# Improving Image Quality of a Color Infrared Digital Camera mounted on a Small UAV Platform: An Iterative Active Learning Experience

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## Introduction

Students from both the engineering and aviation program at the University of Maryland Eastern Shore worked in a team setting with the faculty members to advance research goals of ongoing precision agriculture efforts at the university while gaining significant experiential knowledge in the active area of remote sensing using small unmanned aerial vehicles (UAV). In the summer of 2014, the team began flying a small multi-copter, the 3DRobotics X8, with a Near-Infrared (NIR) camera, the Tetracam ADC Lite. Tetracam images obtained from flights aboard the X8 resulted in light and dark "banding”.

Investigations were undertaken to identify the cause of the image aberrations as well as to make appropriate modifications to improve image quality obtained using the multi-copter system. It is likely the image aberrations and banding effects are due to a combination of factors including rolling shutter of the camera, vibrations transmitted by the multi-copter frame to the camera mount, and orientation of the multi-copter frame during lateral motion while capturing image frames. In an effort to improve image quality, a number of troubleshooting steps were taken to minimize vibrations, isolate the camera from any remaining vibrations from the X8 frame, and capturing images only when the multi-copter is hovering at the waypoints associated with the planned mission trajectory. After each change, test flights were undertaken to determine the effect of the change on the image quality.

This paper will document the procedures used to troubleshoot the banding issue and other image aberrations and the results obtained as each modification is implemented. The paper will also document how the efforts undertaken aligned with the concrete experience, reflective observation, abstract conceptualization, and active experimentation framework of Kolb’s experiential learning paradigm. It is anticipated the paper will serve as a reference document for those experiencing similar issues with small UAV based aerial imaging efforts.

## Project based Interactive and Experiential Learning

In order to aid in the differentiation of learning activities Chi [1] proposed a taxonomy for classification of *active*, *constructive*, *interactive*. *Active* learning activities have been defined as doing something physically. *Constructive* learning activities include the overt actions of hypothesis generation, explanation and elaboration, planning and prediction of outcomes, as well as integration and synthesis of concepts. Cognitively, *constructive* activities require students to infer new knowledge, integrate new knowledge, and repair faulty knowledge. *Interactive* learning activities requires teams or partners. These include the overt and cognitive actions of responding to feedback and incorporating a partner’s contributions.

Some faculty in engineering, aviation, natural sciences and agriculture programs at University of Maryland Eastern Shore have been working together on projects related to robotics, environmental monitoring, precision agriculture and remote sensing funded by NASA and USDA. These projects are conducted by a vertically integrated team of undergraduate and graduate students representing relevant STEM disciplines. Graduate research aspects are complimented by engaging undergraduate students in experiential learning activities consistent with Kolb[2] framework in these cross-disciplinary project activities. The UAV based aerial imaging aspects described in this paper were undertaken under the auspices of these projects. Weekly meetings conducted by the project leaders provide a rich learning environment for the undergraduate participants that not only integrates the dimensions of interactive learning [1] but also involves students in concrete experiences such as the one described in this paper, reflection on these experiences during group interactions, assimilation knowledge through cognitive processes to generate abstract concepts and hypothesis that drive more concrete experiences.

Project based learning engages students in problem-solving activities and serves to facilitate the transfer of learning from one context to another[3].Diagnosis-Solution problems start with the observation of “symptoms” of an unhealthy system with the clear goal of making the system “healthy”. This may be achieved through troubleshooting in a continuous process of data collection, hypothesis generation and testing [4].

**Problem Solving Approach**

A team from the Engineering and Aviation Science Department at the University of Maryland Eastern Shore (UMES) received a Certification of Waiver or Authorization (COA) from the Federal Aviation Administration (FAA) on July 1 of 2014 to operate the 3DRobotics X8 multicopter (see Figure 1) over agricultural fields on the UMES campus.

