A Case Study on Field Maps and Identification of Best Paths using UAVs in Precision Agriculture

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Abstract
Nowadays, fully automated solutions are being considered for precision agriculture. One such solution is the use of Unmanned Aerial Vehicle (UAV). UAVs use a combination of multiple technologies and programming such as Smart Sensors, Digital Electronics, Internet of Things, Satellite Technology, etc. which makes them an efficient technique to a fully automated farming solution. Precision agriculture or smart agriculture include field mapping with multiple onboard sensors to map terrain and detect soil health or vegetation. This paper reviews on the UAVs in precision agriculture and their ability to evaluate the best paths for field mapping.

Keywords: Precision Agriculture, Field Map, Best Path, Unmanned Aerial Vehicle, Drones.

Introduction

The human population is estimated to reach 10 billion by 2050. With this large growth in population, a larger demand for food is expected. To meet with this demand, different forms of complex technologies are being implemented in agriculture such as the internet of things, artificial intelligence and autonomous aerial vehicles. These technologies promise to create a far more efficient and smart future for the agriculture industry [1]. A case study on the use of unmanned aerial drones in evaluating the best paths for covering the field maps in precision agriculture is presented here.

Unmanned aerial Vehicles (UAVs)

An unmanned aerial vehicle is a flying vehicle that does not require an onboard pilot [2]. With the large variety of sensors now available and the use of complex algorithms, this vehicle has been able to achieve almost total autonomism except for a few drones that still require a remote pilot [3]. These drones have a low maintenance and acquisition cost, along with the ability to be deployed in any terrain and vertical takeoff [4].

Types of UAVs

There are multiple types of drones with their own functionality and advantages. All these drones can be divided into two categories as shown in Plate 1 [1].

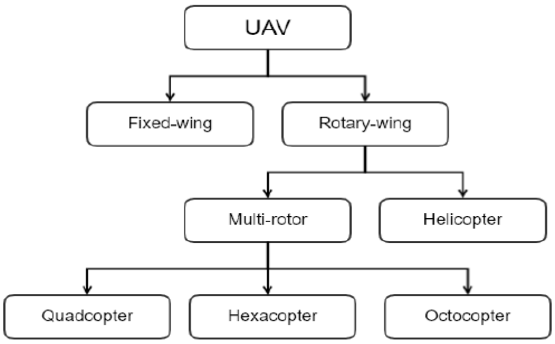

Plate 1: Classification Table for UAVs [1]

Whilst all fixed-wing UAVs share the same characteristics, the rotary-wing UAVs can be further broken down into smaller sub-class consisting of a typical helicopter model and a multi-rotor model. These multi-rotor models can range from quadcopters (four rotors) to Octocopter (eight rotors). These increase in the number of rotors can add more stabilization and functionality but at a cost of weight and power consumption [1].

The fixed-wing drone, like the one shown in Plate 2, uses the same system to takeoff as that of a plane. This means that unlike the rotary-wing drone, the fixed-wing drone requires a forward drive to catch as much wind underneath its wing to take off. However, this type of drone tends to be faster and can go to higher altitudes compared to that of a rotary-wing drone.

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Plate 2: Fixed-Wing Drone [5]

A rotary-wing drone can have multiple amounts of propeller blades from a quadcopter with four rotors to an octocopter that has eight rotors. This drone uses the same mechanics as a helicopter to achieve flight by sucking in air into the propellers and pushing it out beneath the drone. These drones tend to have multiple onboard sensors to keep the propellers synchronized and thus maintain a fixed altitude and balance while in flight. These drones can hover and take off from any position without the need for a runway [1]. A rotary-wing drone is shown in Plate 3.

Plate 3: Rotary-Wing Drone [5]

UAVs in Agriculture

The countless applications of Unmanned Aerial Drones increase as artificial intelligence and autonomous technology improves. One such application is found to be in the agriculture industry. The broad areas covering smart agriculture include:

Terrain Mapping

Mapping areas for agriculture can be used to create a two-dimensional (2D) or there-dimensional (3D) map which can provide certain information on the land, such as, soil pH and soil composition, etc. This can allow the farmer to divide the land for different types of crops with a higher efficiency than normal. Also, it allows the precision agriculture to define zones for homogeneous areas and the establishment of fruit quality zones as shown in Plate 4 [6].

