Do-It-Yourself Helium Balloon Aerial Photography-
Developing a method in an agroforestry plantation, Lao PDR

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Abstract

The aim of this study has been to develop a small format aerial photography, SFAP, acquisition method that is easy to use, inexpensive, and delivers high enough resolution to detect individual trees. Aerial photography has become a valued tool for forest management through time, because of the vantage point and up-to-date information it can provide. In this study, a helium balloon is flown over an agroforestry plantation with the intent of mapping 246 ha. Due to a helium deficit in the balloon and therefore also a lower altitude than intended, only 14.8% of the intended area was photographed. The altitude reached by the balloon is vital for a number of elements during planning. The camera's field of view, FOV, or what the camera captures on the ground, is dependent on the altitude as well as a number of camera specifics. The FOV is used to plan the placement and distribution of ground control points, GCPs, which are necessary for the data to be anchored in a three dimensional space. The ground control distributed during this study was based on a 250 m altitude, and because the balloon only ascended to roughly 75 m, no GCPs were captured in the photographs. This in turn, affected the geographic accuracy and pixel resolution of the processed images. A fuel estimation process has been taken forth to adjust this method shortfall, but is not yet tested. If the balloon altitude can be ensured, then the GCPs can be placed according to the FOV of the desired altitude. Because of these complications, the method is concluded to be close to suitable in terms of the three requirements, but needs further testing to conclude its suitability in the forestry sector due to maneuverability complications. The study was performed through Burapha Agroforestry Company in central Lao Democratic Republic.

Sammanfattning

Syftet med studien har varit att utveckla en metod för flygfotografering som är lätt att använda, relativt billig och ger tillräckligt högupplösta bilder för att urskilja individuella trädkronor. Flygbilder har blivit ett värdefullt verktyg för skogsförvaltning genom tiderna på grund av den fördelaktiga vyn och möjligheterna att erhålla uppdaterad information. I studien flygs en heliumballong över ett skogsplantage i avsikt att kartlägga 246 ha. På grund av för lite drivmedel och därmed för låg altitud, fotograferades endast 14.8% av tänkt area. Kamerans synfält används för placering och distribution av markkontrollpunkter, som behövs för att fästa bilderna i ett tredimensionellt rum. Markkontrollpunkterna som distribuerades i denna studie var baserade på 250 m altitud och eftersom ballongen endast nådde 75 m, kom kontrollpunkterna inte med i fotografierna. Detta påverkade den geografiska noggrannheten och pixelupplösningen av de slutbearbetade bilderna. En helium-uppskattningsprocess har tagits fram för att modifiera metodens begränsningar, men drivmedelsuppskattningen har ännu inte prövats i fält. Om ballongens altitud kan säkerhetsställas, så kan kontrollpunkterna placeras enligt kamerans synfält på den rätta höjden. Även med komplikationer kan metoden ses som något lämplig enligt dom tre kraven; lätt att använda, relativt billigt och högupplösta fotografier. Dock behövs mer prövning för att säkerhetsställa metodens lämplighet inom skogsplantager på grund av manövreringssvårigheter.

<u>List of abbreviations</u>

FOV- Field of view
GCP- Ground control points
GIS – Geographic information systems
LiDAR- Light detection and ranging
RS – Remote sensing

SFAP – Small-format aerial photography
UAS – Unmanned aerial system
UTM- Universal Transverse Mercator

Acknowledgements

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Introduction

Remote sensing "is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation" (Lillesand et al. 2004). Aerial photography is a form of remotely sensed data, without direct contact, that can be collected by a camera mounted on a land, water, air, or space based vehicle either pointing straight down or at an oblique angle towards Earth. For landscape studies, collection of aerial photography occurs along a flightpath where images are collected at equal intervals so that they overlap each other horizontally and vertically (Axelson et al. 1993). The process of deriving measurements and extracting technical information from aerial images is called photogrammetry. Photogrammetry techniques help us visualize the phenomenon studied by putting our image data together correctly in space, whether in a stereoscope, a geographic information system, GIS, or other specialized software (photogrammetry.com 2007). Collected aerial images, or image data, has primarily had uses such as the basis of map production, image interpretation, material for project planning and inventorying of natural resources or urban spaces etc. However, since the 1990's and the development of GIS, these different uses have converged and made it possible to work with all information at once (Axelson et al. 1993). The applications of aerial photogrammetry include, but are not limited to "the measuring of coordinates, quantification of distances, heights, areas and volumes, preparation of topographic maps, and generation of digital elevation models and orthophotographs" (Aber 2010). Photogrammetry and remote sensing allows us to study and analyze the landscape around us without having to be in direct contact with it, but also provides a different perspective.

Understandably, aerial photography and photogrammetry has come to have many applications since it provides an invaluable vantage point and instantaneous view on dynamic conditions such as forest fires, oil spills and wildlife migration (Aber 2010). As early as the 1920's, aerial photography was introduced as a means of mapping forests in Sweden, but it was not until after WWII, 1945, that photogrammetry fully developed in forestry. It was fueled by the demand for fast and cost-efficient methods of mapping the countries resources (Ottoson et al. 2004). In the 1930's, German geographer Carl Toll coined the term *landscape ecology*. In order to view landscape as a spatial and visual entity Toll strongly advocated the use of aerial photography in scientific studies (Aber 2010). The onset of World War II in the 1940's brought with it research, testing and rapid development of remote sensing and aerial photography. In order to spy on each other's progress, both the Allied and German forces used aerial photography in visible and infrared, IR, wavelengths. The ability to sense IR light was developed to detect camouflage in reconnaissance aerial photography (Aber 2010). Unmanned Aerial Systems, UAS, were also 'born and raised' out of the military context and used by the United States in several wars during 1920's and 1970's (Colomina 2014). Around the 1970's, "navigation and mapping sensors were integrated onto radio-controlled platforms to acquire low-altitude, high-resolution imagery" (Aber 2010). Service companies then saw the potential social and business benefits of unmanned aircrafts, UAS, and began to develop, apply and regulate the technology into what are now commonly referred to as drones. UAS became the "smaller, cheaper-to-operate platform" for small-format aerial photography (Colomina 2014) and is now commonly used in everything from landscape studies to movies and still photography to extreme sports videos.

Small-Format Aerial Photography, SFAP, can be defined as aerial photography from small-format cameras; 35-70 mm film or compact digital cameras made for handheld use. These cameras or sensors are mounted on manned or unmanned platforms within the Earth's atmosphere, from tens of meters to hundreds of kilometers (Aber 2010). This type of remote sensing fits the niche for "observational scale, resolution, and height between the ground and conventional aerial photography or satellite imagery… that is particularly valuable for detailed site investigations of environmental conditions at the Earth's surface" (Aber 2010). Because this niche focuses on inexpensiveness and accessibility, SFAP is the type of aerial

data collection ordinary people or organizations often start out with to investigate their surroundings (Aber 2010).