**Figure 1: 3DRobotics X8 multicopter**


**Figure 2: TetraCam ADC-Lite**

A series of test flights were undertaken and the Tetracam ADC Lite color-infrared camera was integrated into the X8 platform. (See Figure 2).The CIR camera blocks the blue band of a regular visible camera with a filter and the sensor captures near-infrared (NIR), red, and green wavelengths of solar spectrum reflected by the imaged object. Healthy vegetation reflects all or most of the NIR light falling on it, which explains the pinkish magenta tinge of the false color composite of CIR imagery for visualization purposes. Aerial CIR imagery is used in agricultural research to ascertain crop health using indices such as normalized difference vegetation index (NDVI) [5] that can be derived from them. The first flight with the operational camera system occurred on July 10. Images acquired during this flight were initially observed to be of acceptable quality. A second flight, on July 31 resulted in images with distinct horizontal light and dark “banding” not associated with terrain or vegetative features (Figure 3). Images previously acquired via the Tetracam on board a kite-based aerial imaging platform had produced qualitatively superior images with no such banding. Upon further review, the July 10 images were found to contain the same horizontal banding, albeit less substantial.

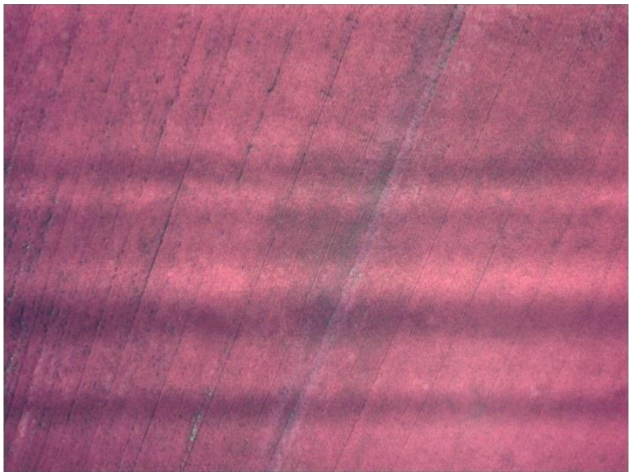

**Figure 3: Image from July 31 flight with obvious areas of horizontal banding..**

In collaborative team discussions which included Aviation Science and Engineering faculty and students, it was hypothesized that the banding effect was a manifestation of the vibrations transmitted to the imaging sensor from the multicopter frame captured at different instances of time by the rolling shutter used in the camera. The rolling shutter issue cannot be easily changed and has been observed by other researchers using similar camera system on UAVs [6]; the project team therefore decided to reduce the vibrations to improve image quality by addressing factors such as improper balancing of the propeller, improved controller tuning, and improvements in vibration isolation capability between the X8 body and camera mount. Data from the onboard flight computer (Ardupilot) demonstrated substantially greater vibrations during the July 31 flight as compared to the July 10 flight (Figures 4& 5). A series of steps were undertaken to troubleshoot and ultimately minimize or eliminate the banding phenomena. First, the team would seek to minimize vibrations created by the X8. This strategy involved the balancing of the multicopter’s propellers. Second, the team would seek to create a mount for the camera which isolated it from the vibration created by the platform.

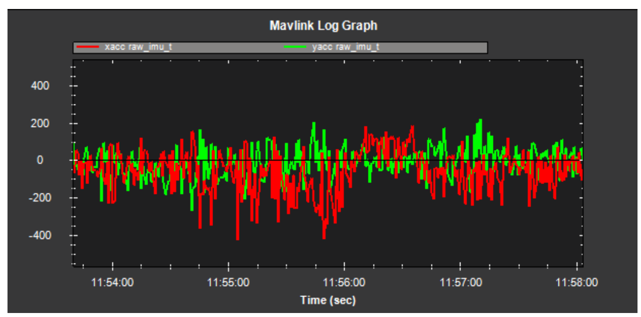


**Figure 4: x axis and y axis accelerations as recorded by onboard Ardupilot, July 10 flight**

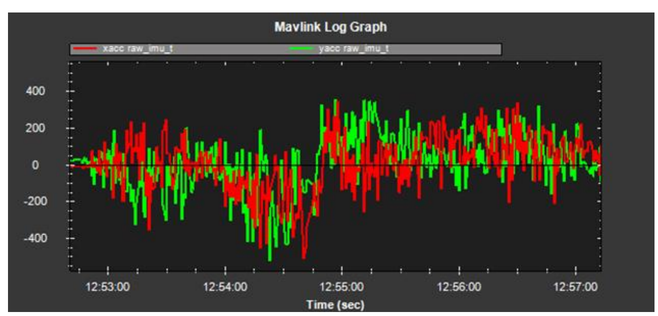


**Figure 5: x axis and y axis accelerations as recorded by onboard Ardupilot, July 31 flight**

**Propeller balancing procedure**

Using a combination of sources and media, a student team created and executed the propeller balancing procedure outlined below:

**Figure 6: The propeller balancer with a propeller mounted. The metal rod that holds the propeller is suspended by magnet on**

- Step 1: Find a flat level surface for the propeller balancer to be placed. Be sure to check the leveling of the balancer before and after installation of the propeller. Not doing this will result in a very difficult propeller balancing, in some cases not being able to balance the propeller at all.
- Step 2: Place the propeller on the metal rod, between the black cones. Each cone should have the cone tips facing inward with the propeller in the middle as seen in Figure 6. Adding the smaller diameter hub insert that is provided in each new pack of propellers might be needed for proper mounting to the rod and cones.
- Step 3: Carefully move the propeller until it is oriented vertically. Release the propeller and note the direction of fall, if any. The blade that falls is the heaviest and will be sanded down for balance. If the propeller does not move, the heavier side may already be in the down position. Turn the propeller 180 degrees until the opposite side (heavy side) is now towards the top end. If the propeller still does not move, the propeller blade area is balanced. Proceed to step 6 for hub balancing.
- Step 4: After determining which side of the propeller is the heaviest, remove the propeller from the balancer. Sand back side of the propeller with ~150 grit sand paper. Work the sanding towards the trailing edge of the propeller. Se sure to work across the entire area. Sand in small increments and check balance often to ensure that too much weight is not taken off.
- Step 5: Once the heavier side is sanded down, mount the propeller again to check its weight. Place the propeller with the side that was just sanded in the top position. If the propeller does not move, rotate the propeller 180 degrees to check the other side. If the opposite side also does not move, the blade area of the propeller is balanced. Proceed to balancing of the hub in step 6.
- Step 6: Balancing of the hub is very similar to balancing of the blade area of the propeller. Mount the propeller to the balancer as in Step 1. Adjust the propeller so that it is horizontal. Release the propeller. Note the direction of fall, which again indicates which side of the hub is heaviest. If the propeller does not move, the heaviest side of the hub is most likely already facing down. Turn the propeller 180 degrees so that the side that was down is now

facing up and the propeller is again oriented horizontally. I there is no rotation, the propeller is fully balanced. Proceed to step 8 for final balance checking.

- Step 7: Once the heaviest side of the hub is determined, dismount the propeller for sanding. Lightly sand the outside area of the hub. Remount the propeller to check balance. Repeat checking and sanding until the propeller does not move when oriented horizontally.
- Step 8: Once the propeller is balanced on each the horizontal and vertical axes, check the overall balance of the propeller. To do this, rotate the propeller in different angles starting with vertical orientation. Move the propeller 45 degrees each time. The propeller should NOT move and should stay oriented as it is placed, regardless of angle. Once the propeller can be stationary in any angle, it is now fully balanced. *NOTE* If the propeller moves in ANY position, check the balance on the horizontal and vertical axes like in the previous steps. Do this for each side of the propeller to find which area is not balanced. Once determined which area of the propeller is not balanced, wing or hub, balance that area. Always check to see if the blade area (vertical axes) of the propeller is balanced FIRST before proceeding to the hub (horizontal axes).

On August 8, subsequent to the propeller balancing, another test flight was undertaken. Acceleration data indicated that vibrations were substantially smaller in magnitude (Figure 7). It was also observed that the X8 was noticeably quieter than in previous flights. Horizontal banding was still present in the photos, but was visibly reduced. (Figure 8)

