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Sensors and Their Application in Precision Agriculture

Mladen Jurišić*, Ivan Plaščak, Željko Barač, Dorijan Radočaj, Domagoj Zimmer

Abstract: The paper depicts sensors in precision agriculture. It encompasses the most significant and frequently used sensors in agriculture. Furthermore, the paper explains the main sensor types according to their design, the recorded range of electromagnetic spectrum, as well as the way of detection, recording, measuring, and representation of the detected energy. The development of remote research has provided deeper understanding of remote sensors and their advantages. The sensors installed on soil testing equipment, fertilizing and crop protection machinery, as well as crop picking machinery have been analyzed relative to precision farming. The paper depicts widely known sensors *OptRx, ISARIA* and VRT technology. The results of the paper assess the data collected by sensors and processed in order to produce maps for agrotechnical operations. The application of maps decreases the employment of human resources, heightens the capacity of data collection, increases the precision of agricultural activities, and finally results in decreasing the cost of final products. The technological progress over the past decade has enabled the development of technology with variable application standards (*VRT*) that, according to current needs, enables input optimization.

Keywords: GIS; maps; precision agriculuture; sensors

1 INTRODUCTION

The basic aim of precision agriculture is to increase the quantity of accurate real-time data that can be deployed by farmers for decision making [1, 2]. Precision agriculture saves time and financial means, and improves crop yield and its quality [3-8]. The authors [9] state that precision farming also serves to improve ecological improvements, reduce environmental burdens and encourage naturally spatial conditions and improve production process documentation. The contemporary agriculture machinery is already equipped with sophisticated technology so the machine operator can get a direct and prompt insight into the farming area, monitor plant development and assess soil conditions [10]. In the future, almost all agricultural farms will be able to use information technology such as the global positioning system (GPS), geographic information systems (GIS), as well as the technology of precision agriculture and navigation systems [11].

The application of various sensors establishes and records the real- time parameters of production processes. Using modern sensors it can causes of operational efficiency as well as inefficiency can be accurately determined [12, 13]. The implementation of precision agriculture has made possible due to the development of sensing technology. Also precision agriculture is possible with the mapping of variables pertaining to a specific agrotechnical operation such as ploughing, sowing, fertilizing, plant protection, and harvesting. The application of optical sensing results in significant savings that make agriculture more profitable [14, 15]. The sensors that facilitate a simple collection of spatial and meteorological data are the principal element of precision agriculture [16].

Depending on the method of the conversion of a physical measurand into measurement information there are: first, sensors using analogue converters; second, sensors using analogue converters for the conversion of analogue signals into a signal with a changeable period or frequency; and finally, sensors with analogue-digital converters [17]. The application of sensors in agricultural machinery, i.e. the use of machine vision, provides numerous information on soil condition, plants, pests, and weeds [18]. The data collected in that manner enable an optimal use of resources. The author [18] proposes that the farmers who utilize data in an efficient way will reach higher yields compared to those who do not engage in this practice. The authors [21, 22] state that sensors are part of key technologies that increase the overall productivity, such as GIS and GPS.

2 DIFFERENT SENSORS SYSTEMS

Navigating agricultural aggregates with different sensors such as yield and fuel sensors and similar installed in agricultural aggregates has enabled an accurate data distribution across the data processing area. Sensors are devices used to detect, record, and measure the radiation of electromagnetic energy, their own (emitted energy), as well as reflected energy. Sensors can be categorized according to their design, the registered range of electromagnetic spectrum, the way of detection, recording, measurement, and representation of the detected energy [23]. Sensors can record both wide and narrow spectral regions, individual spectral lines, i.e. the rays of the same wavelength or a series of separated spectral lines encompassing one spectral region. Since sensors are one of the principal components of contemporary electronic circuits and devices, they are frequently produced together with microprocessors to perform multiple functions. According to the type of the detected energy, sensors can be passive or active. The active sensors produce their own energy, send it to the object, and register the reflected radiation. Passive sensors, they just send and receive energy without producing energy. In remote readings, an active sensor is a device which transmits a light signal of a particular wavelength or an electron that is reflected off the target object carrying the data collected by the sensor through its reflection. Sensing technology is used in remote researches for remote measurements or the measurements of the occurrences that are invisible to the naked eye. Passive sensors detect energy emitted by the object itself regardless of whether the object has its own energy, or it transmits it. The main characteristics of sensors are sensitivity, linearity, precision, and resolution of signals.

