Photogrammetric Image Acquisition with Small Unmanned Aerial Systems

Ioakeim Tellidis
Eugene Levin
Surveying Engineering Department, Program: Integrated Geospatial Technology
Michigan Technological University, Houghton, MI, U.S.A.
tellidis@mtu.edu
elevin@mtu.edu

ABSTRACT

In recent years the developments of small electronics prototyping platforms such as Arduinos and Raspberry Pi's, created a new whole market from electronic equipment and Ideas for various sizes projects. It didn't pass too much time for developers to combine all these sensors and platforms and to create complete and more sophisticated navigation systems and find their way inside small remote controlled airplanes. The next step, the installation of a small digital camera it was pretty much expected due to human curiosity. The results were significantly changed the geospatial community. It was very obvious since the beginning of this technology that we had definitely find a cheap and reliable solution for aerial imaging.

The necessary steps for designing and executing an aerial image acquisition mission are far from being well defined. If we isolate the involved products one by one, we would see impressive specifications: High resolution DSLR or compact cameras, navigation systems with fast CPUs, reliable GPS units and radio receivers. But when all these stuff we are combining into a UAV (Unmanned Aerial System) fuselage and you are exposing it to aerodynamic forces on an environment full of uncertain parameters like weather and atmospheric conditions then, the UAV as an imaging sensor, needs to be studied further.

The overall of our research is to establish the necessary steps for preparing and executing photogrammetric aerial image acquisition. The final products should be vertical or near vertical well defined images with known exterior orientation, high resolution with small GSD and with adequate sidelap and endlap for supporting stereo vision.

KEYWORDS: UAS, Unmanned Aerial Vehicles, Aerial Images, Photogrammetry, Mapping

INTRODUCTION

Although the stories about software development are relatively short, one story among the others is standing up as the longest as all. Maybe it is not known by too many people but at the beginning it was existing only open source (Libre software). Later, the proprietary software was born and quickly dominated the software landscape to the point that it is today. Only the last years the industry again started to think about the Free Open Source Software again as valid solution.

Besides the benefits of adopting the philosophy of Open Source, another important part is the Liberal Ethics that developers been exposed. The idea behind this type of freedom is based on the open access at the schematics and programming code for small prototyping devices having almost unlimited capabilities. As the idea was spreading all over the world, it created a new market. Several companies started to provide components which were adding usability and they were creating more completed and sophisticated systems. Since small remote controlled airplanes have been always a very exciting topic, it didn't pass too much time before developers started to think about the implementation of an auto piloting system. The next step of adding a digital camera on board was probably very natural.
The geospatial community was following the developing of this technology since the very early stage. Probably because they were finally finding a very cheap and easy way to acquire aerial images. A good satellite imagery was too expensive with big temporarily resolution suffering by high percentage of cloudiness and the pure conventional aerial mission, was also expensive. But those small airplanes, equipped with autopilots which allowed them to fly on a much predefined path, was looking very promising. Today after many years of developing and improvements we have arrived to the point of acquiring aerial images using unmanned small robust and lightweight airplanes, UAVs

(Unmanned Aerial Vehicles).

The last years we are following dramatic improvements of the technology that is in the heart of the Unmanned Aerial Systems (UAS). We have reliable electronics, small and better GPS devices, accurate IM Units and many more components that are helping the systems to stable flight over an area and acquire images. But there is no research made on how you must use one of those systems for acquiring good images for applying metric photogrammetry for being able to extract valuable information. There is not even a practical guide to help scientists using those systems. This paper will introduce a new approach and will reveal the way and the parameters that one should take care for planning and executing an aerial image acquisition mission using small lightweight UAVs.

