Optical sensors for precision agriculture: an outlook

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ABSTRACT

The growing human population added to the rural exodus has aggravated the pressure in the agricultural sector for greater production. Faced with this problem, research has developed optical sensors for more productive agriculture with the purpose of minimizing the effects of rural exodus, obtaining rapid information and promoting the rational use of natural resources. Optical sensors have a differential consisting of the ability to use the spectral signature of an attribute or part of it to gain information, often not obvious. This review provides recent advances in optical sensors as well as future challenges. The studies have shown the wide range of applicability of optical sensors in agriculture, from detection of weeds to identification of soil fertility, which favors management in different areas of agriculture. The main limitation to the use of optical sensors in agriculture in most parts of the world has been the cost of purchasing the devices, especially in poor countries. So one of the future challenges is the reduction of final prices paid by consumers.

Keywords: Smartphone; weed; hydric stress; pathogen detection; soil fertility.

1. INTRODUCTION

The growth of the world population implies an increase in food demand. With natural resources, such as limited freshwater and fertilizers, the implementation of initiatives aimed at incrementing a productive and efficient use of natural resources is needed. In this context, several scientific efforts have been made to augment agricultural production. The sensor-based information system is one of these efforts, being one of the bases of precision agriculture and of fundamental applicability for agricultural monitoring and decision making oriented towards greater production and efficiency [1].

For precision farming, knowledge about soil attributes, the health of developing plants and the quality of fruits and grains harvested are extremely important. In view of this, several types of sensors have been researched and developed, either to monitor soil attributes such as moisture, salinity, conductivity and fertility; monitor environmental conditions such as precipitation, solar radiation and relative humidity; or monitor plant attributes such as chlorophyll content, nitrogen requirement, water stress, among others [2].

Among the different types of sensors, optical sensors have a differential aspect compared to others, which is the ability to use the spectral signature of an attribute or part of it. To do this, every optical sensor has the ability to measure reflectance or use the reflectance property for information. This ability to differentiate, for example, the state of a normal plant from one with some problem, be it water deficit or lack of some nutrient, such as nitrogen [3].

Thus, to carry out the present study, we undertook a bibliographic review aiming at seeking for the uses of optical sensors in precision agriculture, presenting future advances and challenges.

2. MATERIAL AND METHODS

The method proposed for this study was based on the review of publications related to the applicability of optical sensors in precision agriculture, presenting future advances and challenges in the exploration of agricultural activity in a global way. In order to meet the objective of the study, the review was comprised of five stages: i) establishment of the theme and selection of the research question; ii) establishment of inclusion and exclusion criteria; iii) definition of the information to be extracted from the selected articles; iv) analysis and interpretation of results; and v) presentation of knowledge review and synthesis. Considering the specificity of the topic, the methodology used and the main results were used as parameters for the definition of the information to be extracted from the selected publications.

The inclusion criteria of the papers used were: publications between 2003 and 2018, which portrayed the subject matter of global use in agriculture; and that addressed the key words and expressions like smartphone, weed control, water stress, pathogen detection and soil fertility.

For the analysis of the data, a thorough reading of the selected papers was carried out, in order to verify the adherence and consistency to the focus of this research. The ideas were grouped by similarity so as to compose a narrative synthesis of the results and discussion of the information related to the study.

3. RESULTS AND DISCUSSION

3.1. Applicability of optical sensors in agriculture

3.1.1. Irrigation

The scarcity of water in various areas of the world and the increase in the cost of its use leads to the need for proper use of this resource. Therefore, knowing the right moment to irrigate and quantity is grounded for rational use of water.

The use of optical sensors such as thermographic, multispectral and hyperspectral cameras is being studied by many researchers to monitor the canopy, identify water stress of plants and estimate the stomatal conduct to assist in irrigation planning.

The use of thermal imaging obtained by thermographic camera, was evaluated by González-Dugo et al. [4] as a potential for irrigation management by serving as a water stress indicator for a commercial 42 ha orchard located in Murcia, Spain. The results showed that thermal imaging was a valuable tool for decision making regarding the timing of orchard irrigation.

