Multispectral Analysis of Farm Corn Crops: A Project-Based Learning (PBL) Program

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In this paper, we examine the learning objectives of using drone aircraft for the multispectral analysis of farmer crops to increase yields while decreasing annual costs. Specifically, we examine the corn, soybean, and winter wheat crop cycles currently dominating Maryland and Pennsylvania farms. This program is formulated as a project-based learning (PBL) initiative. In particular, the program is a Capstone Design 2-semester course that additionally has design and build criteria as a requirement. Completion of this project is a requirement for graduation, and students usually take the capstone design course in their senior year. Because this course is within the Engineering and Computer Science curriculum of the college, however, many of the topics that the students are required to learn are well outside of their typical course requirements. In this paper, we detail the approach to having undergraduate students research and master multiple technology areas and then apply them to the project's main focus. We discuss individual motivational factors in a project where participant selection is based on student choice rather than academic criteria. We follow proven techniques in Self-Regulated Learning (SRL) for PBL activities in this paper. Also discussed is a science, technology, engineering, and math (STEM) drone racing program for younger middle and high school students, which was created as a spinoff to this effort. The object of this subtopic is to get students interested in the sciences. The hope is to continually fill the educational pipeline with motivated STEM students for the future. For the STEM program, we highlight the learning objectives and outcomes as an indicator of student interest and motivation in the topic.

Background

The drone project was proposed to the college as a community-service-based Capstone Design project. The crux of the effort is to help farmers increase crop yields while reducing their costs of spraying and fertilizing their crops, thereby providing an added benefit to the environment. Additionally, the project had an Accreditation Board for Engineering and Technology (ABET) component, requiring a design and build process. Without this component, the project could have been compartmentalized into a data gathering and analysis (agronomy) effort, avoiding the multidiscipline nature of this project.

The overall approach is to have a drone overfly a farm field, collecting different spectrums of light in images that can be stitched together into a global positioning system (GPS) anchored mosaic. This data map can then be turned into a "prescription" to improve the yield of the field, complete with GPS mapping and the ability to be stored on a USB storage device. The data can then be uploaded to the farmer's tractor, where the amount of fertilizer and chemical sprays for specific areas of the field can be controlled, thereby reducing overapplication, waste, and environmental pollution. The reality of the project is, however, far more complex. Therefore, it is important to review some of the components required for the students to design, build, fly, and gather data on a farm field using multispectral camera technologies.

Corn and Multispectral Analysis: Many research studies have already been conducted on corn (our initial choice) using multispectral analysis. Much of the fundamental research work to understand where the highest money-saving payoffs for the farm has been initiated by universities in some of the large U.S. farming states. Hatfield et al. (2003, 2008, and 2010) published a large volume of work detailing the use of multispectral indices for crop evaluation. Lee et al. (2000) used a tractor outfitted with a multispectral camera to assess the nitrogen status of corn plants and acquire real-time data from a sensor on the tractor. Nigon et al. (2015) demonstrated a strategy to reduce the loss of nitrogen fertilizer by administering the fertilizer after emergence. Maresma et al. (2016) provided rankings of vegetation indices vs. crop height to reduce uncertainty. Dickson et al. (1997) showed that breaking the images down by light type and then combining these lights using a formula provided a good estimate of plant health and nitrogen levels.

These and other research efforts afforded an undergraduate project approach where the students are primarily using existing methodologies and practices to acquire data and analysis that will benefit local farmers. Wilkerson et al. (2018) showed that an undergraduate program using project-based learning (PBL) could contribute to the farmer's management of his resources. In surveying the existing literature, it is evident that many studies focus on large farm fields (such as in the Midwest), whereas local Maryland and Pennsylvania fields are typically <100 acres. In fact, the average farm size in Pennsylvania is ~130 acres whereas the average farm in Kansas is ~750 acres (and other Midwest states are far larger). Moreover, the topography of the farms in Maryland and Pennsylvania varies widely. Figure 1 shows a Normalized Difference Vegetation Index (NDVI) image from a portion of a typical Pennsylvania farm consisting of corn, soybeans, and some plowed fields (mainly red) late in the season. Overall, NDVI is a methodology to examine whether or not the vegetation is healthy. Green in this image indicates healthy vegetation, while the red areas on the image are primarily fields that have no vegetation or crops just starting to grow.

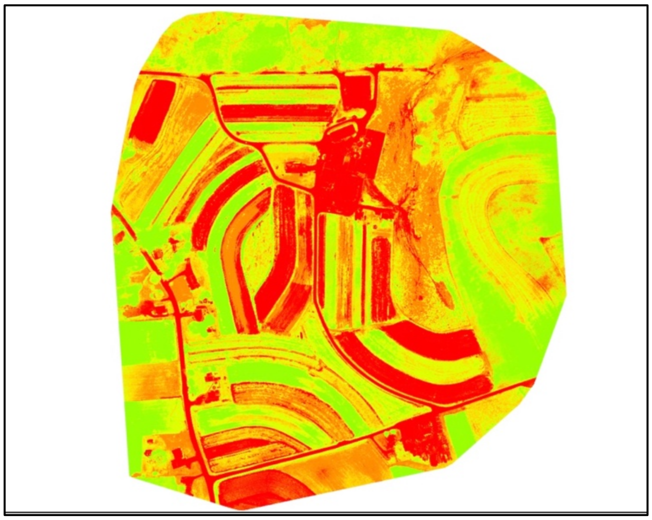

Figure 1. NDVI Image From Multiple Aerial Photos
of a Southeastern Pennsylvania Farm.

Like farms in the Midwest, East Coast corn production depends in part on good soil and crop management techniques, but there are differences. No-till farming practices and crop rotations between soybeans, corn, and, in some cases, winter wheat have proven effective in maintaining good yield in Maryland and Pennsylvania farms. For our project's primary crop, we chose corn (or maize). A corn crop requires a number of soil conditions to be successful, but more than anything else, corn requires nitrogen. Furthermore, while nitrogen is a driving factor in achieving optimal corn yield rates, how to obtain these rates while also managing runoff and other associated factors continues to be of concern as well. Farms in the Maryland and Pennsylvania area typically are made up of smaller fields with their own nuances of topography and soil types. Each field thus requires good data for the farmer to monitor and manage his resources and field health. While the engineering and computer science students who worked on this project had little prior knowledge of multispectral analysis or its relationship to plant health, they were able to master the accurate georeferencing of the farmer's data for a number of indices. These results are provided in the Results section of this paper for a specific farm field in Maryland at five different times in the growing cycle, with several different indices, including NDVI and NDVE. The results of these findings are presented and compared to harvest data from the same field and will serve as a starting point for next year's efforts.

