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Optimization of pasture evaluation through the implementation of multispectral imaging and unmanned aerial vehicle

Optimización de la evaluación de pastos mediante la implementación de imágenes multiespectrales y vehículo aéreo no tripulado

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Abstract: This article develops a way to optimize pasture evaluation using unmanned aerial vehicles (UAVs) and multispectral image analysis. The research was carried out in the Municipality of Pamplona, Colombia, with the aim of understanding and documenting the growth and evolution of pasture in agricultural areas. The methodology used in the research included zoning the terrain to identify favorable conditions for the study, ensuring that suitable areas existed to observe pasture development and facilitate access to experimental instruments. Important aspects such as obtaining GPS points on the ground to create polygons that are arranged as the study area are highlighted, allowing for the planning of UAV flight missions, which in turn lead to the use of autonomous flight management software. The acquisition of multispectral images is made possible using multispectral cameras integrated into the UAV, capable of recording information in multiple spectral bands within and outside the visible spectrum, such as near infrared and red edge. Statistical analysis provided a detailed insight into agricultural conditions by revealing significant correlations between the Normalized Difference Vegetation Index (NDVI) and various soil parameters such as potassium (K) and phosphorus (P). This innovative method provides accurate data and visualizations that assist in making decisions regarding sustainable pasture management in the region.

Keywords: Multispectral images, unmanned aerial vehicle, Reflectance analysis, Remote sensors, Vegetation indices, NDVI (Normalized Difference Vegetation Index), precision agriculture.

Resumen: Este artículo desarrolla una forma de optimizar la evaluación de pastos utilizando vehículos aéreos no tripulados (UAV) y el análisis de imágenes multiespectrales. La investigación se llevó a cabo en el Municipio de Pamplona, Colombia, con el objetivo de comprender y documentar el crecimiento y evolución del pasto en áreas agrícolas. La metodología utilizada en la investigación incluyó la zonificación del terreno para identificar condiciones favorables para el estudio, de tal manera que se pudiera garantizar que existieran áreas adecuadas para observar el desarrollo del pasto y facilitar el acceso a los instrumentos experimentales. Se destacan aspectos importantes como la obtención de puntos GPS en tierra con el fin de crear polígonos que se disponen como el área de estudio y que permitirán la planificación de vuelos de vehículos aéreos no tripulados (UAV), que dan paso al uso de software de gestión de vuelos autónomos. La adquisición de imágenes multiespectrales se da gracias al uso de cámaras multiespectral incorporadas en el UAV, capaces de registrar información en múltiples bandas espectrales dentro y fuera del espectro visible, como el infrarrojo cercano y el borde de rojo. El análisis estadístico proporcionó una visión detallada de las condiciones agrícolas al revelar correlaciones significativas entre el Índice de Vegetación Normalizado (NDVI) y varios parámetros del suelo como el potasio (K) y el fosforo (P). Este método innovador proporciona datos y visualizaciones precisos que ayudan a tomar decisiones sobre la gestión sostenible de pastos en la región.

Palabras clave: Imágenes multiespectrales, vehículo aéreo no tripulado, Análisis de reflectancia, Sensores remotos, Índices de vegetación, NDVI, agricultura de precisión.

1. INTRODUCTION

The current research article has been written considering the results obtained within the framework of the research project titled "Identification of the most prevalent pests and diseases in pastures through multispectral images for bovine production in the Norte de Santander department," conducted by the University of Pamplona and the Government of Norte de Santander. This investigation was carried out in the different climates (low, medium, and high) of the department, collecting information through spectral images. There was an intention to collect samples from ten plots per municipality in each of the thermal areas.

70% of Colombian territory is being used inefficiently, while the remaining 30% is either underutilized or overutilized, primarily due to livestock farming. Colombia has a land area of 114 million hectares, of which 67 million are forests, 2 million are bodies of water, and 332 thousand are part of urban areas. Additionally, there are 26 million hectares that offer opportunities for agricultural production, although it is only produced on 6.3 million hectares, representing 24.2% of the total. Territories primarily dedicated to agriculture cover 11.3 million hectares, of which 35% is utilized. This indicates that the Colombian countryside has significant potential for food production [1].

In recent centuries, the human population on Earth has been increasing, largely due to technological advances. Concurrently, the significant global issue of hunger has also been growing, leading agricultural producers to seek ways to sustain and improve their crops through the implementation of new technologies and primarily pesticides [2][3].

