Modified crop health monitoring and pesticide spraying system using NDVI and Semantic Segmentation: An AGROCOPTER based approach

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ABSTRACT

The technology in agriculture, can help farmers especially in the time of COVID pandemic, where there is shortage of labor and increasing demand for food. The technology solution can effectively and reliably improve crop yield through automated process and Agrocopter. The Agrocopter, an autonomous drone with modular systems and on-board image processing helps in holistic crop management throughout the farm. Agrocopter comes with targeted crop spraying, nutrient dropping and seed sowing modules, that can work in sync with the process of crop life cycle from sowing till harvesting. The drone with edge computing module performs periodic farm surveillance and plant health analysis using combination of NDVI (Normalized difference vegetation index) and semantic segmentation based classification to take targeted actions. It makes use of filter banks and SVM (Support Vector Machine) classifier algorithm to carry out pixel wise stitched image analysis to compute plant health indices in real time. Being very easy to operate and maintain, it can seamlessly be integrated into the farm systems and work along-side humans. It also has a completely modular design with plug and play architecture. What sets Agrocopter apart is its wide variety of applications, reliability and precision all at an affordable cost. Hence, Agrocopter is the perfect aerial farm assistant for today's farmer.

***Index Terms*—** Autonomous, Drone, Edge Computing, Semantic segmentation, Support Vector Machines, NDVI

1. INTRODUCTION

The advancement in drone technologies and edge computing has driven innovative solutions for agriculture. The conventional agricultural practices rely on manual methods specially for monitoring crop health and pesticide spraying. These practices however became cumbersome during the COVID-19 pandemic times. This has motivated to develop Agrocopter after assessing the rising agricultural demands and hardships of farmers. It is designed to analyze the plant health and offer real time diagnosis to help improve yield and reduce the farmer's efforts. A systematic layered process is used to sense, analyze and act upon the field data [1]. The module basically encompasses a central flight control system along with an edge computing module on-board for image processing to perform targeted actions in real time. The analyzed data stored in the cloud system can be accessed by the farmer anytime, anywhere. Agrocopter is fully autonomous and can fly on a pre-planned path and perform instantaneous course correction around obstacles [2]. Being completely modular, the farmer has the liberty to attach any module and select the required mode which involves plantation, targeted crop spraying and solid nutrient dropping. All these functions will be carried out by the drone based on the time and schedule decided by the farmer. The on-board advanced camera system carries out smart on-site surveillance and performs advanced image processing including Semantic segmentation and NDVI (calculation of the amount of the visible and the reflected IR light from vegetation). The image processing algorithm uses in pixel wise reflectance analysis and SVM classifier to analyze crop health and accordingly decide to spray the pesticide. A smart wireless charging station with both portable and fixed configurations are provisioned for auto-docking and uploading mission data during the idle stage. The drone has failsafe features to prevent mishap and guarantee a better level of safety. Hence, this intelligent edge-based drone along with its IoT framework will go a long way in redefining agriculture.

2. LITERATURE REVIEW

At present, many aerial farm solutions rely on cloud-based satellite feed analysis. However, this offers low spatial resolution (30m), is expensive and requires clear skies [3]. Certain drone-based systems rely on wavelength capture using only NDVI parameter through modified cameras for farm analysis [4]. This however is less effective in areas of high biomass content and tends to amplify atmospheric and environmental noise. Alternative methods like Semantic segmentation of videos helps in scene understanding, thereby assisting in other automated video processing techniques like anomaly detection, object detection, event detection [5]. But, certain challenges like repeatability, computational complexity and labelling work offer challenges in this method. However, the Agrocopter uses a dual stage modified algorithm that utilizes NDVI and segmentation through an adaptive weightage computation based on environmental parameters captured through sensors. Current solutions offer complexity in operation, machinery, understanding and hence lead to higher cost [6]. The proposed solution

Agrocopter is a dovetail for the agricultural needs in terms of offering decision support and at the same time ensuring optimal cost. Modern day battery technology is not mature enough to give better flight time due to high power applications [7]. To ensure uninterrupted operations a smart charging dock is also discussed in the course of this paper. Hence the 'Agrocopter' provides a holistic, reliable and affordable aerial farm management system for the modern-day farmer.

3. WORKING AND MODELLING

3.1. System architecture

The basis of Agrocopter's design can be classified into a 4 level architecture which involves data capture, processing and transmission. Fig.1 shows its working with the underlining 4 layers.

1. Site : This is the portion of land under survey for the drone, in our case the crops on the farm. This is surveyed by onboard multispectral cameras.
2. Sensorics : The various sensors placed in the farm along with those on the drone form an integrated IoT network.
3. Drone : This layer involves the drone dynamics for generation of autonomous flight along with edge computing hardware.
4. Communication : In this layer the drone's navigation systems along with the data transmission systems to the cloud are involved.