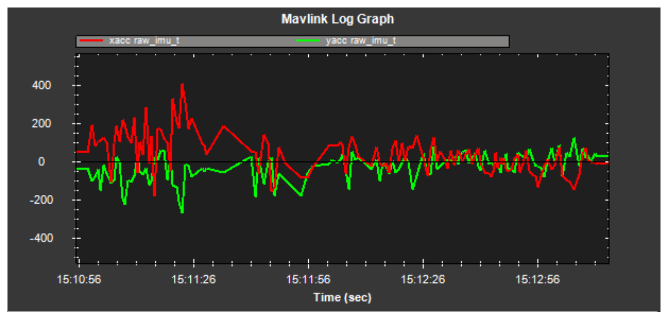


**Figure 7: x axis and y axis accelerations after propeller balancing, August 8 flight**

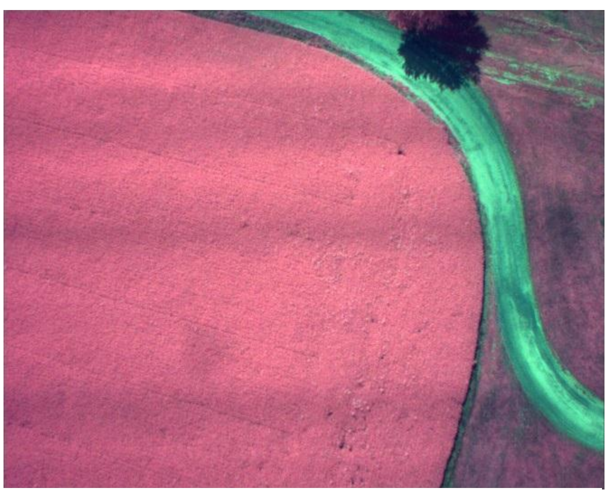

**Figure 8: Image from August 8 flight, after propeller balancing.**

Student team members undertook the task of designing a mount for the Tetracam that would serve to isolate the camera from the vibration created by the multicopter platform. The mount was built with vibration isolation material at every contact surface between the mount and the X8 as well as between the mount and the camera (Figure 9). The additional weight and new location of the camera required that a weight and balance calculation be completed. Subsequent to the build and installation of the mount a test flight was completed on September 18. Minor banding was visible in a few images. (Figure 10)

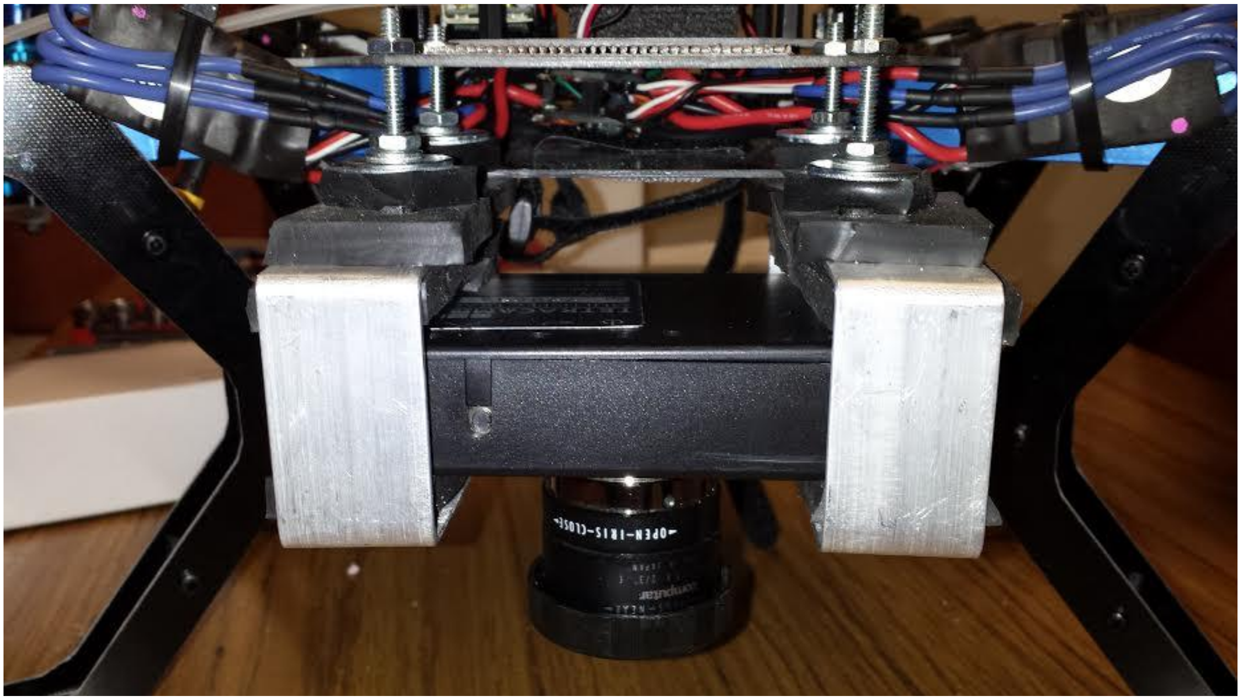

**Figure 9: Student designed and built mount to attach the Tetracam ADC Lite to the 3DRobotics X8. The mount is intended to isolate the camera from some of the vibration created by the multicopter.**

