remote sensing

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Editorial

An Overview of Precision Weed Mapping and Management Based on *Remote Sensing*

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Precision Agriculture face the challenge of feeding an increasing population, maximizing yield while optimizing inputs. In the effort to increase crop yields precision agriculture brings a broad range of potential improvements in prototypical and pre-commercial solutions. In addition, a transition to digital solutions and to a sustainable production demands new research on spatial management to detect problems such as weeds, pests, diseases and decreased vigor before they affect crop yield. The information can be also improved by collecting and analyzing data on different scales and resolutions, emergency models, identification patterns, and site mapping can be generated to enable the design of advanced crop protection strategies and decision support system based. In addition, the integration of holistic information thought Farm Management Information System (FMIS) will improve farm management at different scales. In this regard, agriculture is moving towards digital transformation supported by various technologies such as remote sensing, Decision Support Systems, Artificial Intelligence. In particular, the use of computer vision techniques based on deep learning techniques is highly demanded. Thus, differential management at optimum time and place ensures the efficiency and economic return as well as sustainability of agricultural work. However, Precision Agriculture also involves pest minimization, control of unwanted species, and generation of strategies for dealing with weeds. Continuous improvement in weed control operations is a permanent requirement for the development of agricultural activity. Due to the loss in productive potential and quality that they cause in the crops, the differential management of these weeds is fundamental in a context the search for sustainability and efficiency. Recent advances in this field are based on the combination of remote sensing with the use of cutting-edge technologies such as deep learning, computer vision, UAV robotics, multisensor systems, etc. The current Special Issue, entitled "Precision Weed Mapping and Management Based on Remote Sensing" shows the trends in precision weed research empowering scientist and farmers to keep working on the integration of new techniques to reach the challenge of a more sustainable weed control.

During the last five years there are an increasing number of Artificial Intelligence tools for weed detection and classification. The potential of this low-cost tools using different images has open a new horizon for weed management. On the other hand, the needs of AI techniques are adaptable to the current platforms such us tractors, autonomous on-ground vehicles, UAV, etc. Focusing on remote sensing the series of already published papers have shown the potential to provide accurate spatial and temporal information. Aerial data collection has undergone a considerable change with the growth of UAVs, which have given birth to new, powerful sensor-bearing platforms for various agricultural applications, mainly for data collection. The acquired datasets can be easily processed using different automated and AI approaches. As the adoption of these aerial platforms by producers, both large and small, is gradually taking place, the use of novel deep learning approaches using UAV images could introduce the use of AI in current farms. The use of small aerial

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platforms is quickly increasing in process of weed monitoring for patch spraying. Small and low-cost UAVs or UASs equipped with digital system can map weed distribution for further processes combined with GIS software and on-board algorithms. The reviewed papers have taken echo of the novelty of aerial system for decision making. The novelty of the study relies on the development of open GIS software and algorithms: OpenDroneMap, QGIS, SAGA and OpenCV classification algorithms [1]. The study mapped weed spatial distribution for precision and smart farming applications at field scale, within a conventional cropping system, by using a replicable and scalable low-cost UAS, combined with open Geographical Information Systems software and open algorithms. The system was set up as a budget solution based on an open platform able to assess global performances of different basic and open semi-automatic weed identification methodologies and algorithms directed to a sustainable weed management. The first classification approach adopted the Maximum Likelihood classification following a traditional methodology to create the weed map. The second method was closer to new algorithms based on Artificial Neural Network models. The chosen approach took the OpenCV library implemented in the open-source software SAGA GIS. The ANN and the Maximum Likelihood classification were trained with the same training set. AN Object-Based Image Analysis (OBIA) was also used. The system does not classify the image pixel-wise, and instead it is object oriented. All the aforementioned methods were used to construct SSWM prescription map, which is the outcome of the process which allows the site-specific approach. UAV survey, orthomosaic generation, semi-automatic weed detection and prescription maps generation were properly set up to produce good results from the information acquired by using a small and low-cost UAV. Every of the semi-automatic weed detection procedures were able to successfully map most of the weeds to create a prescription map for in situ management, giving a practical agronomic scenario for weed management to drastically reduce herbicide doses.