AERIAL PHOTOGRAPHY

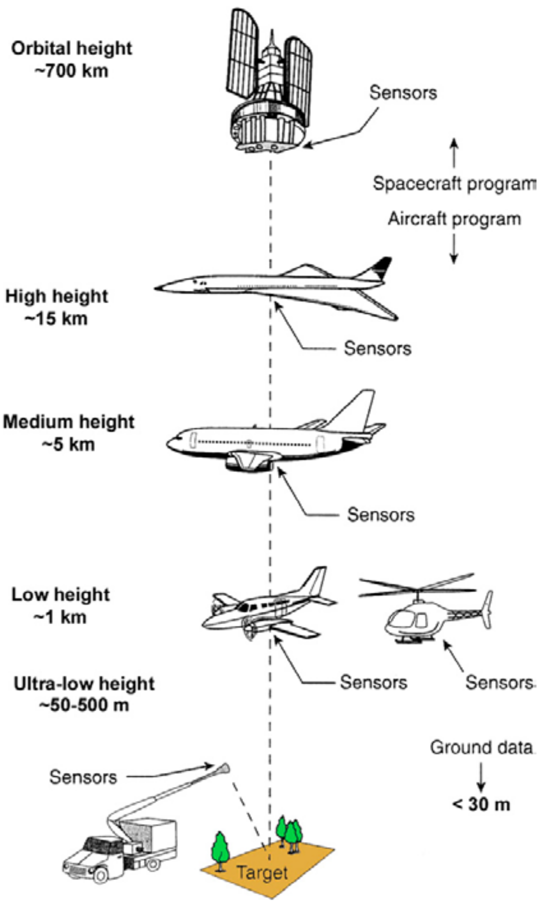

Figure 1 Schematic Illustration of the Aerial Photography Approach (James S. Aber 2010)

An easy definition of aerial photography is the procedure of taking ground photographs from an elevated position. This elevated position could be anything from just a crane vehicle to orbital satellites (Figure 1). The importance of an aerial photograph is well documented through 2 World Wars that we fought and all the natural or manmade crisis that this planet faced at the past. The Chinese philosophy also is teaching that one picture worth more than a thousand words.

What is changing with aerial photography is mainly the perspective which we are looking to an area or object. This perspective is revealing details that we couldn't be able to see with any other type of photograph.

There are 2 different types of photographs; the vertical with taken angle $\pm 3^0$ and the Oblique photographs with bigger angles than the 3^0. Oblique Images also are coming with 2 different type; The Low Oblique where only the terrain is visible and the High Oblique where besides the terrain also the horizon is visible.

For understanding better the concept of aerial photography using UAVs, we need to get through the geometry of aerial photographs.

GEOMETRY FOR AERIAL PHOTOGRAPHS

Probably measuring in photographs distances and object dimensions is the most fundamental ability. For this, we need to calculate the scale or other wise to find every single measured unit on the photograph, how much space is covering on the ground.

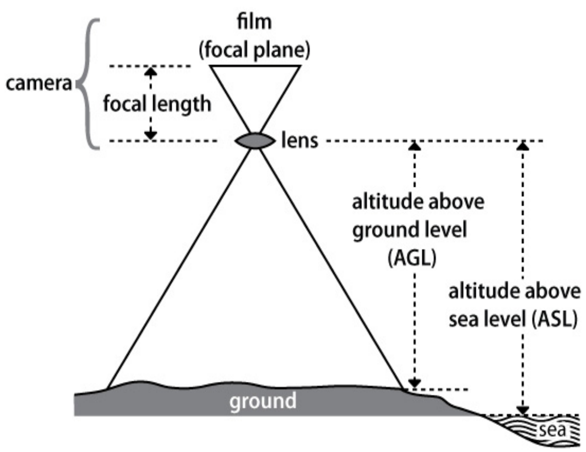

Figure 2 Basic Geometry for Aerial Photographs (Edgar Falkner 2002)

The Figure 2 is showing the basics geometry for an aerial photographs.

For better understanding we need to separate the Figure 2 in two different parts: The Upper part (Figure 3) that is above the lens and the Lower (Figure 4) part that is including everything under the lens up to the ground. These 2 parts are forming 2 different triangles.

According to the figure 4, from the lens to the ground we have known parameters by the flying plan such position and altitude from GPS devices, the rotation angles by the IMU (Inertial Measurement Unit). But for completing the triangle and being able to apply geometry we need to know the focal length and the focal plane (Figure 3). These are parts of the interior orientation of the camera. Here, the focal plane is the size of the CCD or CMOS. By the moment that we have these data available we already know the scale by the equation 1.