It may be noted here that for generating the thrust for the lateral movement the multicopter frame has to tilt to generate appropriate force components in the lateral direction, as such if the images are acquired from a Quad or Octocopter while it is moving laterally the orientation of the frame can induce aberrations in the image. However, if the UAV was made to hover when capturing an image at a way point the quality deterioration due to frame orientation may well be eliminated. Keeping this in mind the project team proceeded to design a circuit that would trigger a relay when a way point is reached to ensure that the platform stops moving laterally and hovers when the images were taken. This effort and its results are pending.

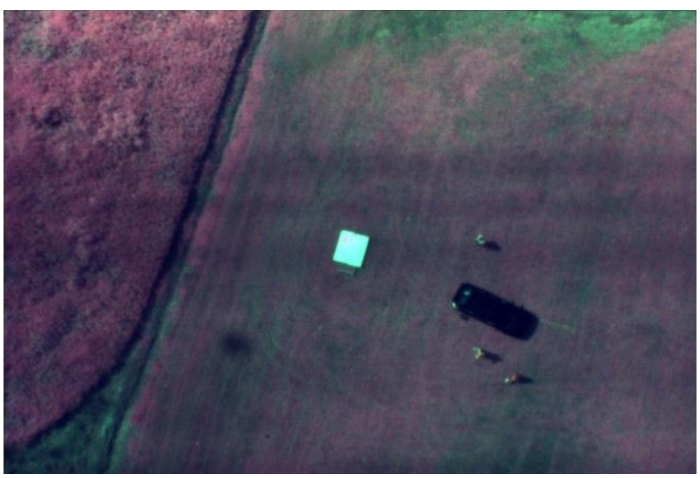

**Figure 10: Image from September 18 flight, with new student- built vibration isolation camera mount.**

## Learning, Development, and Assessment Framework

Consistent with ABET outcome which requires engineering students to work effectively in multidisciplinary teams[7], selected undergraduate students are invited to participate in project team meetings related to ongoing cross disciplinary projects led by graduate students and faculty members in engineering, environmental sciences, agriculture, and aviation programs at UMES. Besides aerial imaging and remote sensing with UAVs and other platforms several other efforts related to agricultural automation, instrumentation and data-logging for Integrated Multi-trophic Aquaculture(IMTA), and automation for environmental monitoring using Unmanned Surface Vessels (USV), and UAV based remote sensing are discussed. The exposure provides a rich learning environment for the students.

The following learning outcomes have been identified from your experiential learning activity. Answer 1-5 according the scale key : category. Elaborate wherever is necessary. Your inputs will be highly appreciated.

1. Strongly disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly agree

**A. Academic outcomes from the project**

| | |
|---|---|
| **The objectives of this project were consistent with my research interests** | ——1——2——3——4——5—— |
| **This experiential learning activity had an impact on my hands-on/laboratory skills and data collecting skills Which one(s) in particular?** | ——1——2——3——4——5—— |
| **This activity had an impact my presentation skills Which ones(s) in particular?** | ——1——2——3——4——5—— |
| **This activity developed my technical skills** | ——1——2——3——4——5—— |
| **This activity enhanced my content knowledge?** | ——1——2——3——4——5—— |
| **I was able to integrate knowledge from many different sources and disciplines (example, chemistry, biology, engineering, technology, computer science, environmental sciences, etc)** | ——1——2——3——4——5—— |

**B. Life Skills Outcomes**

| | |
|---|---|
| **This project had an impact on my critical thinking skills?** | ——1——2——3——4——5—— |
| **This activity improved my ability to work in teams and resolve conflicts?** | ——1——2——3——4——5—— |

**C. Civic Responsibility Outcomes**

| | |
|---|---|
| **This experiential learning activity provided benefits to the community? In what capacity?** | ——1——2——3——4——5—— |
| **My appreciation for integrated STEM (Science, Technology, Engineering, and Mathematics) research grown?** | ——1——2——3——4——5—— |


**Figure 11: Student Survey Instrument and Assessment Data**

Undergraduate students working in the UAV based remote sensing project reported here are required to present their progress, share and reflect on their experiences, and get feedback to troubleshoot problems to progress towards the goal through active experimentation, during the weekly meetings. Engineers and Scientists from USDA and NASA who collaborate with the project leaders are invited to these meetings to attend when convenient. The cross disciplinary framework and active participation of professional researchers from federal agencies provide a rich learning experience for the participants [8].