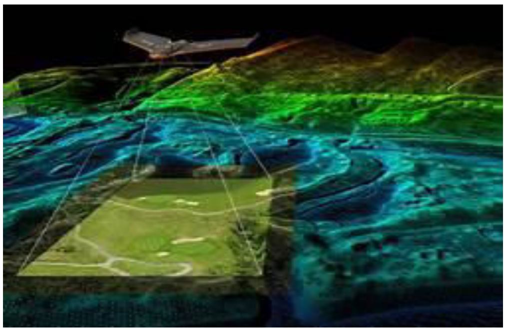

Plate 4: Terrain Mapping [6]

Spraying Crops

Crop spraying can either be to remove pest using pesticides or for irrigation of the plants using water. The use of drones for this job is far more efficient and can also reduce the amount of pesticide used [1]. A crop spraying drone is shown in Plate 5.

Plate 5: Spraying Crops [7]

Furthermore, by not involving workers in the spraying of pesticide, it can greatly reduce the health risk of the workers from the exposure to the pesticide [1]. The use of drones in this operation can decontaminate an area of up to 50 hectare per day and only need approximately 10 minutes of work per 0.5-hectare area [6]. With the advancement in drones, companies such as DJI's new MG-1 model spraying drone has eight rotors, a 10 kg payload capacity and a far more advanced algorithm capable of automatically adjusting the amount of pesticides released according to the flight speed which creates a constant continuous stream of pesticide with the minimum amount required as seen in Plate 6 [7].

Plate 6: DJI Drone [7]

Harvesting Crops

Before crops can be harvested, they need to be examined to see whether they are ripe or not. This can be a tedious labor job that requires multiple employees to accomplish and some yield might be lost due to human error. With the use of UAVs in this task, the crop yield and quality would increase. This can be achieved through the cameras attached to the UAVs which would cover a large area of land in 3D. In one more study, a multi-spectral camera was used to analyze the vegetation index to improve productivity [1]. Hence, a drone can monitor the growth and health of crops in a large area at a lower cost and labor [Plate 7].

Plate 7: Harvesting Drone [1]

Technologies for field mapping

There are multiple technologies available for field mapping by different companies. These range from traditional land surveyor to the modern UAVs with built in sensors and the geospatial technology [8]. Each of these technologies have its own advantages and can be used for different situations, like,

Field-Map RHINO Set

The Field-Map RHINO set is a combination of devices suitable for high precision measurements with an emphasis on distance measurement taken from a stationary position. This device can also be used on plots with magnetic anomalies as the device is not affected by magnetic field as shown in Plate 8 [9].

Plate 8: Rhino Set [9]

The Field-Map RHINO is a traditional land surveyor that is normally placed stationary on the ground. This device though does not use satellite technology still uses digital technology as shown in the Table 1. This device uses a tablet to record and process all the data received so that later it can be processed to assemble a 3D model of the area. This device relies mainly of three parts for measurements;

a) Laser Rangefinder: It allows the user to measure the distance between the device and a fixed point.
b) Inclinometer: It allows the user to measure the elevation in an area based on its current position.
c)TruAngel: It calculates a turned horizontal angle that can be referenced to any desired point or direction.

Table 1: The Field-Map RHINO Set [9]

Field-Map Hardware

For UAVs to operate in field mapping for precision agriculture, multiple sensors are needed. These sensors are normally installed into onboard microcontrollers such as Arduino or Raspberry Pi, [10]. Furthermore, few sensors such as a Global Navigation Satellite System (GNNS) receiver and Inertial Measurement Units (IMU) are installed to aid the drone keep track of its location during its flight [11]. Various sensors along with the communication protocols used in UAVs is tabulated in Table 2.

Table 2: Table of Sensors Used by Drones [11]

Regarding the sensors used for acquiring essential agricultural information or field mapping, the technology has evolved to simple camera to a wide variety of cameras. These cameras range from regular visible light cameras that can give clear resolution pictures from a long distance to cameras such as the hyper-spectral or multi-spectral camera that gives other valuable data needed for precision agriculture. Furthermore, cameras such as the multi-thermal cameras can be used to monitor the topography of rice fields or to confirm the growth of crops in the said area [12]. In addition, the use of the LIDAR instrument that rotates 360 degrees, enables the creation of a 3D map using a laser [13]. These data are sent to a computer with the use of satellite technology and are compiled to form the said map using IoT technology. The LIDAR is the most crucial sensor on the drone to be able for field mapping and creating an accurate depiction of the land [14]. Table 3 summarizes the major type of sensors and their applications in precision agriculture.

Table 3: Sensors types and applications [15]

Field-Map Software

With the progression is technology, UAVs are beginning to use less on-board navigation and localization systems and are more connected to satellites and IoT (Internet of Things) technology with a high level of accuracy in revealing the drone's location. Technologies such as the GPS in USA or GNSS in Russia [Plate 9] uses real-time kinematics to allow these navigation systems to be more accurate in tracking the drone.

