Enhancing Agricultural Efficiency: The Impact of Drone Utilization in Modern Agriculture

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Research Question: How does the utilization of drones impact crop productivity, its efficiency and sustainability in modern agricultural practices?

Abstract

This investigation of drones aims to describe the varieties of benefits, thanks to the drones programmable and mechanical capabilities, in the agricultural sector. Drones offer several advantages in crop management, including remote sensing capabilities, high-resolution imaging, and precision application of inputs. By capturing aerial data, drones enable farmers to monitor crop health, identify areas of stress or disease, and make informed decisions regarding irrigation, fertilization, and pest control. This targeted approach can lead to enhanced crop yields, reduced resource wastage, and optimized resource allocation. Moreover, the use of drones can contribute to sustainability in agriculture by minimizing chemical usage, conserving water, and reducing soil erosion. These are the primary reasons why many farmers have implemented the use of drones in their workflow. However, challenges such as cost, regulations, and technical limitations need to also be considered. This study aims to provide comprehensive insights into the benefits, limitations, and potential improvements associated with integrating drones into crop farming based on agricultural drone components, studies, and farming application, ultimately contributing to the advancement of technological precision agriculture.

Introduction

Agriculture is an indispensable asset to the world. It impacts numerous aspects of our lives through food, habitats, and jobs. Drones or unmanned aerial vehicles (UAVs), are innovations that could impact the workflow of agriculture for the better. In agriculture these UAVs help everybody working in this field from relying on workers to do the hard labor and having less long-lasting damaging effects on humans. Drones can also help farmers make more educated decisions about their own business by monitoring crop health, growth, diseases, soil analytics, precision agriculture, pesticide spraying, and infrastructure inspection.

In 2011, UAVs made their breakthrough in the agricultural sector after becoming more usable and affordable. These drones have branched out in the agricultural business in four main applications: mapping, spraying, monitoring, and harvesting. Most of this utility is due to the UAVs autonomous flight which allows the farmer to have more liberty at taking on the rest of the responsibilities managing a farm. At this point you might be asking yourself, how are these UAVs able to have so many capabilities? Most of the UAV's capabilities are due to their various cameras, sensors, and hardware that are the main support in agricultural areas like, for example, the mapping branch. The cameras can take many photos of a field and join them together to get the bigger picture and with height and distance measuring sensors it provides a broken-down analysis of the state of the farmer's field.

The market for the growth of UAVs or drones has flourished in recent years. In the United States companies like UPS and Amazon have implemented drone-based delivery services. India tried implementing one as well for the delivery of Covid-19 vaccines. [1] Covid-19 could be looked at as a way in which opened our eyes to the use of drones. Since Covid-19, the UAV or drone industry has been growing in research as much as in real-time use and is expected to grow even further now that Covid-19 has been controlled. In 2023, the UAV market is approximately 15.40 billion USD and is expected to increase annually by 14.01% until 2028 when it is predicted to be 29.66 billion USD, according to Mordor Intelligence. [2]

Many of the technologically advanced countries have implemented UAVs in their agricultural departments. Places like China which has world leading drone manufacturing, supplying approximately 70% of all civilian drones sold globally in 2017. [3] Also, studies show that in 2016 there were 4,262 field-operated plant-protection UAVs in the country, of which, electric multi-rotor agricultural UAVs were the mainstay. [3] China's use of drones in the agricultural sector has been specialized to plant protection drones with over 200 manufacturers. [3] China is currently improving plant protection drones by bypassing farmland obstacles with sensing capability, multiple redundancy systems and AI fault prediction.

South Korea has already implemented 30% use of drones for spraying crops. [4] South Korea's implementation of drones has grown the UAV market exponentially in recent years and is not planning on stopping because it is predicted that from 2023-2028 the market size will grow by 12.5%. [5] South Korea's intention of implementing drones was brought by their 1 billion dollar investment in 2017. [6]

Japan has had a major decline in the number of farmers, dropping from 11 million to 2 million, and the government has introduced UAVs in the agricultural sector to make the Japanese agriculture more reliable to yield more crops for the population, and substitute for the decline of farmers. [7] By implementing drones Japan's agricultural practices have become more efficient. An example of this is Yoshinoya Farm Fukushima in northeastern Japan which only had to hire 18 laborers to handle cabbages, onions, and rice. Seeing such small staff the farm underwent many tribulations like bad weather and plagues which are common problems. [8] With the implementation of drones in this farm their workflow will increase in efficiency and eventually give them better business. Which is what Takita, the manager of Yoshinoya Farm, hopes to achieve with the new technology.

Malaysia and Thailand have introduced UAVs as well and Thailand seems to have stayed ahead with Novy, a company that has developed sprayer drones winning various awards. Now as you can see many of the technologically developed countries that have adopted UAVs in their agricultural workflow are in Asia but South and North America, and the Caribbean are now starting to introduce UAVs or drones in their agricultural workflow.

In Venezuela there is an innovative company called Eco Roc Drone which offers fumigation and fertilization services using drones to spray around fields. Eco Roc Drone is the first private entity offering integral solutions with drones for the agricultural sector. Their services use their drones, which are piloted by professional personnel, to accomplish precision agriculture in farms that do not yet have the technological advancements and need the assistance. Their Drones are equipped with many capabilities from aerial monitoring on crops and an early notice on whatever might be wrong in the farm. They provide aerial photogrammetry to map the farm's infrastructure. Lastly, they spray and monitor crops but something unique is that they sell agricultural drones being a pioneer of new technology in Venezuela. [9]

1. Mapping and Monitoring

1.1 Process of Mapping

Mapping is a very important tool for farmers because it allows them to analyze their fields and offer a better growing environment for their crops. Mapping is done by taking aerial images of a designated area and then creating an orthomosaic by joining these images together and practicing photogrammetry. This allows them to get accurate measurements of a specific area through the photos.