Sensors convert a physical quantity into either analogue electrical or digital data. They react to conditions, which they convert into output signals [24]. The measurement of non-electrical signals starts with the conversion into the electrical ones and their subsequent processing. The conversion of nonelectrical quantity into an electrical signal requires energy coming from the domain of the signal or outside of it, which is facilitated through physical effects. Most measurement converters has three main parts: a sensor or a source of information; a measurement system or processor; and some kind of display for representation. Sensors use the energy emitted by a special source to create the data representing the measured quantity. The secondary element i.e. the processor processes the signals emitted by the sensor. The system of information representation is part of the measurement converter that produces the measurement output [25]. Agriculture sensors find their application in soil testing equipment, fertilizing and crop protection machinery, as well as crop harvesting machinery. The most frequent types of sensors in current use are electromagnetic and ultrasonic sensors. *LIDAR* and infrared sensors are currently in scientific investigation for agro-purpose. Electromagnetic sensors work on the principle of the dependence of inductance on changes in magnetic resistance. When a metal object gets closer, the magnetic resistance of the coil decrease while inductance increases. The parameters of electromagnetic flow and the characteristics of the object determine the region of detection by electromagnetic sensors. On the contrary, the working principle of inductive sensors is based on the change of magnetic resistance. The main advantages of inductive sensors are the following: resistance to water, oil, dirt, non-metal parts, object colour and roughness, impact, and vibration. Photoelectric sensors work on the principle of the change of parameters (optical signals) together with the changes of the measured physical data (occurrence of photoelectric effect). There are also some differences about the distance from the sensor to the crops. For example, the *SPAD* and the *ClorofiLOG* sensors need to make static measurements, touching the sensors on crop's leaves [26]. The working principle of thermoelectric sensors is based on the measurement of the temperature difference resulting in electric voltage. Their use are common in in biotechnology, medicine, the environment, and the agriculture [27, 28, 29]. Capacitive sensors rely on capacitivity to determine variable values. The change in the distance between surfaces impacts the change of capacitivity. This occurrence is utilized by capacitive sensors to identify the changes in object positioning. Accordingly, the sensor must be placed in the proximity of the observed object (0.25-2 mm). The inductive transducers include measurement tapes used to measure deformations, such as in statically and dynamically stressed constructions. One of the most common capacitive sensor used in precise agriculture for monitoring soil moisture content is *Field Connect* [30]. The working principle of potentiometer sensors is based on the changes of resistance due to changes in the sliding contact. The disadvantage of these sensors is the contact point between the slider and resistance wire. They are used to measure sensor resistance at close distances. Common use in agriculture is in following trajectory [31]. Ultrasound sensors are used to determine distance when the range of the obstacle is

determined by the time necessary for the ultrasound to travel from the object as a reflected wave. According to the research done by the authors [32], ultrasound sensors (Fig. 1) can detect an object from 0.6 to 6 m with the minimal area of the object to be detected of 0,02 m². Their common use in agriculture is in spraying boom height control [30].
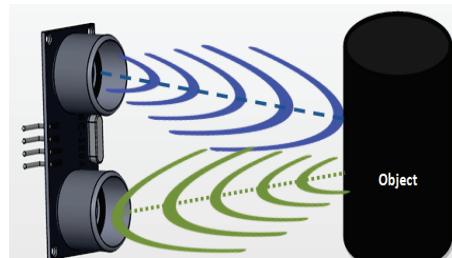
Figure 1 Ultrasonic sensor (Source: https://components101.com/ultrasonic-sensor-working-pinout-datasheet)

LIDAR optical sensors (Light Detection and Ranging) function on the principle of the change of parameters of optical signals in dependence on the change of a measurand. They deploy a measuring instrument that emits laser beams, which in turn, reflect off very tiny particles dispersed in the atmosphere (aerosols, cloud drops), and afterwards get registered by an optical receiver (Fig. 2). Optical sensors are applied in the contactless long-range detections. They are widely used since the object material is irrelevant [23].