Drone Aircraft: In our first year of the project, the seniors were required to design and build an aircraft capable of carrying a multispectral camera to collect data. With all the airfoil design, autopilot, motor, and prop choices involved, there was enough research design work to keep these engineering students busy for a year. In the end, we were able to design and build a viable aircraft capable of flying and collecting multispectral data, but we did not achieve fully autonomous flight (including launch/take-off, flight, and landing), which was a goal of the current semester. In the first year, we had seven students, two mechanical engineers, and a mixture of computer scientist and electrical engineers. In the current year, we have 12 students with a similar mixture of backgrounds. Therefore, our current goals and stretch goals have been expanded to include a drone that will fly autonomously for 1 hour. We currently have two competing designs; one is a flying wing, and the other is a glider-type aircraft. Additionally, students are designing and building their own camera and are examining many different light spectrum combinations, as well as harvest data. The current students have built and demonstrated wing drones that can takeoff, fly, and land fully autonomously. Building a flying wing aircraft is a more difficult task than building a multirotor drone, but this approach will enable longer flight durations. This approach also satisfied our ABET design and build criteria. As of the writing of this paper, the flying wing (shown in Figure 2) is the concept that is furthest in development. To extend the range of the aircraft, students also have designed and built their own batteries based on Li-ion technology. Initial estimates show that these batteries will approximately double the range available from the conventional Li-poly batteries typically used in radio control aircraft.

Flight Operations: Flying drones posed a new level of difficulty for both the instructors and the students. The days of flying whenever and wherever one wants have long passed; and now participants require a drone license, insurance, and a considerable understanding of flight safety issues when operating these drones. In addition, most of the farm fields we are dealing with are located in remote locations, far away from the nearest airfield, thus posing an additional set of time and logistics challenges. Nonetheless, we usually spend far more time doing paperwork and planning then actual flying. To support our flying effort, we required that several students learn the basics of flight safety and obtain their Federal Aviation Administration (FAA) Part 107[1] license before operating a drone over a farm field. This license designates them as Remote Pilots-in-Command (RPICs). During the first year, one student completed his Part 107 course and passed his exam. However, due to timing issues during the first year, we were forced to limit our flight operations primarily to hobby fields and to fly as hobbyists. To facilitate the ongoing multispectral analysis portion of the effort, however, several of the instructors obtained their Part 107 as well. Fortunately, the Wing Nuts (formerly the York Area Radio Control [RC] Modelers) field in Manchester, PA, is located in the middle of a farm that had corn, soybeans, and winter wheat, which allowed us to gather data while we were also learning to operate drones. Since that time, we have focused primarily on larger farms, and we presently have two farms in the >2,000-acre range that we are leveraging.

Student Assignments: From lessons learned in the first year, students were broken into four groups or teams: the **Airframe Team**, the **RPIC Team**, the **Video Analysis Team**, and the **Flight Controls Team**. Their respective assignments, which are shown in Appendix A of this paper, were, for the most part, selected by the students themselves.

As would be expected, the **Airframe Team** was mainly composed of mechanical engineers who understood lift design, loading characteristics, and the importance of structural strength in picking an airfoil profile and design. The team also needed to work with the other teams to integrate the components needed for the aerial photography mission and autonomous flight mission. Fortunately, mechanical drawings and building techniques were well within this group's capabilities. Moreover, the mechanical engineers were able to learn new technology areas, such as wing loading, center of gravity, lift, and propulsion (including prop types), with little assistance from the faculty. More often than not, the students researched and solved problems and obtained solutions completely on their own. In the first year, we focused the aircraft building efforts on durable lightweight foam construction. In the second year, we have expanded these efforts to include new materials (a foam and composite design). In addition, the

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[1] FAA Part 107 registration, https://faadronezone.faa.gov/.

first year's aircraft was only able to fly for 10 minutes on a single charge. As of the writing of this paper, one of the current designs has already flown in excess of 30 minutes on a single charge.

RPIC Team: needed to master the flight regulations and techniques used to operate drones safely in urban airspaces. This requirement was not well-suited to any of the engineering disciplines and therefore fell once again to the mechanical engineers. The first year, this requirement was a particular problem as even the instructors didn't have their Part 107 licenses. Typically, a RC aircraft hobbyist can pass this exam without additional studies. For a student with no prior RC experience, however, a full course on the subject was required. Students needed to master:

- Airspace.
- Weather.
- Unmanned Aerial System (UAS) loading and performance.
- Crew resource management.
- Airport and field operations.
- Radio communications.
- Emergency procedures.
- Preflight and maintenance.
- Sectional charts.
- Waiver requests.

Also needed was the use of specialized phone applications[2] and other software to obtain permission to fly, as well as insurance. In the second year, we were able to tackle this issue early; and by the spring semester, we already had one RPIC who could accompany the students when flying experiments. Nonetheless, this proved to be the hardest of the topics to motivate students to learn. On a related note, we had all of the seven students learn to fly drones in the first year, and each of them was able to fully operate the controls and safely fly and land a drone. In the second year, we wanted to do this again, but the students were noncompliant. Many of the students were not interested in flying drones, rather they wanted to build them. It was simply a bridge too far.

Video Analysis Team: was responsible for mastering the multispectral analysis, cameras, and basic data collection and analysis. In the first year, students were able to stitch images, operate the cameras to collected the farm data that we needed for this project. This responsibility required the mastering of new software, including the Pix4D suite. While there are numerous videos on the topic, there is simply no substitute for actually collecting data from the field and analyzing it. In the current year, we have also included some stretch goals, including the following:

- Comparisons with harvest data, requiring the mastery of additional software and the gathering of harvest data from the tractor/harvester.
- The assembly of multiple flights into a single mosaic.
- Three-dimensional reconstructions of areas to create topographical maps. In particular, Lake Williams (shown in Figure 2), which is located just outside of York, PA, has been drained for repairs to a 105-year-old drain system and improvements to the earth dam at the end of the reservoir. This rare opportunity has allowed the students to overfly the

[2] Phone apps could include Airmap (https://www.airmap.com/airmap-for-drones/), Verifly (https://www.verifly.com/), and Flight Aware (https://flightaware.com/).

reservoir to get data for further analysis while the lake was emptied. The reservoir spans some 170 acres and provides water for the York city municipality. Using the drone data, topographies of the reservoir bed can be reconstructed, and an estimation of the total sediment accumulated in the reservoir over the past century can be found. The opportunity has also spun off several other research areas, which will be discussed in subsequent publications.

Figure 2. Google Map Image of Lake Williams Near York, PA.

In this paper, our results reporting is focused on a corn crop comparison between the harvest and multispectral data taken last summer and fall, as well as some of the pedagogical discoveries of student motivation between different years. Blumenfeld et al. (1991) presented an argument for why projects have the potential to help people learn. It has also been our observation in this nearly 2-year effort that this argument is particularly true when students are vested in the process.

