distribution of mineral nutrients and with the chemical protection of plants. What is more, in that case, the aggregate may include a tractor and two machines. Behind the tractor, an implement/attachment (a fertilizer spreader or a sprayer) is mounted, and in front of the tractor, there is a front tractor multispectral sensor carrier which is used for scouting the crops, or for direct measuring of the reflectance of various light wavelengths from the green parts of the plants, as well as for indirect calculations of one of numerous vegetation indices based on the prior scientific research [13]. Based on this index, the optimal dosage rate is calculated, in line with the adopted recommendations or algorithm, and the obtained data on the variable and location-specific rate are sent to the implement/attachment actuators behind the tractor. The number of multispectral sensors on the carrier is usually two or four, but actually, any number of sensors can be attached. These platforms can be mounted, that is, installed directly onto the tractor with a special construction adjusted to each model of tractor separately, or they can be attached, with a three-point hitch with the tractor in the standard way. The sensors can be attached not only to special platforms – they can be installed onto the tractor roof, or directly onto the implements/attachments: for example, onto the sides of the mounted and trailed high-clearance sprayers. Front multispectral sensor tractor platforms, as well as sensors installed onto the tractor roof can be used, albeit rarely, solely for crop scouting, without simultaneous plot or crop agent dosing. In any case, what all the aforementioned variations of crop scouting have in common is the best possible resolution and a possibility to scout and dose the pesticides and fertilizers with a variable rate.

As carriers of spectrometric sensors, for agricultural purposes unmanned aerial vehicles (UAVs) are also used. They are better known as drones (although drones also include remote-control vehicles that move on land or water). These are low-flying aircraft controlled by navigators or pilots who remotely send signals from the ground or from an autonomous aircraft flying by the memorized data set in advance. A sensor and an aircraft constitute an unmanned aircraft system (UAS) for aerial crop scouting, so this type of scouting belongs to the so-called aerial photogrammetry. With the installation of multispectral sensors for agricultural purposes, it is possible to do the sampling as many times as the client requires, even several times in one day. Scouting is most frequently done by using dedicated software to choose a region to be scouted (a field, for example), then a desired route of the unmanned aerial vehicle is set, as well as the imaging frequency. After that, an unmanned aerial vehicle circles the region by the set route and does the sampling, or imaging. This is how the so-called autonomous mission is achieved. The resolution of the images obtained is of the order of magnitude of several centimeters. For agricultural purposes, fixed wing unmanned aerial vehicles and unmanned aerial vehicles with propellers are used, with the number of propellers typically being four. The former group of aircraft is quicker and more resilient to the wind, which generally presents the biggest obstacle in using drones for crop scouting. Rain is also an extremely unfavorable atmospheric phenomenon during scouting. In terms of spectrometry, these systems are typically equipped with a light sensor, which means they are more independent of daylight than the sensors normally used on agricultural machinery. Of course, in addition to their speed, one of the greatest advantages of drones as spectrometric sensor carriers in comparison with the agricultural machinery is their independence of the state of the soil during scouting, so while scouting muddy terrain or flooded fields drones are employed perforce [14].

Satellite remote sensing is by far the fastest way to monitor fields and crops, but due to a low resolution of sampling ranging from several meters to several dozen meters, the usability of the maps and data they provide is limited. Although a big advantage of determining plant reflectance indices using satellite images is an ability to obtain data for vast regions, there are a number of disadvantages of this method. If the sky is overcast, it is impossible to obtain the data on plant spectral reflectance. Another disadvantage is a low frequency of sampling (depending on the frequency of the satellite flyovers over a certain territory and the time needed for data processing). Depending on the satellites used and the area monitored, the sampling periods range from one day to several weeks. One more disadvantage is that multispectral cameras installed on the satellites do not have fixed filters; that is, it is not possible to alter light spectra in which sampling is performed. All these disadvantages may pose a problem when it is necessary to do crop scouting very frequently (sometimes several times a day), and for this reason monitoring state of the plants using satellite imagery is most frequently used to monitor the effects of climate change on the flora. Satellite imagery is mostly used for the initial detection of the bad state of the soil in terms of the presence of water in the plots, presence of wider areas with crop stress induced by insect invasion, presence of an extreme deficiency of a nutrient, or presence of widespread plant diseases and/or weeds. When a satellite image suggests or identifies any of the alarming states, other available and feasible measures involving more detailed scouting are taken.

5. CONCLUSION

The speed of spectrometric imaging of arable land with crops or orchard plantations with an aim of scouting directly affects the efficiency of the operation itself. The height from which scouting, or imaging is performed, is indirectly related to the precision and detail (resolution) when locationally specific values of vegetation indices are represented. Resolution is manifested by an actual area of a real plot per a corresponding pixel of a digitally mapped image. The expected areas of implementation of all four types of spectrometric crop scouting are depending on the desired speed or scouting precision.

Leading manufacturers of GPS equipment for agricultural machinery focus on the design and functionality of their devices predominantly in the domains of sensors and electronics. Spectrometric crop scouting sensors are delivered in sets including the controlling module and the corresponding cabling. These sets comprise autonomous systems for spectrometric crop scouting. An unanswered question and an unresolved issue that remains is the installation of sensors and their adequate positioning in order to perform optimal crop scouting, to measure the reflected electromagnetic waves, and to do the final calculations of vegetation indices based on which maps of crop nitrogen content are generated.

A specifically designed and manufactured tractor platform for spectrometric crop scouting should have a simple, adjustable construction.

These are the features of a simple construction:

- light weight of a machine
- easy handling and maintenance
- no hydraulic system to operate the wings, as it increases the complexity and the cost of the platform itself

Adjustable construction means

- it is possible to raise the platform wings to the transport position and to lower them to the working position together with the sensors, while there is a quick and simple way to secure the wing position

- it is possible to attach the platform to tractors of all brands and types, considering the types and dimensions of the tractor lift mechanism, as well as how modern the tractors are, meaning how ready they are to support GPS technology
- it is possible to adjust the spacing between the sensors and the crops
- it is possible to adjust the spacing between the sensors, which enables the scouting of the crops with different row spacing
- it is possible to disassemble the platform to its constituent parts easily, to pack them in a small space, and to transport them to distant locations

It is estimated that serial production of these platforms is feasible in all production conditions, and that their availability on the market will encourage and by all means improve crop scouting procedures with autonomous systems for spectrometric crop scouting, motivating indirectly the implementation of the concept of precision agriculture in the regions where the effects of GPS technology on agriculture are still not significant enough. This task above all falls to mechanical and agricultural engineers. Hand-held crop scouting sensors are sufficiently developed in correlation with their usability, while the development of aerial monitoring systems awaits aerospace and electrical engineers.

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