The concept of precision agriculture arises from the initiative to design and implement ideas that enable the efficient use of resources and the development of sustainable agriculture without undermining production performance [4][5]. These ideas revolve around a mobility platform based on unmanned aerial vehicles, which ensure non-invasive monitoring and remote sensing of the most general characteristics of the analyzed crops, allowing visualization of what appears imperceptible to the naked eye [6].

The use of multispectral cameras emerges as a solution to implementing precision agriculture, allowing work with non-visible wavelengths. However, one of the major challenges faced with such technology is the ability to detect the spectral signature related to the characteristics of the vegetation being analyzed [7]. Reflectivity is utilized for this purpose, which is the fraction of incident radiation reflected by a surface; in other words, the camera needs to be calibrated to begin recognizing or capturing the information that indicates important patterns associated with issues such as diseases or pests in plants [8]. This type of technology can be costly in the market, so it is crucial to consider the implementation of commercial multispectral cameras that allow monitoring within a spectral range of 400 to 1000 nm [9]. On the other hand, it is necessary to integrate preprocessing algorithms into multispectral images, since a large amount of data stored per capture can be analyzed and, with these algorithms, irrelevant information can be eliminated [10].

Multispectral cameras allow the recognition of different plants and objects depending on the spectral signature they generate, all thanks to the easy detection of five spectral bands and RGB images. These bands are part of the non-visible spectrum, meaning they are imperceptible to our eyes. Therefore, in projects such as the recognition of cotton plants in groups or individually with the aim of detecting possible locations that may provide a habitat for cotton boll weevils [11] and in discriminating varieties of tea plants using the same type of imaging system and analysis of multiple characteristics [12], one can appreciate the capacity and scope of this non-invasive technology. The use of convolutional neural networks has brought advancements in the research of multispectral image reconstruction [13]. Focused largely on the reconstruction of MSI (Multispectral Imagery) using the R-G-B channels of the MSI as inputs to the model for subsequent data gathering and análisis [14].

The Normalized Difference Vegetation Index allows for the extraction of precise data regarding the amount of vegetation and bare soil, enabling the characterization of different levels of plant presence with varying foliage percentages. Additionally, it can indicate possible water footprint presence and the amount of bare soil within the sampled area [15]. With this index, a comparative process can be conducted, allowing for appropriate monitoring of potential nutritional needs and strategic decision-making [16].

It is important to thoroughly understand the topic regarding the tool implemented in this project, starting from the basic concept of the behavior of electromagnetic waves and how they interact with objects. In the specific case of this project, this refers to the incidence of these waves on plant leaves and how they are reflected or absorbed. From there, the concept of acquiring multispectral images arises and how they can be applied as a useful technology to identify the phenological characteristics of crops or productive soils [17].

The common multispectral system features an optical sensor sensitive to bands within the visible and non-visible light spectra. This system is integrated into an unmanned aerial vehicle (UAV) model, serving as a widely used platform in the commercial and productive sectors for high-performance data collection [18], the multispectral images were captured from the properties through overflights, allowing for the acquisition of high-resolution images at altitudes of 100 to 200 meters, with an overlap between them exceeding 70%. These images were processed to provide accurate and timely information about the condition of the land and, more precisely, the health of the vegetation present and the state of areas without vegetation cover. This was accomplished through the determination of a specific index, the Normalized Difference Vegetation Index (NDVI), which helps to determine the amount of vegetation present in each land area. This relationship allows us to assess whether the analyzed lands have the capacity to support quality plants and indirectly observe whether the lands are fertile or if intervention is necessary to increase their productivity.

It is important for the multispectral images to be provided, whenever possible, labeled by municipality with geographic coordinates and acquisition date. Additionally, the images should be condensed into an orthomosaic with the best possible resolution, and associated with it should be a table of normalized difference vegetation index groupings and the percentage of area covered by vegetation. The formats in which the documents can be provided are: .pdf, .tif, and .jpg as they can be easily shared, and reports can require less digital storage capacity.

Thanks to this technology, we study the best methods to optimize processes and help develop agricultural strategies, generate maps of present biomass, detect significant changes by monitoring for optimal nutrient application, and discover possible diseases before symptoms become more severe. This marks the introduction of a new remote sensing tool [19].

There are multiple methodologies that allow for the optimal implementation of this type of monitoring technology, in which not only images can be acquired in different light spectra but also RGB images, from which contour lines and high-quality images with metadata regarding global positioning at the time of acquisition can be obtained [20]. In the international market, various types of sensors are available that stand out for the quality of images they acquire. Additionally, monitoring can also be done through terrestrial observation satellites, which are highly useful in the agricultural sector.