The task of the final team, the **Flight Controls Team**, was to take whatever aircraft was designed and make it fly fully autonomously. In other words, it must take off, fly, and land without pilot assistance. As mentioned, this task is a relatively simple one for a multi-rotor aircraft; but for winged aircraft, it is far more difficult. Winged aircraft cannot take off and land vertically and therefore require greater planning and care. However, the major advantage for winged aircraft is in their flight efficiency. Winged aircraft can fly significantly longer on the same battery pack and are much easier to operate in windy conditions (less than <15 mph).

In the first year of this capstone, the goals outlined proved to be too much for the students, and the aircraft they built was not autonomous and could not complete a mission unless flown by an experienced RC pilot (which we employed from a local RC field to collect data). In the second year, we addressed this issue by recruiting some students who had some RC experience. This approach proved to be extremely beneficial to the whole project. As of the writing of this paper, we have multiple aircraft that are capable of being launched, flown, and recovered fully autonomously. Moreover, two of the students are highly motivated and work on this project in their spare time. Without a complete buy-in from students such as these, this amount of progress would likely have been impossible.

Initially, students were going to use the Pixhawk[3] as their primary flight control system. However, the choice quickly changed to the Omnibus V3 controller and has continued to evolve

[3] Pixhawk or Ardu flight controller (http://ardupilot.org/copter/docs/common-choosing-a-flight-controller.html).

into other controllers with more capabilities and ease of use. The current flyable aircraft still is using an Omnibus V3, [4] but what controller the final aircraft will ultimately have in it is still evolving. Stretch goals were not provided for this team. However, the team insisted on several of their own, including building a flight battery and their own camera. Both of these projects will be presented in subsequent publications.

The primary goal of this offering is to provide a framework, by example, for a PBL objective spanning multiple semesters and incorporating STEM technologies of a highly diverse nature. The challenge here was twofold: the diverse nature of the topics that the students needed to master and the ABET requirement of design and build. Clearly, the number and complexity of the topics that had to be tackled to provide a drone capable of performing multispectral analysis of farm crops would be more than enough to keep the average researcher busy and challenged. Moreover, as technologies increasingly affect how we solve problems, the problem solutions require specified knowledge in specific disciplines. The original idea for this project was proposed to York College's school of Engineering and Computer Science. The stated goal was to simply help farmers become more profitable by using less chemicals. What has resulted from the project's initiation and progress, however, is a window into a likely future where new technologies can be applied to produce more with less.

As a spinoff to this project, we also provided a drone racing opportunity to a local high school. For this 12-week program, we taught high school students to fly quadcopter drones in first-person view (FPV). Students needed to master flying drones using standard RC controls and navigate an obstacle course. To do this, we provided once-a-week drone flight instructions and practice using computer simulators. Once the students were proficient at flying, we allowed them to fly real drones indoors through obstacle courses. In a similar fashion to the First Robotics[5] experience, the project used the drones as a means to expose students to STEM-related technologies. At the end of the program, a drone race was held on June 1, 2018 at the John Carroll High School in Bel Air, MD, with coverage by the local print press.

Analysis

The end goal was for the students in this project was to provide data to farmers that would allow them to produce more while using less sprays and fertilizers. To that end, we have moved cautiously as we do not want to give farmer's bad advice or have a negative effort on their bottom line. A brief explanation here of what we have found along the way is necessary to understand what needs to be done next.

In the past growing season, we overflew a corn crop in Maryland at Blue Valley Farm in northern Maryland. We needed to collect data while we were still designing and building our drone so that the Video Analysis Team could learn how that process was done before we started flying our drone. To accomplish this task we used an E-Bee-SQ drone and a Sequoia camera system from sensefly.[6] This purchase proved to be highly beneficial as the drone came with a lot of support. Also, we were trained on how to use the drone by one of the authors of this report. Unfortunately, that training didn't take place until May of 2018, when much of the local agriculture was in full bloom and we were in between drone capstone teams. The timing of these

[4] Omnibus V3 is a favorite of the home-built race quads as it is easy to set up, use, and modify for various projects (https://www.readytoflyquads.com/flip-32-f4-omnibus-v2-pro).

[5] First Robotics consists of FIRST LEGO League, FIRST LEGO League Jr., First Tech Teams, and First Robotics. For more information see: https://www.firstinspires.org/robotics/frc.

[6] senseFly is a subsidiary of Parrot (https://www.sensefly.com/industry/agriculture/).

flights was thus somewhat problematic. Nonetheless, the first flight took place on June 12, with the remaining flights following on June 16, July 3, July 26, and August 17. The first flight couldn't be done until we had gotten some training on collecting the data operation of the drone. By that time, the corn in our field was approximately 2 ft high. Table 1 shows the various stages of corn growth.

Table 1. Corn Growth Stages

	Stage	Common Name
Vegetative	VE	Emergence
	V1	First Leaf
	V2	Second Leaf
	V3	Third Leaf
	Vn	n^{th} Leaf
Reproductive	VT	Tasseling
	R1	Silking
	R2	Blister
	R3	Milk

Taken from Seminis[7] and Adapted from Abendroth et al. (2011)

Early growth in corn is designated by the number of leaves on the stalk at the time. When we took our first flight, the corn was at the V6 or V7 growth stage. This was at least a week later than we would have liked. After this initial flight, data were taken whenever our schedule and the weather permitted. Figure 3 shows a Google Earth overlay that was created from the flight of the area in the survey. The mosaic was constructed from approximately 1,400 images taken during a 20-min flight over the field. The area of concern is the cornfield in the middle of the image, which includes approximately 55 acres of corn.

At this point in the field's growth cycle, individual plants can be seen and therefore counted (as shown in the zoomed-in view of the image in Figure 4). Of particular interest to the farmer is how well the farmer's planter is distributing the seeds. This can be found by counting how many plants he has right after emergence vs. how many seeds he has planted. The image data we collect allow us to count the individual plants over the entire field. Blue Valley Farms was planting at a rate of approximately 33,000 seeds/acre. Because the costs of the seed and the equipment and labor to plant it are considerable, they are of great interest to the farmer. Too many plants is not good for optimum yield, and neither is too few.

[7] Seminis (http://www.seminis-us.com/resources/agronomic-spotlights/sweet-corn-growth-stages-and-gdus/).

Figure 3. Cornfield Overlaid in Google Earth.[8]

Figure 4. Zoomed-In Area of the Cornfield.

