PRECISION AGRICULTURE, THE ROLE OF AGRIDRONES FOR A SUSTAINABLE FARMING ENVIRONMENT. A REVIEW

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Abstract

Unmanned Aerial Systems have an essential contribution to the development and improvement of precision farming (agriculture-4.0). Monitoring the vegetation status of agricultural crops is the main factor in precision farming management. One of the methods used to make decisions at the right time is the use and analysis of crop vegetation indices. UAS monitored values of vegetation indices are calculated by measurement reflectance of sunlight on the surface of crops, values related to the state of development and health of plants. The processing of data recorded for monitored crops can be done online or offline and, depending on the correctness of their interpretation, managerial decisions can influence the ROI indicator of the farm.

Keywords: *agriculture-4.0, UAVs, monitoring crops, AI, analysis of agricultural processes*

INTRODUCTION

The concept of sustainable development is defined in the Brundtland Report by the World Commission on Environment and Development (WCED) as follows: “sustainable development is the development that seeks to meet the needs of the present, without compromising the ability of future generations to meet their own needs”, [1]. So, sustainable development aims to find a stable theoretical framework for decision-making in any situation where there is a human-environment relationship, whether it is the economic environment, the environment or the agricultural environment. Currently, industrial-technological development has allowed agriculture to jump from level 3.0 (three) of development to level 4.0 (four) with major implications for sustainable agriculture. Future perspectives of farming, through Artificial Intelligence and Claud Data Bases converge towards agriculture-5.0.

Precision agriculture or agriculture-4.0 is no longer a new concept in the management of operations using agridrones (aerial systems to measure, observe and respond to crop variability) and/or other mechatronic systems (SRS) available for resource efficiency even in cases where they are limited; farm safety for maximum production yield and ensuring the sustainability of the agricultural process; reports and real-time response to the vegetation process of agricultural crops; reducing environmental pollution to near "zero pollution".

The increasingly frequent use of agridrones has as objectives: obtaining high-quality productions; optimization of ROI economic profit; integrated environmental protection (we conclude: to produce more and quality with minimal expenses in a human-friendly environment). By using drones in agriculture, farmers can benefit from maps containing information about signs of vegetation. With these maps, farmers can spray fertilizer only if the soil is poorer, can only irrigate drier areas, and can only treat plants that need protection from pests. In this way considerable savings are made, the plants will be healthier and higher yields are obtained from the monitored crops. The technological agricultural flow represented schematically in Fig. 1 includes the following operations from (a) to (h):

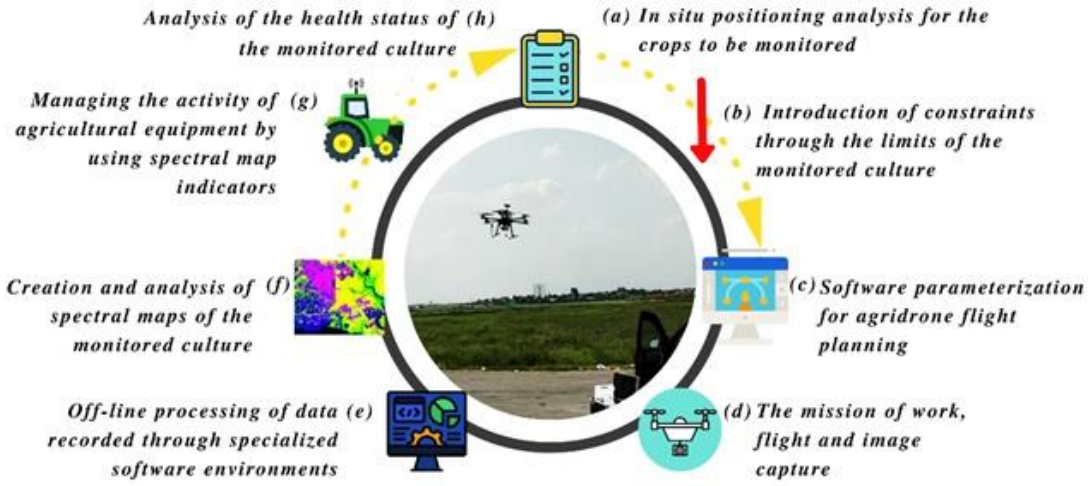


Fig. 1. Schematic diagram of use agri-drones in agriculture-4.0

Basically, a closed circuit is established in this flow, which works in a few simple steps: cause, effect, analysis, planning of technological operations for monitoring crops with agridrones, application of measures and finally verification of the results obtained.

On a global scale, the use of UAS in agriculture is constantly increasing, because compared to other methods of aerial monitoring, agridrones generate more and more accurate data, at low costs, on the state of crops. The economic nature of agridrone use is not to be neglected. Thus, the monitoring of agricultural crops in areas with a size of less than 100 [ha] is indicated to be done with UAS which are much cheaper than the surveillance service performed utilizing "ultra-light aircraft" or satellite imagery. The data obtained through agridrones are stored in the farm PC and analyzed offline through a specialized programming medium. The results obtained are used by the farm manager and/or by a master operator in an adapted way to improve the performance of the farm operation.

