Invited Paper

Drone Based Technologies for Assessing Modern Farming Practices in Undergraduate Research

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ABSTRACT

The modern farm is a technological marvel, from smart tractors to genetically modified organisms (GMOs), along with chemical pesticides and fertilizer. Farms today have continuously increased production by utilizing these various techniques. Many farms on the east coast of North America are growing dent or field corn while also rotating crops between soybeans of various types and winter wheat. These crops have become symbiotic in nature due to the need for specific soil nutrients of the crops and the practice of no till farming. More recently, schools with farm programs have started researching the use of drone technologies and multispectral analysis as a means to reduce chemical usage thereby saving farmers annual chemical costs. This paper investigates the use of drones in capstone projects for undergraduate engineering and computer science programs. Undergraduate capstone projects usually require a design and build element to satisfy ABET accreditation requirements. Therefore, the students needed to design and build an airframe capable of surveying farms with a multispectral camera. In the course of the aircraft design process it was discovered that the students needed to have a broader understanding of federal regulations, experimentation, and a robust understanding of how the drones and data would be used to benefit a typical farm. In addition, we look at the results obtained and discuss the problems associated with making the data and analysis accessible to the farmers who participated in our study. In the process we also discovered other potential uses for the images we created.

Keywords: Drone Technologies, Multispectral Analysis, Modern Farm, Corn, Soybean, Winter Wheat

INTRODUCTION

The overall goal of our work is to help farmers be more productive and profitable, while using less harmful chemicals to increase their production. It has already been shown by researchers that the use of drones and multispectral analysis can help achieve this goal. Abdullahi et. al. 2015 points out methodologies where precision agriculture is benefited by the use of unmanned aerial vehicles using multispectral analysis. Tiwari et. al 2015 argues that the advancements in sensors and ease of use of drones has changed the way we analyze the modern farm. Finally, Wolfert et. al 2017 points out that smart farming is a part of the future and massive data can be gathered using modern technologies to influence the entire food chain.

At the heart of this research is the use of undergraduate students as the primary researchers. Another restriction is that we cannot just buy a system and collect the data[1]. This is due to the ABET requirement of a design and build. A brief review of the approach here seems appropriate. The undergraduate effort was initially broken into 4 teams. Those included *Flight Controls, Aircraft Design*, *Aircraft Operations,* and *Multispectral Analysis* teams. The *flight controls* team was responsible for the flight controls planning and other aspects of flying under autonomous control. They needed to use good power management and achieve flights in the area of 1hour duration with a fixed wing aircraft. They also established stretch goals to design and build their own battery and camera system for the aircraft. The *aircraft design* team was to investigate multiple design types to include a flying wing and a glider type design. They were responsible for designing the aircraft, complete with calculations of lift and weight distributions, solid works drawings and requirements like cargo.

[1] However, a known system can be used to collect data while building our own. For this purposes we obtained a e-Bee SQ from sensefly: https://www.sensefly.com/

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They included stretch goals of a composite wing design and some aerodynamic calculations of the aircraft wing foil. The *aircraft operations* team needed to understand FAA regulations and acquire a RPIC license to operate the aircraft. They were also required to keep flight and maintenance logs on the aircrafts we used to include the one we were building. Their stretch goals included helping the *multispectral analysis* team with their data gathering and the first two groups with their flight testing of the new aircraft designs. The last team was the multispectral analysis team. Their goals is to get us from the analysis to the prescription that would be loaded into the tractor. This required the use of multiple software types and the collection of data from the existing drones we were using. They additionally needed to look at the farm data already obtained and compare it with harvest data from the same fields. They needed to develop a plan for the coming years to collect ground truth data via soil testing and other means. As a stretch goal of the team they were to look at a drained reservoir (Lake Williams in York County) to obtain data on the volume lost by the sediment over the past 105 years[2]. They were also to investigate the accuracy of the methods we are using by including GCP and other data obtained from surveyor equipment.

1.1 Flight Controls

There have been various aircraft of various types capable of performing the multispectral analysis mission for a number of years. Berni et. al. 2009 used a various Commercial off the Shelf (COTS)[3] systems as platforms to obtain remote sensing. Even as late as 2011 these systems were still relatively large, expensive, difficult to use, and in many cases based on helicopter or other RC drone technologies. Xiang et. al 2011 used a 14kg aircraft and demonstrated how multispectral images could be obtained. About 8 years prior there was an explosion of quad copter products from companies like Parrot[4], DJI[5] and 3D Robotics systems[6] to mention a few that provided reliable, stable, programable aircraft, with good autopilots. More recently flying an aircraft autonomously has been available to the layman for at least 5 years, maybe more. One such example is the PixHawk or ArduPilot. The ArduPilot was initially developed by hobbyists to assist with autonomous functions for aircraft and robot cars. It has proven invaluable for researchers and hobbyist alike[7]. Our initial foray into flying our own drones relied on the ArduPilot pilot technology but has subsequently shifted to the Omnibus V3 autopilot system and now the Matek-F722 controller both of which are smaller and lighter than the original Pixhawk. These systems can now be found for under 50 dollars a piece. Figure 1 below shows the integration of that system into one of our flying wing designs.