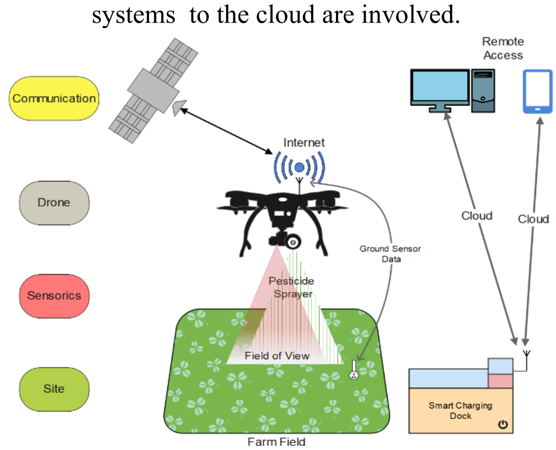


Figure 1. Layered Architecture

Meanwhile the layers are further divided to make optimal use of aerial imagery and modular plant management systems. Hence the Agrocopter is robust in design and working but at the same time easy to operate and seamlessly integrable.

3.2 Aerial System Development

The drone design was done keeping in mind its applications and user centricity. Some of the design parameters include flight time, altitude of flight, terrain and obstacle detection, payload capacity and seamless integration to perform edge computing and autonomous dynamics. The hexa-copter was selected keeping in mind the payload and degree of control. This provided a good balance between sophistication and value for money. The drone auto-stabilizes from LOS communication with the satellite and gets a 3-dimensional GPS lock for precision flight missions. The modular mechanisms were designed to be implemented using a simple plug and play architecture to reduce the learning curve for the farmer. Pesticide spray module[8] was designed to spray the liquid centrally under the drone to provide pinpoint precision. On the other hand, the Seed Box module [9] uses a flap controlled by the servo mechanism. The on-board edge computing unit processes all the operations including image analysis, actuation and decision support to activate plug and play unit such as pesticide sprayer, seed box module and camera vision system. Whereas autonomy is managed by the onboard Flight controller. The core of the Agrocopter is the Image processing unit with camera system this involves IR reflectivity scanning to give overall farm health status followed by semantic segmentation and classification for better precision. The generated masks are scaled, and the health ratio is obtained through the analyzer model as follows:

$$(\alpha * NDVI) + (\beta * Segmentation) = \eta \tag{1}$$

$$(\alpha * NDVI') + (\beta * Segmentation') = \eta' \tag{2}$$

Here, $\alpha + \beta = 1$ which suggests that the 2 methods will be set in a ratio based on environmental factors including weather, sunlight intensity and foliage configuration. In (1), we have the NDVI and scaled health ratio obtained from segmentation. In (2) the NDVI' and Segmentation' represent the ideal crop-specific health parameters obtained through repositories and scientific trial. This helps us to get final modified health ratios η and η'. The system now compares these two values and initiates trigger of sprayer in real time if ($\eta < \eta'$) which indicates unhealthy crop. This 2-stage algorithmic image analysis uses semantic segmentation further to give localized crop health status, thereby increasing the accuracy and optimal use of pesticides.

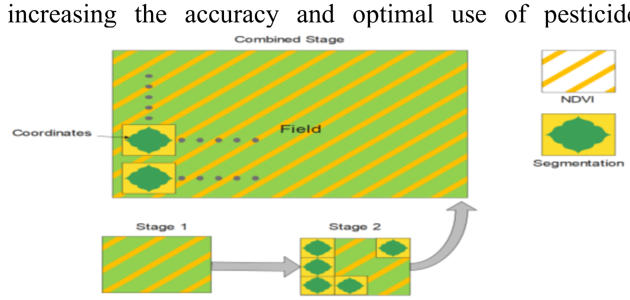


Figure 2. A modified 2 stage image analysis algorithm

Several flight modes can be assigned to the Agrocopter like land, loiter, stabilized, altitude-hold, auto, and return to Home. Auto missions can be pre-programmed and customized for the farmer. Hence, this gives an overview of how the Agrocopter (shown in Fig.2) was designed and the technology behind it.

