EXPERIENCES WITH LIDAR CANOPY PENETRATION IN A DENSE TROPICAL RAINFOREST

Martin Isenburg[1] and Hubert Trunzer[2] and Franz Malmer[2]
[1]rapidlasso GmbH, Casparigasse 16, 97286 Sommerhausen, Germany,
Email: martin@rapidlasso.com
[2]Asian Aerospace Services Limited, 23rd Fl, Chamnan Phenjati Bldg, 65/209 Rama 9, Bangkok 10320, Thailand,
Email: {hubert,franz}@asianaerospaceservices.com

KEY WORDS: airborne laser scanning, ground-filtering, point classification, bare-earth terrain, DTM

ABSTRACT: Measuring the height of trees using Light Detection And Ranging (LiDAR) technology is commonly done for management of natural forests, tree inventories in timber, fruit, or palm tree plantations, and is a crucial input parameter for estimating biomass. A fundamental necessity for carrying out such measurements is to first generate an accurate Digital Terrain Model (DTM) that can then be used to compute the relative heights of the tree canopy from those LiDAR returns that hit the highest part of the forest canopy.

In order to create an accurate DTM it is imperative to have sufficiently many so called “ground returns” that are elevation measurements from the bare-earth terrain. For this the laser pulse needs to be able to penetrate all the way down through the tree canopy to the forest floor. For very dense tropical forests with high canopy and many layers of vegetation this can be a challenging tasks as the light of the laser pulse has many opportunities to be reflected or absorbed before hitting the ground. Often none of the light energy will reach the forest floor or the returning ground echo will be too weak to be registered back at the plane. Other conditions such as leaf-on/leaf-off conditions as well as presence of low clouds or fog can further hamper successful canopy penetration of the laser scanner.

In the following we present canopy penetration results of operating a RIEGL LMS Q680i LiDAR system above a dense primary rainforest canopy in Thailand that has an average canopy height of up to 45 meters. Although leaf-on conditions and low clouds were occasionally affecting the penetration abilities of the laser scanner, sufficiently many ground returns were captured to compute a plausible digital elevation model of the bare-earth terrain.

1. INTRODUCTION

Airborne Light Detection And Ranging (LiDAR) technology is used more and more frequently to assist automated natural resource management. A laser scanning system mounted to a small aircraft can efficiently and quickly capture detailed 3D information about vegetation structure for large areas of land. From the point clouds, which are usually the main deliverable of an airborne LiDAR scanning campaign, quantitative vegetation metrics can be derived. These metrics can give decision makers valuable information for management of natural forests or help farmers with tree inventories in timber, fruit, or palm tree plantations. These type of vegetation metrics are also of great interest for climate change as they represent objective arguments in the on-going political and scientific debates. They give quantitative measurements that serve as input parameters for estimating biomass and monitoring gain or loss of the carbon stored in a forest. A fundamental necessity to compute such vegetation metrics from the point clouds captured by the scanner is the availability of an accurate Digital Terrain Model (DTM).

A DTM models the true elevation of the bare-earth terrain without any vegetation or man-made object. It is needed as baseline information in order to compute the relative height of the LiDAR vegetation returns in respect to the ground. Most aforementioned vegetation metrics express the density and distribution of vegetation returns across different heights above the ground. Another standard product is the Canopy Height Model (CHM) that describes the relative height of the canopy instead of the absolute elevation that is described by the Digital Surface Model (DSM). Like the DSM, the CHM interpolates the highest LiDAR returns across the landscape but instead of simply interpolating the elevation of these points (i.e. their z coordinates) it requires in addition that the elevation of the ground is subtracted – either before or after the interpolation step. Hence a DTM is needed.