2. METHODOLOGY

The first step in executing the research project involves zoning the properties. In this part of the project, the criteria for the areas of study to be considered suitable for research are established. Among the most important characteristics is the ability to monitor the growth and evolution of the pasture in a specific zone. This is essential for gathering information from the beginning of agricultural activity and documenting the process down to the smallest detail. Another essential characteristic is the location and easy access to the tools to be used in the experiment. It is crucial that the study process occurs frequently, and easy access to the area is necessary. Lastly, obtaining the owner's consent for the execution of the project within their property is essential. Once the selection process is completed, the research can begin with a terrestrial exploration of the property. This includes conducting a geographic survey to acquire precise geographical coordinates, which will later be valuable for the acquisition of images.

Thanks to the GPS points acquired on the ground, flight plans can be created, which will then become the image acquisition mission for the aerial vehicle. For this activity, a stable internet connection is necessary, which is why it is not required to be in the vicinity of the property. Through georeferencing management software, it is possible to create the polygon that encompasses the property area. This point cloud is saved as a .kml file, which is later uploaded to the application for automated visual record creation.

Through an autonomous flight management app that allows receiving XML-based markup language files providing all necessary geographical data to establish information regarding the projected UAV flight. This includes setting tracking points, changing trajectory, flight speed, and altitude for data acquisition, as well as establishing the mission start point and safe landing zone. All this information is stored on the mobile device connected to the drone controller for the overflight. Such enterprise platforms provide multiple advantages not easily found in commercial drones, such as maximum altitude, flight stability, and maximum range.

The aerial vehicle is equipped with a sensor capable of detecting electromagnetic radiation with different wavelengths, specifically highlighting five spectral bands: red, green, blue, near infrared, and red edge. The sensor was selected considering the number of available bands, as well as the weight and the capacity to store information on a high-speed writing SD memory card, which eliminates the possibility of image loss. The camera resolution is 8 cm per pixel at 120 m altitude with capture speeds of up to 1 capture per second.

The image acquisition process began with a visual inspection, defining the physical properties of the terrain and identifying potential obstacles that the unmanned aerial vehicle may encounter in order to prevent accidents. Global positioning system points are obtained through real-time satellite navigation equipment, ensuring high accuracy in the acquired positioning. Flight plans are configured to include, among other things, the altitude at which image acquisition will take place, setting the parameter between 100 and 120 meters, and the flight speed. The flight plan is executed by the vehicle under the supervision of the pilot in charge of the aircraft, in case intervention in any maneuver is necessary. For image processing, the use of photometry software is required, allowing for the manipulation of RGB and multispectral images. Pix4D software was used on this occasion, which allows for capturing images with any camera, transforming images into digital models, managing quality reports and calibration details, measuring distances, areas, and volumes, and extracting elevation profile data.

The data collection and analysis involve acquiring six multispectral images for each of the multispectral surveys in the pasture to be analyzed, corresponding to one hectare in each of the selected properties for the project execution in the municipality of San Cayetano. The percentages of area covered by the present vegetation, the evolution of the vegetative material within the specified time frame between each survey, and the daily rate of change of each analyzed coverage are identified. This is done to generate a potential scenario for visualizing the coverage in the near future, and values are generated to develop linear estimations, where the value of x represents the projected days.

It is necessary to mention that when projecting the area of each coverage at a specific time, it is recommended to calculate the percentage error of the sum of the coverages. If the percentage error is not very high, it can be considered valid. However, if the opposite is the case, it indicates that one or more coverages have undergone a drastic change in a short period, either improvement or loss of vegetative material. The circumstances presented must be analyzed, and necessary measures must be taken. Another interpretation of a high error value

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may be that during the time window, pasture management activities were carried out, leading to sudden changes in coverage values.

3. RESULTADOS

The article presents a comprehensive analysis based on data collected over a period of ten months, from October 2022 to July 2023. A detailed evaluation of the results has been conducted, focusing on the benefits and specific changes experienced by each of the beneficiaries involved in this project. This has allowed for a more comprehensive understanding of vegetation dynamics in these geographical areas, as well as their impact on local communities and surrounding natural resources.

