



Precision Agriculture: UAV-Based Soil Mapping and Remote Sensing Applications

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/arja/2024/v17i4598>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/126587>

Review Article

Received: 06/09/2024

Accepted: 08/11/2024

Published: 20/11/2024

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Cite as: Meshram, Pranali G., Yogesh A. Shaniware, Gauri P. Bhondave, Dnyaneshwari M. Zol, and Priya Pandey. 2024. "Precision Agriculture: UAV-Based Soil Mapping and Remote Sensing Applications". *Asian Research Journal of Agriculture* 17 (4):885-91. <https://doi.org/10.9734/arja/2024/v17i4598>.

ABSTRACT

Using Unmanned Aerial Vehicle (UAV) equipped with remote sensing cameras that measure the electromagnetic spectrum of light reflected back from the ground below, this technology does soil mapping and field analysis. The way that different elements reflect different light wavelengths can be used to identify them. Reams of data on those wavelengths are gathered by multispectral image sensors, which power sophisticated AI software that can identify even the smallest variations in the elemental composition of soil. There are numerous positives to soil mapping, including helping farmers choose the best crops, applying the right fertilizers, and scheduling irrigation. Soil mapping also makes it easier to create plans for soil conservation and restoration that work. UAVs facilitate rapid deployment, enabling data collection near end-users, while delivering a more comprehensive and precise dataset compared to traditional camera-based methods. This study will provide effective technical support and decision-making assistance for future agricultural land planning.

Keywords: *Unmanned Aerial Vehicle (UAV); soil mapping; spectral imaging; image processing; soil.*

1. INTRODUCTION

Throughout the history, agriculture is one of humankind's oldest industries and has continuously embraced technical innovations to increase output. But the growing world population also brings new difficulties, such as the urgent need to ensure enough food for everyone. Traditional tillage methods and technology are ineffective in meeting these modern needs. As a result, superior data-driven precision agriculture has become an essential component of contemporary farming methods.

Climate change is expected to further impact crop yields, making it difficult to manage food and water systems [1]. Healthy soil is an essential component of agriculture and the base of the food chain. Nutrient-rich soil is essential for the growth of all food-producing plants, and it has a direct effect on the number and quality of crops that support human and animal populations. A stable base for food-producing plants to grow and thrive is provided by healthy soils, which are rich in vital nutrients, water, and oxygen. "Additionally, soil serves as a buffer, preventing abrupt temperature changes from damaging sensitive plant roots and guaranteeing ongoing productivity. Because different crops do better in different types of soil, farmers must make informed decisions regarding crop selection based on their awareness of the properties and composition of their soil. Soil mapping plays a pivotal role in providing crucial insights into soil composition for farmers. This process involves systematically observing and documenting the various types of soil and their distribution within a given region" [2].

"Using advanced geographic information system (GIS) mapping techniques and photogrammetry

for landform identification, a detailed understanding of on-the-ground conditions can be produced for large amounts of land in just a short amount of time. Modern agricultural operations depend on the monitoring of soil conditions and composition; as with most things, the more precise the data, the better; multispectral soil quality maps let farmers decide when and where to make adjustments in relation to crop planting" [3]. "UAV i.e. drones have the potential to significantly enhance agricultural productivity by providing invaluable information and insights beyond farmers' traditional reach. Also, drones streamline labour intensive activities such as scouting for pests, applying fertilizers, pesticides, and harvesting, thereby enabling farmers to allocate their efforts toward marketing and refining land management practices" [2].

2. CHANGES IN LAND SURFACE

The chemical makeup of the Earth's atmosphere may be ascertained via remote sensing tools, such as satellites equipped with spectrometers. They gather data on aerosols, ozone, various tracegases, and greenhouse gases (such carbon dioxide and methane) [4]. The outcomes of these experiments help scientists track the sources and sinks of greenhouse gases, comprehend changes in atmospheric composition, and evaluate how these changes affect global warming.

3. MAPPING OF SOIL TEXTURE USING UAV BASED HYPER-SPECTRAL IMAGING

One of the most significant physical and inherent characteristics of soil is its texture. "Traditional soil texture measurement methods rely on field

soil sampling and laboratory chemical analysis, which are time-consuming, laborious, and costly, making it difficult to conduct large scale and multi-frequency soil texture content monitoring” [5,6]. The monitoring of soil texture with non-imaging geophysical spectrometers is a major area of current research. Less research, nevertheless, has used hyperspectral data from unmanned aerial vehicles (UAVs) to track soil texture. High-resolution spatial information about soil texture can be promptly and precisely obtained using hyperspectral sensors placed on unmanned aerial vehicles (UAVs). The groundwork has been completed for the use of unmanned aerial hyperspectral data collection in lieu of field sampling to enable quick soil texture studies.

“In recent years, rapidly developing vision-near-infrared hyperspectral technology has been widely used in soil texture content estimation to address the contradiction between the demand for big data of soil texture and high cost” [7]. Depending on the spectral response relationship between soil spectral reflectance and soil texture, many researchers have used ground object spectrometry to develop soil hyperspectral technology as a conventional means of

quantifying soil texture [8-10]. However, “soil texture inversion based on a ground-object spectrometer usually obtains spot like data with low density. This makes it difficult to meet the requirements of rapid visualization of spatial distribution in the context of precision agriculture” [11]. UAV platforms have the advantages of mobility and flexibility and have been widely used in land resource space surveys in recent years [12].