In order to create an accurate DTM it is imperative to have sufficiently many so called “ground returns” that are elevation measurements from the bare-earth terrain. For this the laser pulse needs to be able to penetrate all the way through the tree canopy down to the forest floor. For very dense tropical forests with a thick canopy and many layers of vegetation this can be a challenging tasks because the energy of the laser pulse has many opportunities to be reflected or absorbed long before hitting the ground. Often none of the light photons will reach the forest floor or the energy of the reflected ground echo will be too weak to be registered back at the plane. Other conditions such as leaf-on/leaf-off conditions as well as presence of low clouds or fog can further hamper successful canopy penetration of the laser scanner all the way down to the ground.

In the following we present the canopy penetration results of operating a RIEGL LMS Q680i LiDAR system above a dense primary rainforest canopy with an average canopy height of up to 45 meters near the Khao Yai National Park in Thailand. Although leaf-on conditions and low clouds were affecting the penetration abilities of the laser scanner, we were able to capture sufficiently many ground returns to compute a plausible digital elevation model of the bare-earth terrain (DTM) with a resolution of 2 meters.

2. DATA COLLECTION

The airborne LiDAR data was acquired with a RIEGL LMS Q680i full waveform laser scanner installed into a Diamond Aircraft “Airborne Sensors” DA-42 fixed-wing plane. The complete system is owned and operated by Asian Aerospace Services Limited of Bangkok, Thailand and based out of the Don Muang International Airport where it is available “on call” for commercial or research surveys with aerial LiDAR and/or imagery.

Figure 1: Some of the hardware and software installed “Airborne Sensors” aircraft used in our experiments.

In Figure 1 we illustrate the hardware setup of the scanning system on the “Airborne Sensors” DA-42 aircraft. Due to the compact measurements of the LMS Q680i full waveform laser scanner, it can be installed into the nose of the aircraft (top left) alongside a Hasselblad medium-format aerial camera. The rotating polygon mirror located behind the glass window gives the scanner a 60 degree field-of-view +/- 30 degree off Nadir (top right). The acquired full waveform data is stored on one of the three SSD disks (bottom left) in RIEGL's proprietary SDF format along with the recorded GPS trajectory and the roll, pitch and jaw measurements of the IMU. While in air the scanning process is controlled using a standard laptop running RIEGL's RiAQUIRE software (bottom right).

Although the best flying conditions for Thailand's rainforests are in the coldest and driest leaf-off season from November to December, we did our test flight during the more humid and foggy leaf-on conditions of August. After all, this was only an experimental test flight with the objective to evaluate if and how well the LMS Q680i full waveform laser scanner is able to penetrate 45 meters of dense tropical vegetation. The actual mission, for which this was a “proof-of-ability” demonstration, was not planned to start until November. The “Airborne Sensors” took off from Don Muang International Airport on a largely cloud free August day with reasonably favorable weather conditions for this time of the year, first heading North past Nakhon Si Ayutthaya and then turning East towards Saraburi and the forested areas surrounding Namtok Samlan and Khao Yai National Park.

Figure 2: The "Airborne Sensors" bringing us to an area of dense rainforest near Khao Yai National Park.

In Figure 2 we show some of the navigational aids on board of the aircraft. We initially had plans to repeat the same experiment with different scanner configurations and different flying altitudes. However, the approaching cloud cover in the target area did not allow us to repeat the scan of the same area. The single strip of LiDAR data used in this paper was acquired while scanning for about 90 seconds at a flight altitude of approximately 1200 meters above ground flying at a ground speed of around 220 km per hour with the scanner set to its lowest pulse repetition rate of 80 kHz and the scanning polygon mirror rotating 10 times per second.

Each second our LMS Q680i generates 80,000 laser shots that are reflected by a rotating polygon mirror with 4 facets. As each of the 4 facets only covers 60 degrees – summing up to 240 degrees – there are no laser shots leaving the aircraft for the 120 degrees of "dead-zone" between facets. This results in an effective scan rate of 240/360*80,000 or 53,333 shots per second fired at the terrain below. These shots are reflected over the length of 10 * 4 or 40 mirror facets, meaning a single scan line contains a sequence of around 53,333/40 or 1333 shots spaced about 12.4 microseconds apart. After each scan line comes a short pause of 8.3 milliseconds during which the polygon mirror rotates 30 degrees to the next facet. For each of these 53,333 shots per second both the outgoing as well as the returning waveform are digitized and stored in RIEGL's proprietary SDF format on the SSD drives. We used RIEGL's RiPROCESS software (version 1.5.8) to extract between 1 and 7 returns from the 4,770,152 pulses stored in the SDF file, generating a LASzip-compressed LiDAR file in the LAZ format – the more storage and I/O efficient twin of the ASPRS LAS format (Isenburg, 2011) – with a total of 7,956,587 points.