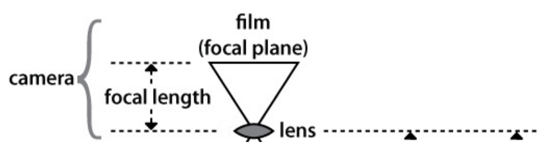

Figure 3 Upper Part of Figure 2

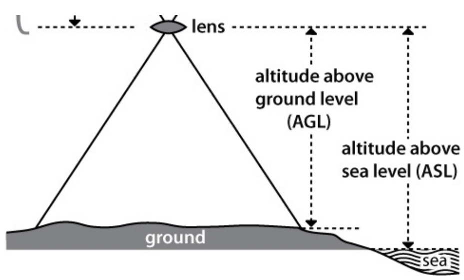

Figure 4 Down Part of Figure 2

$$Scale = \frac{Focal\ Length}{Altitude\ Above\ Ground} \quad (1)$$

GROUND SAMPLE DISTANCE

The Ground Sample Distance or GSD is one of the most important photograph parameters. Is the distance on the ground that is covering every single CCD or CMOS pixel (Linder 2003).
The figure 5 is giving the geometry for this calculation.

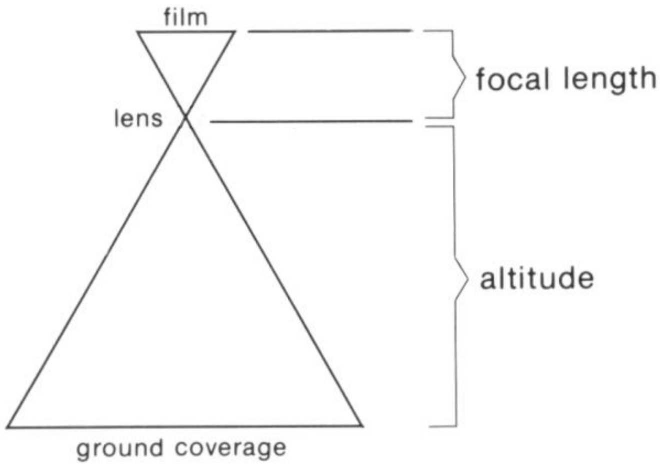

Figure 5 GSD Calculation

$$\frac{f}{Altitude} = \frac{Cx}{Gx} \quad (2)$$

For the GSD calculation, we should substitute instead of the film size, to use the CMOS or CCD size. It is obvious that the GSD is heavily affected by the flying altitude and the focal length of the camera.

Where f is the focal length, Altitude is of course the flying distance above ground, Cx is the side distance of the CMOS / CCD matrix and Gx is the corresponding ground size or the GSD (Edgar Falkner 2002)

Each camera is coming with a theoretical and an effective number of pixels. The theoretical corresponds to the maximum number of pixels that the CMOS / CCD array is constructed. But for many industrial reasons normally the outer stack of pixels are not operational. Therefore we have an effective number of pixels that is always smaller than the maximum. A very important point for the calculation of GSD is that we are using the theoretical maximum number of pixels of the matrix and NOT the effective.

As an example, for a compact camera CANON with sensor area (CMOS) of 6.17 x 4.55 mm, 12.8MP resolution, focal length of 4.5mm, recycling time 2700ms and for flying height above ground 108m we have:

We convert the CMOS sizes to microns, so is 6.17×10^6 μm and 4.55×10^6 μm and therefore the sensors area is 28.0735×10^6 μm^2.

The total number of pixels for the CMOS is 12,800,000 pixels that is equal to 12.8×10^6 pixels. Dividing the sensors area over the total number of pixels we are getting the pixels area.

$$Pixel\ Area = \frac{28.0735\ x\ 10^6}{12.8\ x\ 10^6} = 2.1932421875\ \mu m^2$$

Since the pixels are squares then the pixel side is:

$$\sqrt{Pixel\ Area} = \sqrt{2.1932421875} = 1.48\ \mu m$$

Since we have a specific scale for our mission according to the previous paragraph then we have:

$$GSD = Scale\ x\ [pixel\ size] = \frac{108}{0.0045}\ x\ 1.48\ \mu m\ x\ 10^{-6} = 0.03552\ m = 3.552\ cm$$

Every single pixels of our camera, while flying being mounted at the UAV at 108m above ground, is covering 3.552cm. And this is what we called Ground Sample Distance.