In today's modern world many people are increasingly interested in knowing about the state of our local environment. Through events and disasters that affect the environment and people, scientists, students, concerned locals and activists seem to have realized that power lies in collecting data. Organizations such as the Public Laboratory for Open Technology and Science define themselves as a community where people learn how to investigate environmental concerns (Public lab 2015). "Using inexpensive DIY techniques, we seek to change how people see the world in environmental, social, and political terms" (Public lab 2015). The community sells balloon and kite mapping kits and all users are welcome to take part in documentation and write or read research notes. There are just under a thousand research notes on Public Lab, some of which have over four thousand views (Publiclab.org 2015). Topics include, but are not limited to oil spill documentation in the Gulf of Mexico, spread of invasive vegetation in Portland and New York, volume estimates of trash piles (different locations) and research efforts in underwater mapping techniques. Numerous blogs and websites describing personal or educational endeavors in constructing various remote sensing platforms are available on the internet. A simple Google search on "DIY aerial photography" gives a plethora of results, 1.16 million results, showcasing platforms such as kites, hot air and helium balloons, hang gliders and drones, many for environmental monitoring but also for aesthetic still photography (Google 2015). Viewing ones environment is getting increasingly easy with Google Maps satellite and street view features, even creating your own geographic data and sharing it with the world is easily possible, through open-source mapping applications such as OpenStreetMap, OSM. In fact, the Missing Maps Project uses OSM to map remote areas prone to disasters to aid future humanitarian work (Lopez 2014). Public participation in mapping can play a great role in environmental assessments, exemplified in a Latvian project where high school students surveyed the spread of Giant Hogweed (*Heracleum sosnowskyi)*, a threat to biodiversity and human health in the region (Foteck Fonji et al. 2014). The study showed that the majority of data collectors had an increased understanding and respect for the Giant Hogweed, which will hopefully result in less incidents of rashes or blindness from the weed as well as aid in the clearing process. The growing interest in environmental monitoring and assessment among people has spurred many creative solutions for gathering remotely sensed photography inexpensively.

There is no complete list of forestry applications of aerial photography but their management uses include creating "basic forest maps, cadastral surveys, forest inventorying and record keeping, insect and disease surveys, silvicultural surveys, forest administration (e.g., timber sales), road location, fire protection, forest recreation, and range and wildlife management" (Franklin 2001). Even land appraisal, monitoring of logging and reforestation, planning and assessing applications of herbicides and fertilizer in forest stands, mapping "forest fuels" to assess fire potential are applications of aerial photography (Lillesand 2004). In many countries, aerial photography plays an important role for the National Forest Inventory, in some smaller countries, like France and Spain, photographs are used to delineate all forest areas while other countries integrate these with satellite images (Corona 2003). For businesses, aerial photography provides the up-to-date, "stop action" view from above that allows foresters to see the health and geographic spread of their trees (Aber 2010). Forestry businesses are primarily concerned with timber management, maintenance and improvement of existing forest stands, and fire control (Lillesand 2004). Through SFAP businesses can easily monitor the regrowth of shrubs in fire lanes or power line rights-of-way in order to clear these when needed. In areas of varied terrain, like northern Laos, foresters can benefit from assessing potential slope failures and soil erosion as well as plan forest roads and tree row alinements. Skilled interpreters can relate image measurements to ground measurements of tree height, tree-crown diameter, density of trees, or stand area to produce estimates of wood volume, sometimes called "timber cruising" (Lillesand 2004). Images that are captured in near-infrared or color infrared wavelengths are often utilized to identify or detect tree diseases from bacteria, fungus, virus and other agents (such as air pollutants) (Lillesand 2004). Aerial photography was developed as a useful tool around

the 1930s but it is still the most common form of remote sensing in forestry, most likely because "relative to the information content, [aerial photographs] are inexpensive and easy to use" (Franklin 2001).

Country and company introduction

Lao People's Democratic Republic

Map 1: Map of Lao PDR with neighboring countries. An inset map of Vientiane prefecture, shows a red rectangle which contains the region of the study area, known as at Nabong. The green areas are National Biodiversity Conservation Areas, representing 70% of the country's forests. Along the Thai border runs the Mekong River, shown is also the Nam Ngum Reservoir. The Lao borders contain 236,800 km² of land, roughly the same size of Romania.

Because Lao People's Democratic Republic (Lao PDR) is a UN classified 'Least Developed Country' that relies heavily on natural resources, there is a pronounced need for resource monitoring methods to manage the nation's richness (UNDP 2013) (Southavilay et al. 1999). Agriculture, hydropower, minerals and timber constitutes more than half of the wealth of Lao PDR. The low population, 6.2 million people, does not strain the environment as much as the neighboring countries; three of which are the biggest importers of timber in the world (REDD Desk 2013). The current laws ban the export of all unprocessed timber to instead promote exportation of more valuable products such as wood panels (Helberg 2003). In 2010, the nation was 40 % covered by forests and has deemed twenty-one areas, or 70 % of forest cover, as National Biodiversity Conservation Areas, NBCAs. Despite this, illegal logging of round wood continues, even in protected areas. Radio Free Asia frequently reports about forestry bribery, corruption and the high levels of illegal trade of Lao wood to Chinese, Thai and Vietnamese companies (RFA 2015) (REDD Desk 2013).

A timber and wood flow study conducted in 1999 noted that most NBCAs are not managed correctly and have lost some original value (Southavilay et al. 1999). Data on biodiversity and health of forests are often not up-to-date and some areas are believed to never have exhibited notable biodiversity or watershed protection value (Southavilay et al. 1999). Shown in green, in Map 1, are the twenty-one conservation areas. The forests are of sub-tropical type and the terrain varies from plains along the Mekong River to mountains in the north and along the Vietnam border. Southavilay et al. recommended six years ago that the Lao government complete a detailed survey of their protected areas to investigate which forests should be prioritized. Since the extent of NBCAs encompasses 6.6 million ha, there are not enough resources to effectively manage all forests. As this country develops it relies heavily on the abundance of natural resources, but has to take great care not mismanage them. Primarily, wide inventorying in terms of extent and health of forests is necessary in order for the government to manage resources appropriately. This situation makes low cost solutions for forest monitoring of great value to the country, people and organizations working with forest resources.

Burapha Agroforestry Company, BAFCO, is a Forest Stewardship certified Lao-Swedish company that produces wood products in a socially and environmentally responsible manner. Their head office is located in Vientiane, Lao PDR, and their plantations are located mostly in central Lao. The company sells an array of different wood products, from furniture to fencing poles.

Burapha's agroforestry model has been developing since 1990 and is now considered a model for combined wood and food production. They integrate the villages, or 'kums' in Lao, with the plantations by supplying jobs, intercropping and cattle grazing opportunities. Intercropping upland rice or cassava root has become a natural part of the plantations as the tree rows are planted at 10 m intervals with plenty of space and sunlight. Burapha also compensates villagers for the use of land for wood production with a Village Development Fund that goes towards food security, education, health and sanitation. Another important part of the agroforestry model is that plantations are always established on degraded forestlands that have usually been used in shifting cultivation for many generations. The vegetation on such degraded land consists mainly of shrub and bamboo growth. BAFCO's current land holdings throughout central Lao, are leased for a longer time period either as village, district or government concession land. Land is acquired through a bottom-up approach, starting with a village consultation. If the response is positive, BAFCO and the village leader survey the land together and resolve any boundary uncertainties as well as exclude areas locally deemed as Spirit Forests. From there, the village seeks permission from the government to lease land for wood production.

Project aim

This study investigates a "do-it-yourself" helium balloon method for small format aerial photography, SFAP, within an agroforestry plantation in central Lao PDR. Focus lies with developing the balloon method and observing the cost, ease of execution and image result. Since Burapha Agroforestry Co. does not currently use aerial imagery, visualizing their plantations aerially and up-to-date can provide them with new tools for managing their forests. New potential forestry tools that could come from developing a successful SFAP method include: wood and intercrop yield estimates, efficient planning of tree rows, extraction roads, erosion and fire control, and tree health monitoring. The method will be suitable if it meets these parameters:
- Relative low cost (no amount was specified)
- Provide image resolution where individual trees must be detectable
- Easy to set up and use

A helium balloon was chosen for this method because the chief of forestry at BAFCO displayed an interest in this technique. Other platforms of capturing aerial photographs include by kite, UAS or drone, and buying satellite images; these methods are compared in Table 1. Out of these methods, kite and balloon platforms are considered the cheapest for the type of resolution that is obtainable. Because of wind requirements kite is not suitable in the forests of Lao.

