A UAV Lidar & Multispectral System to Explore the Amazonian Rainforest

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Abstract. In this paper, the initial work of realizing a robust unmanned aerial remote sensing system, equipped with a survey-grade Lidar scanner and a multispectral camera, to study the pre-Columbian Amazonian archaeology are presented. The data collected from this system will be utilized in a novel inter-disciplinary way by combining these data with in-situ data collected by archaeologists, geographers and other specialists to study the nature and scale of the impact of pre-Columbian humans in transforming the landscapes of the Amazonian rainforest. The outputs of this project will also give us insight on the conservation and sustainability of the forest.

Keywords: remote sensing, image processing, geology sensoriamento remoto, processamento de imagens, geologia

1. Introduction

The Amazonian rainforest is a cradle of global biodiversity and plays a significant role in regulating the Earth's climate. Its protection, conservation, and the development of sustainable land-use practices in Amazonia are therefore a global concern (LEWIS, 2006; BONAN, 2008). In order to better understand this aspect of the Amazon, it is imperative that the role of ancient humans in transforming the Amazonian landscapes, and the extent of such modifications, are thoroughly understood.

The role of pre-Columbian humans in shaping the Amazon rainforest is highly debated. While one school of thought believes that pre-Columbian Amazon was a pristine, unspoilt, *virgin wilderness* with negligible human impact(RONNENBERG; BRADSHAW; MARQUET, 2002; MEGGERS, 1973; STEWARD, 1963; WILLEY, 1966), the other group hypothesizes that the rainforest was thriving with inhabitants distributed in social groups throughout the Amazon who actively managed the forest according to their lifestyles. This hypothesis, called the *cultural parkland* hypothesis, is based on the discovery of domesticated landscape features like raised-field agriculture, highly modified anthropogenic soils called Amazonian Dark Earths (ADEs), hundreds of massive geometrically patterned earthworks called geoglyphs and ring-ditches, clusters of villages, well-planned mound complexes as well as the dominance of useful plants in proximity of certain rivers(DENEVAN, 2001; BALÉE; ERICKSON, 2006; SCHAAN, 2013; ROSTAIN, 2012; LEVIS et al., 2012). Some of these ancient landscape features in Amazonia have been revealed as a result of deforestation activities hinting that there is a high probability that many such features are still hidden under the forest waiting to be discovered (see fig.1).

Aerial remote sensing using a high resolution Lidar is a novel and more practical method of finding under forest archaeological sites than manual ground survey. Lidar works on the same principle as Radar and Sonar. Instead of using microwaves and sound waves to calculate

Figure 1: Geoglyph partially revealed due to deforestation.

distance to a target as in the case of Radar and Sonar, respectively, airborne Lidar uses harmless laser pulses in infrared wavelengths to calculate the distance to the terrain below, resulting in a high resolution three dimensional point cloud. However, the real superiority of airborne Lidar lies in its ability to penetrate vegetation and reach the ground below. Effectively, if there is a high density of Lidar ground points, a three dimensional representation of the ground surface below the vegetation can be reproduced by connecting tiny planar surfaces representing neighbouring points e.g. the Triangulated Irregular Network (TIN) (RENSLOW; PHOTOGRAMMETRY; SENSING, 2012). In this respect, Lidar is often regarded as having the capability to see through vegetation, and can be used to identify previously unknown archaeological sites (PRUFER; THOMPSON; KENNETT, 2015; CHASE et al., 2011; EVANS et al., 2013; DAUKANTAS, 2014). In addition, unlike manual survey, airborne survey has the advantage of covering far greater area in a much shorter time as well the ability to record data over inaccessible remote regions of the Amazon rainforest.

This paper briefly introduces the state-of-the-art aerial remote sensing system assembled to document the archaeology in Amazonian rainforest in order to assess the nature and scale of pre-Columbian landscape transformations in Amazonia. It consists of a fixed-wing unmanned aerial vehichle (UAV), a survey-grade Lidar scanner, and low-cost multispectral cameras.

The remaining sections of the paper are organized as follows. Section 2 explains the potential of airborne Lidar in exploring Amazonian archaeology. Section 3 presents the remote sensing lidar/multispectral system. Section 4 lists the conclusions and future work.