Through a statistical analysis of the data obtained from the 10 properties in the municipality of Pamplona affected by the project, important information was gathered to understand soil characteristics, its quality, and suitability for various agricultural, livestock, and biological material conservation uses. Statistical analysis involves collecting, organizing, analyzing, and interpreting data to draw meaningful conclusions, primarily aimed at describing and understanding the data, detecting patterns and trends, and making inferences based on the available information.

3.1. Statistical analysis of the municipality of Pamplona

Before addressing the statistical analysis of the correlation between NDVI variables and data from bromatological tests conducted on the beneficiary lands of the municipality of Pamplona, it is crucial to conduct an exploratory analysis. This project involved 7 monthly samplings over 12 months, which determined the sampling frequency for managing the information.

The approach used generated a total of 7 multispectral orthomosaics, as illustrated in Figure 1. These orthomosaics combine various individual images, providing a comprehensive and detailed overview of the beneficiary property under analysis. Applying the calculation of NDVI to each pixel in the individual images that make up the multispectral orthomosaic results in obtaining NDVI values for each spatial location. These values are visualized using a color scale that, in the case of Figure 1, ranges from purple to red tones. Each color is associated with a specific index value and the percentage of area covered by that index, thus providing a visually rich representation of information.

Furthermore, it is evident that the image is georeferenced, allowing the provided information to be validated by field experts. This aspect ensures the accuracy and reliability of the collected data since georeferencing establishes a direct connection between the visible elements in the image and their actual geographic locations in the terrain. This approach ensures that the results are applicable and useful in practical contexts, supporting the interpretation and decision-making based on the information derived from the multispectral orthomosaics.

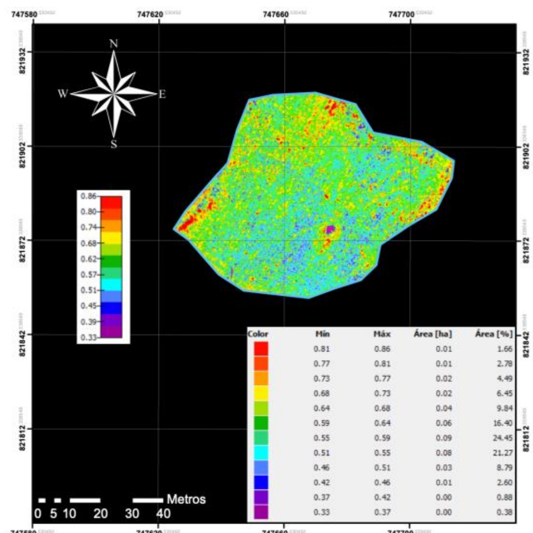

Fig. 1. *Multispectral orthomosaic of the project beneficiary*.

In the initial phase of the research, a significant observation was highlighted: despite conducting a considerable number of image acquisitions in the same month, the trend of change is not very noticeable. This phenomenon is attributed to the limited time window, which does not provide enough time for vegetation to exhibit substantial variations. In response to this consideration, the decision was made to carry out an information reduction with the purpose of obtaining a monthly representation of indices. This approach will allow for a more effective capture of vegetative transformations over time, thus providing a clearer and more representative insight into vegetation dynamics.

The initial exploratory analysis is aimed at generating a detailed soil characterization based on the information collected from multispectral images using the NDVI. In this characterization process, a thorough evaluation of the health and vitality of the vegetation present in the sampled areas is conducted. By synthesizing the information acquired during the flights conducted with the Unmanned Aerial Vehicle (UAV), a detailed visual representation illustrating the condition and distribution of vegetation in the selected hectares is achieved. It is highlighted that vegetation indices can be grouped into categories as follows:

***Table 1:** Intervals and classification of NDVI indices*

NDVI RANGE	CATEGORY
0.75 -1	High Coverage
0.5 – 0.75	Medium Coverage
0.25 – 0.5	Low Coverage
0 – 0.25	Zero Coverage

In Table 1, it is evident firstly that the NDVI values obtained during monitoring fall within the range of 0 to 1. Values closer to 1 indicate abundant and healthy vegetation presence, whereas those close to zero reflect the opposite. By categorizing these values into intervals, we transform a quantitative variable into a qualitative one, allowing us to analyze percentages of area associated with very low or high vegetation coverages. This grouping facilitates the observation of how these percentages evolve over time, revealing potential changes or relationships with other variables in later stages of analysis.