The flight altitude and speed above ground described earlier result in an approximate across swath width of 1430 meters along which an approximate 62 meters being scanned along track every second. Hence, we can expect a pulse spacing of about 1430/1333 or 1.07 meters along each scan line and a pulse spacing of about 62/40 or 1.55 meters between subsequent scan lines. The 90 seconds of scanning resulted in a strip length of about 5.5 km.

The airborne LiDAR data that was acquired in this flight was originally collected as a proof-of-ability demonstration for a biomass pilot project in Thailand whose funding was unfortunately canceled after political wranglings started to interfere with the success of the intended mission. We are happy to offer this particular data set – on request – to other researchers who are interested in experimenting with airborne LiDAR data flown above a tropical rainforest with the setting described above. The photos in Figure 3 illustrate the weather conditions on the day of the flight and the dense canopy of up to 45 meters below the aircraft that was scanned.

Figure 3: Weather conditions on the day of the scan and the dense canopy of the rainforest.

3. DATA PROCESSING

We use lasinfo of LAStools (Isenburg, 2014) with option '-cd' to compute the average last return density (aka pulse density) as 0.64 per square meter. This equals an average last return spacing (aka pulse spacing) of 1.25 meters, which is what we were expecting. Using lasinfo with options '-histo gps_time 1' and '-last_only' creates a histogram of the number of last returns per second. The maximum number is 53,341 and the average 53,182, which nicely matches our expectations for the effective number of laser shots per second when operating the Q680i at 80 kHz.

To classify the bare-earth returns we run lasground of LAStools in the default "nature" mode and option '-fine' which classified only 250,473 of the 7,956,587 points as ground – a mere 3.1 percent. Using las2las of LAStools with option '-keep_gps_time 61778744 61778744.25' we cut a quarter of a second worth of LiDAR data from the strip and visualize it in Figure 4 using the various coloring options available in lasview. Single returns are yellow, first of many are red, last of many are blue, and intermediate returns are green. The left segment shows all, the center only the first, and the right segment only the last returns (top profile). The returns classified as ground are predominantly last of many (middle profile). All points are colored by classification (bottom profile).

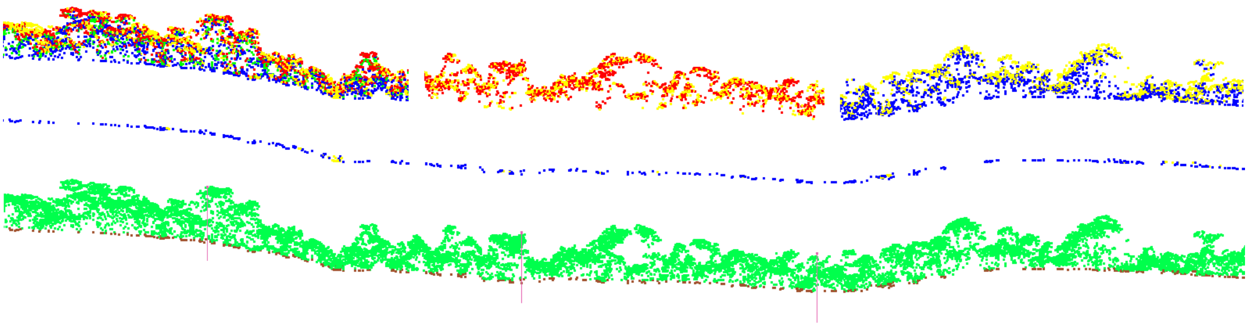

Figure 4: Profile of the scan colored by return (top) and classification (bottom). The pink line segment is 50 meters.