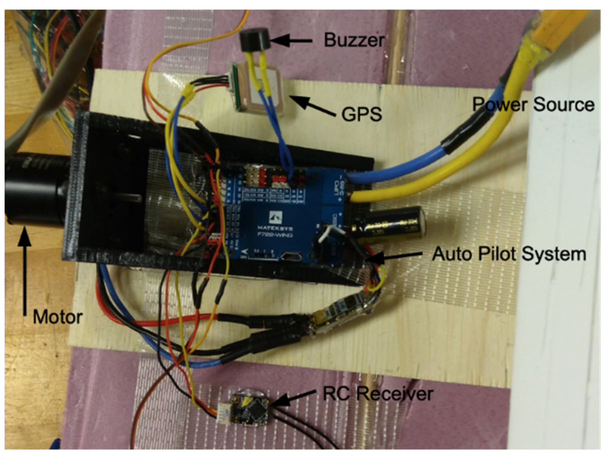

Figure 1 Autopilot system for the student built, drone aircraft.

[2] Some of this data will be included in this report.
[3] Commercial Off The Shelf s(COTS) ystems are systems already designed for one purpose that are repurposed for another: https://en.wikipedia.org/wiki/Commercial_off-the-shelf
[4] Parot; https://www.parrot.com/us/drones
[5] DJI: https://www.dji.com/products/drones
[6] 3D Robotic Systems: https://3dr.com/
[7] ArduPilot: https://en.wikipedia.org/wiki/ArduPilot

The *flight controls* team had additional projects which included, the battery and its management system, prop thrust stand, and custom camera. All of these projects are at various stages of development, but the battery project and the thrust stand are in use so we will mention them here. The battery pack has been shown to be an improvement over the traditional Lithium Poly batteries. Figure 2 details the status of the current battery back and its power consumption. The Lithium Poly battery: (16.8V * 3.60Ah) / 370g = 0.16Wh/1g while the Lithium Ion: (16.8V * 10.35Ah) / 597g = 0.29Wh/1.

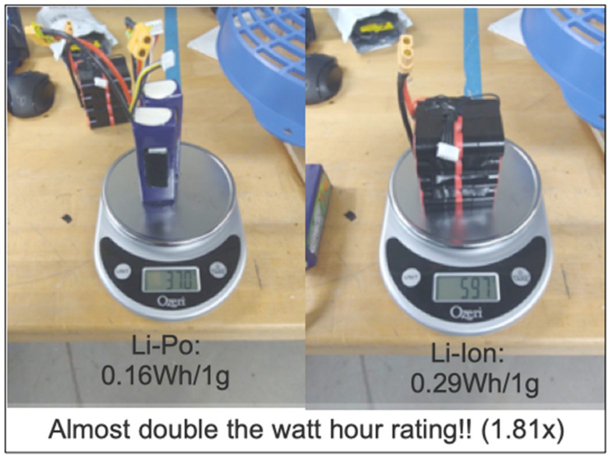

Figure 2. Battery comparison Li-Ion versus traditional Li-Po.

The test stand, Figure 3 below, allows the accurate assessment on the prop and motor choice. When coupled with drag calculations from the airframe team a good estimate of the aircraft flight time can be obtained. In future work we will correlate our findings with the calculations that are made using e-Calc[8]. It is important to note that the students did this work on their own initiative. The student's initiative and research will be further acknowledged in a section of this publication. The camera and other efforts will be reported in future publications.

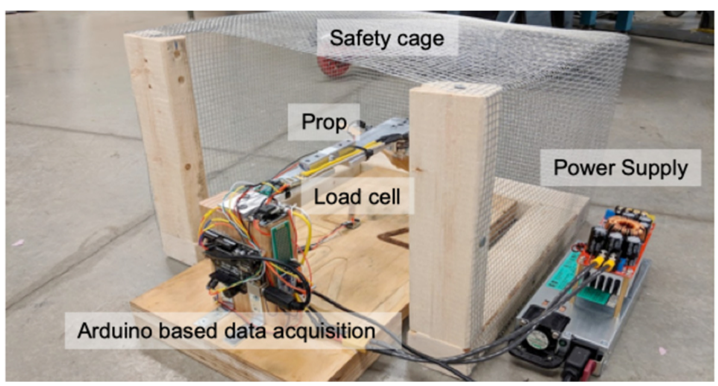

Figure 3. Thrust stand for prop thrusts.