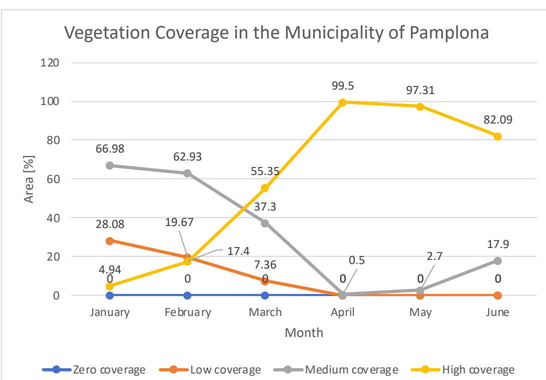

***Fig. 2.** Distribution of vegetation cover in the Municipality of Pamplona.*

In Figure 2, you can observe how the Normalized Difference Vegetation Index (NDVI) has changed in the lands of the municipality of Pamplona. It is notable that, in the initial months, the indices indicating high coverage were below 40% in the sampled plots. However, the medium coverage covers 67% of the sampled hectares, while the low coverage covers 28%.

High coverage increased significantly in the following months, going from 0% to an impressive 99.5%. This increase is the result of a significant expansion of grass with high leaf density and high-quality biomaterial. This phenomenon indicates a notable improvement in soil health and quality.

3.2. Pearson correlation coefficient

The Pearson correlation coefficient was implemented to assess the strength and direction of the linear relationship between two continuous variables, namely, between the NDVI and the different variables acquired in the bromatological analyses. Pearson correlation coefficient values can range from -1 to 1. It is important to note that correlation does not imply causation. Even if there is a strong correlation between two variables, it does not necessarily mean that one causes the other. Further analysis is needed to establish causal relationships.

***Table 2:** Pearson correlation coerfficient.*

VARIABLE	COEFICIENTE
NDVI vs humidity	0.8494
NDVI vs N	0.4184
NDVI vs P	0.7116
NDVI vs K	0.7264
NDVI vs Ca	0.1502
NDVI vs mg	0.5554
NDVI vs FEPpm	-0.8019
NDVI vs MnPpm	-0.3767
NDVI vs CuPpm	-0.1102
NDVI vs ZnPmm	0.5132
NDVI vs BoPmm	-0.2834
NDVI vs NaPmm	-0.1535
NDVI vs S	-0.2893
NDVI vs Ash	0.7031

Phosphorus (P), potassium (K), ash, phosphorus in the grass (FEPpm), and moisture are all significantly related to the NDVI, according to the coefficients shown in Table 2. These coefficient values support the existence of a strong relationship and emphasize the importance of these variables in explaining the variations observed in the NDVI.

3.3. Multiple Regression Analysis

ultiple regression analysis enabled, through statistics, the establishment of the relationship between a dependent variable (or response) and two or more independent variables (or predictors). The developed model is shown in equation (1).

$$NDVI = \beta_0 + \beta_1 Humedad + \beta_2 P + \beta_3 K + \beta_4 FEPpm + \beta_5 Ceniza \quad (1)$$

Where:

$$\beta_0 = 0.05387$$
$$\beta_1 = 0.00382$$
$$\beta_2 = -0.52386$$
$$\beta_3 = 0.25745$$
$$\beta_4 = -0.000195$$
$$\beta_5 = 0.01645$$

This regression allowed us to develop a complex model that captures the interactions between the dependent variable, in this case, the NDVI, and several independent variables, such as humidity, phosphorus, potassium, extractable or present phosphorus in the grass, and ash, which represents the amount of inorganic material remaining after incinerating a forage sample. Thus, we can interpret that through variations in the NDVI, we can indirectly identify part of the chemical composition of the grass components.

4. CONCLUSIONS

It has been demonstrated that the use of advanced technologies, such as the acquisition of multispectral images through UAVs, is a useful tool for detailed pasture monitoring. For agricultural decision-making, it is useful to be able to analyze vegetation, identify anomalies, and evaluate land productivity over time. This method not only improves the ability to detect potential problems, such as pests or nutritional deficiencies, but also helps optimize resource management by allowing for more specific and focused interventions.

To understand the characteristics of sampled vegetation cover in terms of quality and suitability for agricultural, livestock, and biological material conservation uses, a thorough statistical analysis has been conducted on the 10 properties in the municipality of Pamplona. The relationship between NDVI and the bromatological characteristics of the vegetation has been achieved through this statistical analysis, which involves data collection, organization, analysis, and interpretation. The main objective of this process has been the description and understanding of the data, identification of patterns and trends, and derivation of inferences based on the available information.

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