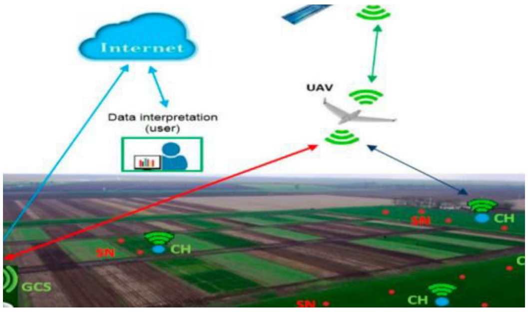

Plate 9: UAV using GNSS for communication [16]

Furthermore, with an addition of an Inertial Navigation System (INS) as shown in Plate 10, that continuously calculates the velocity at which the drone is moving based on its change in position and orientation, can be discovered using either a built in IMU or the use of a GNSS. Therefore, with the combination of these systems and microcontrollers such as Arduino, the drone can maintain flight without any assistance from humans.

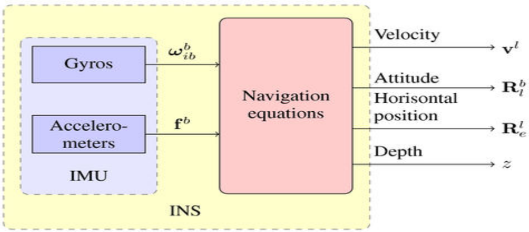

Plate 10: Inertial Navigation System [17]

Graphical User Interface (GUI) processes this information collected by the drone through a direct connection via the internet and displays the necessary information. An example of a website used and area selection for field mapping used by the DJI Mavic Pro are shown in Plate 11 and Plate 12 respectively.

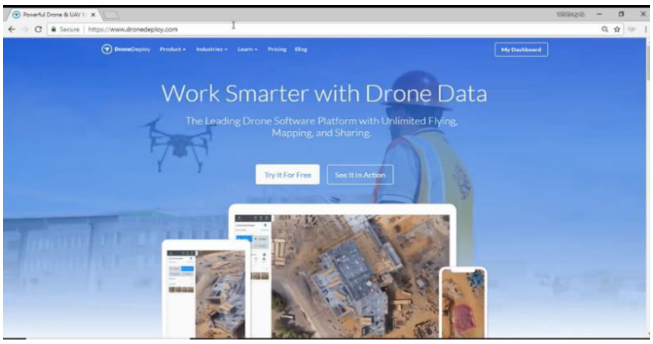

Plate 11: Example of Website used for Field Mapping with drones [18]

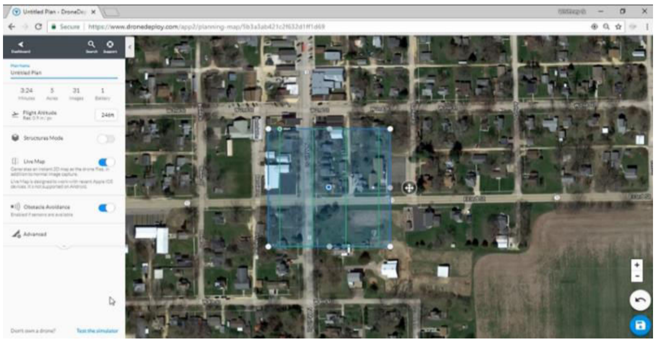

Plate 12: Example of area selection for field mapping with drones [18]

Review on Best Paths

When reviewing the best paths that a drone can take to create a 2D or 3D model of a field with relevant data for precision agriculture, the main characteristics to be considered are efficiency and accuracy. In terms of efficiency, the chosen paths must take the least amount of time needed with a moderate amount of power consumption compared to all other paths that could be chosen and that human workers could achieve. Furthermore, while collecting data via photographs from an onboard camera, there should also be minimal redundancies if not none. Regarding the accuracy, data such as terrain elevation and soil health must be as accurate to the real value (manually measured value) as possible.

Accuracy

Plate 13 shows an example of an accurate depiction of the terrain elevation observed by the DJI Mavic Pro UAV after it has scanned and collected data. This shows the accuracy of the UAV in terms of displaying the data using a fixed range to represent the difference in elevation in the form of color gradient. It shows the estimated time, size of the land covered, number of images required and how many batteries it would take on this journey. If this were to be compared to the time it would take for a human worker or even a team of workers to complete this task, it would be clearly seen that this drone is much more efficient.