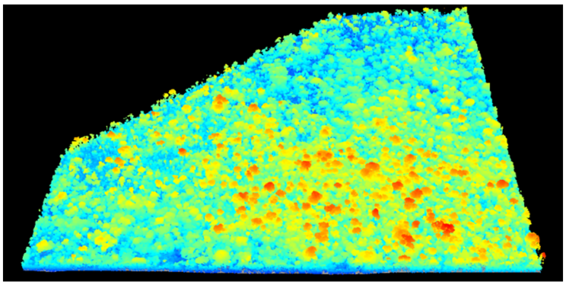
2. Potential of Lidar in Amazonian Archaeology

Considering a Lidar scanner with a fixed laser wavelength and power, the density of ground points on a given area depends on the type & thickness of the vegetation, the measurement rate of the Lidar scanner and the total data acquisition time[1]. The controllable factors are only the latter two. The higher the laser measurement rate and the longer the acquisition time the higher the density of the ground points for a given area. The minimum density of ground points required to identify an archaeological feature depends on its size. However, there is no strict rule of computing this minimum number and it can be more or less empirically determined.

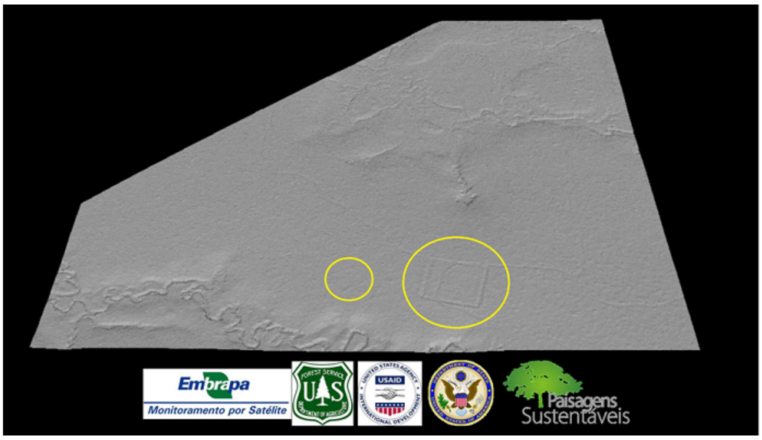
In order to demonstrate the potential of using airborne Lidar data to detect archaeology under the Amazon rainforest, a vegetation removal algorithm was applied to Lidar data collected in Brazilian Amazon under the Sustainable Landscapes Brazil (Paisagens Sustentáveis Brasil) Project. One such data, called the Bonal data, refers to the survey carried out in Rio Branco municipality, Acre state, Brazil. The Bonal data was acquired on 16-09-2013 using the Optech

[1]Data acquisition time also includes repeated passes over the same area.

(a) A data tile from Bonal site - Google Earth



(b) Colour coded Lidar data tile



(c) Vegetation removal algorithm reveals possible geoglyphs

Figure 2: Airborne Lidar data collected in Bonal, Rio Branco municipality, Acre, Brazil reveals under-forest geoglyphs.

Orion laser scanner operating from an altitude of 900m with a flightline overlap of 65% covering a total area of 600ha in 14 data tiles. The average point density was calculated to be approximately 33.39 ppm^2 (points per square meter).

The application of vegetation removal algorithm on one tile of Bonal data is depicted in Fig. 4. Fig. 4 (a) shows a Google Earth image of Bonal data tile demarked in yellow. The Lidar data of the Bonal data tile, colour coded by height, are shown in Fig. 4 (b), while Fig. 4 (c) shows the ground surface formed by connecting the neighbouring ground points using a TIN after removing the non-ground/vegetation points. A close inspection of the ground surface reveals two rectangular features in close proximity to each other, marked by yellow circular boundaries. It is highly likely that these are geoglyphs, especially the larger, more prominent one, owing to the presence of many geoglyphs nearby exposed due to deforestation. However, this is yet to be confirmed by physically visiting these sites.

3. Remote Sensing System

The remote sensing system consists of the NAURU 500B fixed wing UAV system fitted with the survey-grade VUX1-UAV Lidar scanner and two multispectral cameras. The system is explained in more detail in the following sections.

3.1. NAURU 500B UAV

The NAURU 500B is a fixed-wing UAV developed by a Brazilian company, Xmobots. It is a fuel-run UAV with a 55cc 2-stroke engine. It has a wing span of 3.6m and a maximum takeoff weight of about 25kg. It can carry approximately 5.5kg of payload weight with an autonomy of around 2.5 hours and has a stall speed of 31 knots. It requires a runway of about 100m x 10m