“As emerging tools, UAV have the advantages of portability, high spatial resolution, high flexibility, independent selection of flight time, and the ability to carry a variety of spectral cameras” [13]. This can quickly and efficiently achieve remote sensing image (Fig. 1) acquisition in a specified area [14]. A UAV hyperspectral system is an effective tool for monitoring and mapping the spatial distribution of soil textures.

“The hyperspectral camera carried by UAV can not only obtain ultra-high spatial resolution images but also centimetre-level remote sensing images of farmland rapidly and in real time” [15]. This means that they can be used to effectively assist agricultural operators in operation management and regulation [16].



Fig. 1. The flight paths: RGB (above), NIR-RG (below)

4. CHARACTERISTICS OF UAV AND IMAGE PROCESSING

Aerial images were obtained using an unmanned aerial vehicle (UAV) carrier platform. The flight planning with the ground control unit was prepared using "Missionplanner". "The carrier, namely the Multispectral Camera (Tetracam ADC Snap) mounted on the UAV, was used as the sensor. The camera, mounted on the UAV, had 3 filters to constrain the reflection ranges and allow to acquisition of the green, red and near infrared wavelengths, equivalent to the Landsat Thematic Mapper bands of TM2, TM3 and TM4. The TM2, 3 and 4 bands are the basis for standard-false colour composite images associated with multispectral images, which are used to monitor the changes that occur due to plant stress and to evaluate the growing environment under special plant and soil conditions. A 5×5 median filter was used for the cropped images to reduce dust, spores and water that decrease the quality of images obtained from natural environments" [17,18].

"The height for aerial images was approximately 50 m determined depending on the current conditions of the land, flight safety and the sensor used. The forward and side overlap ratios of the

images were 80 and 60%. The flight was carried out with an estimated resolution of 3.99 cm and a total of 122 aerial images were taken for the study. Pixelwrench" [19] Photoscan (Agisoft and St Petersburg, [20] and ArcGIS software were used in the processing, evaluation and visualization of images [21]. "The planned flight time in a light windy and cloudless weather was approximately 5.31 minutes. Unprocessed/raw multispectral images obtained with Tetracam were processed using Pixelwrench 2 software. The Pixelwrench2 performs image processing and editing and capable of extracting various vegetation indices such as NDVI from images. The raw data was first colored and converted to TIFF format for photogrammetric processing" [22,19]. Orthophotos were obtained from aerial images produced in NIR/R/G bands using Photoscan software Fig. 2, [23]. The images were placed on the flight line according to the structure from motion (SfM) principle and a dense point cloud was obtained [20]. "The root-mean-square error (RMSE) that occurred at the end of this process was 0.392 pixels. The total RMSE in the geographic coordinate obtained for the image processing was 0.09 mother orthophoto resolution obtained using the UAV images was 3.21 cm/pixel" [24].



Fig. 2. NIR orthophoto from top and bottom

4.1 Pre-Processing of UAV Images

"The UAV's flight route was examined in Sbgcenter software for pre-processing, and the flight path data was exported. The exported flight path data was then segmented and erroneous routes were eliminated using Omap software. A complete hyperspectral image was obtained by pre-cutting the hyperspectral image using software from Airline Division following airline conditions. Using MegaCube software, radiometric calibration and atmospheric correction were applied to the cropped image. After that, the updated picture was loaded into ArcGIS for geographic registration. The reference data were the remote procedure call file delivered by the UAV and the orthographic base map taken. After registration, the images sliced using ENVI software. MegaCube software was used to create an image hypercube, which was then converted into a hyperspectral image. Therefore, pre-processed viz., Near and NIR images were obtained. The coordinates of the actual sampling points were imported into the hyperspectral image to obtain the UAV spectral reflectance data of all sample points, and noisy bands were removed" [25].

4.2 Measurements from the Survey

Since it was challenging to calculate the distances to the sample regions using the mark sizes, navigation depended on the distance readings; thus, a better scaling of the virtual objects' sizes is required. In addition to scaling virtual items according to the user's distance from them, Wikitude also allows users to scale things to change how big they appear to be in their field of vision. This test indicates that further testing with this value is required [26].

Since the items seemed closer to the user than the distance numbers suggested, they ought to be resized to appear smaller. The radar's size is another scaling issue that has to be improved because the objects were difficult to identify. The radar's dimensions need to have been adjusted to correspond with the field's greater size, as previous testing used a somewhat smaller test field [27].

5. CROP HEALTH

Known as "spectral signatures," the reflectances of the various crops vary. Agricultural identification aids in agricultural inventory management, yield forecasting, crop rotation,

and sustainable management techniques. Sustainable land management requires precise crop classification and mapping. "The optimum input data and classifier approach are needed for crop mapping, particularly in areas with little field data. To evaluate the effect on crop health, the crop monitor is crucial. Abiotic (water stress, environmental conditions) and biotic (insect, weeds, and illnesses) factors have the most effects on health. Under stress, the crops' spectral reflectance changes. When compared to a health crop, the infected crop's temporal profile is lower" [28].

6. CONCLUSION

The findings demonstrate that a set of optimal processing techniques can be obtained by combining machine learning with hyperspectral data from UAVs. By pre-processing the spectral data, it is possible to estimate soil texture with high accuracy and achieve good mapping result. This soil mapping and sensing technique will be well utilized in future and will have great demand. It not only relies on UAV, but also includes various aspects of precision agriculture. Soil Organic Matter can also be determined using this technology. It will also help to reduce soil degradation and will help to create better soil-crop environment.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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