1.2 Aircraft Design

In the current capstone year, we are including more than one drone design. This is possible since we have nearly double the number of students. For this year's effort we are including a wing design as we had last year based on a foam cut

[8] E-Calc is a program used by RC enthusiast and researcher alike: https://www.ecalc.ch/

template. However, to improve that designs weight payload ration we are also including a composite wing design. There are nearly an infinite number of airfoil types profiles etc. The first year we relied on a symmetrical wing foil design. This year's effort focused on a traditional wing foil with a flat bottom. This helps a little when calibrating sensors and during the aircraft's initial set up for flight. A foam wing was initially constructed and used to assure that we would have an aircraft at the end of the year, but this year we would also include a composite design of a single flying wing. The basic design concept of both is shown in Figure 4. The center wing section is used to house all of the electronic equipment, batteries, GPS, camera, and motor. The outer portions will provide the additional lift and stability and to allow the aircraft to fly slowly when taking photographs.

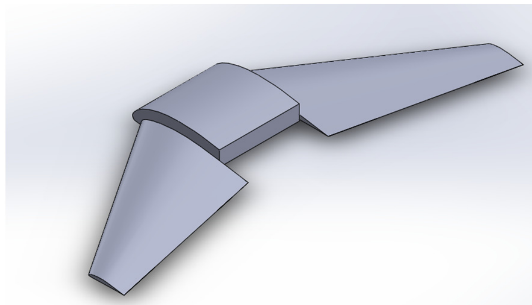

Figure 4 Standard Wing design.

The composite design uses a similar baseline design. Some baseline calculations were done to look at lift versus drag in order to increase the efficiency. With the inclusion of an internal area to reduce drag. In a previous offering to SPIE Wilkerson et. al 2018 detailed how the first aircraft was designed and manufactured. In a similar fashion, once the design was analyzed, the templates were laser cut and then using a hot wire foam cutter the wings were constructed with appropriate stiffeners and then coated in high strength bi-directional tape. While the tape adds significantly to the weight it also increases the strength and durability of the design considerably.

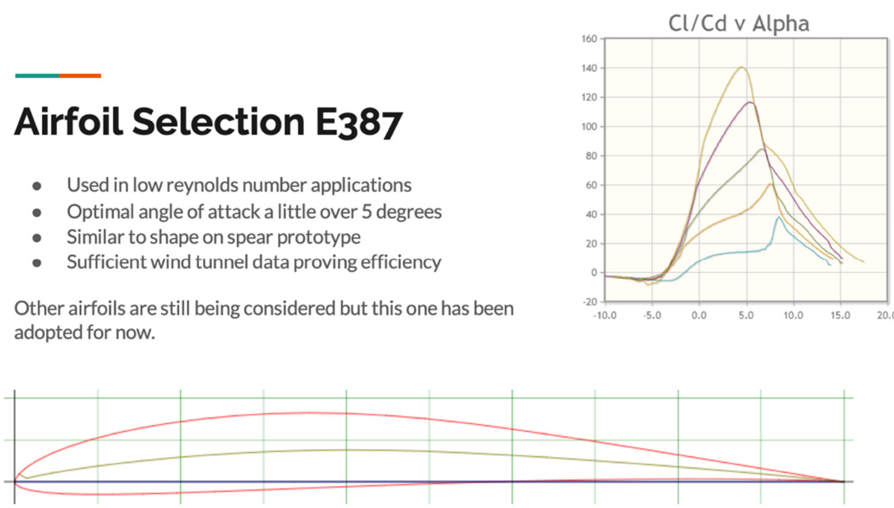

Figure 5 Airfoil calculations using variations of E387

Similar stability calculations were done for the glider design and as of the writing of this paper it is in final preparation for its first flight. Figure 6 shows some of the results from the $XKLR_5$ analysis code. $XKLR_5$ has been shown well suited for low Reynold number calculations. Communier et. al. 2015 showed that the coefficient of pressure on the wing could adequately be calculated using the $XKLR_5$ code.