Machine vision techniques can discriminate weed species creating prescription maps for weed treatments. The use of UAV for image acquisition covering large areas is a powerful tool for site specific management. However, the UAV as itself cannot provide valuable information and the development of methodologies for weed classification and quantification is directly linked. In [2] a weed density calculating and mapping method in the field conditions was developed based on deep learning algorithms. A neural network, based on a modified U-net, segmented crops from images. After removing the bare soil and crops from the field, isolated images of weeds were obtained. The weed density was evaluated by the ratio of calculated weed area under the total area on the segmented image. Combining neural-network-based crop segmentation and threshold-based bare soil and green plant segmentation methods, a weed segmentation algorithm that successfully calculated and mapped weed density was constructed. The system obtained a combination of excess green minus excess red index and the minimum error method that could be used to segment bare soil and green plants with an accuracy higher than 93% at high image frequency.

Although the use of UAV for weed/crop monitoring in combination with AI is showing its potential on weed science, ground-based systems allow for the capture of high-quality details on crops and weeds. There is a great variety of sensors such as image-reflectance sensors, depth-cameras or optical distance sensors that can be used in terrestrial platforms to obtain accurate weed pressure levels, presence or pre-emergence models for specific control. However, advancements in spectral image processing algorithms, and the use of AI-based systems are revolutionizing the evolution and widespread adoption of precision weed management. Digital cameras and Artificial Neural Networks can achieve high levels of accuracy at high speed. This could lead to on-line treatments, avoiding the temporal gap between mapping and treatment, which would reduce efforts and cost while increasing efficacy. Peteinatos, et al. [3] separated different weed species from crop plants in order to perform on the spot herbicide spraying or robotic weeding and precision mechanical weed control. The authors showed how fast those networks can be trained, and how reliable this training can be, over multiple trainings. Three different Convolutional Neural

Networks (CNNs), VGG16, ResNet–50, and Xception, were adapted and trained on a pool of 93,000 images. The training images consisted of images with plant material with only one species per image. A Top-1 accuracy between 77% and 98% was obtained in plant detection and weed species discrimination. ResNet–50 along with Xception achieved a quite high top-1 testing accuracy (>97%). Similarly, Quan et al. [4] tested stream dense feature fusion network based in order to estimate the aboveground fresh weight of weeds for herbicide applications. The use of 3D point clouds and deep learning technique is a promising and powerful tool. Two-stream dense feature fusion convolutional network model based on RGB-D data were developed for the real-time prediction of the fresh weight of weeds. A YOLO-V4 model was chosen to locate weeds followed by use the two-stream dense feature fusion network to predict their aboveground fresh weight. A dense-NiN-Block module was embedded in five convolutional neural networks reaching the best result on DenseNet201. In addition, the results confirmed that convolutional network using RGB-D as the input reached better results than that of the network using RGB as the input without the Dense-NiN-Block module.

Although the use of novel algorithms based on CNNs has shown its potential, from aerial to on-ground techniques, their performance has been shown to be sensitive to image quality degradation. Testing the influence on the algorithms is crucial for its commercial implementation. In a novel study determining the influence of image quality and light consistency on the performance of CNNs in weed mapping was tested [5]. Some of the more representative CNN were tested for were used as CNN examples for object detection and instance segmentation for Faster Region-based CNN (R-CNN) and Mask R-CNN, respectively, while semantic segmentation was represented by Deeplab-v3. The images were degraded in terms of resolution reduction, overexposure, Gaussian blur, motion blur, and noise. Those models trained with lower resolutions were more tolerant against quality inconsistency than those trained by high-quality image, as well as those with light inconsistency.

New tools are rapidly improving. However, there are many issues to cover in order to reach a holistic overview of the needs of SSWM. The sustainability of the current weed managements needs to include novel algorithms for weed and crop characterization, as well as actuators and associated technologies for weed treatment. The acquired and processed information lead advanced weed-control systems (both chemical or mechanical), which rely on an accurate detection of weeds and reliable discrimination between weeds and crop plants. Spatial distribution, severity of the infestation or herbicide resistance degree are considered key parameters for characterizing a weed infestation scenario. Thus, the detection system is intended to collect information on target areas and make spatially selective weed-control decisions. The main studies of this Special Issue have developed detection systems from aerial or on-ground methodologies that will serve as starting point for further research to reach a more sustainable weed management through digital tools.

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