Better GSD means also better resolution and more clear identification of objects on the ground. A gold rule here is for a positive object recognition we need around 10 pixels size.
One of the best satellite imaging mission at the moment GeoEye-1 from Digital Globe Company is providing GSD of 50 cm for image swath of 15.2Km. It is easily here to see the advantages and disadvantages of using this method of image acquisition. We are getting by far better resolution but for a limited ground coverage. For covering the same area of a single satellite image, we should plan more than 100 missions with the UAV.

STEREOSCOPIC VIEW

One of the great benefits that photogrammetry is providing is the stereoscopic view. (Paul Wolf 2000; Kraus 2007). It is the ability to form a 3D view of the imagery by using the same exactly way that human eyes are using.
The human eyes are nothing more than extremely complex optical “cameras” that are observing objects by a slightly different positions. This position is the distance between the eyes. Our brain then is transforming those images giving the sense of the deep (the third dimension)
The stereoscopic view is doing exactly the same. Using stereoscopic devices we are looking 2 consecutive images that are taken during the flight mission with these devices. The left image with our left eye and the right image with the right eye. Even if it sounds difficult, the stereoscopic “glasses” are doing this task extremely easy. As soon as we form this type of view the images are turning to a 3D view and they are allowing us to perform even more calculations. Basically to see a 3D word.
But for forming the stereoscopic view there are some specifications that need to be matched with the way that photographs acquired. The endlap and the sidelap are the most important.
The minimum endlap, which is the overlap of 2 consecutive images taken at the direction of flight path, must be at least 60%. The sidelap, that is the overlap of 2 images that are taken during the fly in parallel lines, should be at least 30% (Edward M. Mikhail 2001).

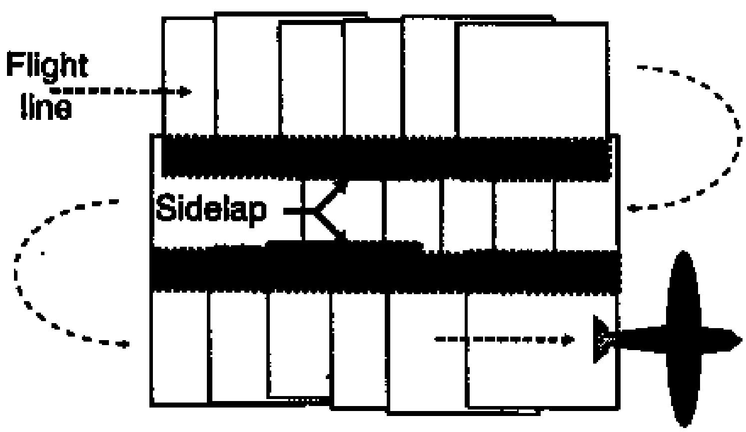

Figure 6 Sidelap Illustration (Edgar Falkner 2002)

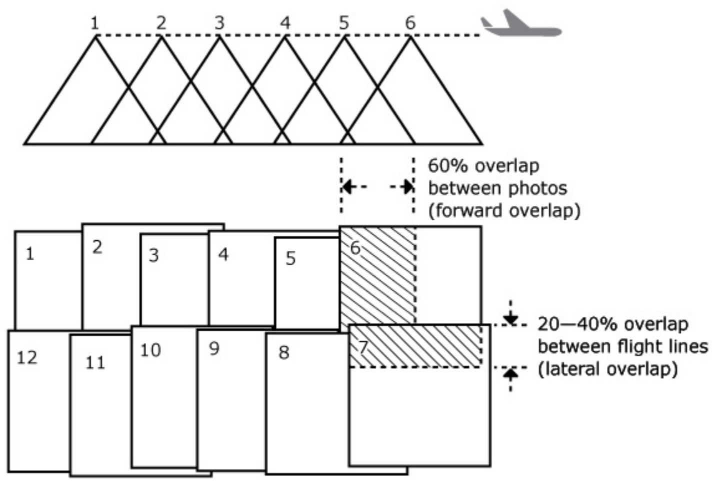

Figure 7 Endlap (Edgar Falkner 2002)