In this perspective, O'shaughnessy et al. [5] evaluated the use of thermal imagery to assess water stress in soybean and cotton crops in Texas in USA. Ballester et al. [6] studied the use of thermographic camera for the detection of water stress in citrus and persimmon trees in Valencia in Spain. Bellvert et al. [7] evaluated the use of a thermal camera to determine water stress in vines in the town of Lleda in Spain. Zarco-Tejada et al. [8] studied the use of VANT to detect water stress in orange and tangerine cultivars using hyperspectral and thermal images in Seville in Spain. These above-mentioned papers have allowed to draw the conclusion that the use of thermal imaging is an efficient tool to identify the water stress of crops and guide the management of irrigation

Multispectral cameras and thermal cameras on board unmanned aerial vehicles (UAV) were used by Gómez-Candón et al. [9] in the cultivation of apple trees for the detection of water stress in the trees. Captured images allowed water stress to be detected at the individual tree level in order to allow localized management of irrigation.

All the researches show great applicability of multispectral, thermographic and hyperspectral cameras to identify plants in experiencing water stress. To achieve this result, complex image processing was developed and good performance computers were required.

These studies must be improved so that they can get into the hands of producers, since the results are still dependent on the laboratory environment.

3.1.2. Management of nitrogen fertilization

The chlorophyll is the most important pigment of the leaf and one of the most important of the plant, since it is through it that plants manages to capture sunlight and to use it as energy source. By means of sensors it is possible to estimate the amount of chlorophyll in the leaf, and thus to be able to evaluate the deficiency of nitrogen in the plant, indicating the necessity of nitrogen fertilization or not. [10].

Nitrogen is one of the most influential nutrients of plant development, being a limiting element of production. Due to this characteristic, it is intensively used in productive crops, aiming to get the crop reaching its maximum potential [11]. However, if used in excess leads to increased production cost as well as contamination of water resources due to leaching and evaporation [10].

Commercial optical sensors such as the GreenSeeker and Minolta SPAD-502 are based on NIR and SPAD Analysis of Soil Plants. With the Normalized Difference Vegetation Index (NDVI), as measured by GreenSeeker, it is possible to estimate the nitrogen fertilization for the crop according to the desired productivity, with the SPAD as measured by the Minolta SPAD-502, the amount of chlorophyll in the plant is estimated and thus it is possible to identify the state of health, as well as to recommend nitrogen fertilization.

Yara N-Sensor is another sensor also used for nitrogen fertilization. It is based on spectral reflection in specific bands related to the chlorophyll and biomass content of the cultures.

The CropCircle optical sensor makes readings of up to 6 spectral bands covering blue, green, red, near-red and near-infrared. With the combination of these bands it is possible to estimate different vegetation indices, among them NDVI [12].

Crain et al. [11] have constructed a prototype of optical sensor to measure NDVI aiming at low production cost. They set up an experiment with corn and wheat to verify the calibration and performance of the prototype with the GreenSeeker commercial sensor. Their results showed that the prototype was a useful sensor to measure NDVI and by means of this estimate of nitrogen fertilization. The performance and accuracy are lower than those of the GreenSeeker, due to the low cost of the prototype, but it does not disturb the farmer who uses it.

Wang et al. [13] and Wang et al. [14] have developed very similar surveys with commercial geraniums. They verified the performance of the GreenSeeker and Minolta SPAD-502 sensors in the identification of nitrogen concentration in two geranium cultivars. NDVI and SPAD measures are possible to identify changes in the nitrogen concentration state, but they pointed out that research must correlate these variations with the necessary dose of nitrogen to be applied in the geraniums.

