Drone ecology on a budget

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INTRODUCTION

There is little doubt that aerial photos are high in value for research, but this value comes at a great cost. Aerial surveys conducted with full-scale aircraft, manned by pilots and technicians, are extremely expensive. They also require a closely located airport, and a pilot that is willing to fly at a moment’s notice. Small Unmanned Aerial Systems (sUAS), by contrast can be on site within moments, and their acquisition costs are less than the cost of just one full-scale aerial survey. With the recent invention and proliferation of consumer grade sUAS’s, that cost less than $2000, these limitations have been reduced. sUAS’s are limited in their own ways. They have relatively low weight carrying capability, which reduces the quality of equipment they can carry. Given these limitations, the actual value of sUAS’s in research requires further study. The goals of the experiments conducted between 26 May and 1 August 2015 at the Biological Field Station (BFS) were to help determine this value.

Using Drones to collect research data is not a new practice. There have been studies conducted in other fields of conservation, such as animal population surveys, and forestry land use monitoring. In 2012 Koh and Wich (2012) performed a series of experiments in Indonesia using a <$2000 fixed wing drone to study human land use change, and to consider the application of low cost uav’s for the purpose of wildlife survey. They reported the following results:

In the images acquired during our transect mission, we could easily distinguish different land uses, including oil palm plantations … maize fields …, human habitation …, forests …logged areas …and forest trails …These geo-tagged photographs and the flight paths of each mission could also be superimposed on Google Earth …, which allows for easy visualization of the location of features of interest from the photographs.

Using commercially available software … we produced geo-referenced mosaics from these aerial photographs … These mosaics are essentially near real-time land use/ cover maps, which could be useful for local conservation workers seeking to monitor land-use change and illegal forest activities. An example is the mosaic produced from our grid mission, which is overlaid on a Landsat-based land use/ cover map … The pixel resolution of our mosaic (5.1 cm) is 600

1 Otsego County Conservation Association intern, 2015. Department of Geography, SUNY Oneonta. Funding provided by the Otsego County Conservation Association.

Funding for the drone and accessories was provided by the Otsego Lake Association.
times higher than that of the Landsat-based map (30 m). “ (Koh and Wich 2012).

Understanding what use this technology is to the research ecologist at the BFS requires quantifying the output of these surveys. Since much of the work done at the BFS falls under the categories of continued monitoring, and education, it stands that the output from aerial survey would have to be something capable of mapping interests on the ground, while also applying time signature to this data. For example: If one wanted to monitor the spread of an aquatic invasive species over the course of a growing season, one could use the sUAS to map its distribution on a weekly basis, but only if they had an acute awareness of when the basemap had been made. The sUAS allows us to construct our own base maps with total documentation of the date/time of acquisition. Many researchers believe that this practice is going to become standard operating procedure in the near future. According to Anderson and Gaston (2013),

“Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Ecologists require spatially explicit data to relate structure to function. To date, heavy reliance has been placed on obtaining such data from remote-sensing instruments mounted on spacecraft or manned aircraft, although the spatial and temporal resolutions of the data are often not suited to local-scale ecological investigations. Recent technological innovations have led to an upsurge in the availability of unmanned aerial vehicles (UAVs) – aircraft remotely operated from the ground – and there are now many lightweight UAVs on offer at reasonable costs. Flying low and slow, UAVs offer ecologists new opportunities for scale-appropriate measurements of ecological phenomena. Equipped with capable sensors, UAVs can deliver fine spatial resolution data at temporal resolutions defined by the end user. Recent innovations in UAV platform design have been accompanied by improvements in navigation and the miniaturization of measurement technologies, allowing the study of individual organisms and their spatiotemporal dynamics at close range.” -- (Anderson, Gaston 2013)

In March of 2015, I learned that the Biological Field Station had received funding to purchase a drone. I immediately responded by submitting an application for summer internship. I have several years of experience building, designing, and operating drones, so I was a good fit for the position. Understanding what use this technology is to the research ecologist at the Biological Field Station (BFS) requires quantifying the output of these surveys. The logical first step of my experiments with the BFS this summer was to determine exactly what it was the drone could do, and what value its deliverables could possibly add to research. To do so I conducted a series of evaluations for each of the following deliverables: photomosaics, orthomosaics, and video footage.