Figure 2 LIDAR sensors-left (Source: https://velodynelidar.com/products/hdl-64e/), Infrared sensor-right (Source: https://ctgrow.com/vpd-sensors/25-vpx-3-vpd-infrared-sensor.html)

OptRX system is one of the most widely known sensor systems in agriculture. Sensors are mounted on an aggregate providing direct readings of crop condition and exerting a direct impact on agrotechnical operations. Additionally, *MSP3* is another well-known approach to the measurement of soil characteristics by sensors. The working principle of sensors is the same, whereas, unlike the former system, it requires processing of the collected data through a computer and mapping software. The data can result in various types of maps, which can be later used in agrotechnical operations [23]. Additionally, sensors are widely used by combine harvesters in annual harvesting. Combine yield sensors can be classified as systems for volume measurement, systems for power/impulse measurement, and other indirect measurement systems. Yield sensors deliver measurement values (grain diameter, grain flow, grain quantity), and for each harvested area (it represents the yield) equation calculations are performed [23]. The yield volume measurement system calculates the volume of the crop that flows past photosensors, which register and measure the time

of rays that are either let through or not. This period is calculated using a corresponding algorithm. The system's main disadvantage is the conspicuous inaccuracy of the data produced by measuring on sloping terrains. The systems for power/impulse measuring determine the mass against the time unit based on the power or impulse action of grains. Two finger-shaped sensors attached to a single power/impulse measuring unit are the main components of a sensor. Instead of the finger-shaped sensors, similar systems deploy electrical trackers and a spring plate for measuring the voltage change [23]. Apart from the mentioned systems, there are indirect measuring systems that deploy gamma rays shined towards the radiation detector by a weak source of radiation. Higher-quality sensors mounted on combine harvesters include microwave or infrared-NIR sensors (Near Infrared Reflectance). NIR sensors produce satisfactory results and are widely used for the measurement of moisture and protein content. NIR sensors are the basis for commonly used sensors in detecting plant disease and stresses [33]. For the crop protection is commonly using the application of variabale rate technology (VRT). The *VRT* use in field crops is based on the sensory approach to light reflection measuring from plants and the collected data analysis. By varying the luminous flux on the sensor, which depends on individual plant properties, an electronic signal is sent to the regulator which performs the dosing device opening and the particular medium's application [34]. According to [35] the plant sensor *PRO Active* has a growing impact on modern agricultural concepts. This sensor has been developed for daylight conditions. It consists of two sensor units and a reference sensor attached to the roof to measure the incidence light (the quantity of insolation). The sensor estimates the status of nitrogen and plant biomass. The data are used to calculate the optimal application level in real-time.

3 RESULTS AND DISCUSSION

The above discussed sensors generally deliver data when the machinery is in motion. Some information needs to be additionally processed through computers and mapping software. The processed data facilitate the creation of various types of maps for further use in agrotechnical operations. The obtained values in forms of dots provide the basis for all maps. The first maps of sensor collected values consisted solely of the measured values represented through dots. The measuring points are assigned the colour of the respective yield value. Fig. 3 depicts a dispersible yield map. Using the grid display, algorithms can be applied to create an isometric yield map with the aim of improving the characteristics of maps (Fig. 4). Isometric design improves the visual design; however, it is not applied in precision agriculture as it cannot be applied to the contemporary machinery. The results acquired by *MSP3* are read by *FieldFusion* software used for measurement of pH soil values (Fig. 5).