As can be seen in the image, the number of plants can be counted with good precision, and the efficiency of the planter can be seen as well, giving the farmer added data for the coming year. And the image shows a number of opportunities for improvement. For example, areas in which the planter jammed and planted no seeds can be clearly seen. In the coming year, we will employ a plant-counting algorithm and get an estimate of losses due to this issue. Additionally, it is evident that the corn in the upper left of the image is much larger than that in the lower right. Some of the questions we hope to answer include why is there such a large difference between different areas in the field, and what happens as the field continues to grow? After all, the entire field in this case was treated with the exact same chemicals, sprays, and fertilizers. Also did that part of the field's corn growth catch up with the other areas later in the growing season, or was there still a problem at harvest? Field yield data will also play a role at the end of the year, but we will need soil tests in these areas to better determine cause and effect. Only by looking at all of the potential effects on the corn (both controllable and uncontrollable) can corn yield cause and effects be determined. This should in turn help determine best practices for a particular field. The help of an agronomist will also be a must in our final analysis.

The corn at this point of the year is growing at a rapid rate. Corn can grow faster than 1 inch/day and has been observed growing multiple inches in a day under the correct conditions. One measure of growth that is commonly used is Growth Degree Days (GDDs), also called Growth Degree Units (GDU). Gupta et al. (1992) describes the crop growth process as a function of temperature. Additionally, Wiebold (2002) provides some simple formulas for corn, allowing GDD to be calculated for corn at various temperature ranges. One formula is:

$$[(T_{min} + T_{max})/2] - 50,$$

[8] Google Earth is a program that renders 2D and 3D representations of the Earth's surface based on satellite imagery. It is free to the user and provided by Google as a public service (https://www.google.com/earth/).

where T_{min} is the minimum temperature for a given day and T_{max} is the maximum temperature for that day. The range of temperatures used spans 50 to 86 °F. This will be important data to have in the coming years as we focus on the variables affecting the farmer's crop. Crop moisture is also an issue. Typically, in Maryland and Pennsylvania, moisture issues are due to too much moisture rather than not enough, but even this is a variable. Another issue that must be considered when looking at the cornfield is the field's topography. For example, crops tend not to grow as well on steep inclines where the drainage pulls away the nitrogen and other soil additives. We also will include some ground truth data from soil testing for nitrogen and other nutrients.

Results

As we have made progress on our understanding of corn, soybeans, and the farms in Maryland and Pennsylvania, we have begun to see some correlation in the data. Here, we compare one field's data in the limited case as a means for discussion for expanding our future work. This is the Blue Valley cornfield shown previously in Figures 3 and 4. Han et al. (2001) showed that corn stress caused by nitrogen deficiencies can be associated with leaf chlorophyll content using NDVI and Green NDVI. The formula for NDVI is:

$$NDVI = \left[\frac{NIR - RED}{NIR + RED}\right].$$

Guo et al. (2008) further showed a relationship between NDVI images and increased nitrogen in corn. Figures 5 and 6 show the NDVI levels from the corn field in northern Maryland, with green indicating a high level of NDVI and red a lower level. This particular field is surrounded by soybean fields. In the August 17 image (Figure 6), it can clearly be seen that growth stage of the corn was reducing while its reproductive stages are taking over. Of interest also are the surrounding soybean fields, which are seen growing strongly in the August 17 image.

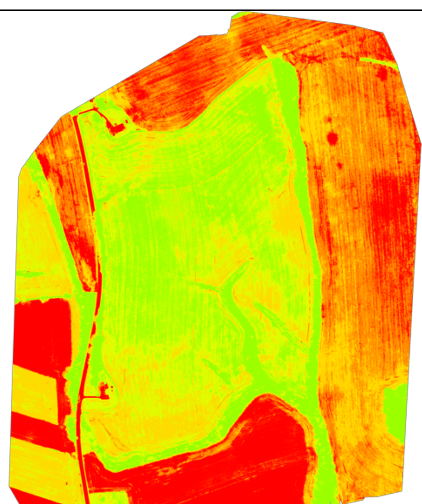	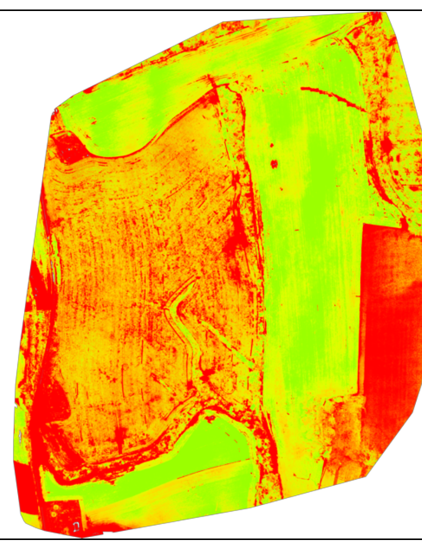
Figure 5. NDVI Image for Corn on June 12, 2018.	Figure 6. NDVI Levels for Corn on August 17, 2018.

In contrast, Figures 7 and 8 show the NDRE calculations at the same time of the year. The formula for NDRE is:

$$NDRE = \left[\frac{NIR - RED\_EDGE}{NIR + RED\_EDGE}\right].$$

In the coming year, the soybean fields will be corn and the cornfield will be soybeans. The soybean fields surrounding these fields were either just planted or just showing signs of emergence. The field at the bottom had no emergence, and the fields at the top and right had only small plants.

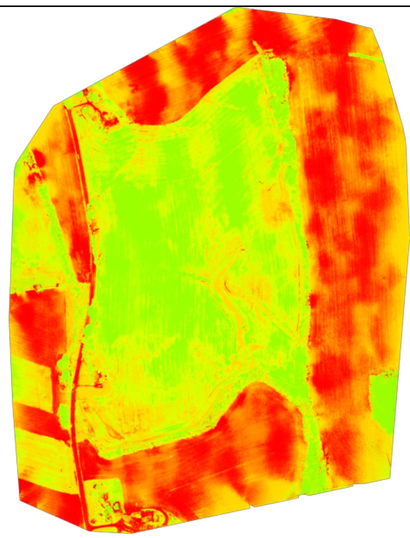	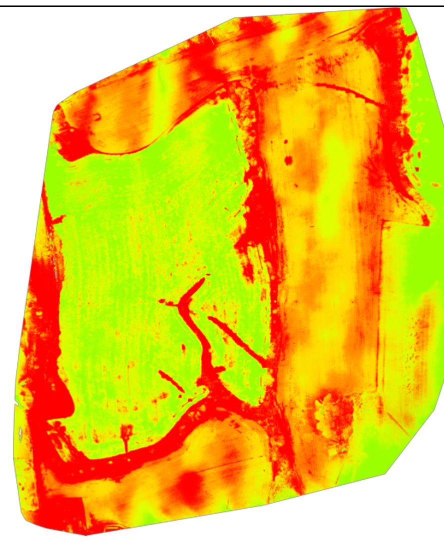
Figure 7. NDRE Image for Corn on June 12, 2018.	Figure 8. NDRE Levels for Corn on August 17, 2018.