Figure 1: An example of an orthomosaic taken by a drone [10]

1.2 GPS System

One of the hardware components that help accomplish drone mapping is integrated GPS systems. These GPS systems allow drones to fly through a preprogrammed area autonomously. While they are flying through the designated space, they take photos all around the field to get the orthomosaic. One of the benefits of these GPS systems is that they accommodate farmers' needs and can be modified to the centimeter of where the farmer wants them to go. One problem that this GPS system faces is that with all the data it receives, it gets many errors while it flies and has very little time to adjust because it is flying all the time. There are two main solutions to help this problem, RTK-Real Time Kinematics or PPK-Post Processing Kinematics. [11] The differences are that RTK corrects the error in real time and PPK corrects the data after the drone has uploaded the data. These two systems allow for the drones mapping to be highly accurate and provide flawless results.

1.3 Cameras and sensors used for the pictures

Another vital component of the quality of the drone's photos used to complete the mapping is the types of cameras and sensors they use. The main cameras drones use are RGB cameras also called true-color cameras. These cameras reflect light in three main colors (R) red, (G) green, and (B) blue, hence the name RGB. These types of cameras allow for pictures to look like what the human eye usually sees. Another type of camera that drones use for mapping are multispectral cameras. Multispectral cameras differ from RGB because multispectral cameras produce pictures in green, red, blue, and near-infrared wavebands. These wavebands give farmers a different perspective on their fields, providing a more in-depth look at visible and nonvisible crops, land telemetry, soil condition and crop progress. [12]

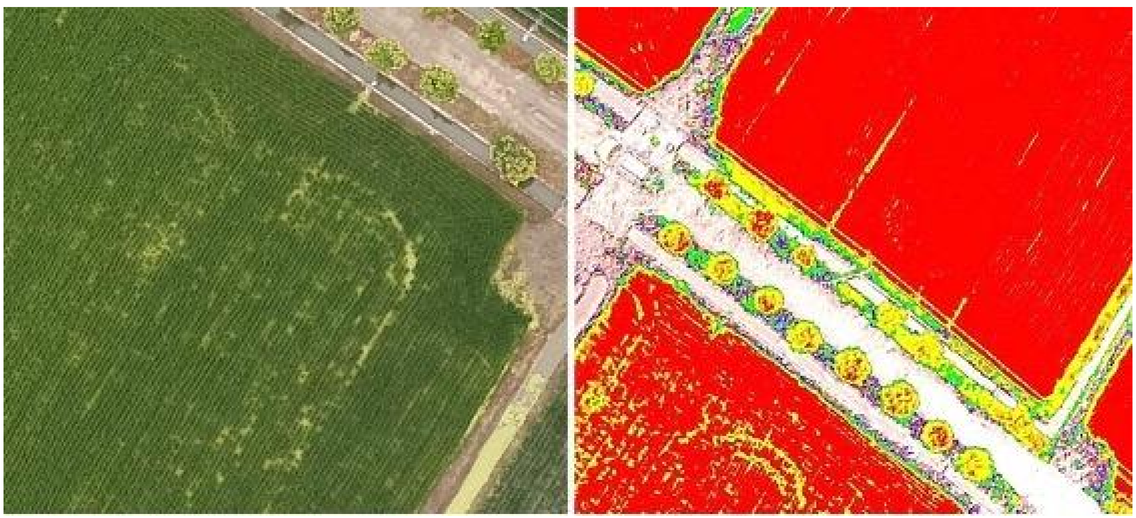


Figure 2: RGB VS. Multispectral Camera [13]

1.4 Soil Mapping

Soil mapping is useful to farmers because it affects the overall health and life of plants. Drones can detect soil properties and contamination levels through a gamma-ray spectrometer. A gamma-ray spectrometer measures the concentration of radioactive elements in the Earth. [13] To evaluate the efficiency of this process and the sensor, a study was made in Flevoland, Netherlands, by Roland Koomans, Han Limburg, and Steven van der Veeke. They mounted a MS-2000 sensor to a tractor that went against a MS-1000 sensor mounted to a DJI M600 drone. The MS-1000 is a low-power, lightweight, and robust gamma-ray detector system specially designed for use with drones. [13] After the Tractor and drone ran their course, the 232Th concentrations were taken to a lab and translated into a clay fraction defined as grain size. To make sure that the measurements they read from both parts of the study were accurate they took 44 soil samples for statistical validation. At the end, even though the results were close, the drone-borne measurements were 'smoother' and showed a lower spatial resolution. This difference in the size of spatial structures is to be expected, as the drone captures radiation from a larger area and thereby has a larger footprint. [13]