As in any other field of human activity, information is vital in terms of developing entrepreneurial capacity and monitoring accurately and in real-time what is happening to cultivated arable land and the evolution of agricultural crops. The use of high-performance equipment and systems in agriculture is a huge advantage in terms of return on investment (ROI). Thus, permanent updates are made regarding the information on the state of the crops, a concept that falls in the field of precision agriculture. This complex concept has multiple advantages, both for farmers and the health of their crops, such as crop density / poor sowing; plant growth ratio; crop variability; the needs of the input lots (water, fertilizer, etc.), [2].

By mapping the targeted arable area, the following aspects can be managed much better:

- Control of the quantities of fertilizers applied, implicitly can be observed the areas where more attention is needed in terms of pollution or reduction of the amount of waste that could have a harmful effect on the environment (sustainable agriculture);
- Neutralization of harmful plants (weeds) that can infiltrate crops, consequently measures can be taken quickly to act to eliminate them and resolve the situation;
- Early detection of diseases and pests of agricultural crops leaves farmers the opportunity to adopt the best solutions to reduce them in a timely manner.

The role of agridrones is therefore crucial in precision agriculture for sustainable agriculture. Aerial monitoring of crop vegetation status is a major factor in precision agricultural management. The health status of agricultural crops is analyzed based on vegetation indices determined by reliable measurements performed with optical sensors installed onboard UAS aerial platforms. The following

are the current validated methods and software programs dedicated to determining these indicators and making spectral maps.

1. Methods for monitoring the vegetation condition of agricultural crops

The monitoring of agricultural crops is done by remote sensing with the help of optical sensors installed onboard the UAS platforms. Oriented to the surface of the agricultural crop to be monitored, the optical non-contact sensors determine, using the electromagnetic radiation reflected or emitted by plants, the state characteristics of their health. In Fig. 2 it is shown the range of the electromagnetic spectrum with the positioning of the NIR band used in the remote sensing of vegetation. The spectral range of near IR (NIR) and short IR is sometimes called reflective IR (0.7 ÷ 3) [μm] because the range is influenced more by solar reflection than by telluric emission, [3].

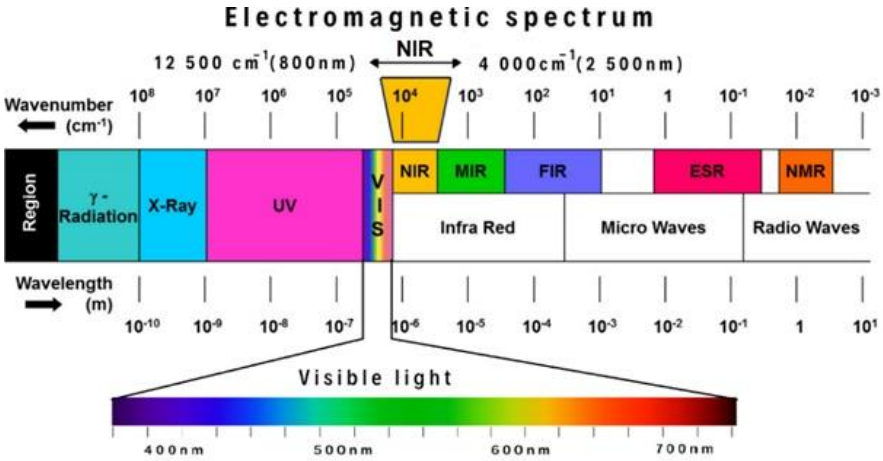
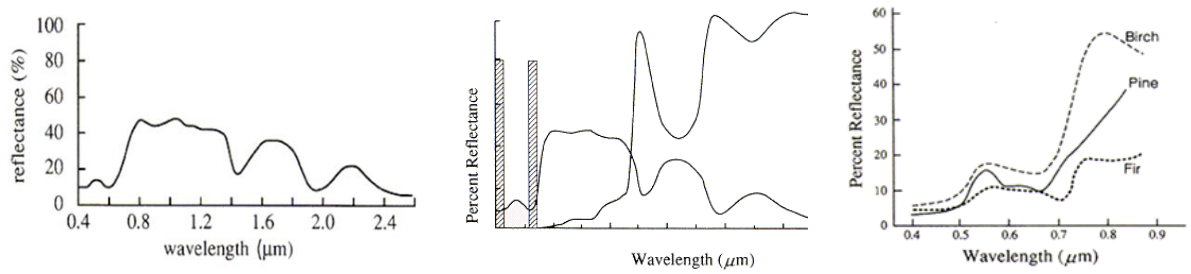


Fig. 2. The field (λ) wavelength range of the electromagnetic spectrum with the positioning of the NIR band used

Albedo is defined as the reflectance when the incident light source is the sun. The reflectance per unit wavelength is called *spectral reflectance*. Basically, it is a unique feature for each object in remote sensing. *spectroscopy* NIR is widely used today in agriculture to determine the quality of feed, cereals and cereal products, oilseeds, coffee, tea, spices, fruits, vegetables, sugar cane, beverages, fats and oils, dairy products, eggs, meat, and other agricultural products. It is used to quantify agricultural products' composition because it meets the criteria of being accurate, reliable, fast, non-destructive, and cheap.