My first task was to select a drone that would be suitable for the type of research performed at the field station. Given the tight budgetary constraints and the richness of capability that was needed for the drone to be of any research value, I endorsed the purchase of a consumer grade drone from a company named 3D Robotics. For around $2000, I was able to put together a package for them that included: 1 Iris+ drone, a GoPro hero4 capable of 1080p video at 60fps, a
3DR/Tarot 2D brushless gimbal stabilization system, a Black pearl combination diversity receiver and video monitor, and several redundant support items including spare batteries and propellers. All of this came with a large waterproof gear case with custom foam insert, which has proven essential for transporting the drone and all of its support gear to various field locations including operations on the lake from motorboats. All of this was acquired for roughly $2000 USD, which was approximately %50 over the budget they originally outlined to me. An ancillary purchase was a 16mp Canon a2400 powershot digital camera, which was converted to a mapping camera using the CHDK script. The CHDK scripts, or Canon Hacker Development Kit is open source software project that in the words of CHDK developers:

“… enhances the capabilities of your camera in a non-destructive, non-permanent way.” (CHDK 2015)

The reason for this was to enable our mapping camera to be remotely triggered by the autopilot. In order to mount the mapping camera to the drone it was necessary for me to design a camera holder that worked with the existing hardware mounts on the Iris. Since nothing was available from any commercial sources, I opted to design one using a 3d part-modeling program called SolidWorks. (http://www.solidworks.com/). By reverse engineering the existing GoPro system mount on the front of the Iris, a case was created that neatly fits the cannon while also easily attaching to any “two tabbed” GoPro accessory mount. The designed part files were then sent to Allan Anderson, who is the scientific technician for the Science division of SUNY Oneonta. He then printed these parts in his 3D printer. An additional piece of equipment required for aerial mapping was a remote camera trigger that allowed the autopilot to trip the camera shutter at key locations. This item was built by myself using the instructions available in a YouTube video titled: Trigger Canon SX260HS with CHDK Using PIXHAWK or APM posted January 16th 2015 by user: TechnoSys Embedded Systems. (TSES 2015) I donated the materials and equipment required to make the camera trigger.

My decision to purchase the Iris+ from 3DR was informed by past experience with the Iris’s flight controller. The Pixhawk flight controller is a product of 3DR, https://store.3drobotics.com/products/3dr-pixhawk (3DR 2015). Considerable time has been spent perfecting hardware that runs the ardupilot flight controller code. Ardupilot is a flight controller code that has been developed by an open source community and is available to anyone. According to the Ardupilot website:

“[Ardupilot is] A constantly evolving repository of knowledge and innovation.

The DIY Drones community provides the life-source and inspiration for Ardupilot. A comprehensive list of features that are continually born from the needs of the community.” - (Ardupilot 2015)

This is an open source flight controller product that has been a staple for autonomous flight researchers as it is a very capable autopilot that costs a fraction of what some other
autopilots with fewer capabilities have. The ardupilot firmware allows the usage of several different ground station solutions on either the windows or android platform. This enables the operator to perform lawnmower-pattern survey missions, which are essential for aerial survey. The Lawnmower pattern survey grid is the item of most interest to us at the BFS.

The logical first step of my experiments with the BFS this summer was to determine exactly what it was the drone could do, and what value its deliverables could possibly add to research. To do so I conducted a series of evaluations for each of the following deliverables: Photomosaics, which are unreferenced images of an area. These are constructed by tiling together a number of photographs obtained from different camera positions. Adjustments to these photographs are required to make them fit together; these adjustments and distortions rule out the photomosaics use as a measuring device. Orthomosaics are similarly constructed of multiple photos taken from different camera positions, but they have the extra step of producing a 3d model using photogrammetry. This extra step enabled the image to be a true 90° projection from the subject to the datum plane. This process results in photographs where distances can be measured. Geo-referencing orthomosaics enables them to be used in conjunction with existing USGS spatial data. To do so one must establish accurate ground control points. Lastly, experiments were conducted to ascertain the value of aerial video footage for research.