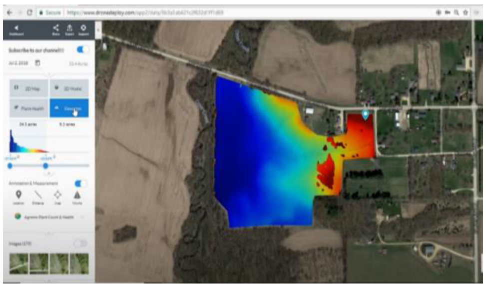

Plate 13: An accurate depiction of the terrain elevation observed by the UAV while collecting data using various onboard sensors [18]

Efficiency

Plate 14 show the efficiency of the DJI Mavic Pro UAV to plot out a path that will cover the whole field with minimum redundancy while trying to stay in the given area. This is done by calculating the right number of samples the area can be divided into to form a zigzag pattern with equal spacing in between each line.

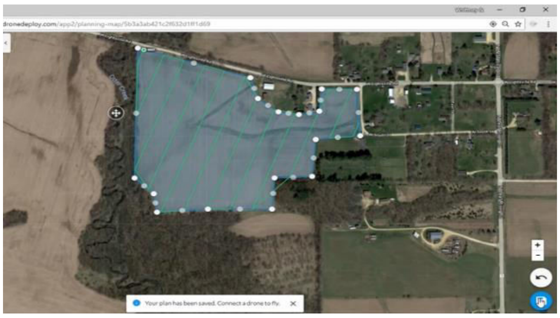

Plate 14: Example of a Selected Flight Path [18]

Drone Paths

When a defined area has been selected by a user for the done to map, the drone will have to plan an efficient path which covers the entire targeted area while remaining inside the given boundaries. This breaks down the path needed to be taken by the drone into two zones, the no flight zones and the flight zone. This flight zone is usually split into non-intersecting regions called cells using a decomposition technique like that or sampling in digital electronics [19]. Depending on the type of decomposition, the size and resolution of the cells may change, and a specific path will be set to guarantee the complete coverage. These cells are typically proportional to the size of the drone or proportional to the sensor's range on the drone. The area of interest (flight zone) can be represented by a sequence of vertices which can be described by a pair of coordinates as shown in Plate 15. This makes it easier for the drone to be able to identify its boundary and remain within it. This makes it possible to set an area of interest that is in a complex shape such as a convex polygon rather than a prime shape such as a rectangle.

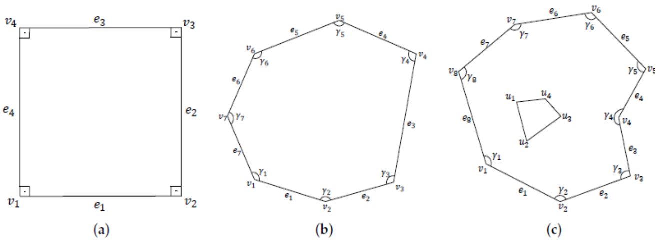

Plate 15: Different areas of interest explored (a) Rectangular; (b) Convex Polygon; (c) Concave Polygon with No-Fly Zones [19]

Back and Forth Path

This method saves the energy of drones whilst in flight. The program determines the best back and forth route within the area of interest and plots a course accordingly with a focus on energy efficiency at maximum altitude and with minimum number of turns. This method ensures that the drone is flying at an optimal speed that is dependent on the distance travelled. The algorithm uses the first vertex of the longest edge and computes the scan direction parallel to it. It then calculates the number of stripes and waypoints, the distance between the strips and consecutive waypoints, and the overlapping rates. These are used to form straight lines with equal spacing that connects the farthest vertex to the first vertex near the start point. By turning the number of stripes in even and increasing the overlapping rate, the returning path can also be used as a scanning path too. It also used online and offline failsafe measures in order to verify if there is enough battery life for the mission and whilst in flight to constantly monitor the remaining battery life to complete the said mission and return to the start point as shown in Plate 16 [19].

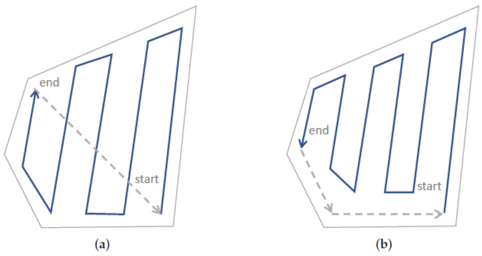

Plate 16: Back & Force coverage path planning: (a) Odd number of stripes; (b) Even number of stripes [19]

Spiral Path

This method was proposed for the use in a regular-shaped area of interest. The algorithm builds a coverage path that passes by each vertex of the area (boundary). Once it has passed by the boundary, it has completed its first coverage layer and the radius of the next coverage passed is reduced to move the vehicle towards the central point as shown in Plate 17. For the spiral method the drone must perform constant turning maneuvers with wide angles and will have to reduce its speed to zero on every turn. This keeps the optimal speed in the straight segments of the path for a longer period, providing an even more effective battery saving than the back-and-forth method. It was found that the spiral method was more energy efficient [19].