Vegetation has a unique spectral signature, which allows it to be quickly distinguished from other types of surfaces in a NIR optical image. Vegetation reflectance is low in both the blue and red areas of the spectrum, due to chlorophyll absorption. In the NIR area, the reflectance is much higher than in the visible band, due to the cellular structure of the leaves. So the vegetation can be recognized by this characteristic of the reflectance shown in Fig. 3.a) and in Fig. 5.a).



a b c

Fig. 3. Spectral reflectance: a) of vegetation; b) a green leaf; c) of different types of plants and / or trees (birch, pine, fir)

It is shown in Fig. 3.b) a comparison between the reflectance of the leaves and the absorption of water. The chlorophyll contained in the leaves has a strong absorption at 0.45 and 0.67 [μm] and a strong reflectance in NIR at 0.7 ÷ 0.9 [μm]. This produces a slight maximum at 0.5 ÷ 0.6 [μm] (green band), which makes the vegetation appear green. The NIR range is extremely useful for vegetation observation and mapping, especially because the pronounced reflectance gradient from 0.7 to 0.9 [μm] is produced only by vegetation. Due to the water content of the leaves, there are two absorption bands at 1.5 and ~1.9 [μm]. This observation is mainly used to monitor the development stage of crop vegetation. The spectral reflectance curves of some different vegetation species are presented comparatively in Fig. 3 c), [3].

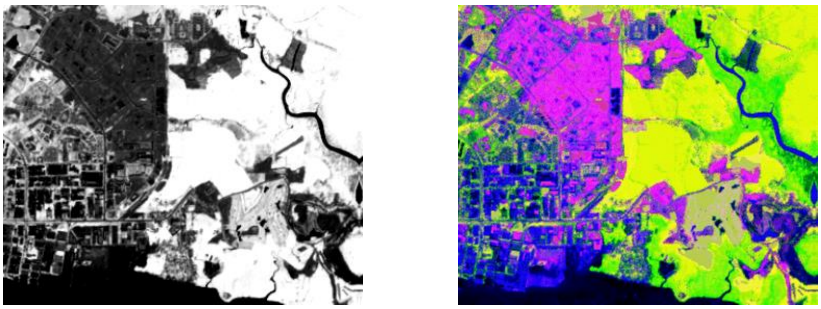
A multispectral image consists of several data bands. For viewing, each strip may be represented in turn as a black-and-white image, or, in combinations of three simultaneous bands, as a colour-composite image. Interpreting a colour-composite multispectral image requires knowledge of the spectral reflectance signature of the targets in the landscape. In this case, the content of the spectral information of the image is used for analysis and interpretation. In a colour-composite image, three fundamental colours are used (R - red, G - green, and B - blue). When these three colours are combined in different proportions, they produce different colours in the visible spectrum. Associating each spectral band with a fundamental colour (R, G, B) results in a colour composite image. The method of combining colours is used in practice to accentuate areas with vegetation. One such combination is the ratio of NIR to red (RED). This report is known as the *ratio vegetation index* (RVI) and is given by relation (1):

$$RVI = {}^{NIR}/_{RED} \tag{1}$$

As the vegetation has good reflectance in the NIR, but low in the red range, the areas in the near IR will produce high RVI values compared to the areas without vegetation. To avoid this, we moved on to another vegetation index used, namely *the* Normalized Difference Vegetation Index (NDVI), calculated with the relation (2):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{2}$$

An NDVI image (see Fig. 4.a) is an image in which the bright areas are covered by vegetation, and the other areas (buildings, river, sea) are generally dark. You can clearly see the trees lined up along the roads, in contrast to the dark background.



a) NDVI b) Imagine colour-compusă

Fig. 4. Images captured with UAS platform model SPOT, [3]

The NDVI band can be combined with other bands of the multispectral image forming a colour-composite image that helps to distinguish different types of vegetation (see Fig. 4.b). In this image the colour display is made according to the following scheme, given by the relation (3):

$$\begin{cases} R = XS3, & \textit{NIR spectral band} \\ V = (XS3 - XS2)/(XS3 + XS2), & \textit{NDVI spectral band} \\ A = XS1, & \textit{Green spectral band} \end{cases} \quad (3)$$

where:

XS3 – represents the spectral band NIR;

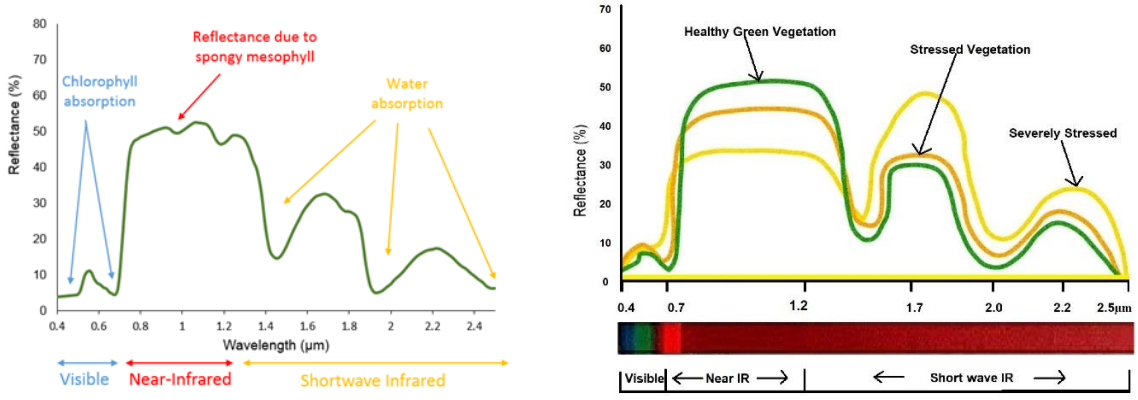
XS2 – represents the spectral band Red;

At least three types of vegetation can be distinguished in this image: areas with green, yellow and golden yellow. The green areas consist of trees though. The yellow areas are covered with shrubs or rarer trees, and the golden yellow areas are covered with grass. Areas without vegetation appear in dark blue or indigo. Geometric and contextual information helps to interpret and process recorded images. The use of geometric and contextual aspects for the interpretation of images requires some preliminary information about the area of interest. Thus, the commonly used "keys of interpretation" are shape, size, structure, location and association with other familiar aspects. They can play an important role in interpreting very high-resolution images. [3].

The method frequently used today in precision agriculture to make decisions at the right time, involves the use of vegetation indices, values calculated by measuring the reflectance of sunlight on the surface of plants and correlated with their development and health. The collected data will represent inputs (input data) of a software system (dedicated programming medium) that will calculate vegetation indices, georeferenced (correlation with the geographical position of coordinates area where the data were collected) and will be able to generate automat, maps of favourability and risk, providing an interpretation of them. The monitoring of resources and vegetation status is performed with non-contact sensors, the automatic data acquisition being correlated with GPS coordinates and their processing in the GIS system for making the necessary maps in spatial and precision management. Detection, identification, and quantification of crop diseases are done by monitoring with optical sensors, the best results are obtained by thermography, chlorophyll-fluorescence, or with multi- and hyperspectral sensors.

When solar radiation encounters a surface, it can be absorbed, reflected or transmitted to a certain extent. The surface of the plants will affect the solar radiation differently, in the sense of the three mentioned actions, depending on its state of vegetation. This principle is the basis for identifying terrestrial surfaces with vegetation and even for determining the state of health or development of this vegetation. Using spectral information, it is possible to identify in advance the stress state of plants due to lack of water, diseases or pests, thus allowing farmers to intervene promptly. The level of stress

can be noticed by a progressive decrease of the reflectance in the NIR field, accompanied by an increase in it in the SWIR field.



a) b)

Fig. 5. a) Details regarding the vegetation spectrum; b) Reflectance curves for plant stress level spectral fingerprints

The spectral fingerprints are highlighting the stress level of the plants (see fig.5.b) from which we can distinguish the following cases, [4]:

- Green curve - healthy vegetation;
- Orange curve - stressed vegetation;
- Yellow curve - heavily stressed vegetation.

Plant stress level spectral fingerprints are usually implemented in specialized programming environments for crop monitoring. We exemplify with GeoSCAN software, which provides information about the evolution of crops in real-time, so you can evaluate areas with different productivity through the vegetation index.