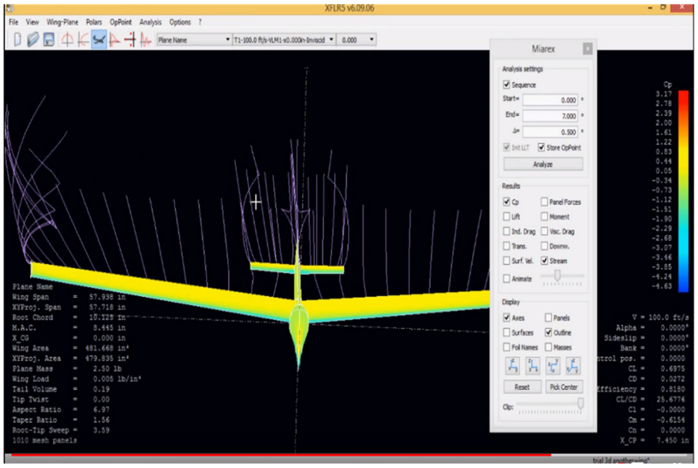

Figure 6 XKLR$_5$ analysis of wing structure. Used in conjunction with other structural codes.

As of the writing of this paper we have one aircraft that is operational and two others in development. In subsequent work on airframes a focus on reducing the weight and size of the aircraft will be the focus of the efforts.

1.3 Aircraft Operations

Aircraft operations also proved to be a restricting parameter on this operation. More often than not, research operations working with drones will simply hire a RC pilot or hobbyist to be a member of the team and look after the operations of the aircraft. This is no longer the case as there are growing federal regulations with regards to operating a drone in commercial airspace. Figure 7 shows a sectional chart of the primary area of operation for the current study.

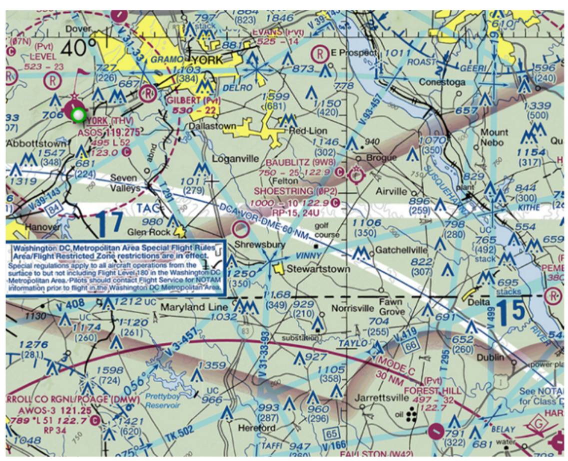

Figure 7 Sectional chart of the greater York PA area.

As can be seen in the figure there are airports, municipalities and considerable urban sprawl to be considered. These operations simply cannot be done safely without a FAA Part 107 Remote Pilot in Charge (RPIC) and considerable knowledge of the area. It would also be beneficial to have that person be a RC enthusiast. As reported by Wilkerson et. al. 2018; an RPIC needs in depth knowledge of a number of topics to operate safely in this airspace. These include: (airspace, weather. UAS performance, crew management, airport operations, radios, emergency procedures, preflight setup, sectional charts as in figure 7, waiver requests, and insurance). Our approach thus far is to have students take online course[9] and then take the FAA exam. The first year we did not have an RC pilot from which to start and this greatly complicated the process. In the second year we had 3 RC pilots with limited experience, and this greatly increased our success. This has allowed the students to conduct experiments without faculty being present.

1.4 Multispectral Analysis

At the heart of our work is the analysis of the farming crop. This will also be the focus of the results presented in this paper. We chose the Pix4D analysis software as our baseline software to stitch the images together from drone flights. The overall goal of this project is to provide data to farmers on their crops so that they might better manage the chemicals and other nutrients they typically use on their fields. Modern farm chemicals and fertilizers use also has an environmental impact so the work done here can serve two positive agendas.

Figure 8 shows how the basic process works. Geo-referenced drone images are taken at a set altitude above the field. The aircrafts, pitch, roll, and yaw are taken into account when determining what portion of the field is in the image. Ground Control Points (GCP) can be added into the images by spotting known locations on the ground and then, by hand, including those locations in the analysis. Additional known Check Points (CP) can also be added as reference points to allow for the estimation of the error in the image stitching and geolocation process. Once this is done, basically every pixel in the stitched image has an approximate geolocation on the map of the farmer's field. These images include, red, green, blue, red edge, and near infrared light spectrums. The lights can be mixed in accordance with known formulas to reveal some important attributes about the crop and its health. The camera we are using is the Sequoia and has a Ground Sampling Distance of 11cm/pixel at 400 feet altitude, ~ 120 meters.