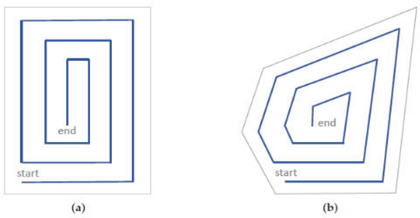

Plate 17: Spiral Algorithm path planning: (a) Rectangular area; (b) Polygonal area [19]

Conclusion

Drones are possibly the future of precision agriculture in multiple fields such as in field mapping, crop spraying and harvesting. These drones use multiple technologies such as GNSS and INS to monitor its location and position. They also contain sensors that allow them to gain data such as terrain elevation and soil health. However, these drones have limitations such as the amount of energy they consume in flight, especially if the area of interest is of a substantial size. This brings an issue of energy capacity against the weight of the battery, whereby if a larger battery were to be used on the drone, then the weight of said drone would have to increase and could either slow down the drone and increase its cost. These issues are being tackled with innovations such as the spiral path planning algorithms. This algorithm as discussed above is far more energy efficient than the traditional back and forth method, therefore could give drones a longer flight time.

Furthermore, innovations in battery technology such as the recent graphene alloy battery that has a larger capacity than that of traditional lithium alloy batteries, could also give these drones the addition energy needed to complete longer flights without having to stop to switch batteries. In addition, the sensors are becoming more detached to the drones such as its navigation system that mainly relies on GNSS and the onboard sensors are mainly for the required task, whilst the computation and storage part of this task is done by an offboard computer and the use of IoT. Although there has been significant innovation in the technologies available, it would take few years for farms to fully depend on drones for field mapping and other agricultural tasks and see them as the future in precision agriculture.

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Table 1: The Field-Map RHINO Set [9]

Hardware	Description	Image
Getac T800 rugged 8.1" tablet	Built for today's mobile workforce, the new tablet features an 8.1-inch display, the latest wireless technology and unique Snapback add-ons and runs on Windows 8.1 Pro.	
Computer and laser frames and brackets	Frame for tablet computers - Inclinable frame for tablet computer and bracket for laser rangefinders	
TruPulse 200X	A Compact, lightweight and rugged laser rangefinder and inclinometer. Data communication is available through standard serial port or via Bluetooth.	
Mapstar TruAngle	The TruAngle calculates a turned horizontal angle that can be referenced to any desired point or direction. It works in conjunction with TruPulse, ForestPro and Impulse laser rangefinders providing the best possible accuracy. The TruAngle is never affected by local magnetic interference.	
Carbon-fibre tripod	Light and durable carbon fiber tripod with leveling base. Panoramic head for tripod - Easy to turn and fix head for tripod.	

Table 2: Table of Sensors Used by Drones [11]

Platform	Sensors	Communication
Fixed Wing (23 Kg)	GPS receiver	Wireless radio
	Photodetectors	Wireless radio
	Multi-spectral camera	-
	Hyper-spectral camera	-
	GPS receiver	-
	RGB camera	-
	Thermal camera	-
Helicopter (22 Kg)	IMU sensors	Wireless LAN
	RGB camera	-

	Multi-spectral camera	Bluetooth
Quadcopter (1.25 Kg)	RGB camera	-
	Thermal camera	Xbee
	Multi-spectral camera	-
	visible-light camera	-
	GPS reviewer	Wireless radio
	Hyper-spectral camera	-

Table 3: Sensors types and applications [15]

Type of Sensor	Application
Digital camera	Visible properties, outer defects, greenness, growth.
Multispectral camera	Multiple plant responses to nutrient deficiency, water stress, diseases among others.
Hyperspectral camera	Plant stress, produce quality and safety control
Thermal camera	Stomatal conductance, plant responses to water stress and diseases.
Spectrometer	Detecting disease, stress and crop responses.
3D camera	Plant height and canopy density.
LiDAR	Estimates of plant height and volume.
SONAR	Mapping and quantification of canopy volumes, digital control of sprayers and fertilizer spreaders.