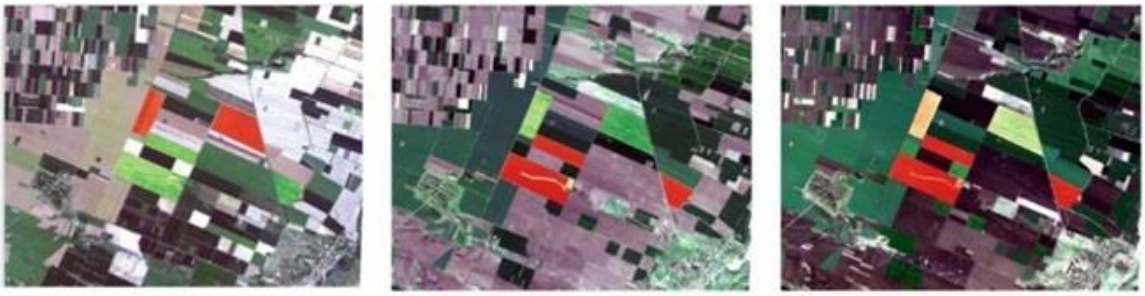


Fig. 6. Updated maps of the cultivated plots obtained with the GeoSCAN program, [4]

It is shown in Fig. 6 mapping the maps of crop plots in a monitored area. Interpretation of these high-resolution images will be based on geometric and contextual information.

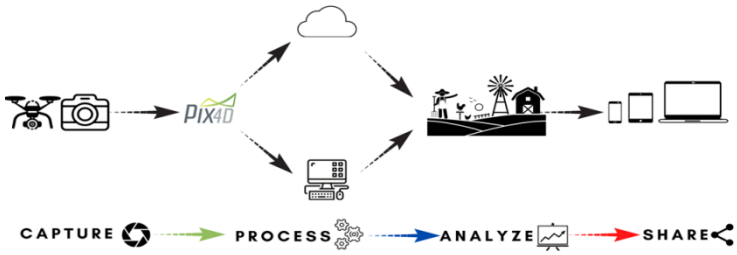


Fig. 7. Architecture of data flow processed by Pix4D software, [4]

Another programming medium, frequently used by farmers is the Pix4D program. This software converts multispectral images by evaluating areas with different productivity through vegetation indices such as NDVI. Using color-composite RGB images, the software generates other high-resolution orthomosaic images. It is shown in Fig. 7 schematically, the information flow of monitoring process from agridrone to farmer's PC (image capture, RGB data processing, analysis of recorded data, distribution of information to farming operator).

2. Sustainable operational practices for a sustainable farming environment

The use of UAVs for scientific purposes to ensure sustainable development is currently a global concern. Precision agriculture, through the role of agridrones, contributes in this respect to a sustainable farming environment. We further report, for example, sustainable operational practices that attest to man's concern for nature in general and for the agricultural environment in particular.

2.1. Surveillance of the coastal zone environment (Romania)

The stages of surveillance, design, implementation and monitoring of coastal hydro-technical protection structures are based on the coastal erosion surveillance program. This program consists of collecting and storing data, by performing specific measurements in order to create a complex database, information support for the development of studies and research in coastal engineering and geomorphology, in order to optimize the design and sustainable implementation of control solutions of erosion. The study of arable lands adjacent to the area was also considered. Drones with a monitoring camera offer researchers a panoramic view of the elements of the coastal environment under investigation, the data collected are quantitative and qualitative. The quantitative ones are determined with precision photo-grammetric equipment, then they are processed with dedicated software and stored in electronic format in the database. Qualitative data consist of investigations and visual observations, made by detailed photography and video recording. For each flight, ~15 min., ~2000 photos are collected that are composed in mosaics, are georeferenced by computer methods with specialized software (Pix4D, EnsoMosaic) and subsequently the data obtained, represented by aerial photographs, DSM/DTM, NDVI images and other reflectance data are analyzed for identification important, significant aspects regarding the evolution of the elements of the coastal system subject to erosion and the adjacent agricultural environment, [5].

2.2. Monitoring the „Small Lake of Brăila" (Romania)

In the Natural Park "Balta Mică a Brăilei" a unique renaturation project was implemented, worth 1.70 M€. This project is unique in Europe in that the park administration, in collaboration with institutions in Norway and the University of the Lower Danube at Galati, is studying the area with special drones, guided in air and water, to find the most efficient solutions. unclogging, so that the lakes in the floodplain area regain their former dimensions. Drones equipped with state-of-the-art equipment are used to collect data from the territory, without disturbing bird and fish populations. The monitoring equipment (worth ~K€400.00) purchased within the project is used by specialists from the University "Dunărea de Jos" of Galati for the sustainability of the ecosystem in Balta Mică a Brăilei as well as for aquaculture and other agricultural environments in the monitored area, [5].

2.3. Drone-monitored vineyards (Republic of Moldova)

In recent years, 20% of vineyards in the Republic of Moldova have been affected by the disease. Viticulture specialists could not find out how the plague (direction, speed) spreads, because it was impossible to check hundreds of thousands of hectares of vineyards at the same time. Aerial filming of vineyards with drone UAVs was used. Currently, the vineyards in the Republic of Moldova are monitored with aerial drones equipped with a multispectral camera (invention of a NASA researcher). The data collected by monitoring reach a University of Canada for analysis, after which the results are transmitted to the Virology Laboratory of the Institute of Horticulture of Moldova. The implementation of the project on the application of these advanced technologies takes place with the support of the US Agency for International Development and the Government of Sweden. The cost of a drone is ~$23,000. The Republic of Moldova has become the second EU country, after France, to benefit from aerial observations to monitor the health of vineyards. Project is successfully part of sustainable operational practices for a precision farming environment, [5].