3.3 Agro-Dock Development

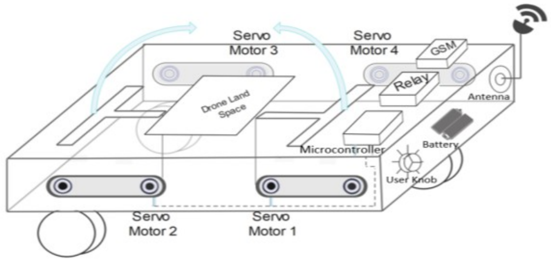
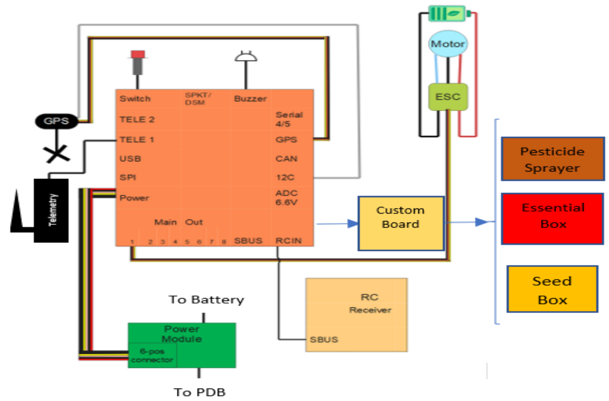


Figure 3. Smart Charging Station Schematic

The AgroCopter overcomes the challenges of modern battery technology for drones that affect the flight time. It comes with an in-house designed smart charging system named as Agrodock. This system is being offered in 2 variants, a fixed dock and a portable dock. The fixed dock is powered via standard power supply to safely charge the drone whereas the portable system uses automotive batteries, rechargeable every 10 days on an average thereby providing multiple recharge cycles for the drone. Apart from the wireless charging feature,[10] it also provides a connection to local Wi-Fi router or uses the mobile data through the GSM module encapsulated in the system. This collected data is relayed to cloud for storage and processing. The system consists of a two T-shaped energized coiled structure separated apart by the drone landing space. This landing platform consists of piezoelectric pressure sensors which makes the system aware of the absence or presence of the drone. When the drone is present on the land space, the dock would sense its presence which would trigger the smart relay that would raise the T-structure and make it move inwards using pulley mechanism. This inward movement would gently push the drone in position such that contact charging is enabled. The drone being powered by a Li-Po battery of 3S (8000mAh), gives a flight time of about 20-25 minutes. The microcontroller would trigger the relays to make the structure lay flat on the platform before the drone departs. Hence, the AgroDock is a perfectly safe and excellent complementary solution to wirelessly charge the Agrocopter.

3.4 System Integration

In the Flight Controller System, (Fig. 4) the series port of the 32-bit controller is connected to a GPS module for navigation using I2C protocol. The pesticide sprayer and seed box modules are connected to the custom board that drives these systems in accordance with the plant health algorithm and flight control system. For our application, the voltage is kept at a maximum of 12.6V generating power which is equally distributed to 6 electronic speed controllers that drive 10-inch propellers via 920kV high torque brushless DC motors. A hardware safety switch and buzzer are also connected to the controller to prevent any accidental arming of the drone. Agrcopter generates 7 kg of thrust and can lift payloads up to 3 kg while providing a decent flight ratio giving it better flight dynamics and agility.



4. SYSTEM IMPLMENTATION

The Agrocopter makes use of several sensors, multi-spectral cameras and custom-built modules that work in sync to ensure targeted operation and optimized system performance. The following sub-systems describe the individual operation, working and contribution in Agrocopter.

4.1 Agro Systems

The Agrocopter has been designed to be completely modular with plug and play systems for agriculture purposes. As shown in Fig. 5 the major systems on board the drone can be discussed as follows :

1. Pesticide Sprayer : This in-house built sprayer provides targeted spraying on crops to mitigate diseases. This is driven by a 5V mini pump with 80 L/H capacity triggered by the edge-based system, in response to poor plant health as analyzed by image processing.
2. Payload box: This can be used to carry up to 500 grams extra required materials, sensors or first aid throughout the farm [11].
3. Seed Box : During plantation season, the drone can be used for systematic positional periodic seed dispersing driven by timed waypoint-based servo release mechanism. This module can be used for solid pesticide as well.

Drone testing was carried out in a field in Manipal India with coordinates (13.344529651512422, 74.79392134764375)

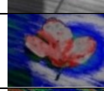
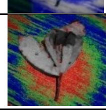

Figure 5. Agro Modules and Camera in Action

4.2 Camera System

The camera used in the Agrocopter is a 1200 TVL CMOS FPV camera with 2.8mm lens that was modified to allow IR imaging. The multi-spectral image data captured is used during NDVI and semantic segmentation computation [12]. This live aerial feed as shown in Fig. 5 is captured and a composite farm image is stitched on Mission Planner software from where it is sent to the cloud, and analyzed using 2 different methods as follows:

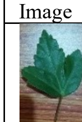
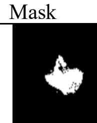
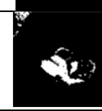
NDVI : In the first method, the image is analyzed pixel wise and each pixel for the crop images is assigned a value between 0 to 1 according to the NDVI scale which generates result as shown in Table 1. NDVI is measure of the difference in reflectance of visible and near-infrared light from the vegetation, expressed as a ratio. This helps to analyze rudimentary plant health and take actions accordingly.