There are certainly correlations that can be seen between both the June 12 and August 17 NDVI and NDRE images. Of interest are also the harvest data (shown in Figure 9) from the same field taken in October 2018. Actually, the entire field was not harvested in one day due to other activities on the farm. We mention it here since we do not know the importance of this fact. What is clearly visible in the harvest image is the correlation to the June 12 NDVI and NDVE images and the amount of corn harvested in different areas of the field. In an attempt to see this better, the images were overlaid on one another and then faded in and out between the two.[9] Further analysis (beyond the current year's effort) is needed to better understand the correlation between the harvest data and the NDVI images. In particular, the data from each of these GPS-anchored images need to be examined over more than just NDVI data and then correlated. This analysis is planned to be conducted and reported on in future publications.

[9] Video simulation fading between harvest and NDVI image from a farm field (https://www.youtube.com/watch?v=oMhmS4Fx2RI&t=21s).

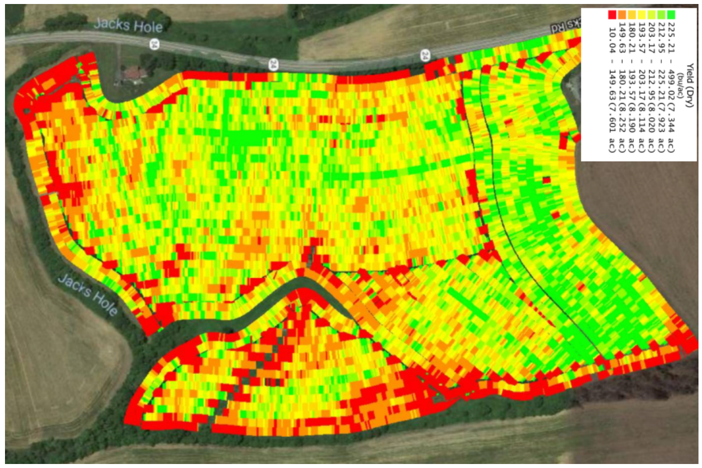

Figure 9. Corn Harvest Data, October 2018.

As a test of the importance of nitrogen on one particular field, additional nitrogen was sprayed during one pass while less nitrogen was sprayed on a subsequent pass. This can clearly be seen in the harvest data in Figure 10 (along the lower bottom of the field).

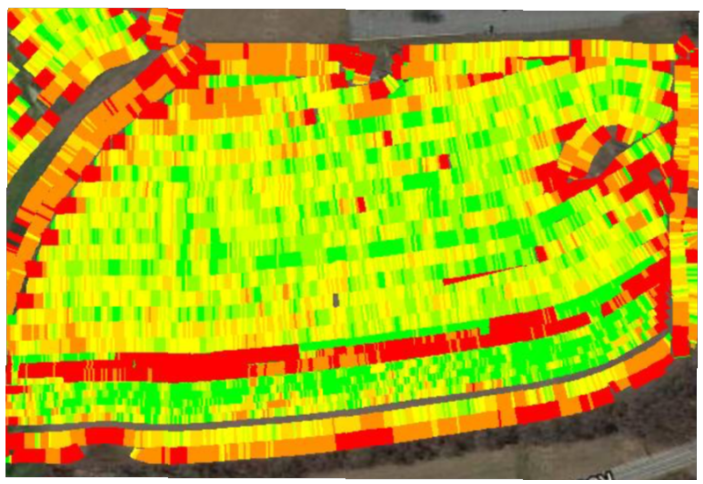
Figure 10. Farm Nitrogen Experiment.

Student Challenges

The project required that students learn the skills they needed to complete this project. Moylan (2008) argued that PBL helped close the gap between student learning and developing skills to complete tasks successfully. Barron et al. (2008) showed that effectiveness relies heavily on student readiness. To that end, much of the current effort here relies on preparing the students through education, and much of the first semester of the program relies on learning while the second semester focuses on doing.

As a measure of student readiness, we compared the students perceived knowledge in 16 generalized areas when they began the project to their perceived knowledge in those same areas ¾ of the way through the year's work. In addition to student readiness, student confidence (conceptualized as predicated on knowledge and experience) was a powerful catalyst to success. A student survey was conducted to assess perceived improvements to knowledge from the start of this project to the end. Capstone Design is, to a large extent, based on student motivation.

Will the students do the minimum, or is this something worth doing well and putting in extra effort? The survey questions were rated on a scale of 1 to 10, where 10 was internationally recognized knowledge on the topic and 1 was almost no prior knowledge of the topic. Final scores were expected in the 5 or 6 range. It was hoped that the increase in perceived knowledge would occur in every category, but this was not the case. In general, students working on the airframe had their knowledge in related areas grow, with little or no growth in other areas (such as autopilots). Students did, however, perform biweekly reporting, so they did gain knowledge outside of their particular team's required expertise by being briefed on other teams and their progress.

Figure 11 is a measure of the students' perceived gain in knowledge during the year-long course. In this area, most students learned a great deal. However, the students doing the multispectral analysis who were focused primarily on the data analysis did not gain a lot of aviation knowledge, a fact that can also be seen in the figure.

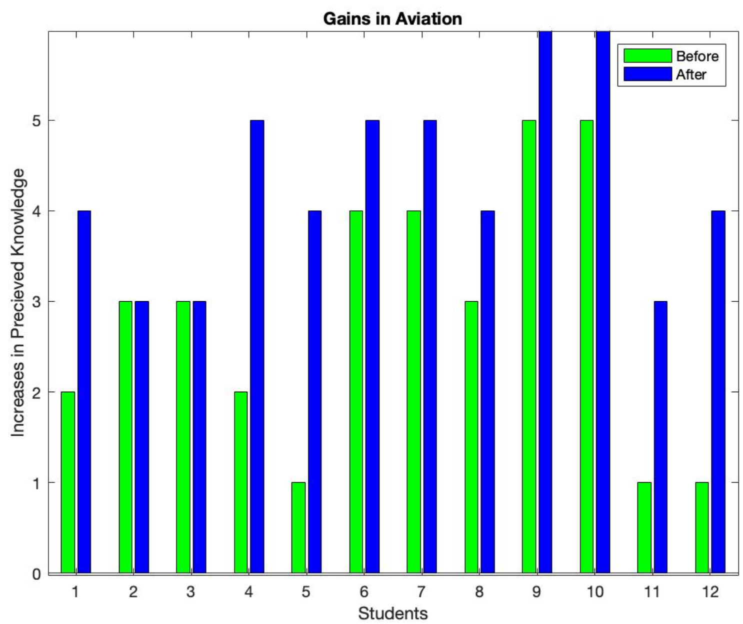

Figure 11. Student Perceived Gains in Aviation Knowledge.