**Evaluation Series #1 Photo-Mosaics Method**

This series of experiments was conducted to determine which method of acquiring photographs for photomosaics produced the best results. In experiment #1 I flew several missions collecting only GoPro video footage. Later in post-processing I used QuickTime to export stills from that video at timed intervals. I then used Adobe Photoshop to merge those together. In the Second Experiment, I used the Canon A2400 Mapping Camera running a CHDK intervalometer script which simply snapped one picture every second for the duration of the flight. For the third experiment, I used the mapping camera and the remote camera trigger in conjunction with the Mission Planner flight planning software to fly a precise scanning ground track while assuring uniform overlap in photographs.

Experiment #1: Still images from video: Extracting frames from GoPro footage, obtained while flying video recon at Shadow Brook Inlet on 06-15-2015. These derived photos were then fed through Adobe Photoshop cc’s “photomerge” automation.

Experiment #2: Pilot controlled scan pattern/intermittent camera shutter at 1 sec interval: This Experiment was conducted on 1 July 2015 at Hayden Creek. The drone was set up with the mapping camera only. The drone was then flown in loiter mode in a pilot controlled approximation of a scanning pattern. The purpose of this experiment was to determine the reliability of data collected with little to know mission pre-planning. This condition mimics the use-case-scenario that is often found on the site of a suspected plume event.

Experiment #3: Autonomous photo collection with 65% overlap (every other photograph discarded to simulate %25 overlap). These experiments were conducted at three different locations on 9 July 2015: Hayden Creek, Rat Cove, and Shadow Brook. The survey patterns
were created on a laptop in the field. This method was used at these locations for the purpose of establishing baseline control representative of a “no suspended sediment condition”.

The results of each of these three methods were imported into Google Earth, where they were stretched, rotated, or distorted to fit into the Google basemap. Each method was evaluated individually based on how easy it was to make them fit the Google basemap, and how completely they were able to be fit to the Google basemap.

Hypothesis to be tested: The fewer steps required to fit a photomosaic into the Google Earth basemap, the more accurate the method.

Evaluation Series #1 Photo-Mosaics Results

Experiment #1: Still images from video

Resulted in vignette free, tiled photograph that provided a larger overview of the 15 June 2015 Shadow Brook sediment plume. The images obtained were incredibly distorted; because of extreme un-rectified barrel distortion, and lack of geo-referencing, these images serve little measurable purpose (See illustration 1).
Illustration 1: Photomosaic created using extracted stills from GoPro video footage. Shadow Brook inlet, Lake Otsego, NY15 June 2015

Experiment #2: Pilot controlled scan pattern/intermittent camera shutter at 1 sec interval: The photomosaic produced during this experiment produced a decent overlay that was then compared to a baseline survey conducted later (Illustration 2). The mosaic provided a clear visual indication that conditions on the day of that survey were different than those conditions on the day of the baseline survey; however, since they are not ortho-rectified or georeferenced, they lacked measurability.
Illustration 2: Comparison of Photomosaic areas to Orthomosaic areas: Underlay is a Photomosaic that was created for the purpose of establishing a baseline of a non-sediment condition. Later, the same group of photos was used to create an unreferenced ortho mosaic. The lines in this illustration show the difference between placement of identifiable features in the photomosaic, and the orthomosaic. The heavy solid line represents the ortho rectified image, and the dashed-dot line represents the same identifiable objects as they are shown in the photomosaic. Note that the difference in placement of these features is non-liner.
Experiment #3: Autonomous photo collection with 25% overlap. The photomosaics that came out of this survey are by far more accurate, less distorted and more usable than the previous two experiments. These required the least amount of modification to fit into the Google Earth terrain imagery. Since they lack georeferenced ground targets, area measurements taken from photomosaics using this process would be good for estimation purposes only (See Illustration 3).