Shiratsuch et al. [15] has used the CropCircle sensor to measure the Meris Terrestrial chlorophyll index (MTCI) of corn crops in Brazil submitted to different treatments of nitrogen fertilization. With the MTCI data and the correlation with the nitrogen dose used in each treatment, they have created an algorithm to estimate the application rate of nitrogen in corn. Dunn et al. [16] has evaluated the performance of the NDVI sensor prototype developed by Crain et al. [11] and the SPAD-502 sensor in the identification of the nitrogen concentration in Gaillardia. The results indicate that both sensors can be used to identify the nitrogen concentration of this flower, as long as the sampling time is not short. Dunn et al. [16] pointed out that in order to develop fertilization guidelines it is necessary to further investigate the different production practices and additional cultivars with the NDVI and SPAD measured values.
The studies indicate that there is a field of research to develop algorithms that estimate the nitrogen dose to be applied in different commercial cultivars according to the value of SPAD or NDVI measured, or other index. GreenSeeker, for example, uses algorithm that recommends only dose to be applied to grains. Therefore, there are a variety of agricultural species still to be studied.

3.1.3. Chemical properties of soil

Studies have shown that the number of ions in the soil and organic matter affect the reflectance, absorption or transmittance of electromagnetic waves by the soil. This fact may be interesting for the use of optical sensors as a measure of soil chemical properties [17].

Schirrmann et al. [18] has used a mobile NIR spectrophotometer to map the surface layer of organic farms and to study the correlation among the spectral data with the results of the laboratory analysis for P, K, Mg, soil organic matter (OM), N and pH. For the local calibrations, the best results were pH, N-total, MO, K-total and Mg-total, with r^2 representing 0.71, 0.69, 0.61, 0.55, 0.53, respectively; therefore, showing correlation between NIR spectral data of the soil with the chemical properties of this soil. However, they concluded that the correlation between the spectra and the parameters was location dependent, and this would make it difficult to develop general calibration models.

Christy et al. [19] has developed a prototype using NIR spectrophotometer to map soil reflectance and correlate with chemical parameters. The results of an initial study indicated that the locally weighted regression analysis was able to predict moisture, C-total, N-total and pH, with r^2 representing 0.82, 0.87, 0.86 and 0.72, respectively. The experimental unit produced data with a high level of repeatability, thus showing soil patterns related to NIR spectral reflectance.

3.1.4. Detection of pathogens in plants

Studies in the literature show that plants after being attacked by pathogens suffer damage that causes changes in the rate of transpiration and flow of water throughout the plant or in organs. This leads to increased temperature in localized parts of the plant, such as leaves [20, 21].

Sankaran et al. [22] have studied the applicability of the multispectral camera and thermographic camera for the detection of Huanglongbing disease in citrus trees. The experiment was carried out in the experimental field of citrus of the University of Florida in~~,~~ USA. Their results concluded that using the band of the visible and thermal infrared as input characteristics, the overall average classification accuracy of 87%, with 89% specificity and 85% sensitivity, could be achieved to classify trees with leaves infected by Huanglongbing. The support vector machine model was used for identification.

Garcia-Ruiz et al. [23] used a multispectral camera coupled to UAV to diagnose citrus trees affected by Greening's disease, based on spectroscopy. For this, the data generated from the processing of six spectral bands and seven vegetation indices derived from these bands, among them the NIR / R (near infrared / red), were used in the classification algorithm. Among the indexes analyzed, NIR / R showed a better significant difference between healthy trees and infected plants. The authors concluded that the processing of multispectral images taken at low altitudes is reliable in the detection of Greening disease (the classification reached an accuracy of 85%), being a tool that could reduce the production costs of the citrus crop due to the rapid identification of the disease.

3.1.4. Apps for smartphone

Smartphones are devices that in addition to presenting a fast processing system also have a camera feature, being an interesting platform for image capture and possible processing. In view of this, the work was developed using images captured by the RGB camera to create applications for precision agriculture.

Vesal et al. [10] created an application called SmartSPAD responsible for estimating the SPAD of corn plants by means of contact image obtained by the camera of smartphones. Its application is based on two models of SPAD prediction from the corn leaf image: neural network model, and the multivariate linear model. For the validation of SmartSPAD, the SPAD values measured by it were compared with the SPAD values measured by the Minolta SPAD-502 device, used as standard. The validation r^2 values were 0.88 and 0.72 and the mean square error was 4.03 and 5.96 for neural network and linear model, respectively. The application proved to be a good estimator of SPAD values at a low cost.