Finally, Figure 12 contains all of the categories used as a percentage. The data were normalized, with the bar chart indicating overall gains across the diverse range of topics needed in this PBL course. The topics are enumerated as follows:

1 – Aviation.
2 – Airframe Design.
3 – Autopilots.
4 – Model Aviation.
5 – Radio Control.
6 – Aviation Safety.
7 – The Modern Farm.
8 – Multispectral Analysis.
9 – Battery Energy.
10 – Aircraft Building Techniques.

11 – Aircraft Materials.
12 – Photography.
13 – Video Analysis.
14 – Farm Chemicals.
15 – York Area Farm Products.

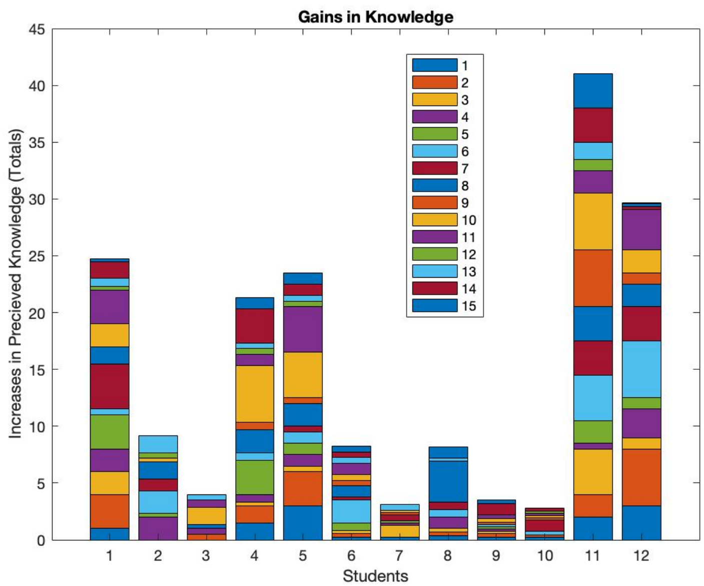

Figure 12. Student Perceived Gains in Knowledge.

Pedagogy (A discussion of the approach)

PBL is an exceptional approach to implement in effectively facilitating real-word opportunities for STEM students. PBL has been defined as "a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic (real-life) questions and carefully designed products and tasks" (Buck Institute for Education, 2003, p. 4). The pedagogical focus of this study is to determine how much guidance and structure to provide to STEM students to maximize learning, growth and ultimately, achievement. A discussion of the current approach and what guidance is available in existing literature is discussed below.

English et. al. (2013) provides an outline to support student Self Regulated Learning (SRL) in a PBL environment. Self-regulated learning is built upon PBL, which refers to student-centered, inquiry-based pedagogical approaches of problem-based learning and project-based learning (English, 2013). SRL refers to the extent to which learners are metacognitively, motivationally, and behaviorally active in their own learning process (Zimmerman, 1989). As noted by (English 2013) students must be responsible for setting goals and sustaining motivation throughout the project. However, it is also noted that this does not always come naturally to a 21-year-old college student. English further points out that PBL is a teaching method that requires students to gain knowledge to solve real world problems. Ram et. al. 2007 points out that student lack of interest is often attributable to the lack of real-world relevance found in a typical course. Ram further points out that using PBL successfully helps develop skills in lifelong learning that are not always present in the classroom. PBL helps students develop self-assessment independent of a teacher directing them. Mills et. al. 2003 poses the question "does problem-based learning work in engineering?" Mills concludes that "chalk and talk" pedagogy alone, is not the answer to teaching. Rather a mixture of traditional coursework and PBL is likely to be more successful. This is true here too, and after some reflection, some instruction particularly when students are stuck is required for success in the PBL. It is also proposed by (Mills, 2003) that PBL may be more successful later in the student's curriculum as it is done in this study. Here we are applying this PBL coursework in the student's senior year.

The problem as posed in this work was well suited to the PBL as defined in the previously referenced studies above. The farm issue is a real-world problem that is not well structured, requiring knowledge in a large array of topics not previously mastered by the students. This is in part why we took the time to describe some of the technical details at length in the introduction of this work. The added complexity that we had with this project was due to the fact that single source (professor) has all of the background experience required to guide students through this PBL course. This can be seen in the above technical sections that the knowledge required to develop a detailed plan to solve or make headway in the overall problem is diverse. To be clear, the object is to help farmers save money on chemicals and fertilizers by using them optimally. Most farms in the York area apply chemicals and fertilizers uniformly on their crops. Just the same, the question remains; how much structure will be required to make this program successful for the students? Insufficient structure can result in students not knowing where to start, becoming frustrated by a lack of progress, and having the PBL goals as outlined above fail. With inadequate scaffolding and insufficient structure coupled with guidance, students may become frustrated and disengage thus losing motivation when faced with challenges.

Sensitive to the need for a great deal of time, scaffolding and patience, we pitched this as a three-year effort to cultivate required skills and competencies in students to achieve results. In the first year we proposed modest goals but attempted to assess our progress and make adjustments to our level of involvement as mentors and project leaders. Our goals for the first year were simple: produce an aircraft to do the mission and learn how multispectral analysis is done from the existing literature. In year two of the project, our goals were far more robust and detailed. In keeping with the guidance given by (English 2013), we will detail the three phases of a PBL used in this capstone course followed by how we attempted to assess our progress.

The question posed at the beginning was: "Can we use multispectral drone data to help farmers reduce the amount of fertilizers and chemicals on their crops while increasing or holding constant their current harvest?" During ***Phase 1*** of the process students should research the driving question and propose a course of action for a solution. In the first semester we focused on the hardware and software we would need to collect the data and how to use it. It was well understood from the beginning that we would not be able to achieve our goal in the first year. What was discovered during that first semester was that far more structure regarding the goals needed to be provided to the students early on. Some of the structure from this project is detailed in the Appendices of this work. For example, initially we broke the problem into two basic elements -- one for the aircraft and its operation, the other for the data gathered from the aircraft. In the current semester we have four groups focused on their areas. More adjustments will be required for the coming year.

Phase 2 of this program involves gathering information, designing and testing solutions, and making adjustments and improvements. Interactions with peers and working in groups is paramount in this phase of the problem. During Phase 2 it was necessary for the instructors to help students self-assess and continue their development. In both semesters there was a tendency for the students to complete a prototype with an experiment and then conclude "good enough." Like every capstone program, the student makeup was a mixture of great, good, and marginal, students. This is true for both ability and motivation. Since every part of this program is primarily interdependent on another the need to have a balanced set of groups has become evident. The biggest weaknesses thus far have been the areas where the instructors have limited experience. These are mainly centered around the farm. Unfortunately, this is also a weakness of the students who are well trained in math and science, but have little experience applying this to farms and their problems.