Illustration 3: Autonomous photos collected with 25% overlap.

Evaluation Series #1 Photo-Mosaics Discussion

Un-referenced photo-mosaics may at first sound like a waste of time for their lack of measurable date, but they do have certain applications that make them attractive. In cases where it is not possible to place the GPC required for ortho-rectified images, the simpler Photo-mosaic is a good alternative. Mosaics can help by showing areas of coverage that are too wide to capture with a single image, and they can, with some work, be fit into Google Earth for the purpose of illustrating change. Making them requires much less expensive software, and in most cases they can be produced within an hour of the flight in which they were captured, versus the four hours or more that it takes to construct an Ortho-rectified image.

Experiment #1: Extracting stills from video. Though this method produces the most distorted mosaics, it is still of some value because it makes it possible to image a large area using only the initial reconnaissance video as a source of images. In some cases this may be a necessary step in order to justify a full blown survey of an area of interest.

Experiment #2: Intermittent photography using mapping camera, while flying a crude lawnmower pattern: This process produced decent enough results for my purposes, and the setup time was very short. This is a completely usable method when the object of the survey is to simply image a large area as quickly as possible. This method is very useful for obtaining a
decent aerial survey when ground prep time is too limited to facilitate establishing and executing a survey pattern.

Experiment #3: Mapping camera remote triggered, and autonomous mapping flight plan: this method requires the most setup, but also delivers the best results. This is my preferred method when time allows not only because the photomosaics that are produced by this method are superior in every way, but also because it enables making an un-referenced ortho and 3d models at a later time if it is done with sufficient photographic overlap.

Evaluation Series #1 Photo-Mosaics Conclusion:

The best way to obtain photomosaic is to establish a survey and use the mapping camera trigger to assure consistent overlap. The overlap required for a photomosaic is less than that required for an ortho-mosaic. Overlap should be adjusted to no more than 25% since the requirements of mosaics are less than that of ortho rectification, and few photographs mean longer flight times. However, if the flight is conducted to provide ≥60 overlap, then that group of photos can be used to also construct a 3D model and Ortho-mosaic as we will discover in the next section.

The true value of the photomosaic over the ortho-mosaic is the ability to launch and complete a mission in shorter time, and also with greater coverage per flight battery. The fewer photographs that are required to capture an area the faster the drone can maneuver over that area. This means that the drone can cover a bigger area at a lower altitude. As altitude decreases resolution increases. In cases where a large area photograph is all that is needed, the ≥25 overlap method of data acquisition is recommended.

Evaluation Series #2 Ortho-Mosaics Methods

Ortho-Mosaics or orthogonal projection is a two-dimensional graphic representation of an object in which every point on the landscape is projected at right angles to a theoretical datum plane. A true orthograph will not have any error of parallax, nor will it have any linear distortions. Ortho-mosaics require an additional software step in post processing. That software step relies on a process called photogrammetry, to facilitate the building of a 3 dimensional model. This process would take several academic papers to sufficiently explain, so for the purpose of this paper I will only paraphrase. Photogrammetry is a process where by depth can be determined by comparing the apparent locations of items appearing in two or more photographs taken from different camera locations. The following excerpt from the website found at: www.geodetic.com, which outlines the process further.
“The fundamental principle used by photogrammetry is triangulation. By taking photographs from at least two different locations, so-called "lines of sight" can be developed from each camera to points on the object. These lines of sight (sometimes called rays owing to their optical nature) are mathematically intersected to produce the 3-dimensional coordinates of the points of interest. Triangulation is also the principle used by theodolites for coordinate measurement. If you are familiar with these instruments, you will find many similarities (and some differences) between photogrammetry and theodolites. Even closer to home, triangulation is also the way your two eyes work together to gauge distance (called depth perception).” (Geodetic 2015)

As mentioned earlier, the drone can be used to collect a photographic scan of an area with controlled overlap. These photos are then fed through a photogrammetry program (AgisSoft Photo Scan) to produce a 3D model from which an orthorectified image can be generated. In order to give meaning to this orthograph, we also need to include geographic data so that the photo can be imported into GIS software packages such as ArcGIS or Global Mapper. Once our models have been imported, very accurate area measurements can be derived from them. In order to make this all work a reliable source of Ground Control is required.