Table 1: This table compares four alternative SFAP methods by their benefits and disadvantages.

Alternative data acquisition methods	Benefits	Disadvantages
Helium balloon	Easy to launch.	Cost of helium.
Kite	No fuel, Inexpensive.	2 – 9 m/sec winds necessary (Lippincott 2013).
Buy satellite imagery	High photogrammetric precision and previewable, customizable areas; useable data, much larger coverage, less work. Infrared available.	More expensive, can take time to order. For one 250 ha plantation the price will likely be around $ 25 – 150.
Hire drone consultant	High photogrammetric precision and usable data, more coverage over only relevant areas, less work. Infrared available.	More expensive, around $400-$800 per hour.

Method

Construction

Developing this remote sensing method and the platform for it, started with the construction of the rig that held the camera. The rig needed to be relatively light in weight, not more than one kg, hard to protect the camera, adjustable for different kinds of cameras, attachable to the helium balloon, and reusable. A protective outer case was fashioned from a PVC pipe, 16 cm in diameter and 12 cm in height. Six attachment holes were drilled around the top of the pipe. Two strips of metal wiring net, commonly referred to as chicken wire, were folded over and into the pipe like a basket for the camera. The bottom of the netting was cut to fit the expanding lens and the basket was filled with plastic foam to protect and stabilize the camera. This net can easily be replaced and the foam can be remodeled to fit another sort of camera if necessary in the future. The chicken wire basket was fastened with zip ties in the drilled holes. To attach the rig to the balloon, three thin ropes were strung through two holes each and tied together at equal length to help the camera stay horizontal. When stretched, the strings secure the camera in the basket. The strings tied together into a loop at the end, which attached to the balloon with a carabineer clip. A fan was attached as a fin for increased aerodynamics. The design of the rig can be seen in Picture 1 below.
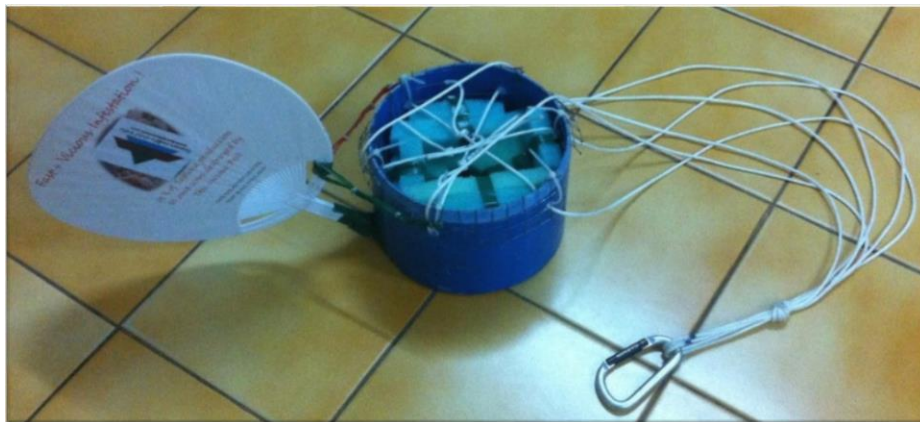
Picture 1: The camera rig was constructed out of PVC pipe with a chicken wire basket with a hole for the lens, foam protective casing, fin for stabilization, attachment rope with carabineer clip.

The platform needed to be controllable by the ground operators both horizontally along the ground and vertically into the air. To prevent the equipment from floating away, and also to stabilize the balloon between the operators, two heavy duty fishing lines were used for control. These 250 m long lines were rolled onto two hand held reels and the other ends were tied to a metal ring. All knots were professional fishing line knots to avoid breakage. The carabineer clip with the rig, was also to be attached onto the metal ring, which itself was folded into the balloon neck once it was inflated in the field. The actual balloon was called "Cloudbuster Chloroprene Balloon", 170 cm in diameter, and was bought from the Swedish website ballonger.nu. According to their website it is made of natural synthetic latex which makes it resistant to a range of weather conditions (ballonger.nu 2015). Chloroprene "is a type of dipped latex product that is treated with a substance somewhat like household bleach after dipping to modify the latex and make it more environmentally resistive" (University of Hawaii 2015).

Camera

The camera of choice was the Canon IXUS 160, a 20 megapixel point-and-shoot camera that cost just under 1000 SEK ($119). The dimensions of the camera is 9.5 x 5.4 x 2.2 cm, and it weighed approximately 127 g with battery and memory card. It was chosen because of the low price and the "continuous shooting" mode. This mode allows the camera to capture images continuously as long as the button is pressed. To push the button while the camera was in the air a "trigger band" was made from rubber bands and tape. The trigger band was the last element to put in place, by sliding it over the camera, before launching the helium balloon. With the intention of getting the best quality images, the large photo quality was chosen, which are 5152 by 3864 pixels.

In order to assess the data and time limitations of the method a physical test on the camera, battery and memory card was carried out. On "Continuous Shooting" mode the Canon IXUS 160 takes 0.8 photographs per second (Canon UK 2015). According to SanDisk one of their 8 GB memory card should hold 2784 large quality (5152 x 3864 pixels) images (Kb.sandisk.com 2015). With a fully charged battery and camera formatted memory card, the trigger band was slid on and a timer started. After 58 minutes the camera stopped shooting due to full memory, it had shot around 1600 photos. The limitation on data collection was concluded to be the 58 minute time constraint.

Planning

Due to the camera time constraint and with the general field efficiency of data acquisition in mind, a flight plan needed to be developed, like those of UAS or airplane aerial photography platforms. This plan would also help in positioning out adequate ground control points, GCPs. To properly plan this, one needs to know the area on the ground that the camera will capture in one photograph, generally known as the image footprint. Calculations for this same area are usually referred to as the field of view, FOV. Footprints of the correct size can then be distributed in a GIS to plan how to cover the study area in the most efficient way (see more information under *Ground control*). Things to keep in mind when planning a flight path is what obstacles there might be on the ground and in the air. Obstacles present in the study area in Lao PDR were a small seasonal lake and powerlines.