The students participating in these multidisciplinary team projects are surveyed at the end of every semester to assess the impact the exposure is having on some of the desired academic, life-skills, and civic responsibility outcomes using the survey instrument provided in Figure: 11. The bar graphs corresponding to the results of the survey conducted at the end of 2014 fall semester are also shown. The survey results indicate that the students perceive the project experience to be valuable. No attempt has been made here to separate the surveys for the students participating in different projects that are discussed as a team in the cross disciplinary project meetings. As a result, the responses with regard to question C4, “This project enhanced my technical skills”, may not be an accurate reflection of the students on this project. Future surveys will identify the project and make links to particular student reported outcomes. However, anecdotal evidence and informal discussions with the students involved in this project revealed, that besides other tangible benefits, the project experience provided an avenue for dialog during job interviews.  The deliberations helped the students to create a positive impression with the interviewer which may have helped with their selection.

## Future Work

While the circuit for triggering the camera shutter has been completed and integrated into the Ardupilot, no test flights have yet been undertaken. A second-generation camera mount, which provides more space for camera activation has already been installed. This mount incorporates the same vibration dampening material as the first. A third-generation camera mount, which uses a cable suspension structure and 3D printed parts is in the design phase. The authors plan to describe the results of these steps in a future paper.

Concurrent with the efforts detailed in this paper, the 3DRobotics X8 and Tetracam were used to image a 2-acre experimental plot. Waypoints were carefully chosen in Mission Planner, with the goal of covering the entire split plot experiment with a series of mosaicked images. (Figure 12) The experimental design involved six levels of nitrogen fertilizer applied to two different varieties of corn seeds [9]. Processed NDVI image show clear variations in crop reflectance patterns due to varying nitrogen levels. (Figure 13) It is anticipated subsequent to improvements outlined in this paper, the remote sensing data obtained from the UAV-CIR camera platform will also be enhanced.

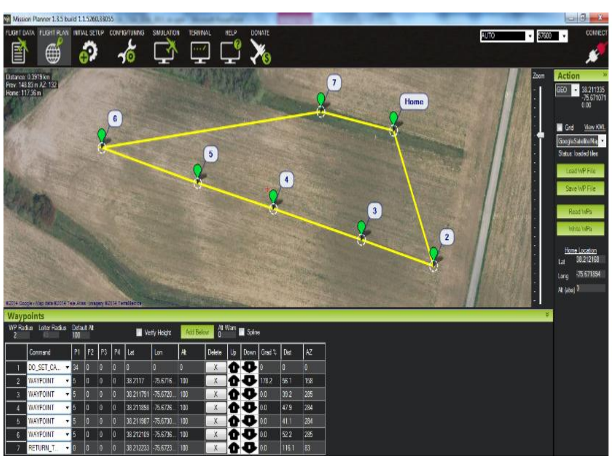


**Figure 12: Mission Planner flight plan for imaging of 2 acre experimental field.**

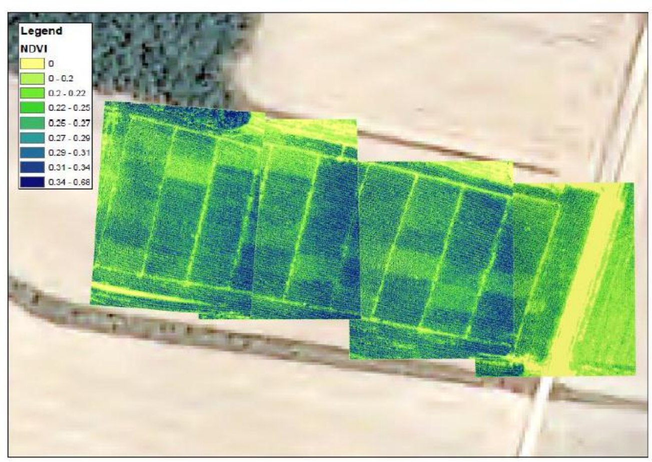


**Figure 13: Mosaic of images NDVI post-processed captured during June 10 flights by the Tetracam onboard 3DRobotics X8 multicopter.**

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