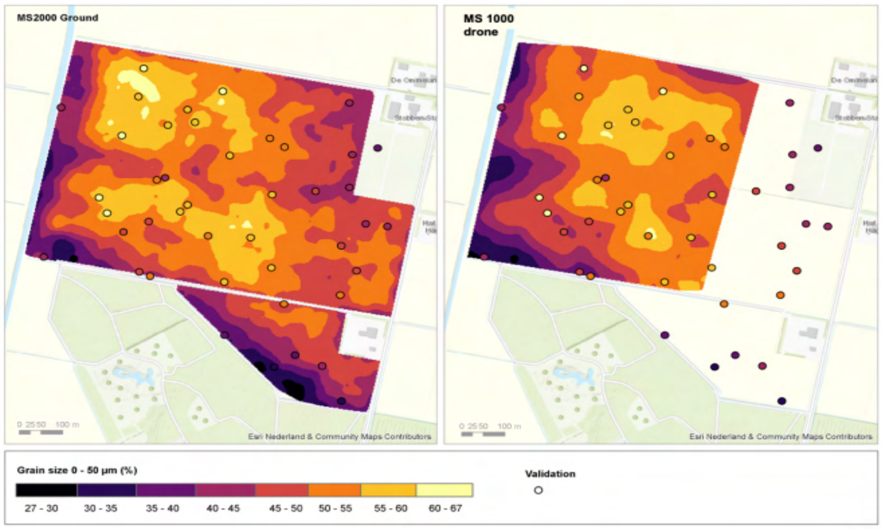


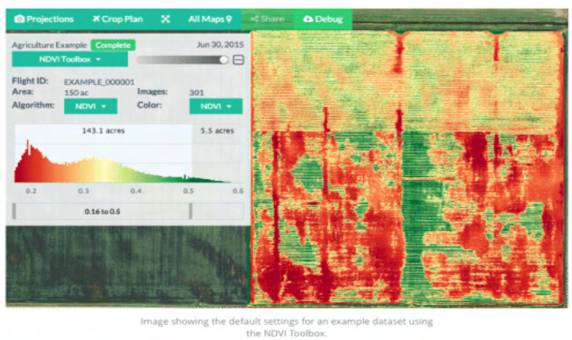
Figure 3: [13]

1.5 Process of Monitoring Crops

After mapping the field and setting up crops, crop monitoring can help to optimize crop output. The utilization of UAVs in farms opens a new door to a different perspective of looking at crops with more than just the human eye. The technology allows you to analyze plant progress and health to detect and prevent diseases. Monitoring crops requires the UAVs to have a programmed route of the farm where most drones utilize the GPS system and fly over the crops classifying and analyzing their environment but also making predictions about the crops. This helps farmers attend different parts of the field at a faster pace and prevent more mistakes. Monitoring and sensing crops with UAVs gives farmers precision agriculture at its best because it is a management strategy that improves sustainability and efficiency in agricultural production.

1.6 Hardware Used for Monitoring

Monitoring drones use RGB, multispectral,and thermal cameras. These drones also are equipped with LiDAR sensors and the Normalized Difference Vegetation Index-NDVI sensor. NDVI allows drones to use color-coded information to determine crop health. The concept of NDVI is considerably simple: observing the best NIR light reflected by the chlorophyll and red light radiation absorbed by green plants. The results from the algorithm are then used to derive index values ranging from -1 to 1. This index value indicates whether the crops are healthy or not. [14] To determine this, the NDVI has algorithms that use the equation: NDVI = NIR -Red/NIR + Red. The NDVI sensor has programmed systems that after the drone is done scanning, the data becomes available to the farmer. This allows the farmer to better understand which parts of the farm are thriving and which parts are suffering. An example of such systems is in figure 4. Another important component of monitoring crops in the farm are the LiDAR sensors that measure the distance between the sensor and a target based on the elapsed time between the emission and return of laser pulses, or based on trigonometry so that 3-D information about the target can be obtained. [15] LiDAR sensors show farmers detailed 3-D base models of their crops. One last tool that allows for crops to be best monitored are thermal sensors, which measure the heat signatures of plants and show farmers the places of stress in the farm caused by pests, diseases, or changes in the environment.



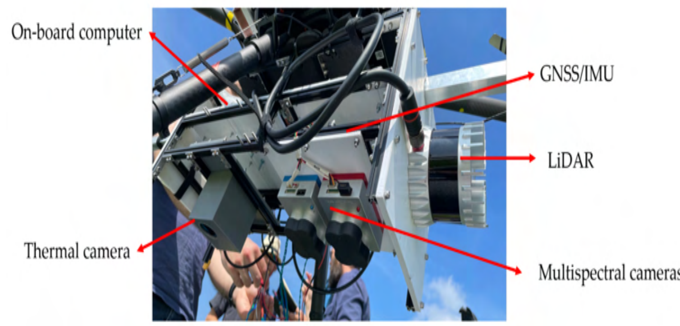


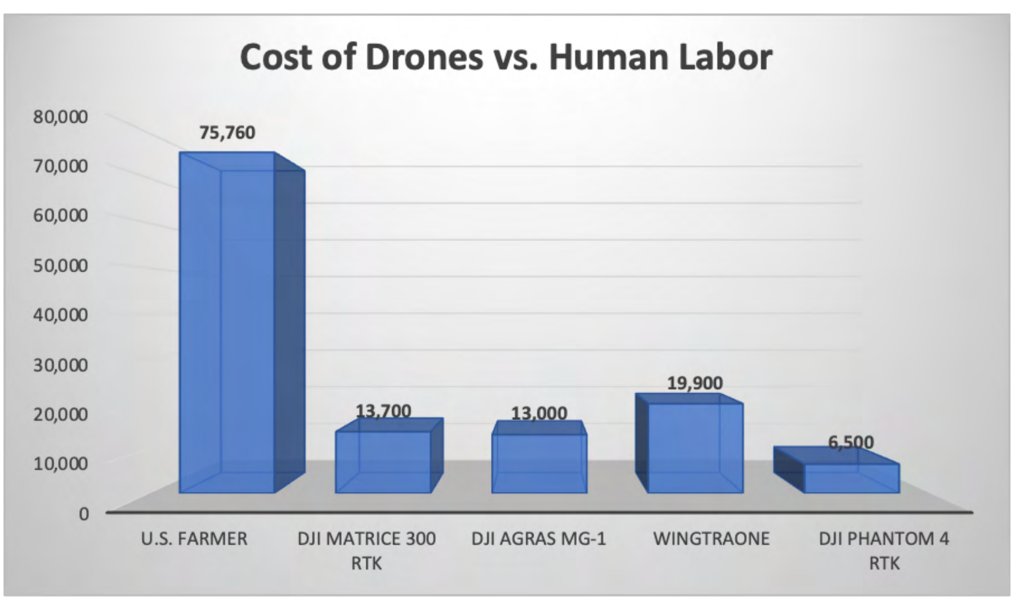
Figure 4: [16]