2.4. Research on aerial mapping of agricultural crops (INMA - Bucharest), [4]



a) b)

Fig. 8. Aerial mapping of agricultural crops by specialists INMA- Bucharest; a) Aerial aeronautical spectral monitoring UAS; b) System with video-live ground telemetry, portable

Through the national NUCLEU Program (2018), the National Research and Development Institute for Machinery and Installations for Agriculture and Food Industry – INMA Bucharest executed under the national contract PN 18300101 – „*Innovative technologies and systems for the production of bioresources*", the project entitled *„Experimental research on aerial mapping of agricultural crops according to the concept of agriculture-4.0"*. Within this project, the was acquired the UAS platform as "edge-technology", an aerial agronomic spectral monitoring system used in the farming and forestry field. With this type of agridrone, vegetation assessment flights can be performed in the infrared spectrum in order to highlight early changes in plant health, before they become evident in the visible spectrum. It is shown in Fig. 8 images with the UAS platform used during the experimental operations in the monitored agricultural area.

The aerial UAS spectral monitoring system, agridron model consists of the following:

- Tilt camera stabilization support; Roll with brushless motor and vibration damper;
- Mapir Survey 3 camera with built-in GPS; Agricultural drone, hexaotor multicopter type FAE750H;
- Mapir camera radio-controlled shutter release; 2.4 GHz digital radio station, 16-channel receiver, range 3 [km];
- Computer telemetry system of flight parameters and location on the map; Radio station battery;
- Professional laptop with Mission Planner navigation software;
- Software license for the Agisoft Photoscan photo processing environment;

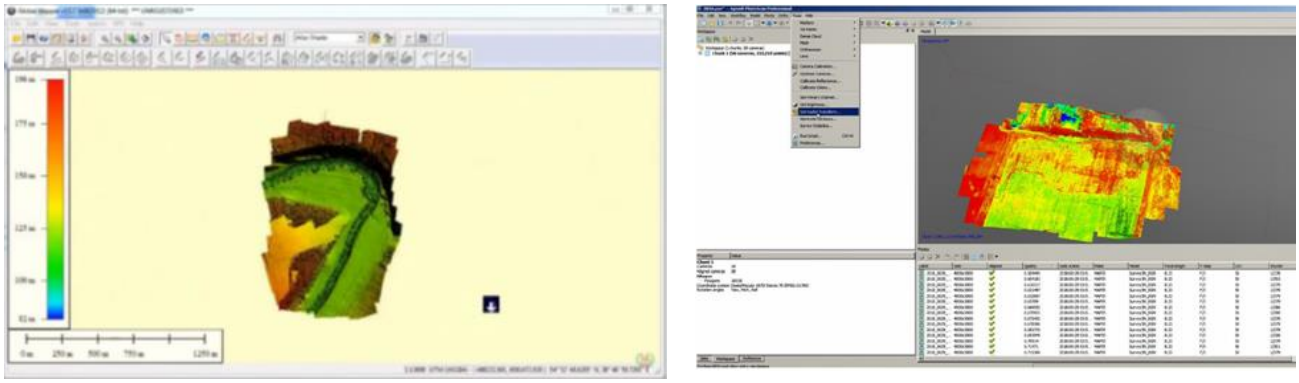
- Li-Po battery charger with cell balance of 1000 [W]; Li-Po battery: 3 x Li-Po 6S 10000 [mAh];
- Video transmission system *live* ground, portable, with telemetry (includes 3000 [mA / h] 3s battery, 8" PAL display, control recorder, receiver, 2 [m] stand for all ground equipment, circular antennas with circular polarization; Transport box and accessories.



a) b)

Fig. 9. Agridron piloting for aerial mapping of agricultural crops: a) Mission Planner flight parameterization; b) The mission of monitoring the researched culture; 1 - live flight monitoring screen; 2 - flight parameters configuration screen; 3 - agricultural crop location screen; 4 - flight altitude set for monitoring

The mission of working with the agridrone type aerial monitoring system for obtaining the spectral maps is done according to the flight preparation and realization procedures described in the operation manual of the UAS platform. For an experienced operator (routine min. 5 flight hours) piloting the agridrone is simple and efficient. It is shown in Fig. 9 two of the flight stage slides. And Fig. 10, it's shows the spectral maps obtained by aerial mapping.



a) b)

Fig. 10. Spectral maps obtained by aerial mapping: a) Spectral map of the analyzed region; b) NDVI map of the vegetation surface of the monitored crop surface, [4]

After the aerial monitoring online of crops, we move to the stage of processing offline recording data for the production of spectral maps. These maps are made in stages by processing images obtained using Agisoft PhotoScan software. The export of ortho-photogram in geographical projection was done in order to obtain the georeferenced map of the monitored crop area. The spectral maps obtained (see Fig. 10) following the processing of images recorded by the multispectral camera onboard agridrone contain information on the state of vegetation of crops. This information will be evaluated in the next and final stage, "decision analysis".