4. RESULTS

It is not possible to do a rigorous qualitative analysis of whether the bare-earth points that were classified by lasground are correctly representing the terrain as it is impossible to do ground validation in this inaccessible area of primary rainforest with measurements in the field. However, the main goal of our experiments was to find out whether we will get sufficiently many ground returns to even consider generating a DTM and whether this gives a plausible model of the bare-earth beneath the canopy. One may argue that there are not too many applications that need a survey-grade terrain representation in the middle of untouched primary rainforest in the first place.

Of the 250,473 points classified as ground – an extremely low 3.1 percent – only 30,931 are single returns where the laser had an unobstructed view of the bare earth. More than half of the ground returns come from laser shots that have produced two or more vegetation returns before reaching the ground and 7,665 of them had their light energy weakened by grazing four or more vegetation layers before hitting the forest floor. Their average density is 0.30 ground points per square meter, which equals an average ground point spacing of 1.83 meters.

We use the first returns to generate DSM and the ground returns to generate a corresponding DTM – both at a resolution of 2 meters – by rasterizing a Delaunay Triangulated Irregular Network (TIN) of their x/y coordinates as implemented by las2dem or blast2dem of LAStools. The corresponding hill-shaded rasters are shown in Figure 5.

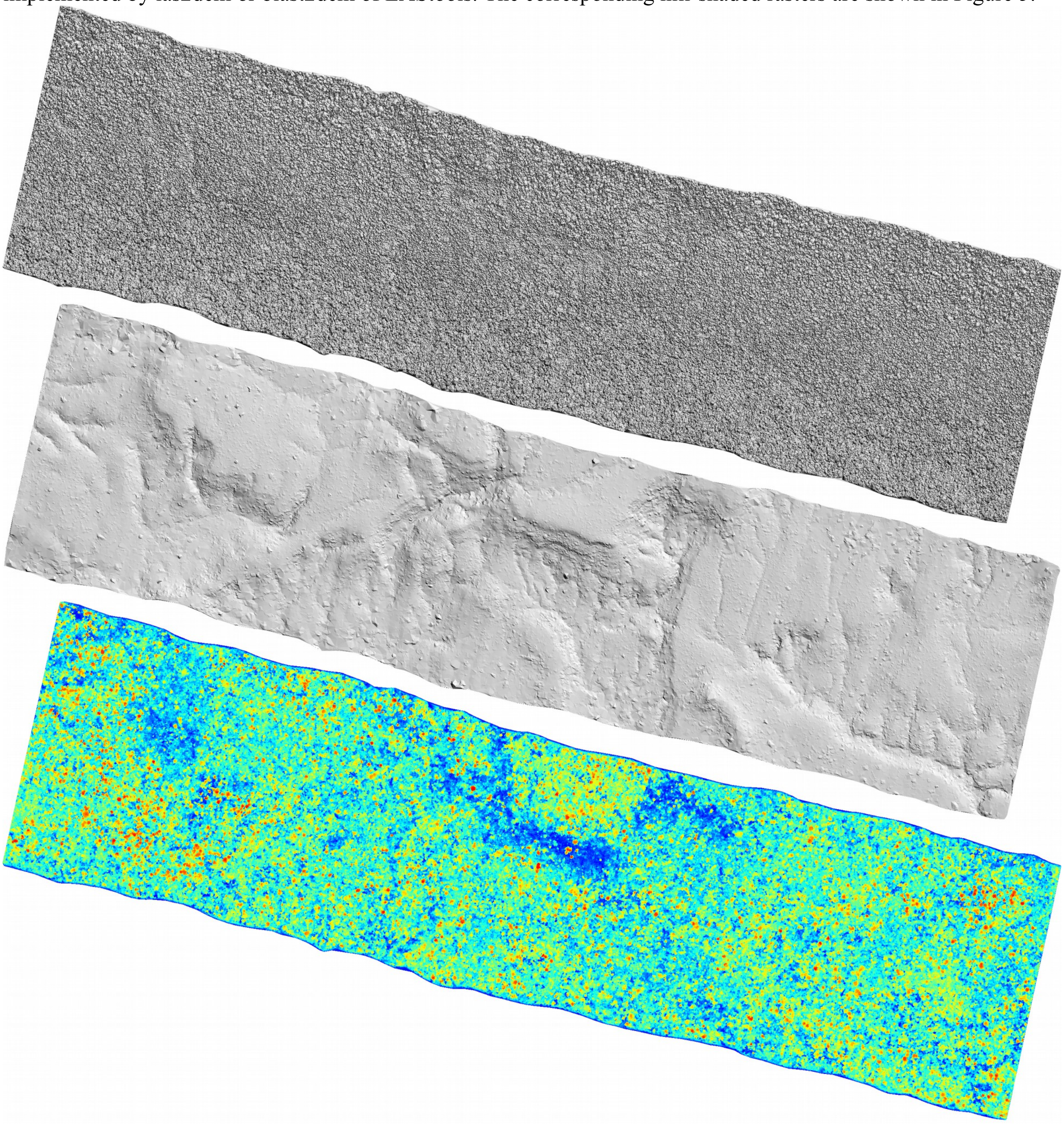

Figure 5: Digital Surface Model (top), Digital Terrain Model (middle) and Canopy Height Model (bottom)

The intricate topographic features of the bare-earth terrain are clearly visible in the hill-shaded DTM and what is uncovered by digitally removing the canopy is a highly plausible landscape showing streams, steep slopes, and other complex terrain features. The proof-of-ability experiment was a success. Although the percentage of ground-classified points is drastically lower than we have experienced in the past for other projects, we are able to generate a plausible DTM