Figure 5 : [17]

1.7 Cost Efficiency

While drone capabilities are amazing to have at a farmer's disposal, we have yet to see if they are cost efficient. Agricultural drones may cost thousands of dollars, but they can save hundreds of thousands of dollars in the salary of employees providing human labor. One of the best agricultural drones are the DJI Agras MG-1, Wingtraone, DJI Phantom 4 RTK, and the DJI Matrice 300 RTK. Comparing the cost of these drones to the traditional method of human labor, the average salary of a farmer is $75,760 but because a farm can be run by a group of 5 people or 40 people we cannot precisely say how many farmers per farm there are on average.[18]

Figure 6:



This comparison of the price of monitoring drones and the WingtraOne, which is an exceptional sprayer drone, with the labor cost of a U.S. farmer year round Figure 2. I chose these drones because DJI is currently developing stellar drones which can be used for agriculture and all of the DJI drones in the graph have the hardware to compete with a farmer's traditional tasks. These drones have multispectral and RGB cameras with NDVI sensors, GPS systems and some of them can even be used for mapping.

1.8 Limitations

While drones that have the capabilities to map and monitor are efficient in their ways we have to consider some limitations. For example, while drones are undergoing their desired tasks, from taking photos to detecting discrepancies in plants, they are out in the open field susceptible to many environmental factors. One of the factors could be the weather. If the weather is very windy, the flight time of the drone mapping a field will vary with the drag forces that change the power requirements. Another factor is connectivity. Most farms are in rural areas where there is limited wifi which makes it difficult to establish a connection with the drone during its flight. But in the drone industry, there is one type of precaution that makes people reluctant to buy drones, drone regulations. In the US drones must be registered with the FAA, drone pilots must take The Recreational UAS Safety Test required by the FAA, and if drone owners wish to fly the drone publicly they must obtain the certificate form the FAA and abide by the guidelines. [19] If a person does not follow the set guidelines there could be legal action taken against them.

2. Spraying

2.1 Process and Benefits of Spraying with Drones

Spraying using agricultural drones has been in development during recent years, and more efficient ways to spray crops keep coming. In order to spray effectively, the mapped areas of the fields are uploaded to the drones, which then execute their commands by flying through specific areas until the coordinates are completed. The benefits of having UAV or drone spray crops are their precision in the amount of liquid used for each crop. Because of their running algorithms, one can program the UAV or drone to spray a certain amount per crop. This can improve the efficiency of a farm's workflow because if a human were to spray too much or too little per crop it could affect the output of the farm's overall yield of crops. Another benefit of using drones to spray is that they help protect the health of the environment because a UAV sprayer uses 90% less water and 30–40% less insecticide. Reducing pesticide use significantly impacts the environment by preserving soil fertility and pest resistance to pesticides as a result of the correct treatment quantity. [20]

2.2 Hardware for Spraying

Sprayer UAVs are usually composed of a tank, nozzles, pump, hoses, flow meters, and GPS systems to map the course of a drone's trajectory while spraying the crops. The drones also have multiple sensors to detect objects and avoid them while flying. In Japan they have introduced stellar sprayer UAVs since 1997, the Yamaha RMax drone looks like a small helicopter. It has a single rotor with a diameter of about 10 feet, weighs 207 pounds, and has over 4 gallons of spray tank capacity. [21] While Japan leads in drone innovation, there are newer examples of better drone hardware that make it more efficient: the DJI, T30 Agra drone. It weighs approximately 58 pounds, has a work efficiency of 40 acres per hour and comes equipped with a Spherical Omnidirectional Radar System, which provides obstacle detection and avoidance and allows the drone to adjust to the field. The drone provides a RTK/GNSS system, which is a satellite that allows the drone's data to be accurate to real life. Finally, it comes with 16 nozzles that spray up to 9 meters and a 30 liter pesticide tank with a high-precision flow meter that has a maximum flow of 8 L/min with the XR11001 nozzle. [22] These two drones spray crops more efficiently, leading to a better output for the farm.

Figure 7:Yamaha RMax drone [23]

Figure 8: DJI, T30 Agra drone [24]

2.3 Sprayer Drone Comparison to Normal Tractor Spraying

Sprayer drones have vast benefits, but do they surpass the traditional tractor spraying method in agriculture? Arthur Erickson of Hylo, an agricultural drone manufacturer in North America, gives an example of one of Hylio's biggest drones: the AG-272, with a 14-foot tip-to-tip diameter, can carry 400 pounds of agricultural inputs — fertilizer, herbicides, pesticides and fungicides, and can cover as much acreage in a day as a $700,000 modern spraying tractor. Yet all-in cost for the AG-272 is about $200,000. Even a second-hand tractor that covers less ground per hour will likely cost $300,000. [25] It can also take up to a year to deliver a tractor, while Hylo's drones come within a few months. Tractors also have a hard time in the terrain avoiding obstacles, and you often can't run tractors in wet fields when fungus is blooming because they'll get stuck or rip up the ground. Erickson suggested 3% to 10% benefits from avoiding soil compaction, but studies show 9% to 55% crop reductions from it. [26] Of course this is not a problem for a UAV, since it flies 10-15 meters above the crops fertilizing the soil and does not smash crops but helps them grow. Finally, financially for the farm, it is the better decision that saves potentially hundreds of thousands of dollars.