Using formula 2 is easy to calculate the ground coverage by a single photograph and then the necessary overlaps for the stereo. Using the values of the above example we have:

$$\frac{f}{Altitude} = \frac{Cx}{Gx} \Rightarrow \frac{0.0045}{108} = \frac{0.00617}{Gx} \Rightarrow Gx = 148.08\,m$$

$$\frac{f}{Altitude} = \frac{Cy}{Gy} \Rightarrow \frac{0.0045}{108} = \frac{0.00455}{Gy} \Rightarrow Gx = 109.2\,m$$

Every single photograph is covering 148 x 109 m.

Endlap = 148m - (148m x 0.6) = 59.2m (minimum 60% overlap)

Sidelap = 109 m – (109 x 0.3) = 76.3m (minimum 30% overlap)

During UAV flight, every 59.2m must trigger the camera for acquiring images. The distance between the flying strip lines is 76.3m.

PLANNING MISSIONS

A successful Aerial Image Acquisition Mission has 3 important tasks that need to be completed with a very specific way.

- Target Area and Preparation for the mission.
- The Camera that we will use.
- The UAV that will execute the mission.

Each one of those task is critical for the mission. Each one need to be completed before moving to the next. And this is happening because each one of these tasks is giving information for the next one (Edgar Falkner 2002).

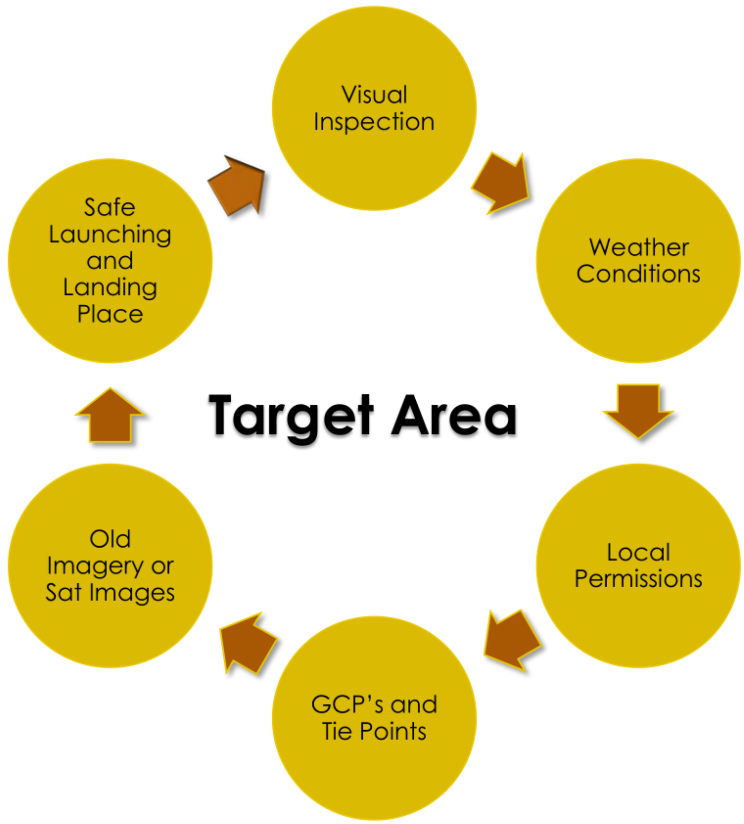

Figure 8 Target Area Circle (Tellidis 2013)

