DESIGN AND IMPLEMENTATION OF A GEOGRAPHIC INFORMATION SYSTEM FOR SMART AGRICULTURE

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TABLE OF CONTENTS

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In recent years, agriculture has benefited from numerous improvements, thanks to significant technological advances in this field of the economy. Precision agriculture has introduced methods to enhance agricultural production while reducing costs. This has been made possible using technology and data to manage agricultural crops at a higher level of detail. By collecting, analyzing, and interpreting data, informed decisions can be made regarding agricultural practices, optimizing the use of resources and reducing the environmental impact of agricultural activities, without compromising crop yield. Industrial robots, both physical and software, are increasingly present in technological processes, mainly due to their increasingly diverse capabilities and continuously decreasing prices. These systems are capable of performing a variety of tasks with far greater precision and success rates than human labor. Additionally, the repetitive nature of certain types of activities, as well as the level of effort required by a person to perform them, leads over time to reduced productivity. Through technological advancements, these types of activities can be performed by specialized robots, leaving human labor available for tasks that require a high level of skills and abilities that a robotic system cannot easily or affordably develop.

Although agricultural activities are generally not highly complex, human labor still dominates this important economic sector. For example, an agricultural worker may be responsible for crop monitoring against pests, measuring soil parameters, manual irrigation or operating irrigation systems. These activities, by their repetitive nature, can easily be performed with much greater precision by a robotic system.

The aim of this work is to create a complete and integrated solution for monitoring agricultural areas using advanced technologies for processing geospatial data, unmanned aerial vehicles, and artificial intelligence. This project had several well-defined objectives, structured in key stages. Thus, it was necessary to study and deepen key concepts regarding modern techniques applied in precision agriculture. The analysis of the state of the art allowed the identification of areas that require improvement in terms of agricultural monitoring. Subsequently, workflows were defined through which users of a geographic information system platform could benefit from increased monitoring capabilities. This allowed the design and implementation of a web platform, consisting of six modules, brought together in a common web interface. Additionally, to take advantage of existing technology in this field, integrations were made with existing software systems that provide image processing capabilities, particularly in the field of photogrammetry, as well as command and control systems for unmanned aerial vehicles.

The first module of the platform enables the definition of the geographic boundaries of agricultural plots, as well as crop plants or pests. This step involves identifying the geographic coordinates of the agricultural lands, uploading them to the platform in the form of a CSV file, and storing the resulting polygon in the system. Based on this information, the aerial mission planning module offers users the ability to configure flight parameters and the areas where crop monitoring is to be performed. This module integrates with the specialized drone command and control platform UgCS, using an SDK built on top of the .NET platform. With this, users can automatically generate flight routes for monitoring operations, considering both the physical boundaries of the land and the specific characteristics of each crop. After the defined flights are carried out, users can perform geometric and radiometric correction operations on the raw images, based on advanced photogrammetry techniques, resulting in georeferenced high-resolution images called orthoimagery. These can be used in complex analyses, both through sophisticated mathematical models based on light reflectance from various surfaces and through artificial intelligence and artificial neural networks. The use of vegetation indices, both those based on light reflectance in the visible spectrum and those based on the near-infrared spectrum, allows platform users to quickly identify areas where different forms of stress may affect plants, by interpreting the spectral response of surfaces under different conditions. Based on this information, they can go to the field and photograph affected plants, with the platform offering analysis techniques for detecting anomalies at the leaf level. Additionally, the machine learning techniques used in the platform allow users to accurately estimate the agricultural potential of their crops by implementing a convolutional neural network capable of segmenting and quantifying objects of interest in the studied crop. All these functionalities are exposed in a user-friendly and intuitive web interface to allow users to manage these operations in a unified way.

To test and validate the platform, three case studies were conducted. In the first scenario, the functionalities of four modules were tested in an integrated workflow. Thus, an agricultural plot in Vaslui County, planted with cabbage in an advanced vegetative stage, was identified. In the initial step, the geographic boundaries of the agricultural plot were calculated and submitted into the system, successfully stored on the platform. Next, an aerial mission was planned to use a drone equipped with a conventional camera, capable of capturing high-resolution images of the studied land. As a result of the aerial mission, a set of 116 images was saved in the dedicated cloud container. Subsequently, these images were used to generate a georeferenced orthophoto, which was later used for agricultural yield estimation. This process involved labeling a satisfactory number of cabbages, of different sizes and shapes, to allow the artificial neural network to extrapolate during execution the characteristics identified in the labeled dataset. The preprocessing of the data involved dividing the orthophoto into segments and generating binary masks corresponding to the objects in them, based on the previously defined labels. After training and evaluating the artificial neural network, the process identified a total of 2,145 cabbages, with an accuracy of 93.2%.

The second case study followed the same approach as the first regarding orthophoto generation, with the only notable difference being that, instead of a drone equipped with a conventional camera, an aircraft with a multispectral sensor was used. As a result, the generated orthophoto had a higher level of detail, as the data related to multi-band reflectance values were individually stored in the resulting file. This allowed the calculation and graphical representation of 13 vegetation indices, 5 being based on multispectral data and 8 using visible spectrum reflectance.

In the third scenario, the platform was tested for identifying leaf-level anomalies. Thus, after analyzing the results revealed by the vegetation indices, users can identify areas where vegetation shows anomalies in terms of development and can visit the site. With the images taken on-site, which can represent affected leaves, they can be uploaded to the platform, where the anomaly detection module can identify with high accuracy whether the leaf presents anomalies. To validate this aspect, the network was trained on 2,152 pictures representing potato leaves affected by various pathogens. To validate both the network's performance and to compare how it behaves in different use scenarios, the same images were used to separately train two more models, applying image transformations such as grayscale or background removal. After evaluating the network's performance, an accuracy rate of 93.48% was obtained for the grayscale dataset, 97.2% for the original images, and 97.67% for the images with the background removed. The results demonstrated that the platform could detect these anomalies early, allowing farmers to address issues in a timely manner.

Through these case studies, it was demonstrated that the use of drones, geospatial technologies, and artificial intelligence in agriculture improves efficiency, while also reducing costs. This paper presents a platform that provides farmers with a powerful tool for resource management and maximizing production, enabling continuous and detailed monitoring of agricultural lands.