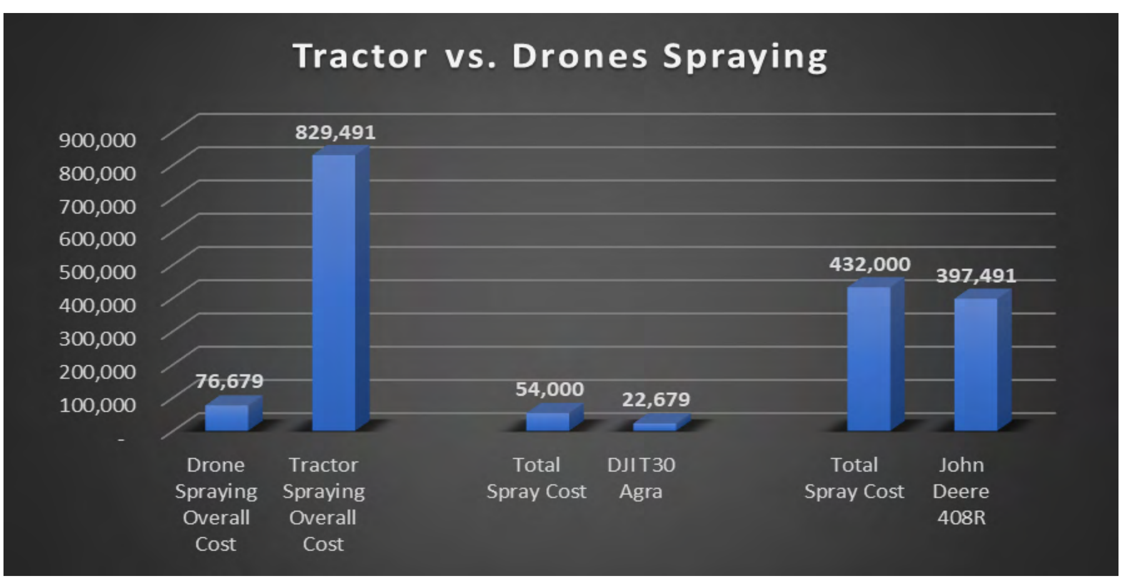
2.4 Effects of Agrochemicals

A drones controllable capabilities with nozzles, chemical dosage, and flow rate while spraying allow for the reduction of impact in the environment with agrochemicals. If the wrong dosage of agrochemicals are given in farms, the bacteria living in the plants and soil will begin to adapt to their environment and either migrate to a new area or genetically mutate so that they can survive under toxic conditions. [26] Drones do not have this problem because they can be programmed so that the right dosages of the agrochemicals are given to the according crops to kill the bacteria. This could avoid major disasters from plagues that can lead to financial losses with less crop yields. Another potential detriment of spraying agrochemicals is that strong winds can drift the agrochemicals away from the plants and harm the air we breath, affecting humans, animals, and bodies of water which can have a ripple effect in ecosystems. When agrochemicals drift, they can expose important pollinators like bees, fruit flies and some beetles to pesticides either through inhalation or ingestion. Overtime, this can lead to the loss of plant species because of the lack of adequate populations of pollinators. [27] Agricultural drones end up playing a huge role in farm spraying because they do not only have the goal of making spraying more financially and practically efficiently, but also to reduce the negative impact in the environment and in ecosystem with their technological precision.

2.5 DJI T30 Agra drone vs. Traditional Spraying

We put the Agras T30 drone to the test with how much it would cost to spray an entire farm as compared to a traditional tractor. The average farm in the U.S. has 445 acres and the T30 Agra drone has a 30L spray tank, which is approximately 8 gallons. [28,29] The drone can spray up to 2 gallons per acre (gpa). Thus, if the drone can cover 4 acres in one full tank and the average farm has 445 acres, then we would need to refill the drone approximately 111 times. If we sprayed a farm with the pesticide Acuron by Syngenta, which cost $67.50 per gallon, then one full tank would cost $540. To spray one full farm with one drone it would need to be refueled 111 times so then it would cost $59,940 to spray a farm with one drone. On the other hand, if we sprayed with a John Deere 408R tractor with a tank capacity of 800 gallons and if we used the same Acuron by Syngeta, one full tank would cost $54,000. Most sprayer tractors with 500-800 gallon tanks usually around 15 gallons per acre. Thus, one full tank sprays approximately 53 acres. The average farm being 445 acres, then the tank would need to be refueled approximately 8 times, which would cost $432,000 to spray a farm with one tractor.

Figure 9:



We considered the cost of a tractor as well as the cost of the drone. The spraying tractor method is very costly and exceeds the drone method by about $752,812. While the amount is large, we must also consider how the tractor can spray 15 gallons per acre and according to the National Agriculture Safety Database “Solid applied herbicides generally work better with larger volumes of spray mixture.” [30] In application terms, the amount sprayed per acre is better by 13 gpa, but with the drone’s capabilities and precision it doesn’t need that much gpa. However, the drone method could be more efficient if you were to spray with more than one drone because the tractor method still exceeds $752,812. This way the drones could spray more gallons per acre and still be less expensive than the tractor method.

3. Harvesting

3.1 Shortage of Farmers in Harvesting

Harvesting is another vital task in farming, and even though drone utilization in harvesting is still in the early stages, there has been progress in recent years. Fruit rotting on trees or on the ground costs farmers some $30 billion in sales per year. Fruit picked even two weeks late loses 80 percent of its value. This is a result of the global farmer shortage. An example of this is that the National Agriculture Statistical Service’s Farm Labor Survey (NASS FLS) reported a 73 percent decline in self-employed and family farmworkers from 1950 to 2000. The number of hired farm hands declined 52 percent within the same time period. This downward trend is translating into higher labor wages for farm workers. For instance, in 2018 the agriculture industry experienced a 7 percent decline in hired help and a 5 percent increase in labor wages. [31]. This is one of the principal reasons that the agriculture industry is also trying to expand drone utilization in harvesting with new innovations like fruit picking drones.