The FOV can be calculated through countless online photography calculators, Tawbaware Dimensional Field of View was used in this study, complimented with a manual method. The manual FOV estimation makes use of trigonometric functions with some known camera parameters. The parameters needed are focal length, the size of the camera sensor (width and length), and height above ground. I have formulated an estimation method so that the FOV can be calculated manually, see Appendix ii. It was decided that the balloon should ascend to 250 m altitude because the FOV would be 1200 x 800 m, or 800 by 800 m to account for the spinning of the camera in the air. This was a large enough area to include all corners of the plantation study area while maintaining a flight path that was mainly on the existing roads, see Map 2 below. In the flight plan, Map 2, the stabilization points shown correlate with the middle of each image footprint. The idea behind marking these was to stop and observe the camera rig for a moment, if the camera rig was swinging around too much one should wait to ensure capturing a stable and focused image. The only roads in the plantation, shown in brown, fork out in the north and south directions from the main road in the middle going west to east. The distances in between the roads, along the turquoise path, would have to be walked in the 10 m space between the tree rows. The flight path was 5.3 km long which would take a little more than an hour to walk without complications. To account for obstacles and an inconsistent walking pace the balloon would have to be reeled in after 58 minutes to change batteries and memory cards, then launched again for the last part of the flight path. Helium advice was sought from the balloon retailer, they indicated that a balloon in total weighing 1027 g, should be filled to about 120 cm diameter with 30 L helium to go to 250 m height (Vallsäter, Eloise. Personal communication 30 march 2015).
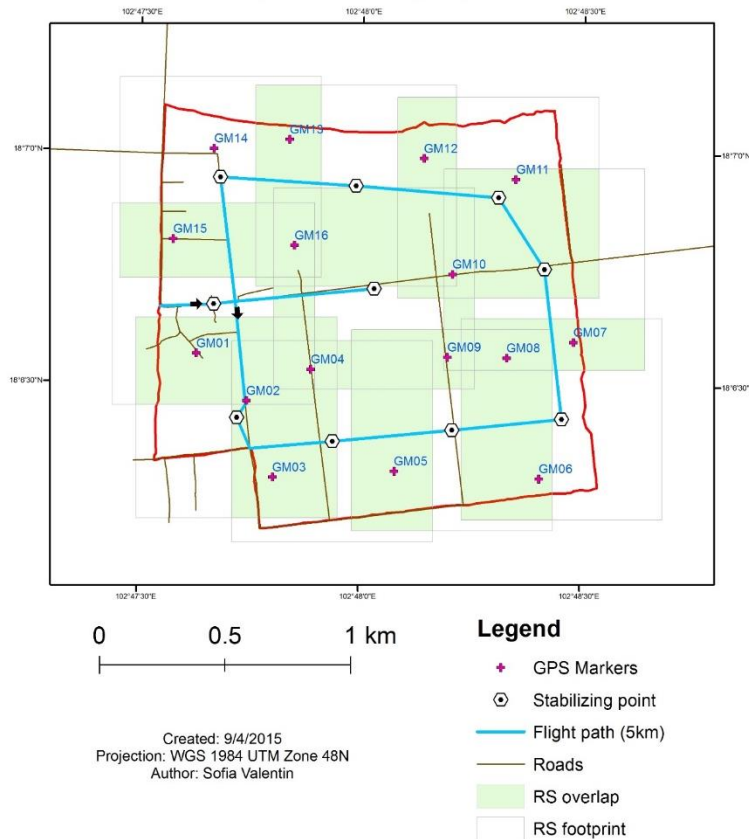
Map 2: This map shows the flight plan prepared according to on FOV calculations displayed in Table 4, in the Result section. The flight path starts in the west and follows the turquoise line counter clockwise in the plantation (plantation border is red). Ground control points are marked as pink crosses. The green areas are where the images will overlap and show the same content. The middle of each expected image footprint is marked by a stabilization point.

Ground control

An important element of this mapping method is successfully placing accurately located GPS points on the ground to anchor the resulting images in space. Ground control markers were made from a blue plastic tarp, sixteen 70 x 70 cm squares were cut out and an orange cross was spray painted on them. When placed in the plantation these were nailed down into the earth in all four corners to make sure the wind or cattle did not move them, their distribution can be seen in Map 2 above. As previously touched upon (in *Planning*), these ground control points, GCPs were distributed over the study area in ArcMap along with the estimated image footprints. To orientate the photographs, a minimum of three GCPs per image were set out (Aber, 2010). The GCPs were spread out in each image so that there would be a stable anchoring, while also placing as many as possible in the green overlapping zones, see Map 2. The overlapping zones were derived by intersecting the image footprints or FOVs. If a GCP is placed in the overlapping zone it will most likely be visible in at least two or more images and make georeferencing easier. Even though a plan was made for exactly where the GCPs should be placed, there was a chance that the position of some GCPs would have to be adjusted due to obstructed visibility from above. The flight plan made it possible to say that no GCP should be moved more than 50 m either direction from its given position. This limitation ensured that all points meant to be within overlapping zones were still remained visible in other images. In the field, the ground markers were distributed by first driving to the general region of the point, following the GPS device to the correct location, then assessing the visibility from above and

repositioning if necessary. A coordinate GCP form is provided in Appendix iv, this should be filled in with the GCP positions derived from a flight plan and later used in the field to document their actual GPS position.

Software

Once data acquisition is over and the images have been uploaded to a computer the idea is to put all images together into one image and then georeference that in a GIS. The two computer programs that were used to do this were ArcMap and Pix4D. Pix4D mapper is a program that automatically processes images into one image. During the initial processing Pix4Dmapper computes key points on all images and uses these to find matches in the dataset. Then the software runs an automatic aerial triangulation (AAT) and a bundle block adjustment (BBA). As described on the Pix4D support website, the program can detect what model camera was used from the images and optimizes the camera calibrations with respect to the images. Since this method does not use an internal or external GPS logger, whose files could be read in Pix4D, the GCPs were marked during georeferencing in ArcMap.

Results

The image pixel resolution was altered during the Pix4D processing. This alteration was most likely due to the increase in pixel size that is necessary for the pixel raster to align during the orthorectification process. The fact that each raw photograph had a different image orientation, from inflight camera rotation, the pixel size had to increase to form matching pixel rows and columns. The difference in resolution between the raw photos and the processed images, can be seen in the count of pixels per square meter in Table 2 and the visual comparison in Figure 1. The second method suitability objective, the capability of detecting individual trees, is somewhat affected by this pixel resolution alteration. The projection and coordination system that was used in georeferencing the final Pix4D image in ArcMap, was a conformal projection on Universal Transverse Mercator, UTM, ellipsoid of zone 48 north.

Table 2: Pixel size and pixel resolution by number of pixels in one m^2. Sizes measured in ArcMap.

Image	Pixel size (m²)	Pixels per m²
Raw	0.000437	2288
Processed	0.34	2.9

Figure 1: Visual comparison in pixel resolution between raw and processed images. The pixel resolution of processed images are notably poorer than that of the raw photographs. Individual trees can be dected amongst the older trees, as in image 2b, but not for younger trees as in image 4b. This plays a role in terms of the suitability of the method.

Raw image	Processed image (Pix4D)
1a Netted nursery plant rows	1b Netted nursery plant rows

2a Tree rows

2b Tree rows

3a Corner of house, detail green watering hose

3b Corner of house, no detail
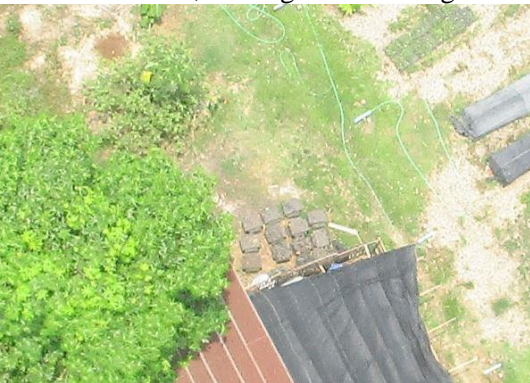
4a Trail among young tree rows

4b Trail among young tree rows

Helium balloon aerial photography

First flight in western area of plantation. 1001 images processed in Pix4D.
Aerial images collected in May 2015. Total image area of 18.1 ha.
WGS 84, zone 48 N. Nabong, Vientiane Province, Lao PDR

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Map 3: Resulting georeferenced aerial photography in the western part of plantation. The images somewhat resemble an upside down U, the inside of the U along the road is where the flight path had to be abandoned due to the 2 m gate.

Helium balloon aerial photography

Second flight in eastern area of plantation. 800 + images processed in Pix4D.
Aerial images collected in May 2015. Total image area of 18.4 ha.
WGS 84, zone 48 N. Nabong, Vientiane Province, Lao PDR

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Map 4: Resulting georeferenced aerial photography in eastern part of plantation. This was captured during the afternoon, and cloud shadows can be spotted in the images.