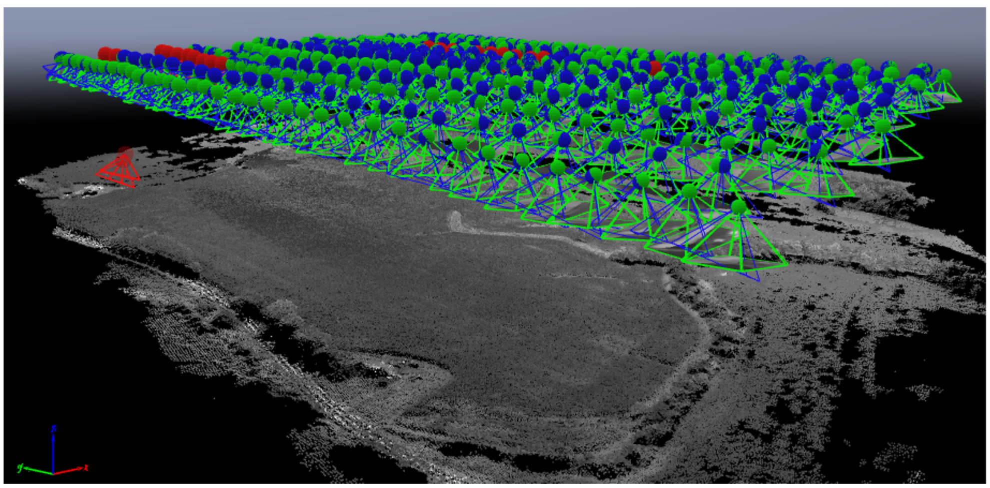

Figure 8 Done images from above the Blue Valley Farm site

Camera and it's 4x monochrome sensor details are as follows[10]:

- Pixel size: 3.75 µm
- Focal length: 3.98 mm
- Resolution: 1280 x 960

[9] Thus far we have used Remote Pilot 101 to train our FAA RPICs: https://remotepilot101.com/resources/

[10] For more details please see: https://www.pix4d.com/product/sequoia/faq#14-What-Pix4D-software-version-is-best-to-process-Sequoia-images-

The individual cameras have a spectral band width of, green: 530-570 nm, red: 640-680 nm, red edge: 730-740 nm, and near infrared: 770-810 nm. The Red Green Blue rolling shutter is:

- Pixel size: 1.34 µm
- Focal length: 4.88 mm
- Resolution: 4608×3456

The Pix4D software will do a reasonably good job stitching the images together provided that the camera is calibrated, the light conditions are good, and it is not too windy. Images from multiple flights can also be stitched together without issue. However, GCP are really invaluable for the process. As of the writing of this paper we did not have a GCP system that we could use for the farms that was accurate. Hence, the data and analysis from the farms in the next section does not include GCP. None the less we were able to get surveyor points for the 3D mapping results that we present here and a discussion of their importance for those type calculations is included in the results section. In addition to the Pix4D Software we also employed Global Mapper[11], QGIS[12] and AgLeader[13] software packages. Each of these packages has their own capabilities and provides a wealth of information.

RESULTS

In our introduction to multispectral analysis we chose corn as our focus crop. After some research on the topic it became evident that we needed to understand the complete cycle of crops to include corn, soybean, and winter wheat. We examined one corn field in northern Maryland and made flights at 5 separate intervals during the growing season. We then obtained the harvest data from that same field later that year. We provide this data here and some discussions about what is needed in the coming season. The details of the Ebee-SQ and Sequoia camera's image stitching and correlation have been well documented; we do not attempt to further those efforts. Rather the focus of our undergraduate research here is to examine how best to use that data to assist the farmer in using less chemicals and fertilizers while maintaining or improving their current crop yields. In these results we will present the NDVI indices for a corn field taken over a 2-month period. NDVI is the ratio NDVI= (NIR-RED)/(NIR+RED) where NIR is the near infrared light and RED is the red light in the frequencies previously given.

The Parrot Sequoia camera has been shown to be a good fit for ground truth models. Cevallos et. al. 2018 showed good correlation from a ground based geostatistical model based on a FieldSpec4 terrestrial spectroradiometer and the Parrot Sequoia camera. Duchsherer et. al. showed that NDVI can be used under certain circumstances to increase farmer profitability. For our current effort we have focused on the NDVI reading of the corn crop. Figure 9 shows the NDVI readings from the farm field we surveyed in 2018 on June 12, 16, July 3, 26, and August 17 respectively. In the coming year the field will be planted with soybean. We will continue to survey this site on multiple years and correlate our findings between what was found by the multispectral analysis versus what was obtained from the New Holland harvester.