Ground Control Points or (GCP) are items that are located on the ground in an area of interest. These can include targets that were placed for this purpose, or it can be permanent features of the landscape that are easy to locate in the photo data set. Whatever object is chosen for GCP, the same principles apply. GCP must have the following characteristics: It must be easy to see in several of the photographs for any given survey data set. It must have a unique and accurate position associated with it, i.e. latitude, longitude, elevation. It must remain static throughout the process of surveying. And there must be a minimum of three ground control points per survey.

The intent of this study is to inform our expectations for modeling precision given the variability of different methods of locating GCP’s.

Two different types of experiments were used here.

Experiment #:1 Orthography without GCP
Since the photographs there were obtained on 9 July 2015 at various locations around Otsego Lake, and were obtained in a manner consistent with mapping survey, with the exception of laying down GCP, I decided it was prudent to post process these in the same manner as any other photogrammetric survey omitting the step of locating GCP. The idea here is to test the theory that Orthography is more or less useless without reliable GCP.

Experiment #2: Orthography with GCP
All Orthomosaics were obtained using the same method of sUAS survey. A gridded survey pattern was created and flown, using the Mission Planner software. The drone was commanded to fly a lawnmower pattern over the subject area maintaining the same heading and altitude throughout the mission. The autopilot was told to execute a script that instructed the camera to trigger remotely based on the location of the drone. These shooting locations are determined in the software in order to assure the required photographic overlap for the mission is
being met. In the case of orthomosaics, that overlap is %60 minimum. Photogrammetry is then used to construct 3D models of the subject area. Agisoft PhotoScan Professional Edition, Version 1.1.6 Build 2038 (64bit), is the software that was used to perform this task.

The workflow of this software is as follows:

1. Import group of images collected during survey
2. Compute pairwise matches between the images (generate sparse point cloud)
   Intermediate steps:
   - Identify GCP’s in photos
   - Import geodetic locations for GCP’s
3. Generate Dense Point Cloud
   Settings to High
4. Generate Mesh
   Settings to High
5. Generate Texture
   Projection to “heightfield”
   Vertexes to “high”
6. Export Orthophoto

There are several options for this, but the two that I concerned myself with for these experiments were: Ortho-rectified geo tiff, which will fit into a GIS application in the correct location, assuming the GCP is properly located, & Ortho-rectified.PNG for publication.

The following three methods were used to locate GCP in the WGS84 geodetic datum. The coordinate system used for these studies is UTM *Universal Transverse Mercator*. All of these test cases were conducted in UTM zone 18N.

Method 1: Total Station / DGPS located Ground Control Points. Post processed to sub-centimeter resolution and adjusted for the ellipsoid height. GCP’s consisted of fluorescent orange compact disks held in place with a dimple headed surveyor’s nail. Later tests were conducted using two Home Depot yardsticks that had been painted white, a hole drilled in the center, and a dimple headed cabin spike driven through two of them to make a white cross on the ground. The GCP were placed in the field where they were located relative to each other using a total station. The position of the total station and local network of points was then tied into the geodetic datum by means of two differential GPS receivers that took averaged readings for the duration of each survey. The data collected from the DGPS receivers was then post processed using a combination of *Spectral Precision’s* GNSS software and data from the existing network of CORS stations operating within this region.

Method 2: Consumer Grade GPS placed on top of existing ground references. Consumer GPS for this study is a Garmin Etrex20 which has the ability to “average” a waypoint. All of the GCPs in this study where put through such a process until the GPS unit reported 100% certainty. These points were then entered into the software in exactly the same way as the Differential GPS points from step 1.