Han et al. [24] have created a ground classification sensor based on smartphone application. The sensor is formed by external optical support and a smartphone application. The support is formed of two external lenses and a shading cover, since the classification application is based on the linear discriminant analysis model. The Munsell color card was used as the soil classification standard. The results reached by the authors showed that the sensor had hits above 90% for all soil samples evaluated.

A similar research to the work of Han et al. [24] was also developed by Mulla [25]. The latter authors also applied an application for Android smartphones with the aim of classifying soil in relation to Munsell color card through RGB images. Their results were obtained in controlled lighting environments and showed that the ratings by the application were good and acceptable in a controlled lighting environment.

3.2. Future challenges regarding optical sensors

The maximum nitrogen fixation by plants, in the traditional form of fertilization, is around 50%, with the world average being 33%. This is due to several factors, either by leaching, evaporation and / or plant losses [11]. Thus, of all the nitrogen fertilization used in the world for agricultural production, an average of 67% is wasted.

The use of commercial optical sensors with GreenSeeker, Yara N-Sensor, CropCircle and SPAD-502 promotes improved fixation rate, but these sensors are expensive and not very accessible to many farmers, especially in developing countries. These countries correspond to about 70% of the nitrogen consumption for fertilization in the world [11].

According to Mulla [26], it is realistic to expect crops in the farms in the future to be managed plant by plant. This approach will require the collection and analysis of massive data on a scale not considered today and the need for stationary or mobile sensors that can measure individual plant characteristics in real time.

Real-time point-to-point sampling is possible today but at a very high cost. And due to cost, sampling in a productive area is done with few points, which decreases the accuracy of the final result, and inefficient becomes the whole set.

The acquisition cost of a thermographic, multispectral and hyperspectal camera is high, especially in countries not benefited by the local currency. This makes it difficult for many research centers around the world to carry out research and development in many areas that could leverage technology to improve their research and make new discoveries [21].

Table 1 presents summarizes most studied research fields with emphasis on the use of optical sensors for the monitoring of agricultural crops and agricultural processes.

Table 1. More developed research on the use of optical sensors for the monitoring of crops and agricultural processes

Country	Product	Optical sensor feature	Reference
Spain	Water stress in almond, apricot, peach, lemon and orange	Thermal	[4]
USA	Water stress in cotton	Thermal	[5]
Spain	Water stress on persimmon and citrus trees	Thermal	[6]
Spain	Water stress in the vine	Thermal	[7]
Spain	Water stress in orange and tangerine feet	Hyper-Spectral and thermal	[8]
France	Water stress in apple trees	Thermal	[9]
USA	SPAD reading application	CCD	[10]
USA/ Mexico	Management of nitrogen fertilization in maize	NDVI reader	[11]
Brazil	Management of nitrogen fertilization in maize	MTCI Reader	[15]
USA	Management of nitrogen	NDVI/SPAD Reader	[16]

	fertilization in Gaillardia		
USA	Chemical properties of soil	Multispectral NIR	[18]
USA	Chemical properties of soil	Multispectral NIR	[19]
USA	Huanglongbing on citrus trees	Thermal	[22]
USA	Huanglongbing on citrus trees	Multispectral	[23]
China	Application to sort soil	CCD/lenses	[24]
Spain	Application to sort soil	CCD	[25]
Greece	Identification of *Silybum marianum*	Multispectral	[27]
Spain	Identification of *Sorghum halepense*	Multispectral and RGB	[28]

In analyzing Table 1 as well as the various literature cited in this study, it is noteworthy that the USA followed by Spain are the countries that present the most published study on the use of optical sensors in various areas of agriculture, including the identification of the soil chemical properties, as well as the classification and identification of diseases.

Given the current context, it will be future challenges to develop low-cost optical sensors and make them as accessible as possible to the producer and the research centers. That these sensors promote the improvement of the nitrogen fixation in different agricultural crops and that they can monitor in real time the plant or the homogeneous set of these, facilitating the management at the varied rate.

Another challenge will be to develop optical sensors that all steps of image capture, processing and final result take place on the same equipment. This will facilitate the immersion of this technology in the field.