For the most part, by the time we took this data there was very little that could be done to change the outcome of the harvest. The crops and or soil had been sprayed with nitrogen and other chemical and fertilizers at least twice. As can be seen by the sequence here the NDVI shows healthy plants undergoing photosynthesis. As the season progresses much of the plant's energy moves into the reproductive stage and the bright green and yellow colors seen on June 12 begin to fade while the surrounding soybean fields are now at maximum growth by August. Using NDRE will show the opposite trend. Figure 10 shows the harvest data from the same crop taken in October. Data from this image was obtained from the copulations done on the New Holland[14] tractor's data collection. For the most part there appears to be no real correlation to the NDVI plots with the exception of the early images taken on June 12th, 16th and July 3rd. On those dates it is somewhat evident that the early growth rates of the corn seem to follow what was actually obtained in the field during harvest. The images were overlaid on one another and a video was made switching between the two data displays and the visual evidence evident[15].

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[11] Global Mapper is a Blue Marble Geographics mapping program: https://www.bluemarblegeo.com/products/global-mapper.php
[12] QGIS is a free and open sourse geographic information software package: https://www.qgis.org/en/site/
[13] Ag Leader is a farm product to help farmers analyze their yearly crop results: http://www.agleader.com/
[14] New Holland Tractors: http://www.newholland.com/Pages/splash.html
[15] Video can be seen here: https://www.youtube.com/watch?v=oMhmS4Fx2RI