Helium balloon aerial photography

Aerial images collected in May 2015. Total image area of 36.52 ha.
WGS 84, zone 48 N. Nabong, Vientiane Province, Lao PDR

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0   0.5   1 km
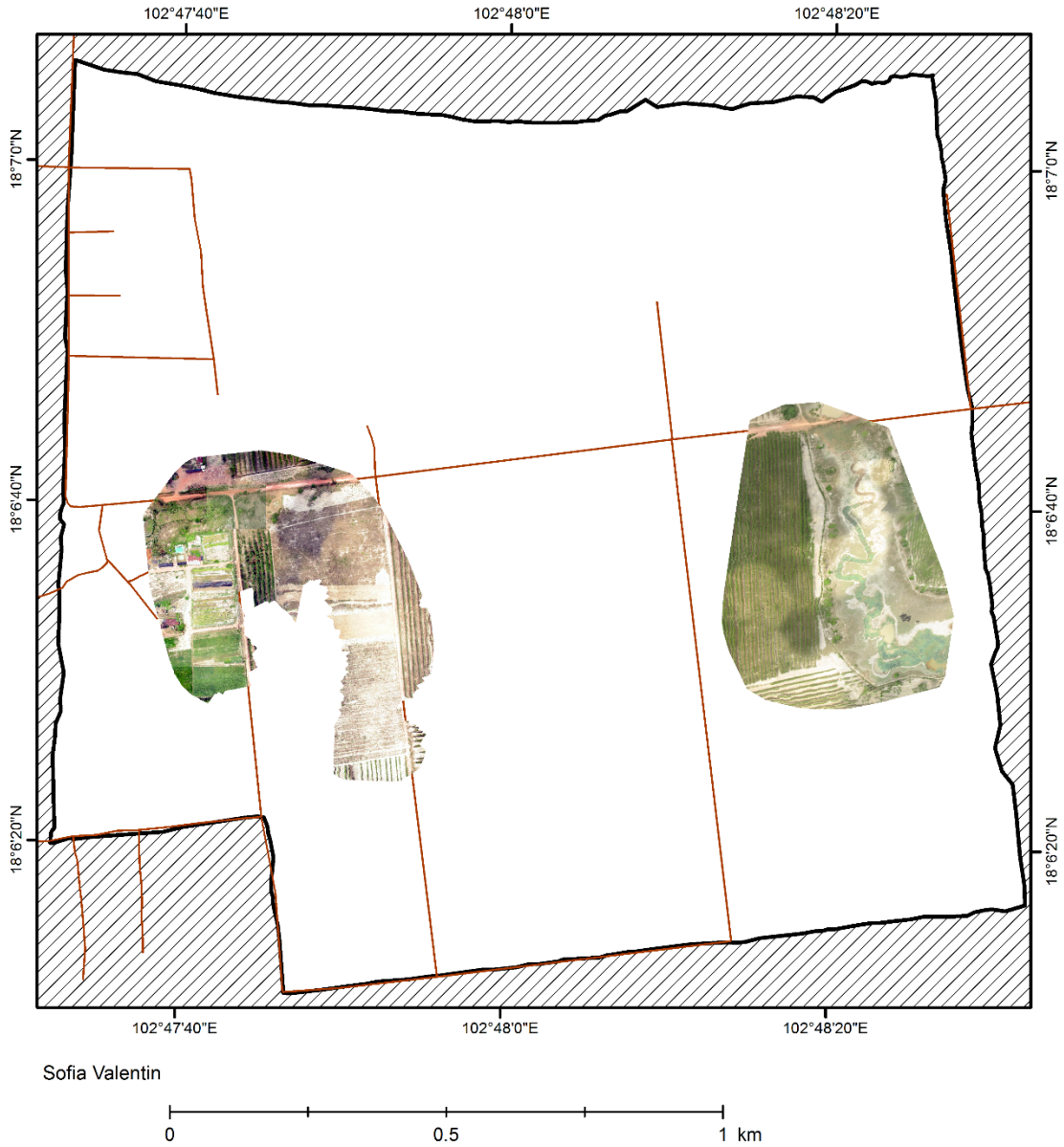
Map 5: Resulting georeferenced aerial photography showing both captured areas within plantation. The aerial photography covers 14.8 % of the 246 ha, or 36.52 ha. The plantation border is shown in black, and roads in orange.

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Table 3: Problems associated with the method and suggested solutions for the refined method.

Problem/Area to improve	Potential Solution	Benefits
Low altitude-Uncertainty of height	Measure temperature and pressure of air at ground level, and inside the balloon before launch, use formula to check helium amount.	Would ensure a height so that the ground control points are recorded.
Low geometric accuracy *no accuracy test has been done	Better suited flight plan and sufficiently distributed GPS points. Distribute more GPS points (depending on the FOV). Using a camera with built-in GPS.	As intended, more known locations will enhance geometric accuracy.
Little coverage	Reaching higher altitude with camera. Make sure there are no unexpected obstacles along flight path.	Enhances chances of capturing expected area. Follow flight path to ensure data acquisition over complete area.
Balloon turbulence	Replace the fan tail with a longer "arrow" tail. Flight should take place during morning, after the shadows are long.	Better aerodynamics. Less turbulent air.
Poor maneuverability	Lines should be attached to the rig instead of metal ring at balloon base.	Less twisting of the lines.
Inflation – ill-fitting tank nozzle	Use a section of a rubber hose, fasten to tank with uninflated party balloons as sealant, then tape. This has been tested and works well.	Gives much more room for movement and freedom to comfortably hold the balloon. No sharp edges near the balloon.
Balloon steadiness during inflation	Use electrical tape instead of rubber bands to secure the balloon while inflating it.	Less hassle and tear on latex.
Unknown altitude	Mark the line before reeling in balloon after data collection. Or use camera with GPS capability. With helium formula this will be less important.	Measuring the line to the mark will derive approximate altitude. Observe z value.

The FOV calculations that were used in the beginning of the project were unfortunately done with the wrong camera parameters. This was not known until after the data acquisition. The horizontal and vertical FOV dimensions were longer at the decided altitude than what correct calculations show. The pixel resolution was lower than obtained in raw photographs.

Table 4: Field of View Estimations by altitude, with incorrect camera parameters. Focal length 5mm, Focal length multiplier 1.5. The altitude of balloon flight was based on this table.

Field of view on ground	Resolution

Altitude (m)	Horizontal distance (m)	Vertical distance (m)	FOV area (ha)	Horizontal pixel/m	Vertical pixel/m	Pixel/m²
100	480	320	15.36	11	12	130
150	720	480	34.56	7	8	58
200	1000	640	64	5	6	31
250	1200	800	96	4	5	21
300	1440	960	138.24	4	4	14
350	1680	1120	188.16	3	3	11

Table 5: Field of View estimations for Canon IXUS 160 by altitude with 5mm focal length, 5.6 focal length multiplier. Also the expected pixel resolution of the aerial photographs. These are the correct parameters, hence these FOV values should have been used during GCP and flight path planning.

Field of view on ground				Resolution		
Altitude (m)	Horizontal distance (m)	Vertical distance (m)	FOV area (ha)	Horizontal pixel/m	Vertical pixel/m	Pixel/m²
100	128.6	85.7	1.1	40.1	45.1	1806
150	192.9	128.6	2.5	26.7	30.0	802
200	257.1	171.4	4.4	20.0	22.5	452
250	321.4	214.3	6.9	16.0	18.0	289
300	385.7	257.1	9.9	13.4	15.0	201
350	450	300	13.5	11.4	12.9	147

Discussion

The main results of this study are the aerial photography maps, the pixel quality of these and the suggested modifications to the method. The image results can be seen in Map 3 – 5, 3 and 4 depicts two individually mapped areas and Map 5 shows these two areas within the plantation borders. The intention of data collection had been to gather images for the entire 246.8 ha agroforestry plantation, this was unfortunately an over-optimistic target, since the data collected covered only 36.5 ha, or 14.8 percent of the expected area. The unexpectedly low coverage was due to the balloon and attached camera reaching an altitude much lower than 250 m, the altitude the GCP positions had been based upon. A back calculation of the image size through the FOV online calculator yielded an altitude of 75 m, and a trigonometry back calculation done on four georeferenced images supports this altitude by yielding a 73 m average. This means that the helium balloon was not inflated with enough fuel, which in turn was due to a naïve approach in the fuel decision process, as well as difficulty finding and defining helium volume in Lao. It is clear that this is the key issue impacting the effectiveness of helium balloon aerial photography method.