The total of 18 works published from 2003 to 2017 including one in 2003, two in 2011, two in 2012, six in 2013, one in 2014, two in 2015, three in 2016, and one in 2017. About 33.3% were thermal, 5.6% hyperspectral, 16.7% charge-coupled device (CCD), 27.8% multispectral and 16.7% studied reading sensors of vegetation indices. The year and type of publication are shown in Figure 1.

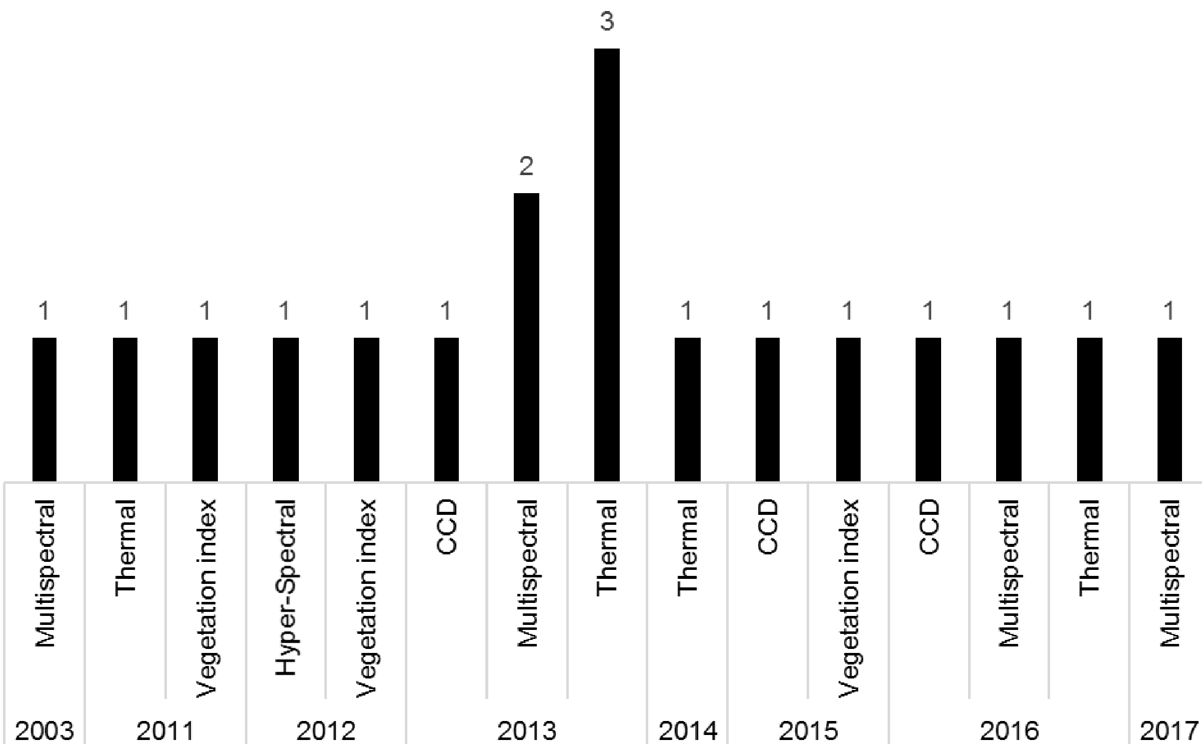

Fig. 1. Number of publications by type and year.

4. CONCLUSION

The studies developed and presented show the great applicability of optical sensors as a precision agriculture tool from identification of water stress and weeds to nitrogen fertilization management in crops.

The main limitation to the use of an optical sensor in agriculture in most parts of the world is the cost of purchasing the devices, especially in poor countries where agriculture is the basis of the economy. Therefore, the challenge is the production of cost-effective sensors.

Image processing for precision farming is a very effective information method, however, the results are not immediate and you need a computer that performs well to get them. smartphones have combined processor and camera into one device. Due to this feature, the smartphone has proven to be very useful for digital image processing. The trend is for processing to become better, given that every day better smartphones, in terms of processor and camera are launched with cost-effectiveness.

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