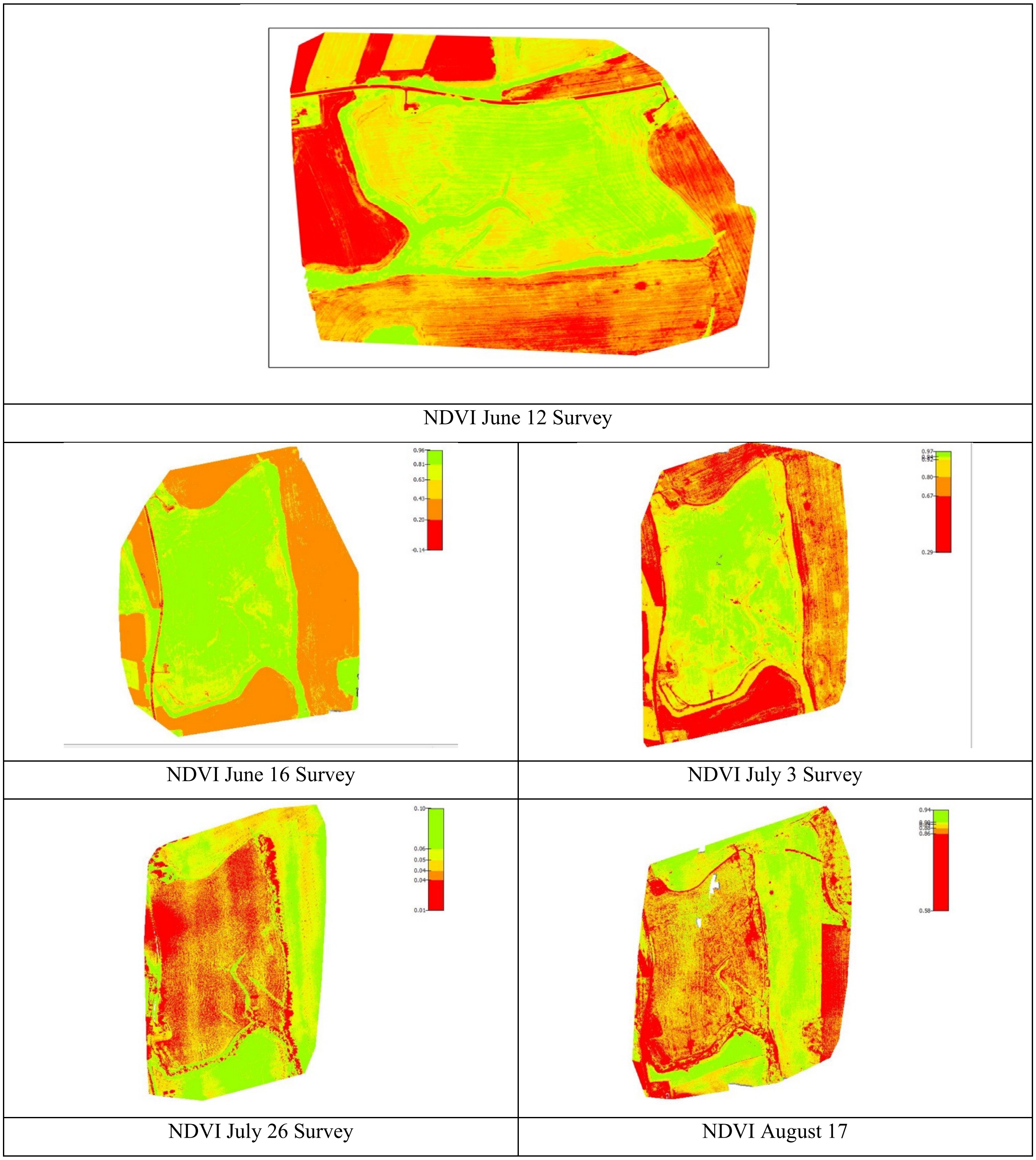

Figure 9 NDVI plots at June 12, 16, July 3, 26 and August 17 respectively

However, a more robust statistical correlation is needed to have confidence in the results. This will be done in the coming year. If the correlation suggested exists, this raises several questions. Will the same results persist in that particular field in the years to come if the farmer continues to rotate the crops between corn, soybean and winter wheat while spraying nitrogen and other additives uniformly? This hypothesis assumes no major climate issues like excessive drought or rain fall during our collection process. If true, then this begs the question, are the conditions where the field produces less, affected more by the topography or by some other factor. Therefore, once written, a prescription for the field should work on that field so long as no unforeseen circumstances arise. The spraying prescription may need to be tweaked, but should work provided there are no other major changes in soil pH nutrients, pests etc.

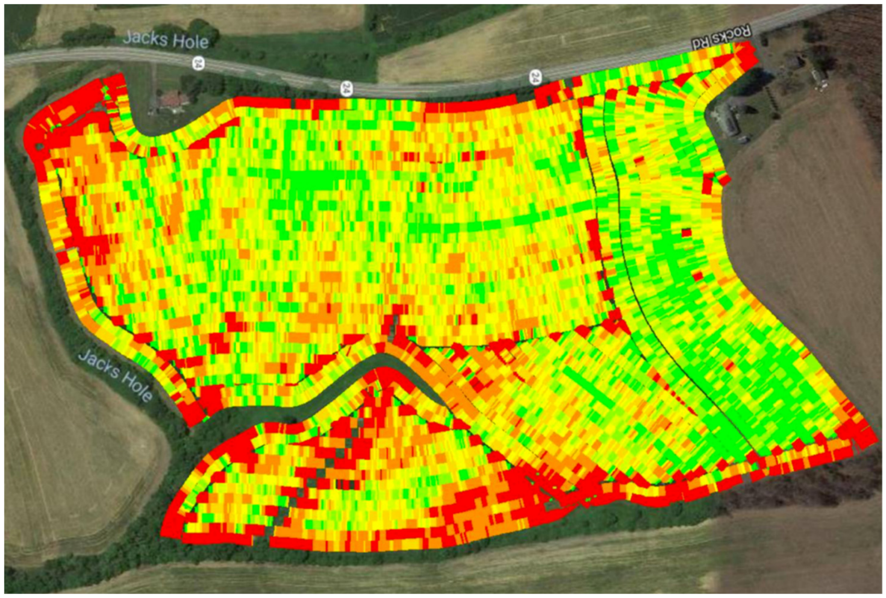

Figure 10 New Holland Harvest data as calculated by AgLeader software package

CONCLUSIONS

The modern farm is truly a technological marvel. The continued growth of the population is easily being matched by improvements to farm productivity through a number of technologies. Many farms on the east coast of North America are growing dent or field corn while also rotating crops between soybeans of various types and winter wheat and this was our focus here and will continue to be our focus for the foreseeable future. Many schools with farm programs are researching the use of drone technologies and multispectral analysis to reduce farmer costs. As the software improves, and the cost of the equipment for analysis decreases, our knowledge will continue to grow on how best to improve farmer productivity. This paper provided some initial data from a corn field in Maryland. The results seem to show a correlation between what was seen early in the growing season with the actual crop yields. The results also seem to indicate that uniform spraying may not produce optimal results and that more information is needed. Our hypothesis was based more on observations then hard statistical data. Therefore, we will gather additional information in the coming year including ground truth soil tests, and additional flights at closer intervals. We will continue to survey this particular and surrounding fields to see if the problem areas (areas where the field produces less) are more a factor of the topography/crop or other controllable or uncontrollable factors.