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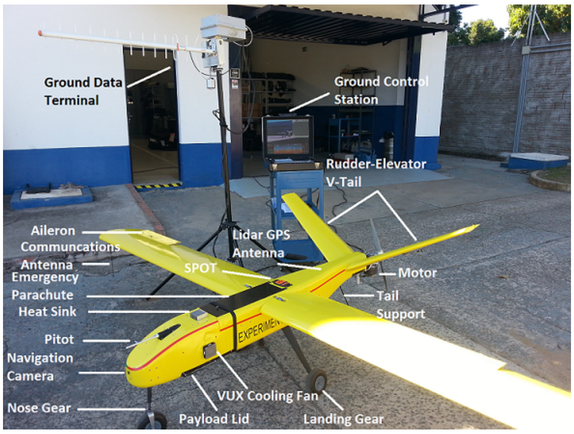
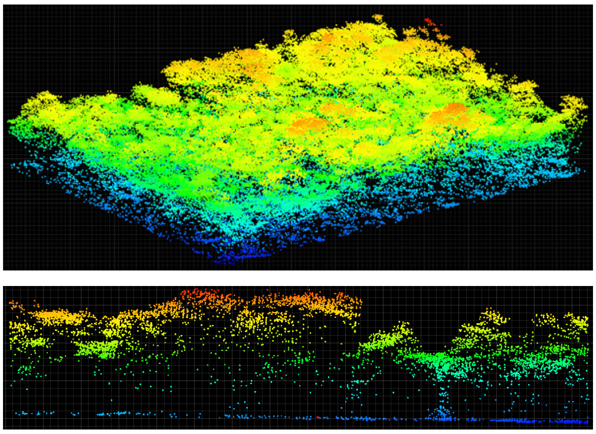
for safe takeoff and landing. NAURU has an autopilot system which can automatically execute a flight mission once the UAV has taken off manually. After completion of the mission, the UAV circles around the base station before it is manually landed by a remote control pilot. The UAV also includes a ground control station (GCS) and a ground data terminal (GDT) with an antenna that automatically tracks the aircraft. The GCS receives the flight telemetry, including the navigation camera video, through the GDT to continuously monitor the mission, and also control the aircraft and its payloads from a single user terminal. The NAURU 500B UAV, GCS, and GDT are shown in Fig. 3.1 (a).



(a) NAURU 500B fixed-wing UAV by Xmobots.



(c) Forest structure in 3D.

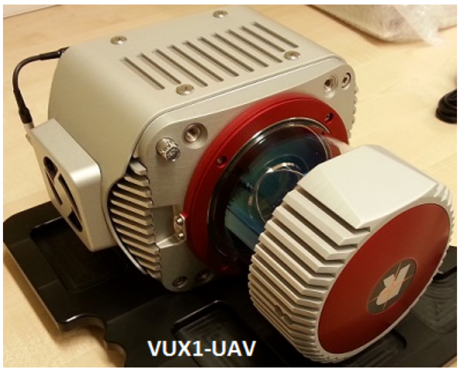
Figure 3: Nauru 500B UAV and Lidar data collect during one of its test flights on Jun 29, 2016 near the city of São Carlos, São Paulo state, Brazil.

3.2. VUX1-UAV Lidar

The VUX1-UAV by RIEGL is arguably the first survey-grade Lidar scanner designed for UAV applications. It has a class 1, eye safe laser with a maximum effective measurement rate of 500,000 measurements/sec, a field of view of 330°, and a maximum operating flight altitude of 350m. It is a light-weight and compact equipment weighing about 3.85kg and measuring 227 x 180 x 125mm in dimensions. It requires a voltage input of 11-32 V DC and typically 60W power. Due to its high measurement rate it can produce a dense point cloud, e.g. at 380 kHz pulse repetition rate, flying at a speed of 50 knots, and a range to target of 250m, the point density is approximately 10 ppm^2 with a decimeter level accuracy. The point density can be further increased by overlapping adjacent flight lines. The VUX1-UAV Lidar scanner and its integration in NAURU are shown in Fig. 3.1.