OptRx sensor uses the wavelengths of 670, 730, and 760 nm to calculate NDVI and NDRE. *OptRx* sensors are not sensitive to ambient lighting and can consequently be used both during the day and night-time. Additionally, they belong to few sensors that combine more than six values. A sensor must be able to discover crop stress (for crops such as potato

and wheat) in early and later growth phases as well as to record exact VI values under the dusty field conditions. Plant growth significantly impacts the change of reflexion. Fig. 6 shows that it is necessary to change the red border in later growth phases and maintain the comparison of healthy against unhealthy plants when plant sensors read only the red light with the reflexion change being significant due to plant growth. The *OptRx* sensor manages this situation in the most reliable, practical and economical way on the market. The results show the relation between NDVI and NDRE and a kilogram of nitrogen per hectare (Fig. 7). The *OptRx* sensors have displayed their ability to discover crop stress, e.g. in potatoes and wheat, during the earlier and later growth phases. A major advantage of the *OptRx* sensors is the recording display of the exact value of VI in field conditions (Fig. 8).
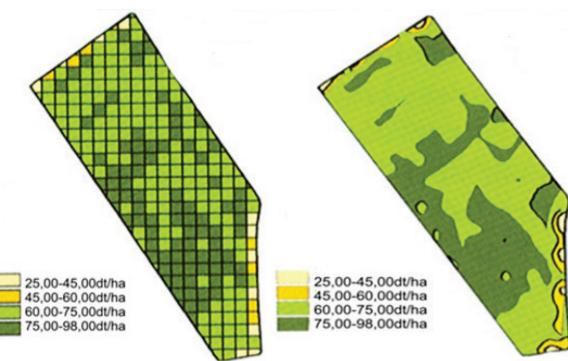

Figure 3 Scatter yield card-left, **Figure 4** Outline map of yields (Source: http://polj.savetodavstvo.vojvodina.gov.rs/sites/default/files/precpoljplascak.ppt)
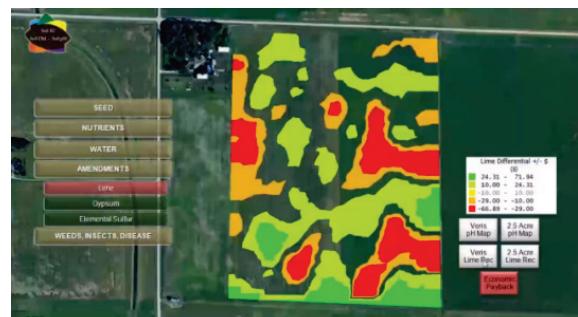

**Figure 5** Example of soil pH measurement results
(Source: https://veristech.com/the-solutions/fieldfusion%E2%84%A2)
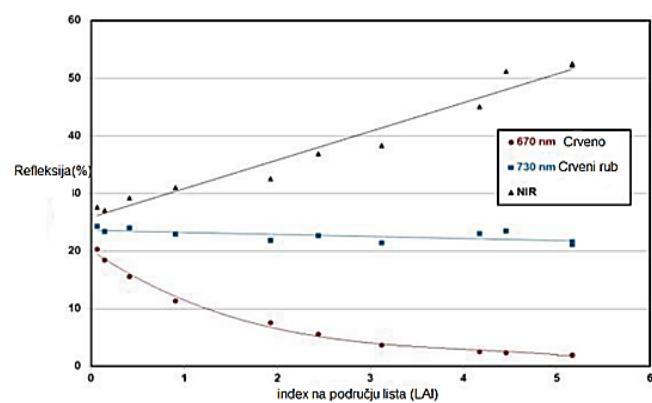
Figure 6 Reflection / Index diagram in the sheet area
(Source: Hans Stiekema Ag Leader Europe)
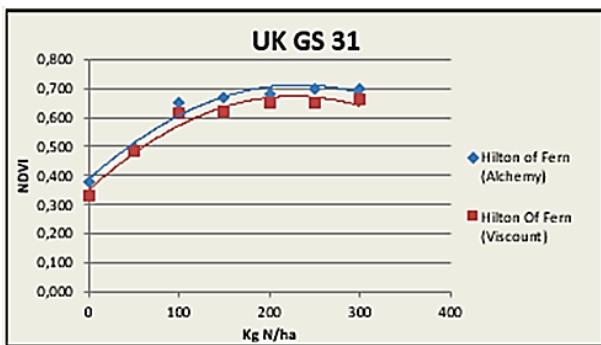
Figure 7 Diagram NDVI / kg nitrogen per hectare
(Source: http://www.findri.hr/agleader/download/OptRx_2012.pdf)
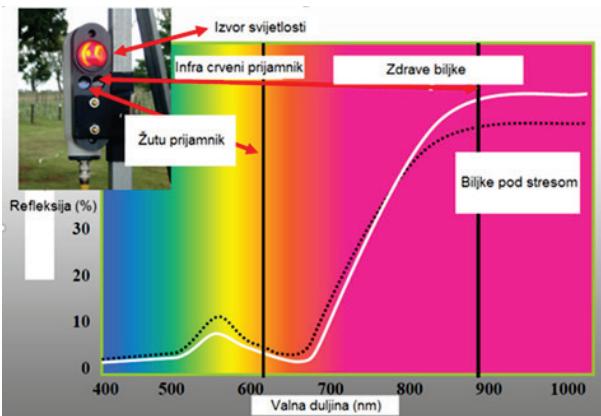
Figure 8 Readings of different wavelengths of OptRx sensors
(Source: Hans Stiekema Ag Leader Europe)