It is of course mandatory to know about the area that we will deploy the UAV for the mission. During our research we established what we called the Target Area Circle that is including all the necessary steps (Tellidis 2013).
We are starting by inspecting visually the place. We are looking for features or objects that could possibly interfere or with the imagery or with the flying mission itself. Maybe there are high buildings near the site, or high trees. We are moving next to check the weather conditions of the area. Weather portals that are keeping historical data is our first stop. We are looking for weather conditions around the period that we will deploy the UAV. Next step is to obtain any local permission from the authorities. A visit to the county or the police station will help avoiding further problems. Now is the time for marking Ground Control Points (or GCP) and Tie Points. The GCPs are ground points with known coordinates. We need surveyors for this job. Theoretically with just 3 points we are getting acceptable accuracy but practically 6 points at least are giving the ability to apply special models such as polynomial models for Photogrammetric analysis if this is required. Last part is to find safe place for launching and landing the UAV.

GROUND MARKINGS FOR GCPS

The GCPs should be spread out covering the whole target area. On the ground we are marking those points with such a way that they will be visible on the imagery while the UAV passes over the area to perform the mission.
A typical ground marker is having a cross shape with some specific dimensions that are related with the mission characteristics.
For example assuming that we have GSD = 5 cm. A typical Ground Marker should have the following size:

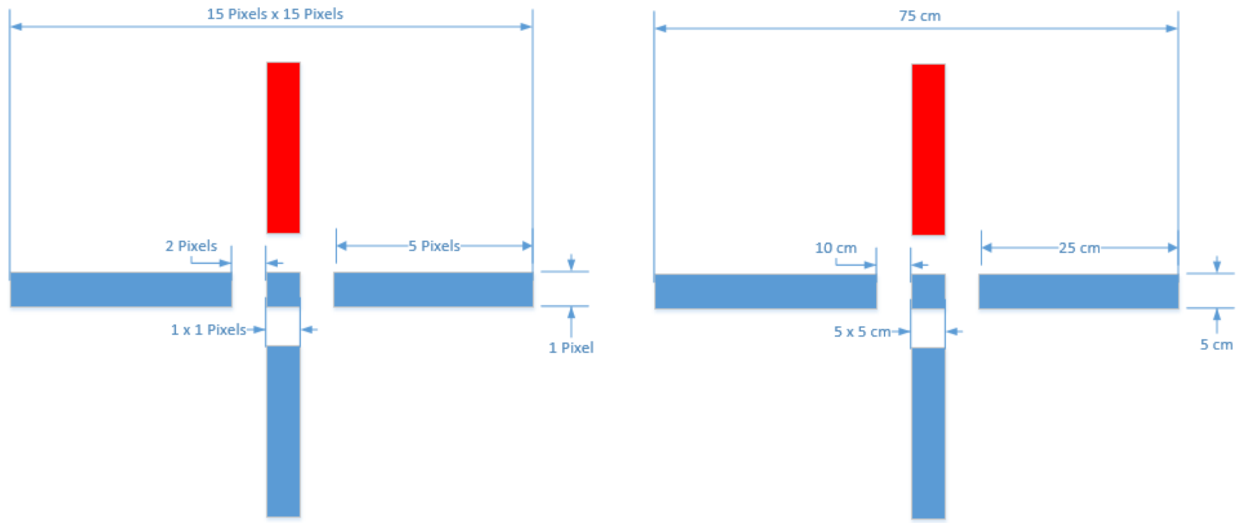

Figure 9 Ground Markings Design

Every marker that we are using it must be installed with such a way to be oriented indicating the North. This is helping a lot during the image interpretation. The marker that we are using is having one part of the cross with red color and this part should always point to the north.

Figure 10 Ground Marking with Orientation

CAMERA AND UAV

The term of recycling time of a camera refers to how fast a camera is able to shoot and image, save the image on the storage card and shoot again the next image. This time for the example's camera is 2.7sec. Since pushing the electronics of the camera along with other components of the UAV is never a good idea, we are introducing a safety factor of 50% to increase the recycling time for being sure that we are giving the necessary time at the camera to complete a full imaging process cycle.
Therefore we have: 2.7sec x 1.5(safety factor 50%) = 4.05 sec.
Having the distance of 59.2m that must be each image separated by the next one – because of the endlap – and the recycling time of the camera, we are calculating the UAV Mission Speed:

$$Mission\ Speed = \frac{59.2m}{4.05s} = 14.617\ ^{m}/_{s}$$

FACTORS WHICH ARE AFFECTING THE MISSION

There are several factors which are contributing with one way or another to the success or failure of an image acquisition mission. The most important are two: The Lighting and the Atmospheric Conditions.