In the process of making these images we also discovered that we could accurately reconstruct the topography of the field. However, to do this we required accurate ground control points. Surveyor grade ground control points and the associated state plane coordinate system enable images to be assembled with very accurate geolocated 3D images. As part of this we reconstructed a 3D dam at Lake Williams reservoir. The reservoir had recently been drained for maintenance on a drain and this gave us a once in a lifetime opportunity to survey the entire reservoir. Estimates of the reservoir capacity and the effects of erosion on reservoir volume reduction over the past 105 years are also possible from this data and will be reported in future publications by these authors. The analysis of the reservoir dam and the volume analysis gave these researchers an indication of ground truth data like surveyor Ground Control Points (GCP). In future work we hope to include this in the agriculture analysis. The dam analysis and problems associated with that work are briefly summarized in Appendix A of this report.

Appendix A

The dam analysis provided some interesting challenges. The data was taken using the Pix4D app with an DJI Mavic Pro platform with a 12 Mega-Pixel resolution. Images were collected from 160-foot altitude. Unfortunately, due to a DJI bug the altitude of the aircraft resulted in the images not being represented correctly in the state plane coordinates. However, after including 3 surveyor GCPs the data improved dramatically. After that an additional dozen or more GCPs were easily included and the 3D representation of the dam became very accurate. Figure A1 below shows the image adjustments in the pix4D software. Figure A2 shows the final 3D representation of the dam. In both images the survey grade GCP and check points can be seen as circles with arrow on them.

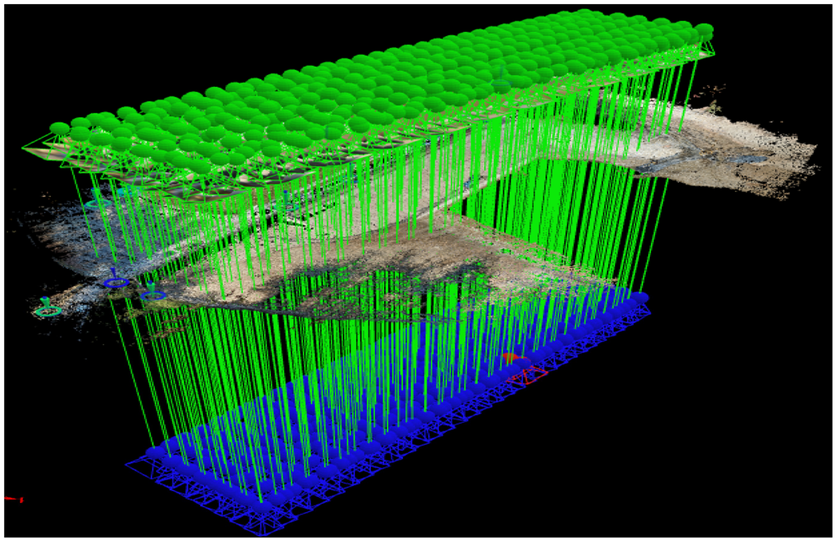

Figure A1 Image adjustments in Pix4D due to DJI bug

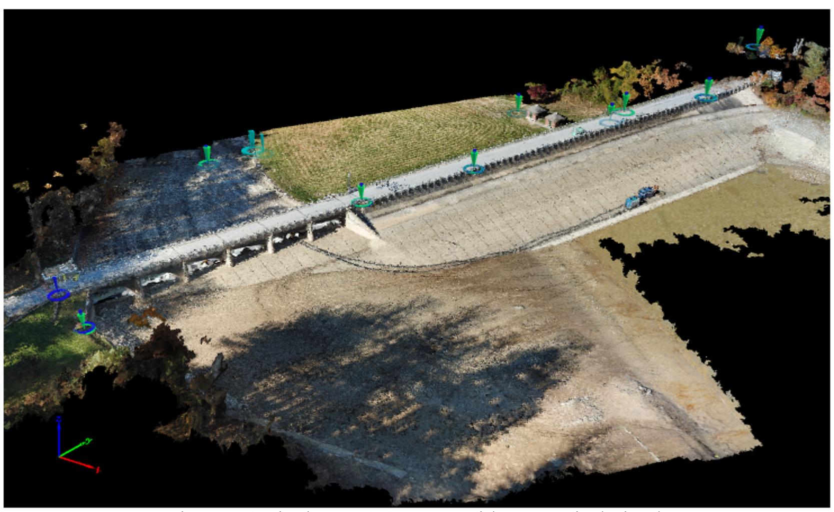

Figure A2 Final Dam 3D Image with reservoir drained.

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