3.2 Harvesting Drones

Though harvesting drones are still in the early stages, there are places that are pioneering these new innovations including Tevel Aerobotics Technologies in Gedera, Israel. Tevel created a flying autonomous robot that continuously collects data on every single piece of fruit it picks, providing extraordinary real-time harvesting data. The cost-effective flying robots are durable and light, allowing for the harvest of a wide range of fruit, from a 50 g (2 oz) apricot to a 700 g (25 oz) apple. [32] These drones are tethered to a ground vehicle which they orbit around to then put the fruit they pick into the vehicle. They are designed with robotic arms and grippers that grab the fruit from the trees. A program lets the drones know which fruit is ready to be plucked and will only select, pick, and box the ones that are ready for market. [33] The Tevel drones aren’t in commercial use yet but are expected to hit the market later in 2023. [34] These harvesting drones are one of the first of its kind but with the rapid pace that technology has we can expect for more harvesting drones to come in the near future.

Figure 10:
Tevel FAR drone [35]

4. Automation

4.1 What is Automation?

The automation of agriculture drones enables farms to control every aspect of the drone from takeoff, path, to landing, all autonomously with set parameters. Automation would minimize the interference of humans in the operation creating almost a potential UAV or drone running farm. Most farmers implementing UAVs in their operation have yet to completely automate them; instead they supervise and control the drone by hiring professional pilots that have experience with the equipment. There are some challenges that come with finding the right pilots for drones, if the drones are being piloted and the drone loses connection. With automated drones these worries would be gone because they wouldn't need to connect to a pilot, they would function based on an algorithm that is already implemented in the drone. The benefits of having automated drones is that they can gather more data consistently and accurately while minimizing human errors.

4.2 How are Drones Automated

There are many ways in which drones can be automated, one of which can be implementing a GPS system and setting coordinates for the drone to fly through autonomously. Again, this depends on the task because you can have an algorithm uploaded to a drone that can fly a certain course using the GPS system coordinates and while it's running have the nozzles open and spray the crops at the same time. This way you would be efficiently spraying the crops in the field and human interference is minimal. An example of a proposed automated method for plant detection from high-resolution drone imagery is shown in figure 1. [36] This algorithm would allow the drone to take the input image and validate what it is seeing by itself by parsing the image and reconstructing it adding information that fits the pre-programmed parameters implemented in the drones framework. Also, this algorithm would save many hours of a person tediously going through the images that the drone produces of countless crops.

Automated drones are still in infancy for the agriculture department because they are still in research, and development since creating frameworks like this for the masses of farms is quite difficult, and while a small percentage of farmers use them most are still with semi-automated drones.

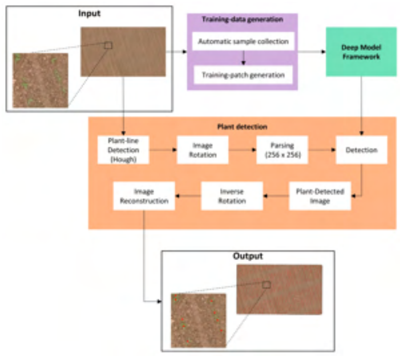


Figure 11: [36]

5. Machine Learning

5.1 What is Machine Learning?

Machine learning in agricultural drones is an analytical method in data analysis in a natural environment. Machine learning is paired usually under the category of AI drones. They can process real-time data, find patterns and implement choices in minimum latency. [37] They have the ability to do this because of an implemented algorithm with validation images and parameters. From there the drone would learn of that algorithm and find a pattern of the images and parameters that it has, and identify and classify them. This could easily be done with plants, and provide a detailed report to the farmer, without the farmer ever even having to touch the drone or look at pictures of crops.

5.2 How Drones Use Machine Learning

While Machine Learning drones are still participants in research there are many ways in which these frameworks by which machine learning drones are guided. Tendolkar, created a farming drone that would analyze and classify crops health and his study was quite interesting in its functionality as well as in its efficient results. The system assessed plant health on the basis of the NDVI index, texture, and color features of the individual pixels. These features were extracted utilizing a filter bank of 17 Gaussian and Laplacian filters. SVM were then used to perform semantic segmentation on the image pixels and to classify the pixels as healthy or unhealthy. Lastly, a segmented mask was generated and used to find the health ratio of the images, according to the ratio of the area of healthy pixels to the total area of the image. The health ratio was then used to classify images into healthy, moderately healthy, and unhealthy. The trained model had 85% precision, 81% recall, and an F1-score of 79%. [38] He created a drone that, through NDVI, SVM, and filter bank, finds patterns in the pixels of the images and classifies them into different categories, which is astonishing, and this type of drone is exactly what farmers would utilize while monitoring crops.

5.3 How Machine Learning Drones Relate to AI Drones

Machine learning is basically a part of artificial intelligence and the same applies in drones. AI enables machines to learn, analyze data and make decisions based on that knowledge. This is exactly what we saw in the machine learning study in the previous paragraph where the multipurpose agricultural drone learned from every pattern of each plant and decided to put each of them in according categories. Something important to notice is that AI algorithms have that none of the semi-automated or previous drones we talked about have, is that the algorithm tells the computer how to learn and operate on its own. Fully AI drones are still rare to see and are in early development and there are other ways in which AI technology is still making its way to farms. In today's age farmers are having trouble finding the right time to plant seeds due to climate change. AI learns weather patterns and crop planting cycles making it easier for farmers to predict the weather and efficiently plant seeds in the field. We are also seeing a company Precision AI, which is a Canadian startup that is pioneering with an AI powered UAV called SOLV, that with their computer vision and onboard edge processing can differentiate weeds instantly and they have full precision weed control with customized spray tips that reduces chemical use by up to 90%. [39] This UAV can reach up to 50 miles per hour and has an AI chip embedded in the drone for real time data analysis that the team receives. [40] The Precision AI team does not have the drone for sale but they help farmers with their drone services and their AI subscription. There are many applications for AI in the agricultural space and while they are still being developed and in research they have a promising future and we are seeing the beginnings already with automated and machine learning drones.