Based upon the infield experiences, I have developed a number of recommended changes for the balloon method to achieve its full potential. In order for this method to be reliable, there needs to be a process for ensuring the balloon's floating altitude is high enough to comply with the coverage and GCP plan. One such process has been formulated and requires some measurements to be taken in field. Air pressure, air temperature and helium pressure and helium temperature inside the balloon will need to be measured before the balloon is completely sealed. This gives the operator a chance to insert the observed values into the equation, to check if there is sufficient fuel in the balloon before launch. The procedure is described in

more detail in Appendix iii, which has been put together by consultations with Vaughan Phillips, senior lecturer and researcher in meteorology at Lund University, as well as physics student Alexander Bengtsson at Lund Technical Faculty. By utilizing this helium check procedure, I hope that the method will become more reliable in terms of collecting more image data and allowing all GCPs to be captured for accurate geographic anchoring. The fuel estimation formula remains untested, but should assist future efforts with the method in deciding on the appropriate gas amount.

It is possible that operating the balloon would be easier with higher altitude. When the balloon only reached approximately 75 m the lines slacked significantly, meaning they were pushed in the wind direction horizontally along the ground and after that shot up into the sky similarly to an exponential equation. This made the balloon difficult to maneuver among objects that were never expected to be obstacles. During image collection the flight path had to be abandoned because of a gate that was around two meters high. Even a stand of young Acacia trees had to be rounded, which did not bode well for the part of the flight in between the mature tree rows. Another element that made data collection challenging was the wind. While in the planning stage, photographs were expected to be directly above the balloon operator, but in field this was not the case. Even slight wind makes it difficult to understand what area is being photographed. Wind direction should be carefully considered if photographing narrow strips or complex shapes. Increasing the flying altitude, to allow greater capture area, might be the simplest solution in that case.

Acquiring helium in Lao PDR was not an easy task. A Lao party store was found in the Si Muang district of Vientiane that imports helium from neighboring Thailand, otherwise local balloon vendors make their own lighter-than-air gas. If planning to use this method, one should start with locating a source of pure helium and order well in advance. Although helium is one of the most abundant elements on Earth it is also considered rare, according to wallstreetdaily.com our supplies on Earth will only last 25 more years (Goldberg 2015). And of course as the supply dwindles, the prices rise (Cima 2015). The price that was paid in Lao was 1000 SEK for around one cubic meter of helium, with the same amount in deposit for the tank. Helium was not the only cost for this study, there was also material for the rig, the camera, the chloroprene balloon, and to take a step further, the cost of labor. The costs are summarized in Table 6 below. The labor cost was added to put the method in perspective to other aerial photography methods that include an operator's cost. Table 6 is the budget for a first time user since the method provides a design for the camera rig, methods for helium, altitude estimations, and ground control points and does not include the hours of research. For the interested that means that approximately 10 hours of labor go towards building the rig, the GCP markers, planning camera altitude and GCP distribution, as well as the infield preparation and the image acquisition. At least half of the hours are spent infield nailing down GCPs according to the flight plan and gently walking with the balloon, this time also depends on the size of the study area. The area in this case ended up being 36.5 ha, if planning to cover more than 40 ha, additional time for data acquisition should be allowed. One should keep in mind that most materials in this study were bought in a developing country and prices vary with location.

Table 6: First time cost of project, including 10 hours of construction, preparation, and balloon operation.

Item	Cost (SEK)	Notes
Camera	990	Digital compact camera
Materials for rig	500	
Chloroprene balloon	365	
Helium	1 000	Around 1m³
Labor	1 800	180 SEK/hour x 10 hours
Total	**4 655**	

To put this cost, 4 655 SEK, in perspective and decide if this is an inexpensive method or not, some alternative aerial photography acquisition methods need to be looked at. One obvious alternative method is utilizing a UAS platform. Drones can be bought in a wide range of qualities and costs from 400-16 000 SEK ($50-$2000), but they can also be rented or hired with a drone operator. The cost per hour of a drone and its operator runs around 3 300 – 6 700 SEK ($400-$800) an hour. However, even though they are relatively expensive per hour, the capabilities of drones are preferable. They are powerful enough to carry additional equipment such as light detection and ranging, LiDAR, which is an excellent tool for creating digital elevation models. Consulting firms can also have near IR and multispectral capabilities for the same or similar price as aerial photographs (dronehire.org 2015) (AAM Group 2015). They are also much more reliably steered than the helium balloon and run on battery instead. The absolutely cheapest platform for aerial photography would be the kite because it needs no fuel. However its reliance on constant wind makes it an unviable option for forests in central Lao. There is also the option of buying satellite images. Satellite images are of high photogrammetric precision and can be ordered over a specified area for a cost of 200-1200 SEK ($25-150) (mapmart.com 2015). Unless satellites are geostationary, data is not necessarily available all the time and resolutions vary. An additional benefit of ordering satellite imagery is that infrared wavelength data is most likely available to order as well. Infrared allows for vegetation health monitoring and moisture content analyses (Dare et al. 2001). However if you want to collect aerial photography, the plausible options are either to purchase a drone or hire a consultant. For two hours a drone consultant could charge around 10 000 SEK. If a drone was purchased, the DJI Phantom 3, for example costs 9 190 SEK (DJI.com 2015). Less hours would have to be spent preparing and the data acquisition would also be much faster than in the helium balloon method. If three hours of labor is added onto the drone cost for a total 9 730 SEK, the cost of a drone consultant is only a few 100 SEK higher. When viewed in perspective to the drone costs, the helium balloon method, with its first time cost, is roughly half the price and can be considered relatively inexpensive.

In the *Results* section, Table 3 summarizes some of the problems that were noticed in the field. The area that was the most in need of improvement was the low altitude, which was mentioned in the beginning of the *Discussion*. This problem should be circumvented by following the helium estimation procedure in Appendix iii. It should be kept in mind that this is an untested estimation procedure that for simplicity has excluded elements such as the pressure exerted on the helium by the balloon latex or its bursting pressure. The image results from this study captured no GCPs, and therefore had to be anchored by the vector shapefiles that existed; a few houses and roads. Therefore the problem of low geometric accuracy will not exist if the camera ascends to the altitude that GCP distribution was planned according to. The problem of low coverage is also attributable to altitude, with higher altitude more area will be covered in the collected images. The balloon turbulence was not a major hindrance to data collection, but the aerodynamics of the rig could be improved by replacing the fan tail with a longer smaller arrow-like tail. By attaching the two control lines to the rig, through two attachment holes opposite to one another, instead of to the metal ring between rig and balloon, the balloon could have better maneuverability. If the balloon operators spread out along the path, one ahead and one behind the balloon, and put more tension on the lines, it could be easier to both steer and understand what is being captured by the camera. If the helium tank is fitted with a short nozzle, one can extend it by tightly wrapping some uninflated party balloons around the short nozzle and then weld on a section of a pipe. The party balloons acts as a sealant so no helium can escape by being channeled along the pipe section. Having a longer nozzle creates a safety distance from the tank to the balloon while it's being inflated. A modification already employed in the field was using electrical tape instead of rubber bands to fasten the balloon neck over the nozzle. To help verify the altitude as the balloon is ascending the control lines should be marked every 50 m or so. This could also help to verify the helium estimation procedure while in field.