Atmospheric Conditions

An aerial imaging acquisition mission is considered as successful only when you get the quality of images that serve the scope of the planning mission. But the most common feature that every image must have is to be illuminated by light as much as it can. Pour atmospheric conditions such as bad weather, crosswinds or wrong season might heavily affect the results and by this, we mean extensive hidden areas around the objects or introducing image noise, or blurry images (James S. Aber 2010).

The position of the Sun is the main factor of creating shadows. Typically the best time for aerial image acquisition is between 10am to 2 pm. Depending by the latitude of the area that we are scanning, somewhere around 12pm is the best time due to minimum shadows.

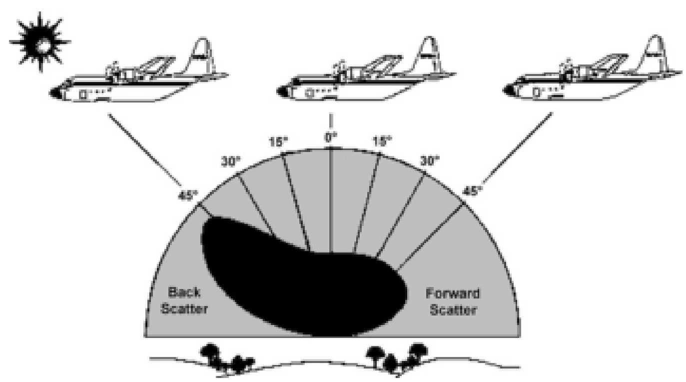

Figure 11 Diagram of aerial photography and typical BRDF[1] (James S. Aber 2010).

Another important issue that we must avoid is a phenomenon called "Hot Spot". This is a relatively small area – a spot on the image - that is reflecting heavily the sun light. Normally hot spots are created because of the direct alignment of the camera and the sun light. The hotspot is located at the antisolar point that is on the ground point that is opposite the sun in relatively with the camera.

Hotspots are subject of great investigation in recent years. A fast explanation of the phenomenon is the absence of visible shadows causes the spot to display extensive luminosity than the surrounding area.

[1] Bidirectional Reflectance Distribution Function (BRDF). Reflectivity pattern in the solar plane is marked here by the black area. Maximum reflectivity occurs directly back toward the sun. Illustration adapted from Ransom et al (1994 fig 1).

Figure 12 HotSpot (James S. Aber 2010)

Weather

The weather is probably the most dangerous condition that may affect badly the mission. Most of the electronics are not very friendly with humidity or even worse the direct water exposure due to rain or snow conditions.
The solution of enclosing the electronics into a tight sealed waterproof box doesn’t solve the problem because of the accumulated heat inside the case. This is a very dangerous condition that could easily lead to a massive failure. On the other hand the GPS units must be positioned in a way that should be able to have clear sight of the sky for better results.
Most of the UAVs are having small holes or hatches on their fuselage for allowing small amount of air to pass inside the fuselage and to cool down the engine and / or the other electronics like the batteries regulators, or the Arduinos boards. Flying on a rainy day it is a high risk situation.
High environmental temperatures are extremely dangerous for electronics that are working on a so small airplane bay like the UAV fuselage. Additionally to this situation the camera is also having problems working in high temperatures (Sandau 2009). The adoption of small holes on the fuselage that could allow air intake to cool down the components are compromising mission on rainy days.
A solution could be small fans positioned on the back part of the UAV to remove hot air from inside the fuselage. This solution could be also good for the camera electronics because it’s lowering the temperature at the sensor bay where the camera is located. It should be very good design and aerodynamic analysis because it is possible the fans electric engine could produce noise at the images.