3. Preliminary discussions on the sustainability of the farming environment

This paper reviews the current state of agricultural processes so that farmers can make optimized decisions to save money while protecting the environment and sustainably transforming food production with future population growth. Valuable benefits (ROI optimization) come with objective information obtained through sensors and monitoring devices, to maximize productivity and sustainability. Precision farms based on data (input/output) through the transfer functions of the farming process can increase efficiency by avoiding misuse of resources and environmental pollution. It's shown in Figs. 11 the eAGRI-EASY concept for horticultural farms based on the "Farm to Fork" strategy.

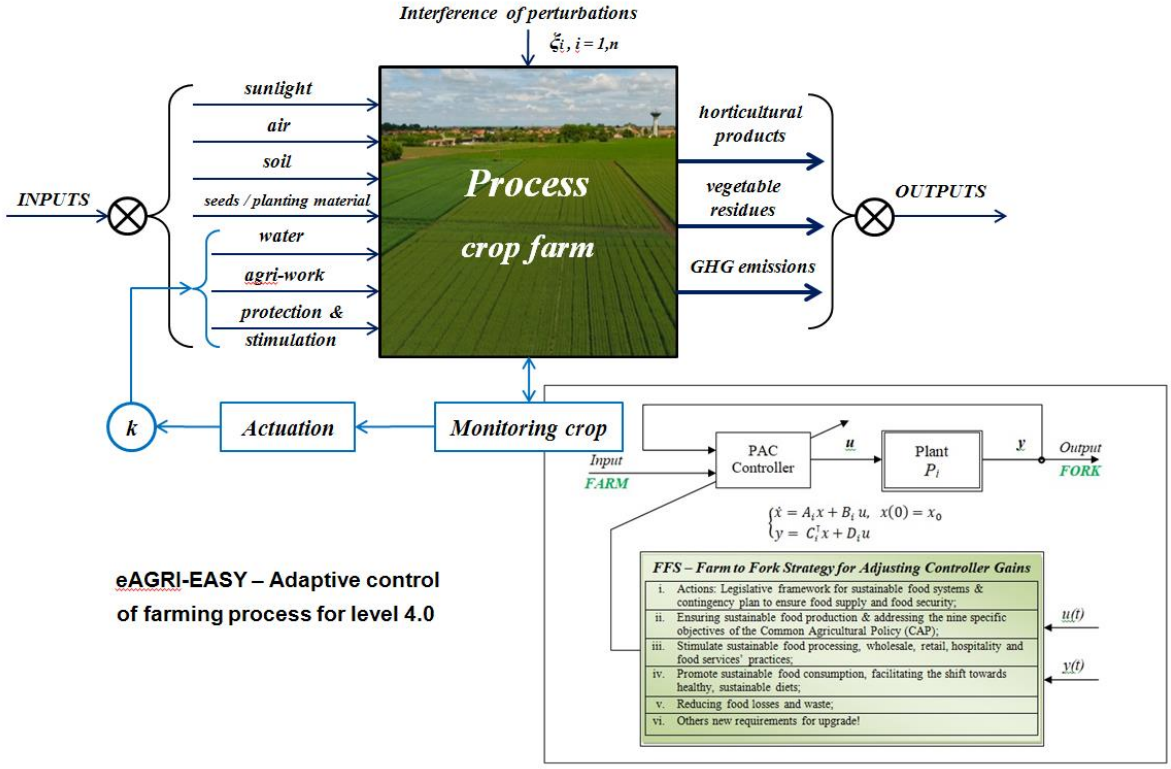


Fig. 11. Inputs / Outputs of the process for a sustainable crops farm

After the Industrial Revolution, especially since the advent of mechanization and during the Green Revolution, farmers and their machines collaborated effectively to cultivate crops with a tendency to farming digitize. The following points summarize some of the specific ideas extracted from other reference studies:

- *Integration of a monitoring and centralized warning system on technical equipment designed to phytosanitary treatments in the concept of precision agriculture*, [6];
- *Realization of agricultural maps experimental models by determining the electro-conductivity in concept of precision agriculture*, [7];
- *Comparative study regarding the sowing precision of precision sowing machines distribution devices*, [8];
- *Determination of sowing precision in simulated laboratory conditions*, [9];
- *Creating Agricultural Productivity map Models on Different Romanian Soil Textures Through the Concept of Precision Agriculture*, [10];

- *Applications and perspectives of using drones in precision agriculture*, [11];
- *Experimental researches on determining the qualitative working indices for vegetable and leguminous plants sowing machine on sandy soils*, [12];
- *Considerations on the construction and operation of a device for soil modelling in interrupted furrows for weeding crops*, [13];
- *Drones and windbreaks*, [14].