The raw aerial photography was 5152 by 3864 pixels large and when georeferenced this equated to a 294 pixels per m² resolution. It has to be noted that the first FOV calculations, shown in Table 4, was incorrect. The wrong focal length multiplier was used and this resulted in a much larger expected area of

capture. Hence the altitude of 250 m was decided upon because of an incorrect capture area. Table 5 shows the FOV calculations with the correct focal length multiplier of 5.6. Table 5 shows a much closer relationship to the horizontal and vertical dimensions of the aerial photographs, as well as the pixel resolution. At roughly 75 m altitude a raw image had estimated dimensions between 83 by 60 m to 105 by 70 m, with a pixel size around 34 cm² and a pixel resolution of about 2288 pixels per m². This resolution is fairly high and, as can be seen in Figure 1, significant detail is available in the raw images. Particularly in 3a, a green watering hose can be seen very well, a feature that in reality is roughly 2 cm wide. This resolution allows for identification of individual trees, and is therefore high enough for potential usage in agroforestry management. However once the images were processed in Pix4D, the pixel resolution was reduced to only 3 pixels per m². This resolution is fine for mapping and monitoring, individual trees can sometimes still be identified, but is not ideal. The reduction in pixels is thought to be partially due to the matching of "pixel rasters". Since the camera spun during data capture, pixel rows and columns are not always facing the same directions. This makes alignment harder and pixels have to be enlarged to incorporate differently rotated pixels. Unfortunately when photographs are put through any process that transforms pixels, to fit a certain topography and projection, their resolution will most likely be altered in some way. Perhaps if the GCP would have been visible in the raw images, and these were identified in the Ground Control marking that can be done in the Pix4D program, this alteration can be minimized. This theory will have to be tested when the method is replicated with the recommended implementations.

Conclusion

The small format aerial photography method developed in this study does function. The method could be a useful monitoring tool for everything from first aerial investigations in smaller companies or organizations to interested "do-it-yourselfers" due to its relative inexpensiveness. The resolution it delivers, dependent on altitude, is high enough to detect details necessary for inventorying trees. With proper altitude and GCP placement the reduction in raw image resolution during processing can likely be avoided. And thus, the final maps can be equally high in detail. The method involves significant time and effort spent on planning ground control, estimating fuel amount, as well as the actual data acquisition process. However, with the modifications produced during this investigation, the method is now better equipped for successful data capture.

The terms of suitability, which applies mostly to the preliminary investigation that Burapha Agroforestry Co was interested in, were that the method should be relatively inexpensive, easy to use, and produce good enough resolution to detect individual trees. I would say that the method is very near to meeting these three requirements. With labor costs, the method is still cheaper, but close to the cost of UAS operator fees, and the ease of using the balloon will increase with experience, but has included some challenges. How easy the balloon is to use will have to be reassessed when the recommended changes to the method described in this report has been tested. I could recommend testing this method to environmental monitoring do-it-yourselfers and aerial photo enthusiasts that already have a compact camera, time and operate the balloon themselves.

The suitability of this method in agroforestry applications is uncertain. More testing of the method is required in order to see if obstacles still occur while maneuvering the balloon along a flight path. If trees still become obstacles the method will not be suitable, in which case drones are likely to be more suitable. In the long term, a number of factors could render the balloon method obsolete. The fact remains that drone platforms are only becoming more affordable and reliable while the supply of helium gas is dwindling. Ultimately, this means that even if the modifications solve the problems associated with altitude and GCPs, in a number of years this method might be more expensive than utilizing a UAS platform.

APPENDIX

i.   Balloon launch instructions
ii.   Field of view FOV trigonometry
iii.   Helium calculation
iv.   GCP Form

Appendix i

Balloon Launch Procedure

Before starting the inflation of the weather balloon it is important to read through these pages: Inflation Procedure (http://www.highaltitudescience.com/pages/how-to-inflate-a-weather-balloon) and Tie off Weather Balloon (http://www.highaltitudescience.com/pages/tying-off-a-weather-balloon). To make sure you are bringing all the necessary materials into the field, go through the Pre-flight checklist.

Pre-flight checklist:

Canon IXUS Camera (set to Continuous Shooting Mode and Large quality photos)

2 x Canon batteries, fully charged + battery charger

 8GB SD memory card, + extra memory card

Laptop that can upload images from SD card

Balloon rig, with foam casing and carabineer clip

Rubber band trigger

Gloves for everybody involved

2 reels of fishing line tied to metal ring with anti-break knots

Electrical tape + rubber bands

Helium tank + nozzle

Weather balloon and the extra balloon (do not open until launch prep)

Measuring band without sharp edges

GPS device: Garmin GPSmap 62s (datum and spheroid set to WGS 84 and position format Meters)

Flight Plan

GCP Form

Launch

The Balloon Flight Procedure document was taken into the field for guidance and as a checklist before driving to the plantation. It contains the steps for ground control marking, inflating and launching the balloon. Presented below are the launch steps after the preparation work:

1. Place the helium tank in an open area near GM01. Screw on the balloon nozzle.
2. Have the Tie Off kit ready (electrical tape and rubber bands)
3. Place some rubber bands over the nozzle onto the hose.
4. Carefully unwrap the balloon and have at least one person gently hold it in their hands, slide on the balloon neck onto the nozzle, taking care not to poke it. Place the rubber bands over the neck to secure it, but make sure it's not too tight.
5. Slowly open the helium and let the balloon rise in the hands of the helpers. Keep an eye on the neck of the balloon, don't let it twist as this will form a bubble and pop it. Always keep one hand on the gas valve, for such emergencies.
6. Once the balloon is floating and nearing 120cm, measure the width of the balloon with the help of the white string (it is 170cm long, with a knot at 120cm). Use the string instead of a measuring tape to avoid any sharp edges near the balloon.
7. Be sure to turn off the helium.
8. Have a helper grip the balloon on the upper neck, carefully take off the rubber bands and slide off the balloon. Use a couple of rubber bands as one, and twist tie one under the helper's hand. Then tie another one a little further down on the neck. Put the ring or clip in between the bands and fold the neck around it. At this point you can see and feel if the balloon will lift the camera rig and decide if more fuel is needed. Tie some bands around the folded neck over the ring to secure it.
9. Wrap electrical tape around neck, down through the ring and up around the neck, so that all rubber bands are covered.
10. Clip the rig onto the balloons metal ring with the carabineer clip.
11. Make sure the fishing lines are securely tied to the balloon or rig.
12. Set the camera by pressing power, slipping the trigger over the button, and laying the camera in the foam. Make sure the rig is straight and that the camera has a clear view.
13. Set a timer to remind you when the camera is full.
14. Make sure there is nothing blocking the balloon's ascent and let line run slowly. Keep an eye out for how much wind the balloon catches.