During ***Phase 3*** of the program student are expected to reflect and report on their findings. This is in part done through presentations and a final report. This will be detailed in the assessment section to follow. In year one we had the students present what they had learned and the problems that occurred throughout the year to our industry partners at the end of the semester. In the current semester we will include having the students report their findings and recommendations to the incoming students. As it turns out, there is very little cross communications between the outgoing senior class with the incoming juniors at York College. To facilitate better communications between outgoing and incoming students we will provide time and structure to this aspect of the program in the current semester. This should help capitalize on the gains we have made in the current year. Hopefully we can facilitate a working relation between the new students and the old students to prevent us from revisiting mistakes already made. It is interesting to note the pride that can be observed in the students when they share their knowledge and accomplishments with others.

Assessment: All of the items in this capstone design project are assessed through weekly presentations, reviews of their lab books, milestones (usually set by them or co-constructed between professor and students), poster and oral presentations, the final report, peer reviews, and through the professor's observations. As a figure of merit in this program we provide 3 areas of assessment in tables 1-3 below.

Table 1: An ability to identify, formulate, and solve engineering problems

Attribute	**Exceeds Expectations**	**Meets Expectations**	**Below Expectations**
Final Presentations	Student acquires information through research and independently synthesizes it for use in a project, report or engineering problem.	Student acquires information through research and with some assistance synthesizes it for use in a project, report or engineering problem.	Student is unable to acquire information through research and/or is unable to synthesize information for use in a project, report or engineering problem.
Student Achievement			
Number (percent) of EE/ME students:	5		
Number (percent) of CE/ME students:	4	3	

Table 2: An ability to communicate effectively

Attribute	**Exceeds Expectations**	**Meets Expectations**	**Below Expectations**
Final Report	Student conveys ideas and information clearly and concisely in written documents and observes grammar and formatting rules appropriate to the document	Student conveys ideas and information clearly and concisely in written documents and observes grammar and formatting rules	Student is unable to convey ideas and information clearly or concisely in written documents.

	without significant editorial assistance from an instructor.	appropriate to the document with significant editorial assistance from an instructor.	
Student Achievement			
Number (percent) of EE/ME students:	5		
Number (percent) of CE/ME students:	4	2	1

Table3: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice			
Attribute	**Exceeds Expectations**	**Meets Expectations**	**Below Expectations**
Observation	Proactively sets and follows schedules and milestones related to an engineering project. Demonstrates a high level of proficiency in organizational skills needed to support work on an engineering project.	Able to follow schedules and milestones related to an engineering project. Has more limited ability to set realistic schedules/milestones. Demonstrates adequate proficiency in organizational skills needed to support work on an engineering project. Occasionally needs guidance from the instructor or the project team.	Needs assistance and/or reminding to follow schedules and milestones related to an engineering project or requires significant instructor assistance to set realistic schedules/milestones. Needs assistance in organizing the student's project work, demonstrating a lack of proficiency in organizational skills needed to support work on an engineering project.
Student Achievement			
Number (percent) of EE students:	2	3	
Number (percent) of CE students:	3	2	2

Conclusions

In this paper, we have examined learning objectives of using drone aircraft for the multispectral analysis of farmer crops to increase yields while decreasing annual costs. We initially based our study on corn crops but expanded the study to include soybeans and winter wheat. This program is formulated as a PBL initiative. The program is supported by a Capstone Design 2-semester, 1-year course. During the course, students in the Engineering and Computer Science curriculum were required to design and build a solution to a real-world problem. The program was relatively difficult to organize due to its multi-disciplinary nature. However, although we originally anticipated that it would take 3 years to make significant progress and actually help farmers with data taken from drones, based on the progress we have made so far in the program, it appears that most of the goals to help farmers are well within reach. That said, there is much more work, particularly in the area of data analysis, that is needed. In the coming year, we hope to include more data and some experiments on corn and soybean crops.

As a spinoff to this effort, we also included a 12-week STEM drone racing program for younger middle and high school students. The object of this subtopic was to get students interested in the sciences. This effort proved far more difficult than originally envisioned. Students need to invest considerable time in drone flying skills to be able to successfully race them. In general, high school students didn't want to invest this amount of time, which was evident during our final drone racing event. In addition, flying a semi-autonomous drone is not difficult for the average person, but flying a human controlled drone using FPV at high speeds is far more difficult. What was discovered in the process of the program was that using computer simulators was critical to the rapid advancement of the student's flying ability. Therefore, future efforts in this area will be focused on computer simulated drone racing only. There is no question, however, that continually filling the educational pipeline with motivated STEM students for the future is a must.

For our current year's effort, two of the project students had some drone racing experience, and this attribute proved indispensable in designing a drone that operates fully autonomously. This along with their ability to run experiments with newly designed drones was a necessity for this program. Another observation about these students was that their motivation was without equal in this program, probably because they were already passionate about drone technologies. Accordingly, it was not unusual to see these two students working late into the night and weekends on the project. Having even one student who is determined not to let the project fail would have been fantastic, but in this case, we had at least 2.

This PBL capstone course is at present a bottomless-pit in terms of what is needed and known. It really moved students and the professors out of their comfort zone and into unknown areas. Moreover, the goal represents a real-world project with impact. Therefore, as noted by (English 2013) it becomes what the students put into it in effort. Any of the topics we needed to master could easily be a year-long course by themselves. For example: airframe design. The problems of airfoil types (there are thousands), propulsion, design parameters, control services, balance, drag, efficiency, props, maintenance, durability, safety and flight operations are many faceted topics. By and large our students had little or no knowledge what so ever on how an aircraft is designed and built. Furthermore, building and testing must be done in accordance with a number of FAA regulations. The aircraft must carry a payload (camera) must operate fully autonomously and collect data. The data needs to be analyzed and be compelling enough to encourage farmers to change their tried and true practices. Therefore, students must be able to convince the farmers of their product's utility. Not unlike the capstone car programs, the reality is that this program will take several years to get right.