Discussion

The benefits of drones are outstanding, proving to be more efficient than traditional agricultural methods with better efficiency while creating a higher yield of crops. Yet the agricultural drone industry can still improve. A larger percentage of the drones that are currently in use for agricultural purposes are semi-automated and require more assistance, which can result in better crop efficiency but it can be a hassle for farmers, in finding pilots and trained personnel to fly the drones. Another hassle that could be holding the agricultural drone industry back is finding the right drone because there are many drones for each branch of agriculture and if farmers would want the efficient results that drones give, they would have to buy many drones that do separate tasks resulting in a less cost-efficient implementation of drones in their workflow. A way the drone industry could solve this issue is by developing an automated drone that could have capability of doing many different agricultural tasks. This could take time and we would have to find the right ergonomic design which would have to hold the weight of all the hardware, have the right programmation, and most importantly still produce the efficient and accurate results that the agricultural drones mentioned in the research have. But if a drone like this would be developed in the future it would save farmers the hassle of finding pilots and trained personnel and it would be cost-efficient because you wouldn't have to buy various drones for separate agricultural tasks.

Conclusion

Agricultural drones have been in development since the early 2000's. Yet, we can see how this new technology is causing waves in the practice of agriculture and farming. The market for these drones will keep growing, along with new technologies that will come, having a positive effect on the present population and the population to come. Hopefully, now farmers can compare their traditional methods' efficiency in terms of equipment and results with the hardware and programs embedded in agricultural drones. Also, with the added results of the tractor fueling and spraying cost vs. the drones cost, now farmers can make more financially adequate decisions with the implementation of drones in their farms. With the fruitful technology of drones we must not only inform ourselves of the benefits but of the precautions and certain limitations that come with these drones. That includes following the FAA regulations and certain issues that can interfere with drones. This research aims to enhance agricultural efficiency, leading to increased crop yields and consequently, a greater availability of food for the world. I hope this research will help farmers become more aware of the benefits and certain limitations with this technology and how they could utilize it to improve their workflow, not just for them but for the world.

References

1. "i-Drone, ICMR-led Pilot Project , Drones to Deliver COVID-19 Vaccines." *i-Drone, ICMR-led Pilot Project , Drones to Deliver COVID-19 Vaccines*, 29 Oct. 2021, www.who.int/india/news/feature-stories/detail/india-deploys-drones-to-deliver-covid-19-vaccines.
2. "UAV Market - Unmanned Aerial Vehicles - Size, Analysis, Growth." *UAV Market - Unmanned Aerial Vehicles - Size, Analysis, Growth*, www.mordorintelligence.com/industry-reports/uav-market.
3. Wang, Linlin, et al. "Applications and Prospects of Agricultural Unmanned Aerial Vehicle Obstacle Avoidance Technology in China." *MDPI*, 3 Feb. 2019, https://doi.org/10.3390/s19030642.
4. "Croptracker - Drone Technology in Agriculture." *Croptracker - Drone Technology in Agriculture*, 29 Sept. 2022, www.croptracker.com/blog/drone-technology-in-agriculture.html.
5. "South Korea Agriculture Drone Market Share, Size, Price, Growth, Analysis, Report and Forecast Period of 2023-2028." *MarketWatch*, www.marketwatch.com/press-release/south-korea-agriculture-drone-market-share-size-price-growth-analysis-report-and-forecast-period-of-2023-2028-2023-06-16.
6. "The Impact of Drones in South Korea for the Enterprise." *The Impact of Drones in South Korea for the Enterprise | Commercial UAV News*, 15 June 2022, www.commercialuavnews.com/regulations/the-impact-of-drones-in-south-korea-for-the-enterprise.
7. O'Donoghue, J. J. "Is Farming in Japan on Its Last Legs?" *The Japan Times*, 23 June 2018, www.japantimes.co.jp/life/2018/06/23/food/farming-japan-last-legs.
8. *https://cen.acs.org/food/agriculture/AI-drones-come-farm-Japan/98/i36*. cen.acs.org/food/agriculture/AI-drones-come-farm-Japan/98/i36.
9. "Ecorocdrone – Sembrando a Venezuela Desde El Aire!!!" *Ecorocdrone – Sembrando a Venezuela Desde El Aire!!!*, ecorocdrone.com.