Winds are the main reason for bringing the necessity for a mission to repeat many time the flight. The main problems occurred because of winds are 4:
Drift, Crab, Drift and Crab, Oblique images where we need Vertical (David P. Paine (Deceased) 2012)

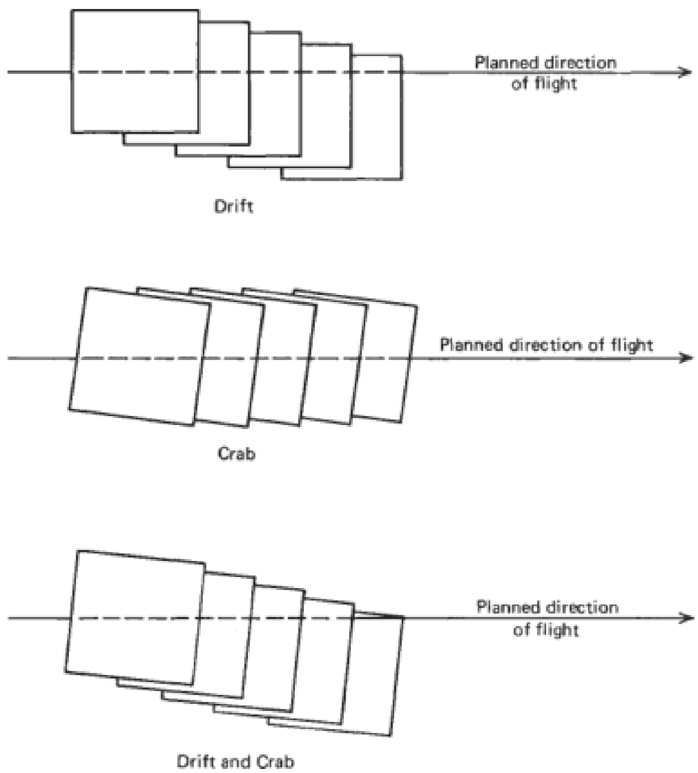

Figure 13 Mission Results of Crosswinds (David P. Paine (Deceased) 2012)

Drift is the result of not be able the UAV to keep the planned navigation bearing. The Crab is the result of been able to keep the planned navigation bearing but because of side winds it doesn't have an alignment yaw position with the bearing. Because of extensive crosswinds there is a great possibility that we will have a combination of the 2 situations, Drift and Crab.

The Oblique images is a result where the UAV is not able to compensate winds from multiple directions or circulations due to presence or big buildings near the site of the mission, or trees or high slopes and during the navigation reposition moves the exposure station goes off. As we mentioned before vertical and near vertical images are those that are taken with an angle between 0^0 to $\pm 3^0$.

As we early mentioned oblique images might not be always a catastrophe. They are giving better results for image interpretation since the interpreter is looking the area in a more familiar perspective than the vertical.

SYNOPSIS

This paper is answering the question "How we can use lightweight unmanned aerial vehicles for acquiring high resolution aerial images?".

The technology is giving today all the tools that we need for designing better UAVs with more capabilities. By using those tools, we can reduce for example the food cost by applying cheaper precision agriculture technics or we can save life's by just finding on time who is in danger or we can prevent disasters or reduce the impact from natural phenomena. Or, we can just learn better the planet we are living, our Home.

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References

David P. Paine (Deceased) JDK. 2012. Aerial Photography and Image Interpretation. John Wiley & Sons, Inc.
Edgar Falkner DM. 2002. AERIAL MAPPING. Methods and Applications. Lewis Publishers.
Edward M. Mikhail JSB, J. Chris McGlone. 2001. Introduction to Modern Photogrammetry. Wiley.
James S. Aber IM, Johannes Ries. 2010. Small-Format Aerial Photography: Principles, techniques and geoscience applications.
Kraus K. 2007. Photogrammetry: Geometry from Images and Laser Scans. Walter de Gruyter.
Linder W. 2003. Digital Photogrammetry. A Practical Course. Springer.
Paul Wolf BD. 2000. Elements of Photogrammetry with Applications in GIS. McGraw Hill.
Sandau R. 2009. Digital Airborne Camera. Introduction and Technology. Springer.
Tellidis I. 2013. Lectures on Aerial Imaging Acquisition. Michigan Technological University.