The advantage of the plant sensor *PRO Active* is the application of real-time relative to crop growth and without the atmospheric factors impact. The main working parameter is nitrogen (Fig. 9).
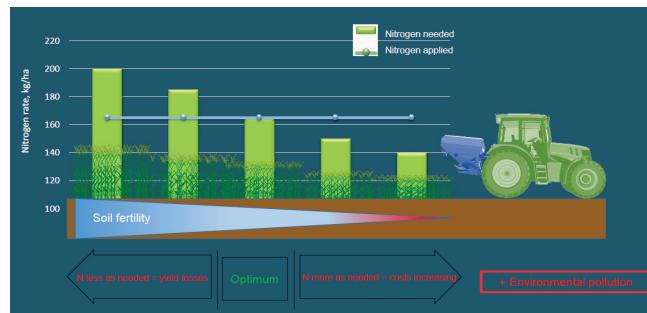

Figure 9 Nitrogen distribution area according to PRO Active
(Source: https://www.isaria-digitalfarming.com/en/product/isaria-pro-active/)

4 CONCLUSIONS

In addition to the navigation system, precision agriculture requires the support of other systems to be completely functional. The most important systems are the system for the application of artificial fertilizers and plant protection. They are equipped with various sensors that read and send data to a processing unit that makes decisions based on the collected data. Technology development has resulted in a wide availability of precision farming. Besides the navigation of aggregates, every bigger farm uses a system of precision

agriculture including the growing use of sensors. Nowadays, every new machine comes with a range of various integrated sensors. They convert analogue signals to the digital ones, read and processed through a computer. The data collected by sensors determine further steps of agrotechnical activities with the aim of production improvement. One of the most well-known sensors is *OptRx* with aim to calculate the vegetative indices NDVI and NDRE at the wavelengths of 670, 730, and 760 nm. These sensors can perform in difficult field conditions, unlike other sensor types, which failed to produce accurate data in the same conditions. The advantage of the plant sensor *PRO Active* is the driver's ability to change the settings even in movement, and to adjust the steps of calculations in one work phase. Using application of variabale rate technology (*VRT*) farmers have immediate insight into the condition of the crops and simultaneous application of the product. Farmers must deploy modern agricultural systems to ensure the survival of their production. The large EU market provides ways of easy placement and export of agricultural products of differing quality. The quality as well as the product price can be improved through the application of modern systems and a wise use of resources, which is the goal of the sustainable agricultural production. Future use in precise agriculture is having autonomus robots with sensors for each agrotechnical operation so farmers will be only for monitoring and sending a robot scout as needed.

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