10. Wrangham, Jack. "High Precision Boundary Mapping - Drone Ag." *Drone Ag*, 22 Mar. 2017, droneag.farm/high-precision-boundary-mapping.
11. Institute, Pilot. "Drone Mapping – a Beginner's Guide - Pilot Institute." *Pilot Institute*, 9 Dec. 2022, pilotinstitute.com/drone-mapping-guide.
12. eynde, domien van. "Multispectral Imaging: What Is It Used For?" *Photography Course*, 17 Oct. 2018, photographycourse.net/multispectral-imaging-used-for.
13. McNabb, Miriam. "Enterprise Scale: DJI Introduces New P4 Multispectral for Precision Agriculture and Land Management." *DRONELIFE*, 24 Sept. 2019, dronelife.com/2019/09/24/enterprise-scale-dji-introduces-new-p4-multispectral-for-precision-agriculture-and-land-management.
14. "Soil Mapping With Drones." *Soil Mapping With Drones | GIM International*, 5 Oct. 2022, www.gim-international.com/content/article/soil-mapping-with-drones.
15. Akbar, M. R., et al. "Mangrove Vegetation Health Index Analysis by Implementing NDVI (Normalized Difference Vegetation Index) Classification Method on Sentinel-2 Image Data Case Study: Segara Anakan, Kabupaten Cilacap - IOPscience." *Mangrove Vegetation Health Index Analysis by Implementing NDVI (Normalized Difference Vegetation Index) Classification Method on Sentinel-2 Image Data Case Study: Segara Anakan, Kabupaten Cilacap - IOPscience*, 1 Oct. 2020, https://doi.org/10.1088/1755-1315/584/1/012069.
16. "The Use of Terrestrial LiDAR to Monitor Crop Growth and Account for Within-field Variability of Crop Coefficients and Water Use." *The Use of Terrestrial LiDAR to Monitor Crop Growth and Account for Within-field Variability of Crop Coefficients and Water Use - ScienceDirect*, 9 Sept. 2021, https://doi.org/10.1016/j.compag.2021.106416.
17. "Agriculture - SouthernDronePro." *SouthernDronePro*, 12 Oct. 2019, southerndronepro.co.uk/agriculture.
18. Vlaminck, Michiel, et al. "A Multisensor UAV Payload and Processing Pipeline for Generating Multispectral Point Clouds." *MDPI*, 10 Mar. 2023, https://doi.org/10.3390/rs15061524.
19. "Farmers, Ranchers, and Other Agricultural Managers." *Farmers, Ranchers, and Other Agricultural Managers*, 25 Apr. 2023, www.bls.gov/oes/current/oes119013.htm.
20. "Drone Laws in the U.S.A. | UAV Coach (2023)." *UAV Coach*, uavcoach.com/drone-laws-in-united-states-of-america.
21. Hanif, Adhitya Saiful, et al. "Independent Control Spraying System for UAV-Based Precise Variable Sprayer: A Review." *MDPI*, 28 Nov. 2022, https://doi.org/10.3390/drones6120383.
22. "Drones for Spraying Pesticides—Opportunities and Challenges." *Drones for Spraying Pesticides—Opportunities and Challenges | Ohioline*, 24 Jan. 2023, https://ohioline.osu.edu/factsheet/fabe-540
23. "T30 - Specifications - DJI." *DJI Official*, www.dji.com/t30/specs.
24. "Drones for Spraying Pesticides—Opportunities and Challenges." *Drones for Spraying Pesticides—Opportunities and Challenges | Ohioline*, 24 Jan. 2023, https://ohioline.osu.edu/factsheet/fabe-540
25. "DJI Agras T30-A New Digital Flagship for Agriculture." *DJI*, photo.
26. Barnard, Michael, et al. "Massive Spray Drones Are Transforming Agriculture With Win After Win - CleanTechnica." *CleanTechnica*, 21 Mar. 2023,

cleantechnica.com/2023/03/21/massive-spray-drones-are-transforming-agriculture-with-win-after-win.

27. Kenyi, Sarah. “The Effects of Agrochemicals on the Environment.” *Initiative for Coffee&Climate*, 22 Nov. 2021, coffeeandclimate.org/the-effects-of-agrochemicals-on-the-environment.
28. “USDA - Farming and Farm Income.” *USDA - Farming and Farm Income*, https://www.nass.usda.gov/Publications/Todays_Reports/reports/fnlo0222.pdf
29. “T30 - Specifications - DJI.” *DJI Official*, www.dji.com/t30/specs.
30. “NASD - Sprayer Calibration Fundamentals.” *NASD - Sprayer Calibration Fundamentals*, nasdonline.org.
31. Jeff. “(Infographic) the U.S. Farm Labor Shortage | AgAmerica.” *AgAmerica*, 26 Feb. 2020, agamerica.com/blog/the-impact-of-the-farm-labor-shortage.
32. “Technology – Tevel.” *Technology – Tevel*, www.tevel-tech.com/technology.
33. Mircea, Cristina, and @_autoevolution_. “Tevel’s Flying Robots Aim to Change the Way We Harvest Fruit.” *Autoevolution*, 31 Jan. 2022, www.autoevolution.com/news/tevel-s-flying-robots-aim-to-change-the-way-we-harvest-fruit-180423.html.
34. Claver, Hugo. “Tevel’s Flying Autonomous Robots to Start Harvesting - Future Farming.” *Future Farming*, 18 May 2022, www.futurefarming.com/tech-in-focus/drones/tevels-flying-autonomous-robots-to-start-harvesting.
35. “Autonomous Drones Designed to Harvest Fruit Show Their Skills at World Ag Expo.” *Autonomous Drones Designed to Harvest Fruit Show Their Skills at World Ag Expo*, 17 Feb. 2023, www.freshplaza.com/north-america/article/9504619/autonomous-drones-designed-to-harvest-fruit-show-their-skills-at-world-ag-expo.
36. Hosseiny, Benyamin, et al. “An Automated Framework for Plant Detection Based on Deep Simulated Learning From Drone Imagery.” *MDPI*, 27 Oct. 2020, https://doi.org/10.3390/rs12213521.
37. “A Systematic Approach to Agricultural Drones Using a Machine Learning.” *Taylor & Francis*, https://doi.org/10.1201/9781003132110-4.
38. Zualkernan, Imran, et al. “Machine Learning for Precision Agriculture Using Imagery From Unmanned Aerial Vehicles (UAVs): A Survey.” *MDPI*, 6 June 2023, https://doi.org/10.3390/drones7060382.
39. “Bloomberg - Are You a Robot?” *Bloomberg - Are You a Robot?*, www.bloomberg.com/news/features/2023-04-19/ai-drone-cuts-chemical-use-in-big-farm-weeding.
40. “Technology - Precision AI.” *Precision AI*, www.precision.ai/technology.