of 2 meter resolution. We then height-normalized the LiDAR points with lasheight of LAStools to generate a "pit-free" Canopy Height Model using the algorithm proposed by (Khosravipour et al., 2014). The resulting CHM is shown in Figure 5 with a false coloring that maps canopy heights of 0 meters to blue and heights of 45 meters to red. By comparing the CHM and the DTM one quickly notices that there is either no or much lower vegetation (more blue) in those areas that appear to be in the very steep parts of the hill-shaded DTM.

5. DISCUSSION

We have shown that it is possible to penetrate the dense 45 meter canopy of tropical rainforests in Thailand with a RIEGL LMS Q680i full waveform laser scanner operating 1200 meters above the ground at 80 kHz and get sufficiently many ground returns to construct a plausible DTM with a resolution of 2 meters. The high flight altitude of 1200 m above ground means that fairly wide swaths of 1400 meters. This will require fewer flight lines when carrying out a larger survey, but also means a lower pulse density (or a wider pulse spacing). The low pulse repetition rate of 80 kHz contributes further to the low pulse density but should also mean the highest possible light energy per shot, which seemed crucial given how many layers of vegetation the laser has to penetrate. However, we have since experimented with running the RIEGL LMS Q680i at 200 kHz and were also able to get satisfactory canopy penetration. In the future we hope to repeat the same experiment with different flying heights and pulse repetition rates over the same area to determine ideal survey trade-offs for different target ground point resolutions.

REFERENCES

Isenburg, M., 2011. LASzip: lossless compression of LiDAR data. In: Proceedings of European LiDAR Mapping Forum, Salzburg, November 2011, available from http://laszip.org
Isenburg, M., 2014. LAStools – efficient LiDAR processing software (version 140831), Retrieved September 3rd, 2014, from http://rapidlasso.com/LAStools
Khosravipour, A., Skidmore, A.K., Isenburg, M., Wang, T., Hussin, Y.A., 2014. Generating Pit-free Canopy Height Models from Airborne Lidar. Photogrammetric Engineering and Remote Sensing 80.