Walk along the flight path and stop for about a minute at every stabilization point (center of image foot prints), to make sure a clear image of this area is produced. Be careful to avoid power lines etc. If the timer rings while data acquisition is ongoing, the balloon has to be brought down in a very cautious manner, preferably in an open area where the balloon cannot get caught in anything. The balloon has to be secured while battery and SD card is changed.
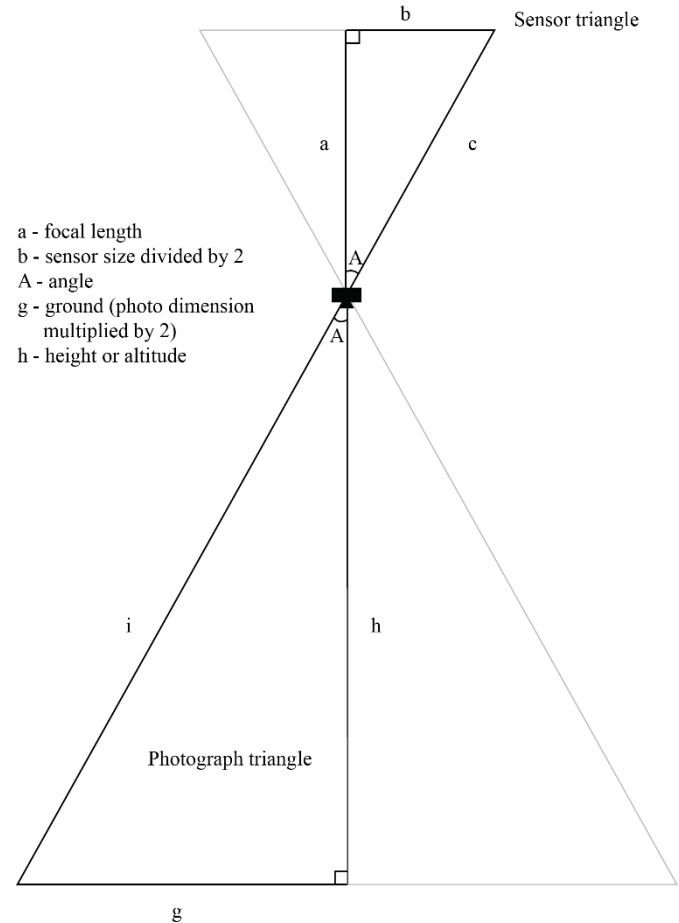
Appendix ii.
Manual method: Field of view trigonometry

In order to find out the cameras field of view you have to know some specific camera parameters as well as the distance to the subject, or the altitude. The FOV has to be calculated twice, once for each side of the camera sensor (horizontal width and vertical length). The horizontal and vertical FOV corresponds to the width and length of the image footprint, simply multiply the two to get an area estimation. Below are listed the parameters for Canon IXUS 160, but details for other camera types can be found via manufacturer.

a - focal length
b - sensor size divided by 2
A - angle
g - ground (photo dimension
    multiplied by 2)
h - height or altitude

Sensor size: 6.17 x 4.55 mm
Focal length: 5 mm
Altitude: 250 m

Sensor triangle — Photograph triangle (with labels b, a, c, A, g, h, i)

Sensor Triangle
1. Use Pythagoras theorem; the square of the hypotenuse is equal to the sum of the squares of the remaining sides, to calculate c.

$$c = \sqrt{(a^2 + b^2)}$$

2. Find angle A by using an inverse trigonometric function. There are 3 alternatives; sin (A) = b / c, cos (A) = a / c, or tan (A) = b / a.

$$A = \tan^{-1} b/a$$

Ground Triangle
3. To find the length of the g side of the triangle, there is only one possible equation.

$$g = \tan(A) * h$$

4. Multiply the answer, g by 2. Then repeat the process for the other side of the sensor.

Field of view result
5. The two g's multiplied by 2 make up the horizontal and vertical dimensions of the image footprints. This estimation has a small error margin in low altitudes, but it increases exponentially with height in comparison to other Field of View calculators that are easily found online. This is due to focal length multiplier is not taken into consideration in this FOV approximation.

Appendix iii

Helium Estimation

This estimation procedure will take place in the field, and therefore an altitude for flying the balloon, z, will have been decided already, this can be filled in the table for variables and constants gathered below. M, weight of equipment, should be measured before the field day while temperatures and pressures should be measured on site once the balloon is inflated to roughly 120 cm diameter, and pulls upward. Measure temperature and pressure at a one meter height above ground and document the values in Table 1 below.

Table 1: Variables and constants to be used in equations of Table 2

Symbol	Meaning	Value	Units	Notes
T_0 *Air*	Temperature outside balloon (air)		K	Measured at 1 m height
T_0 *He*	Temperature inside balloon (helium)		K	Measured at 1 m height
P_0 *Air*	Pressure outside balloon (air)		Pa	Measured at 1 m height
P_0 *He*	Pressure inside balloon (helium)		Pa	Measured at 1 m height
M	Weight balloon and equipment		kg	
z	Altitude		m	
ρ *Air*	Density outside balloon (air)		kg m^{-3}	To be calculated
ρ *He*	Density inside balloon (helium)		kg m^{-3}	To be calculated
Cp *Air*	Specific heat capacity at constant pressure for air	1010	J kg^{-1} K^{-1}	Constant
Cp *He*	Specific heat capacity at constant pressure for helium	5190	J kg^{-1} K^{-1}	Constant
R *Air*	Gas constant for dry air-	287	J kg^{-1} K^{-1}	Constant
R *He*	Gas constant for Helium	2077	J kg^{-1} K^{-1}	Constant
g	Gravity	9.81	m s^{-2}	Constant
H	Height Scale	7300	m	Constant

Table 2: Equations with brief explanation of output

#	Equation	No. of variables	Purpose
1	$T(z) = (-g/Cp) * z + T_0$	2- altitude, temperature	Estimates temperature at height z, calculated separately for air and helium
2	$P(z) = P_0$ EXP $(-z/H)$	2- altitude, pressure	Estimates pressure at height z, calculated separately for air and helium
3	$\rho = P(z) / (R * T(z))$	2- pressure, temperature	Calculates density for pressure and temperature at height z, calculate separately for air and helium
4	$V = M / (\rho \, Air - \rho \, He)$	2- densities	Calculates volume of balloon from density difference at height z

The variables and constants from Table 1 and the equations from Table 2 combine into one volume formula, Equation 5, shown below. The four infield measurements and the equipment weight should be entered into the equation and the output volume should be compared to the infield or current size of the helium balloon.

$$V = \frac{M}{\dfrac{\mathbf{P}_0\,\boldsymbol{Air}\;EXP\left(\frac{-z}{7300}\right)}{287 * \left(\frac{-9.81}{1010}\right) * z + \mathbf{T}_0\,\boldsymbol{Air}} - \dfrac{\mathbf{P}_0\,\boldsymbol{He}\;EXP\left(\frac{-z}{7300}\right)}{2077 * \left(\frac{-9.81}{5190}\right) * z + \mathbf{T}_0\,\boldsymbol{He}}}$$

The volume can be viewed as a diameter measurement to help with observing the difference in current and altitude appropriate volume. To find the diameter the balloon should be filled to, plug in the volume, V into this diameter equation, derived from a regular volume of a sphere equation.

$$Diameter = \sqrt[3]{\frac{3V}{4\pi}} * 2$$

Measure the balloon's current diameter and if the diameter based on the calculated volume is bigger, continue inflating the balloon until they are the same. If it's smaller, deflate the balloon a little. It should be pointed out that this helium volume estimation does not consider the pressure added by the latex balloon, or its expanding ability. Therefore the balloon altitude should probably not be higher than 300 m since the bursting pressure of the latex balloon is unknown.

Appendix iv

GCP coordinate form

GCP Marker	Flight Plan		In Field	
	Latitude	Longitude	Latitude	Longitude
GM01				
GM02				
GM03				
GM04				
GM05				
GM06				
GM07				
GM08				
GM09				
GM10				
GM11				
GM12				
GM13				
GM14				
GM15				
GM16				
GM17				
GM18				
GM19				
GM20				
GM21				
GM22				
GM23				
GM24				
GM25				
GM26				
GM27				
GM28				
GM29				
GM30				

GIS coordinate system:

GPS coordinate system:

Movability of GCP:

Reported by:

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