Method 3: Photo derived (incidental) Coordinates: Identifying items in the subject photographs that are recognizable in corresponding orthographic photos available through the
USGS database. Northing, Easting, and Elevation Data for these identifiable ground features are derived after loading these georeferenced images into a GIS application called Global Mapper. The resulting coordinates are then written into a spreadsheet and imported into Photoscan where they are then applied as GCP to the corresponding features in the model/survey photographs. Examples of these features are: manholes, parking lot lines, corners of pavement, etc.

**Evaluation Series #2 Ortho-Mosaics Results**

Experiment #1 Orthography without GCP: The resulting Orthography was neatly rectified, and showed signs of being measurable; however, the scale, placement, and rotation are not verifiable. Once these photos had been placed in Google Earth and manually manipulated to fit, the results were somewhat measurable. Though this process would be useful for providing extremely estimated area measurements of new events, it would not be very optimal for measuring change over time, because it is not possible to certify any of the locations without conducting a proper field survey. The following photographs are a result of applying ortho-mosaic building techniques to the same photographs obtained during the control surveys conducted at three different locations on 9 July 2015: Hayden Creek, Rat Cove, and Shadow Brook (see Illustrations 2&4).

![Illustration 4: Ortho rectified images from Hayden Creek, Rat Cove, and Shadow Brook. Created with the same images used for the photomosaics shown in illustration 3.](image)

Experiment #2 Orthography with GCP: Results were as variable as the methods of ground control used. For the Photo CD’s and the yard sticks the results were very good; these surveys produced ortho-rectified and geo-referenced photographs that had horizontal accuracy at the sub-decimeter level. This is a conservative figure; actual results are closer to 1.5 cm. For the other methods of approximating GCP the results were not as favorable. The GCP placed using consumer grade GPS devices yielded 5-meter discrepancies for horizontal position, and no correlation at all in the vertical. The results of the photo-derived coordinates were even worse, producing orthophotos and models that were less accurate than un-rectified Photomosaics by hand.
Illustration 5: Ortho-Rectified, and georeferenced .tiff of the wastewater polishing wetland located south of Cooperstown, NY.
Illustration 7: Geomorphological study of cut-bank migration. Conducted 2 July 2015 at the Wheeler Field Bend on Butternut Creek, UTM 4707300.70 m N, 478369.04 m E, 18T.
Comparisons of the channel location over time

Illustration 8: Vertical Profile of Transect through 3D photogrammetric model of Wheeler Field Bend, Butternut Creek: Showing a comparison between the vegetated surface model created by Hasbargen, Booth, Busby, (2015), and the USGS “bare earth” model created using lidar in 2007. The Model clearly shows terrain match, as well as area of lost cutbank (dashed line).

Evaluation Series #2 Ortho-Mosaics Discussions:

Experiment #1 Orthography without GCP: the main difference between an un-referenced Ortho-mosaic and a photo-mosaic is that the ortho mosaic can be scaled, rotated, and manually inserted with relative ease into a GIS application. Though the manual placement somehow cheapens the value of measurements obtained from this type of deliverable, the errors appear more linear and therefore correctable. In situations where it is not possible or practical to place GCP, the un-referenced ortho-mosaic runs a close second to its fully referenced brother.

Experiment #2 Orthography with GCP:

Though I was able to produce highly precise results using terrestrial ground survey methods that located the GCP at sub-centimeter precision, the equipment and intellectual requirements for placing this GCP makes this process inaccessible to most researchers in this field. Of the alternative methods that I have explored, all produced results that were simply too un-precise and variable to be relied upon for data.
Evaluation Series #2 Ortho-Mosaics Conclusion:

Evaluation Series #2 Ortho-Mosaics: The ortho-mosaic is by far the most valuable product in terms of delivering usable data. With this process there is near limitless application for time base studies of anything having to do with area measurements. Just a few examples that leap to mind are: The study of open water areas before and after major storm events, distributions of invasive aquatics before and after mitigation efforts, or the spread of nitrogen fixing plant species in a mitigation area. This is just to name a few, and I am sure time will expose even more uses. One drawback to the Ortho-rectified image is that it requires a lot of “front end” work. By this I refer primarily to the difficult task of setting reliable ground control points. The results of all experiments conducted using methods other than traditional terrestrial survey are unreliable. It is necessary to find another solution for locating GCP. One possible solution is to build permanent survey points that can serve this purpose for subject areas that are to be repetitively surveyed. Another possible solution which I have not had the chance to test, is to obtain a “mapping grade” GPS. These devices are capable of sub-decimeter precision, and they cost a fraction of what a total station, and two differential GPS units would cost.

Evaluation Series #2 HD Video Methods

Video: All video experiments were conducted with the drone outfitted in aerial video gear. That gear list includes: an HD GoPro camera recording at a resolution of 1080p at 60 frames per second, a video transmitter broadcasting a 5.8hz signal at 800mW, and a combination diversity video receiver/monitor. This apparatus allows for the drone operator to see a real-time video feed from the GoPro mounted on the drone. The Video signal resolution is degraded down to 480x640.

Experiment #1 Pilot controlled video: Innumerable flight experiments have been conducted in this fashion. The method is to simply fly around an area using the video screen to “have a look around”. While conducting this type of mission there are two options. The first is to record video only, the second is to record video and still images simultaneously. This is accomplished with settings in the GoPro itself.

Experiment #2 Pilot Controlled/Free Flight: These experiments were conducted in the same way as the previous experiments, with the addition of putting the drone in stabilize mode and allowing it to float downwind in a stabilized fashion. These experiments were conducted throughout the internship mostly in wide-open spaces like those found at Thayer farm.

Experiment #3 Autopilot controlled flight. This experiment was conducted with two different variables. In the first experiment the drone was instructed to fly straight line paths while the camera filmed. In the second experiment the drone was instructed to fly along a “splined curve”. The purpose of these experiments was to determine the best way to obtain smooth video of a subject that twists and turns. Using the example of a riparian corridor, one experiment was conducted flying a mission path in line segments, and another in splines. Although this
experiment was designed to evaluate a method for flying riparian corridors, the actual experiment was conducted over Moe pond on 20 July 2015 in conjunction with an electro-fishing survey that was being conducted on that date.

Experiment #4 Pilot controlled from moving platform. The previous experiments in this series were conducted from static ground locations. Differently, in this experiment I operated the drone from a mobile platform (motorboat). The purpose of this experiment was to evaluate the difficulty level and feasibility of conducting such flights. This experiment was conducted at Moe Pond on 22 July 2015 during an electro-fishing survey.

**Evaluation Series #2 HD Video Results**

Experiment #1: Pilot controlled video: The results of these experiments are varied; factors such as wind speed, and lighting greatly affect the outcome of these videos. This series of experiments did expose a technical issue with the gimbal, which results in the gimbal periodically flopping over and struggling to right itself to the horizontal. All feasible attempts were made to rectify this situation including: making adjustments to the gimbal settings, and adding counterweights to the gimbal itself to accommodate for a shift in weight distribution that occurred between the GoPro 3 series that the gimbal was designed for, and the GoPro 4 series. The results of this tampering appear to be favorable so far.

Experiment #2: Pilot Controlled/Free Flight. This experiment was designed to ascertain if the flying style of the drone was contributing to the gimbal stability issues. Since the gimbal issue seemed more pronounce when the drone was stationary in high winds, or if the drone was flying quickly in one direction, I reasoned that the problem might be exacerbated by airflow around the camera itself. Since “stabilize” mode holds the drone nice and level while leaving it free to drift away with the wind, the drone will then be in a 0 relative wind condition. I reasoned that this would expose the camera gimbal’s tendencies in a 0 wind condition. The results are quite favorable as seen in the video: /BFS DRONE /VIDEO/GoProVideo/2015-06-11/GOPR0560.MP4 between time marker 6:20 and 6:28 the drone is performing this maneuver and the gimbal is stable.