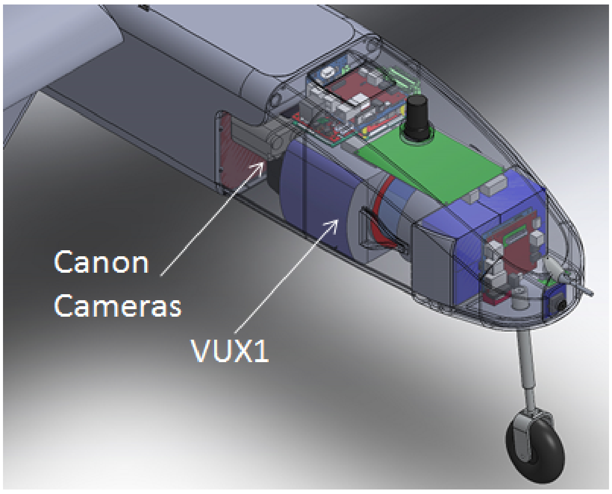
3.3. Multispectral Cameras

Two low-cost multispectral Canon Powershot cameras (16 Megapixel) are also installed in the NAURU UAV. Together they form a 5-band multispectral system with one camera capturing in Blue-Green-NIR 680-800nm, while the other camera capturing in Green-Red-NIR 800-900nm. The camera settings are adjusted to suit aerial photography e.g. the focus is set to infinity, shutter speed and aperture conditions are set for the conditions etc. The cameras are installed in the fuselage of NAURU and are simultaneously triggered to take photos such that a pre-defined frontal overlap between adjacent photos is maintained. Similarly, the adjacent flight lines are also planned in such a way that the desired lateral overlap is achieved. Fig. 3.1 shows one of the two identical multispectral cameras and their integration in NAURU's fuselage.



(a) VUX1-UAV Lidar Scanner by RIEGL

(b) Canon PowerShot Elph110HS Camera



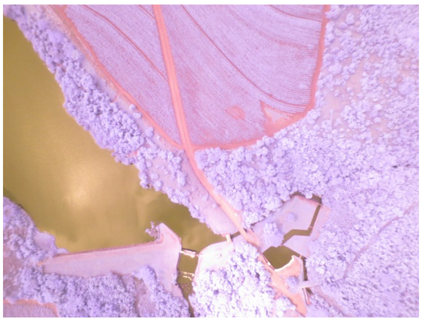
(c) Integration of Payloads in NAURU (courtesy Xmobots).

Figure 4: System payloads and their integration inside Nauru 500B aircraft.

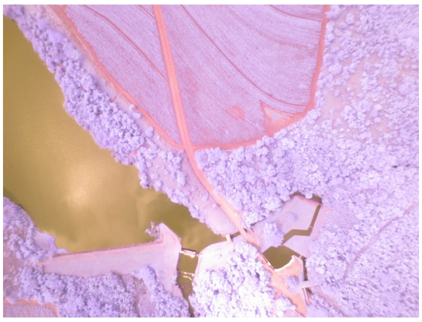
3.4. System Status

The NAURU UAV flight tests were performed in September and October, 2015, and June-July, 2016. Many flight missions were successfully completed which tested manual take-off/landing, automatic/semi-automatic mission execution using GCS, automatic tracking and communication range of GDT, live navigation camera video and flight telemetry at the GCS, and cruising and stall speed of the UAV. The Lidar scanner and multispectral cameras were also installed in the UAV, and aerial data were acquired. The VUX1 laser scanner has been integrated in the UAV, and a mock weight was included in NAURU's fuselage during testing to simulate realistic flight conditions. Fig. 3.1 (c) shows the three-dimensional (3D) Lidar point cloud acquired over a forested area along with its cross-sectional profile view. The point cloud is coloured by height. Similarly, Fig. 5 shows sample images captured from the two cameras in a test mission.

The images acquired from the multispectral cameras had the following issues: 1) they were not always properly focused despite setting the focus to infinity and disabling the auto-focus function, 2) the two cameras did not always trigger exactly at the same time with an average gap of about 20 ms resulting in additional processing to register the images between the two cameras. One solution to co-register the images from the two cameras is to first build the mosaic from the images from each camera and then use common features/markers between the mosaics to register them. The possible solutions to both of the above issues are currently under investigation.



(a) Green-Red-NIR 800-900nm camera



(b) Blue-Green-NIR 680-800nm camera

(c) Corresponding Google Earth Image

Figure 5: Sample photos from cameras.

4. Conclusions & Future Work

Lidar technology has a great potential in exploring the under-forest archaeology in Amazonian rain forest. The remote sensing system presented in this paper has the capability to use a survey-grade Lidar scanner for exploring the hidden archaeology in the Amazon, and also multispectral cameras to analyze the health and spectral properties of vegetation over archaeological sites. Camera focusing and image co-registration between cameras are currently being investigated, while the VUX1 Lidar scanner has been successfully integrated into the Nauru 500B UAV.

In November, 2016 a team of scientists including the authors of this paper are going to the Acre, Brazil to fly the UAV over patches of the Amazon rainforest with high likelihood of finding Geoglyphs under the forest using the VUX1-UAV Lidar scanner data. The results of this expedition will also be shared with at the Brazilian Symposium of Remote Sensing.

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