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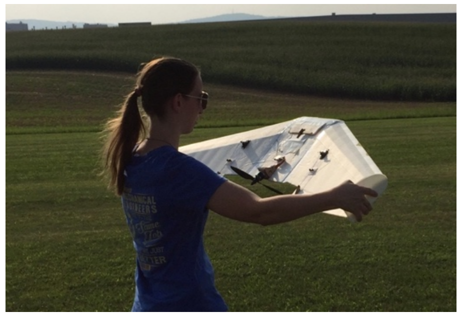
Appendix A Team Assignments

Airframe Team



Airframe Team (Design and Material Intensive)

All of the other teams are dependent on one-another, but this team is critical to experimentation. In order to have reliable flight vehicles we need to build and fly them. Unlike the car and other projects, aircraft that are not properly designed and built fall from the sky and turn themselves into a lot of pieces. Therefore, this requires attention to detail. Some of the things that are expected from this team include:

1. You will design two types of aircraft, fixed wing and quad copter. For the fixed wing aircraft, you will need to have a complete solid works model similar to the 2018 design, with improvements. You will need to know:
    a. Solid Works design
    b. Wing designs
    c. Wing design materials and building techniques
    d. Lift CG locations
    e. Reinforcements
    f. Compartments for components
    g. Weight balance
2. You will need to understand the flight characteristics of the aircraft to include:
    a. Propulsion
    b. Energy Management
    c. Weight distribution
    d. Methods to protect critical components in the event of a crash.
    e. Flight time and endurance
    f. Durability.
    g. Maintenance
3. Must interface with Autopilot and Video analysis team.
4. Must interface with RPIC team for preflight check, safety, Flight Logs, Maintenance Records.
5. Responsible for Battery charging, maintenance and safety.
6. Responsible for all repairs.
7. You will learn how to fly drones and winged aircraft.
8. You will help other team members as required to scratch build a flyable aircraft before the capstone project is complete.

Flight Controls Team

Flight Controls Team (Knowledge and Accuracy Intensive Intensive)

This team is also critical to aircraft experimentation. Bad flight controls will lead to flight failures, loss of aircraft, or worse. Members of this team must have a record of working without making errors. Some of the things that are expected from this team include:

1. Understand all of the aspects of the Pixhawk autopilot system to include:
    a. Mission Planning, Flight plans.
    b. Computer Drone connections.
    c. Parameters.
    d. Altitudes, speeds, maps.
    e. Potential Data dumps to Video Analysis team.
    f. Help with power management
2. Work with Airframe team to assure reliable flight operations.
3. Download and analyze Flight logs after all flights.
4. Document setup procedures for next year's team.
5. GPS, Google Earth, Flyover simulations.
6. Transmitter and Receiver communications.
7. Help maintain RPIC records.
8. Aircraft Recovery Plan.
9. You will learn how to fly drones and winged aircraft. Someone from this team should be the best or one of the best pilots.
10. Experimentation.
11. You will scratch build a wing aircraft and demonstrate flight with same

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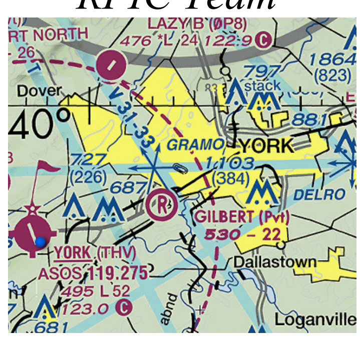
RPIC Team



Remote Pilot in Charge (Time intensive project)

This team is crucial to our ability to fly and collect data for the multispectral analysis team. In order to experiment there must be someone from this team at every event we do off site. Therefore, it's time critical. Some of the things that are expected from this team include:

1. Take an online course and obtain a FAA RPIC license. School will support. You are expected to pass the RPIC exam.
    a. FAA Rules and regulations.

    b. Airspace.
    c. UAS weather and Weather services.
    d. UAS loading and Performance.
    e. Crew and Resource Management.
    f. Airport/Field Operations.
    g. Radio Communications.
    h. Emergency Procedures.
    i. Preflight and Maintenance.
    j. Waiver Requests and Insurance.
2. Research crops to include Corn, Soybean, and winter Wheat. Understand the farmers concerns, economics and timelines for growing these crops.
    a. You will know soil Ph levels, nutrient requirements, fertilizers, pesticides, fungicides.
    b. You will know what insects are a problem for corn in the York PA area, and how they can be dealt with.
    c. You will know planting season and times for additives.
    d. Required water levels and any other environmental issues affecting crop yield.
3. You will be the first line to interface with the Farmers who's field we fly at.
4. Interface with Waterworks employees.
5. Responsible for when we fly and where we fly.
6. This team will handle all PR events, Open Houses, College needs.
7. You will maintain all flight operations with the following:
    a. Flight logs.
    b. Flight maintenance records (Will need to work with other team for these items).
    c. Responsible for filing for waivers and insurance.
    d. Maps/Data/Records.
8. You will be responsible for flight Safety.
9. You will be responsible for Lost Aircraft Recovery.
10. You will learn how to fly drones and winged aircraft and obtain your Pilot rating with RC aircraft.
11. You will be responsible for our AMA charter.

You will help other team members as required with Autopilot, Aircraft Design, Flight Controls and Video Analysis. You will have some knowledge of all of these

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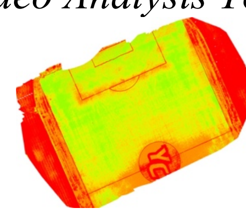
Video Analysis Team

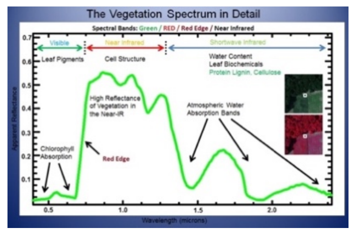


Video Analysis Team (Software, Electronics Intensive)

This team is crucial to the project in as much as it is the end product that we are trying to deliver. Therefore, this requires data analysis and software development. Some of the things that are expected from this team include:

1. Understand Analyzing images from flights NDVI and NDRE

a. Canopy coverage & density detection
b. NDVI with time provides accurate growth trending
c. Frost Damage Detection
d. Large Scale Pest Outbreaks
e. Optimizing crop rotation duration
f. Ecological Benefits
g. Vegetation dynamics or plant Phenological changes over time
h. Biomass production
i. Vegetation or land cover classification
j. Soil moisture
k. Carbon sequestration or CO2 flux



2. You will also start work on our own Video Analysis capability with our own system designed at YCP. This will include:
    a. Cameras
    b. GPS time Stamps
    c. Synchronized images
    d. Red, Green, Blue, Red Edge, Visible and Near Infrared cameras.
    e. Printed Circuit design to support same.
3. Video Camera set up. Camera Safety.
4. Work with and develop Software Pix4D/ Global Mapper and Matlab.
    a. Watch all of the Pix4D videos and document for next year best techniques, tactics and practices.
    b. Create 3D images from flight data.
    c. All things reported.
    d. Post videos and images from flights
5. Develop software to count pumpkins in field and estimate Bio Mass.
6. Understand Multispectral Analysis.
    a. Stitch Videos
    b. Analyze Data Sets
    c. Work with Agronomist if we can find one.
7. Work with RPIC to understand the modern Farm. and for PR activities.
8. You will learn how to fly drones and winged aircraft.

You will scratch build a wing aircraft and demonstrate flight with same.