Experiment #3: Autopilot controlled flight: The test case footage for this can be found at: BFS DRONE /VIDEO/GoProVideo/2015-07-20/GOPR2007.MP4 between the time marker 6:10 and 7:40. This experiment was inconclusive, and further study is needed.

Experiment #4: Pilot controlled from moving platform: video of this experiment can be found at: BFS DRONE /VIDEO/GoProVideo/2015-07-22/GOPR2011.MP4. This experiment was successful. This method worked well for collecting informative and interesting images.
Evaluation Series #2 HD Video Discussion:

The research applications for aerial video are still questionable, although I have reason to explore this as an option more in the future. As can be seen in my time study of the Willow Brook sediment plume there are things that can be seen using these techniques that are not macroscopic in the human time frame. It has been my experience that anything that exposes a new perspective must have research value.

Evaluation Series #2 HD Video Conclusion

Experiment #1 Pilot controlled video: This is a staple for recon; it is the perfect method for quickly deploying a reconnaissance flight. This process is essential for gathering spatial information relative to setting up a successful autonomous mission later. The recon flight offers information such as minimum obstacle clearance altitudes, or environmental factors that may affect autonomous flight.

Experiment #2 Pilot Controlled/Free Flight: This is a good method for collecting long stable aerial tracking shots. The research value of these shots is questionable, but they do lend themselves well for inclusion in documentary films and process documentation.

Experiment #3 Autopilot controlled flight: Further study is required to formulate any strong conclusions for this method.

Experiment #4: Controlling drone from moving platform: Even as a seasoned drone pilot, the initial disorientation of flying from a moving platform while looking up into the sky at a drone required some adjustment. I do not recommend using this technique until one has become a very confident pilot. Once an operator becomes confident with this method of flight, the resulting shots can be quite exciting.

Final Recommendation

At the time of this writing I have learned that the FAA has prohibited drones for commercial use of any kind. As to whether or not this applies to the kind of not-for-profit research conducted this summer, I cannot say. The FAA has a protocol for Public organizations to obtain the authorization to fly drones for research purposes. Details on how to obtain this authorization can be found on this website: https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aim/organizations/uas/coa/

The Certificate of Waiver Authorization is defined by the FAA as follows:

“COA is an authorization issued by the Air Traffic Organization to a public operator for a specific UA activity. After a complete application is submitted, FAA conducts a comprehensive operational and technical review. If necessary, provisions or limitations may be imposed as part of the approval to ensure the
UA can operate safely with other airspace users. In most cases, FAA will provide a formal response within 60 days from the time a completed application is submitted.” - (FAA 2015)

I recommend that the BFS begin the process of obtaining this waiver before any future drone related research is conducted.

GLOSSARY

GCP (Ground Control Points): Ground Control Points are defined as points on the surface of the earth of known location used to geo-reference aerial images.

Orthographic projection: Photograph where all of the subject matter has been projected to the reference plane at 90-degree angles. This removes errors cause by parallax, and perspective. Since this error has been removed, orthographic projections can be used to generate linear and area measurements.

Orthomosaics: Orthographic projection generated using data acquired by several cameras in several locations.

Photomosaics: assemblage of photographs that have been stitched together to provide increased ground coverage. These are especially necessary when the altitude restrictions of the drone in concert with the Field of view limitations of the camera, make it impossible for the operator to obtain a singular picture of a wide area event. For example a single digital camera still from our sample camera produces a ground footprint of approximately 1 square acre, yet often times a sediment plume covers 10’s of acres. Photo-mosaics are not referenced to a geodetic grid, and they are not orthorectified, thus they are more useful for demonstrative purposes.

REFERENCES

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TSES. 2015. Video is available at the following:
RL:https://www.youtube.com/watch?v=x7iN3UeQ2_w