A new approach driven by digital technology implies that growers must act as supervisors of their crops rather than as workers, thus avoiding repetitive, demanding and tiring tasks in the field. In this modern farming framework, Agri-Data-Bases are key, and the information-based management cycle described below (see Figure 12, [15]) provides the practical approach that unites the eAGRI-EASY concept and farming tasks.

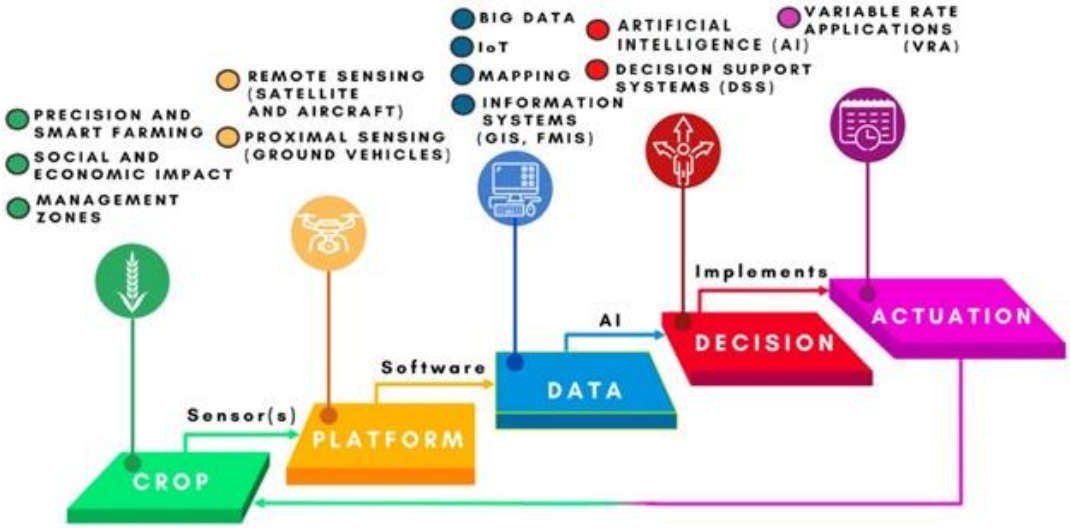


Fig. 12. Architecture of flow process toward agriculture-5.0, [15]

Agriculture based on big-data bases of crops and farming environment, with the aid of SRS that incorporates AI techniques, lays foundations for sustainable agriculture of the future (agriculture-5.0).

CONCLUSIONS

Agriculture-4.0 is made with agridrones and other mechatronic systems (SRS) available to increase the ROI, ensure the sustainability of the farming process and reduce environmental pollution near to "zero pollution". So, the role of agridrones as UAS platforms is crucial in precision farming for sustainable agriculture. Aerial monitoring of crop vegetation status is a major factor in precision agricultural management. The health status of crops is analyzed based on vegetation indices determined by reliable measurements performed with optical sensors installed onboard agridrones. The monitoring of the resources and the state of the vegetation is performed aerially with non-contact sensors, the automatic data acquisition being correlated with the GPS coordinates and their processing in the GIS system for making spectral maps, all necessary in spatial and precision management. Detection, identification, and quantification of crop diseases are therefore done by monitoring, the best results are obtained by thermography, chlorophyll-fluorescence, or with multi- and hyperspectral sensors.

Basically, by aerial mapping of the arable area concerned, the following technological aspects of agricultural crops can be managed much better:

- Control of applied fertilizers, implicitly can be observed areas where increased attention is needed in terms of pollution or reduction the amount of waste that could have a detrimental effect on the environment;
- Neutralization of harmful plants that can infiltrate crops, consequently measures can be taken quickly to act in order to eliminate weeds and solve the harmful situation;
- Early detection of diseases and pests of agricultural crops leaves farmers the opportunity to adopt the best solutions to reduce them promptly.

After the online aerial monitoring of agricultural crops, we move to the stage of offline processing of recording data for the production of spectral maps. These maps are made by processing images using a dedicated programming medium. The spectral maps obtained from the processing of images recorded by the multispectral camera onboard the agridrone contain information on the state of crop vegetation. The evaluation of this information is performed only by personnel or programming medium specialized in the processing of experimental data so that decisional analysis is correct. The degree of confidence increases in proportion to the decrease of the degree of uncertainty and this is obtained only by developing the application of aerial mapping to several types of agricultural crops. The use of UAS platforms to ensure sustainable development in agriculture is currently a global concern. The examples of sustainable practices described in this paper are few compared to national concerns in the field of precision farming. The dissemination of sustainable operational practices that attest to human concern for nature in general and for the agricultural environment, in particular, falls into the category of good BKT practices.

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