Table 1. NDVI results

Color Image	NDVI image	NDVI value	Health
		0.80	Healthy
		0.32	Moderately healthy
		0.15	Unhealthy

Semantic segmentation : The second parallel process involves assigning a class to every individual pixel in an image and classify it into healthy and unhealthy classes based on a machine learning algorithm. It uses an architecture consisting of a feature descriptor and classifier. In general, there exists color and texture variations between healthy and unhealthy crops as shown in Table 2. Texture and color features are considered as a feature descriptor. Texture features are calculated using filter banks which consist of multiple filters that represents different patterns. The filter bank considered in the present study has 17 filters of Gaussian and Laplacian. The Gaussian filter is applied at varying scales by setting standard deviation (sigma) to 1, 2 and 4. These filters are applied to R, G and B color channels. X and Y derivative of Gaussian filter is applied with sigma value set to 2 and 4. Laplacian filter is applied with sigma value set to 1, 2, 4 and 8, whiles RGB and LAB color features are considered along with the texture features Support Vector Machine (SVM) classifier is trained to map the feature vector to two classes. The parameters of SVM classifier are identified by utilizing 10-fold cross validation. In the present study, the gamma value of SVM is set to 0.0001 and the C parameter which provides penalty is set to 10. For every pixel, texture and color features are extracted and classified by utilizing SVM classifier. Based on Texture and pixel wise probability of green color intensity, we compute the individual pixel health status. This is then converted to a mask based on if the values are greater or smaller in comparison to the healthy threshold. The observed masks as in Table 2, help to get a net pixel area ratio (white area / total image area), which forms the health ratio of the complete image. This is then scaled to fit the weightage-based parameter model equation.

Table 2. Sample Field Images with segmentation masks

Color Image	Segmented Mask	Health Ratio	Scaled Health Ratio	Health
		0.0729	0.729	Healthy
		0.0646	0.646	Moderately Healthy
		0.0256	0.256	Unhealthy

The performance of the semantic segmentation model is evaluated by calculating standard metrics, i.e., precision, recall and f1-score. The algorithm gives a precision of 0.85 and a recall of 0.8 on the training dataset. Further, the performance was evaluated against samples consisting of only one class (healthy or unhealthy) as shown in Table 3.

Table 3. Classification Report

Metric	Training set	Healthy	Unhealthy
Precision	0.85	1.0	1.0
Recall	0.81	0.91	0.86
F1-score	0.79	0.95	0.92

Although NDVI is computed without environmental parameters, it is non-linear and is sensitive to crop background brightness. Whereas Semantic segmentation can overcome the above issues but has computational complexity and poor scaling. The generated models and masks are scaled by factors (α and β) that give the modified and accurate result for crop health analysis. Hence, this dual step-based approach not only gives a more robust solution, but also provides a reliable method of monitoring the health of the crops with increased accuracy.

5. CONCLUSION

The above sections give an idea of the blueprint of the Agrocopter's design along with its associated image analytics technology capabilities. The implementation of modified crop health analysis based on sub-weightage allocation through environmental factors helps to strategically exploit the benefits of segmentation and NDVI methods and prevents their drawbacks. The modular approach along with pesticide sprayer, seed module and payload box offer holistic service and aid agriculturists. Moreover, it is seen that the drone is able to remotely manage farms and mitigate crop health issues real time thereby maximizing profits and reducing efforts for farmers across the globe. Agrocopter will surely go a long way in providing the modern farmer a low-cost, reliable and intelligent aerial farm assistant system.

5.1. Future Development

The Agrocopter is soon to be industry ready. It is fully capable of carrying out autonomous missions and farm image surveillance with crop management. The on-board controllers and systems are capable of integrated NDVI imaging and segmentation on the edge. The subsequent development will involve turning the Agro-Dock idea into a reality to ensure seamless charging and data porting. Work is also going on to make it water and dust proof to survive the harsh scenarios in farms anywhere across the globe. It can be used to analyze ripe fruits and pick them during the season thereby reducing labor costs. The image analytics can understand the diseases faced by the plant and spray the exact required chemical from its on board payload catalog. Moreover, being completely modular, it can be used not just in the agriculture space but also for geospatial mapping, search and rescue, medical emergencies, food and goods deliveries and much more. Having a robust design and payload lifting ability, it can also carry heavy cameras, parcels and equipment. Hence, it is seen that the applications of Agrocopter are endless, and it will surely go a long way in the holistic and sustainable progress of mankind.

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