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Figure 1: Location Map

Introduction

Airborne LiDAR data acquisition of small mountain glaciers in high-altitude areas poses a unique challenge for the quantification of both volumetric and vertical change over time. This is due to high vertical variations over short horizontal distances, making flight-line planning and execution a challenge. While high-cost airborne laser scanners exist that are capable of collecting data from high above-ground-level (AGL) altitudes, the cost to purchase and operate these sensors is limiting. We describe the development and use of a lower-cost airborne laser scanning (ALS) system designed for terrain-following data acquisition of small mountain glaciers. Through the integration of a compact LiDAR scanner, IMU, and GPS in a helicopter-mounted external cargo pod, and the efficient installation and calibration process, it is possible to collect high quality, multi-temporal data of glacier surfaces.

System Design

In order to access and map small mountain glaciers in high-altitude locations from low AGL altitudes, it was necessary to create a helicopter-based ALS system to exploit the maneuverability of the aircraft (Figure 2). We chose the Robinson R44 Raven II helicopter for the following reasons:

1. Availability of both an externally mounted cargo pod capable of being modified for sensor payloads and a tail-mounted GPS antenna mount, both with FAA/STC certification.
2. Lower cost of operation compared to larger aircraft: ~$700/hr vs. ~$1,600/hr for the Eurocopter AS565.
3. Popularity of the helicopter worldwide, increasing the chartering options for future surveys.

We integrated a Riegl VQ-490 laser scanner, XBut ATLANS-G inertial measurement unit (IMU), a tail-mounted GPS antenna and the NeoTrack 2 Flight Management System for the main system components. We custom designed a mounting system in the pod to isolate the sensors from aircraft vibration (Figure 3). Power was supplied directly from the aircraft battery, passing through a voltage conditioner before being distributed to the system components. A single operator runs the ALS system, while the FMS provides flight-line guidance to the pilot via a tablet display.

Data Acquisition & Processing

Data was collected at Wolverine Glacier on 7 May and 10 September 2016, based out of Girdwood, AK. A temporary base station was installed at the USGS Hut at Wolverine Glacier for trajectory post-processing. Flight AGL was 400m, with flight lines planned to provide 50% overlap of target surfaces. Surface reflectance greatly drops with increased surface water saturation and exposed, dense ice, therefore the quality of point returns was monitored by the operator in real-time. AGL was reduced (to approximately 300m) where reduced reflectance was observed. Additionally, the operator called out AGL, as measured with the laser scanner, so the pilot could adjust height with changing terrain.

Trajectory solutions were calculated and applied to the flight lines using the IMU/GPS files from the ALS system and base station file from the temporary setup on 7 May, with the following results (Figure 4):

- Vertical error ranging from 5 - 15mm
- Horizontal error ranging from 12 - 28mm
- Heading error: 0.01° - 0.03°
- Roll and Pitch error: 0.00° - 0.01°

Results: Change Detection

From the point clouds collected for both survey dates, 50cm DEMs were produced to use for both surface height change detection and volume change calculation (Figure 5). Figure 6 shows the height change results between the two surveys overlaid on the 10 Sept. 2016 DEM. We measured an average height change ranging from 0 to -12m, with smaller areas of larger snow/ice loss. Areas of drifting, tilled crevasses, snow and ice ablation, and significant meltwater at the glacier terminus are apparent.

Results: Volume Calculation

By differencing the DEM surfaces between the surveys, we calculated a volumetric change of -210,056,253 m³ for the Wolverine Glacier using a signed delta volume calculation, which calculates the net change in volume for a defined ACI bounded by the X-Y plane.

Results: Surface Intensity

Using the intensity values from the laser scanner (range-independent, scalar value of surface reflectance), it is possible to differentiate between snow, ice, vegetation and rock/soil surfaces within the ACI. While further work must be done to better classify these surface changes, Figure 8, an intensity-colored point cloud from the 10 Sept. 2016 survey, illustrates the utility of using intensity to identify areas of differing surfaces. Areas of exposed, saturated ice (dark blue) are seen in the crevasse zone just up from the terminus. Fresh, dry snow is shown by the light-green area in the Northeast corner. Rock, soil, and vegetation are indicated by the warm colors, with the areas recently deglaciated visible by the lighter-colored sections in the lateral recessional moraines.

Conclusion & Future Work

With the developed sensor package, aircraft platform, and acquisition/processing techniques, we are able to capture multi-temporal, high-resolution, precise topographic measurements of small mountain glaciers for the quantification of surface height and volumetric change. These results may be utilized for comparing in-situ measurements and as input for glacier mass balance modeling. In addition to full glacier mapping, the system may be used for measuring glacier centers of very small, difficult to access glaciers, complimenting ongoing data acquisition of glacier centers measurements in Alaska through the use of a fixed-wing aircraft. Future work will include validation of the results against in-situ measurements, and the comparison of these results to Structure-from-Motion (SfM) products of Wolverine Glacier.

Acknowledgments

This research would like to thank Tanner Pull from Alaska Air for solo, reciprocating Rating as difficult terrain. Rieg1 Ultra flight times, thank the USGS team for their help餐馆 in the design, implementation and use of the Wolverine Glacier study, including Luke Van Gool (USGS) for help with logistics during flight periods. Thank you to the USGS for the use of the aerial images in Figure 7.

Figure 2: ALS pod installed on R44

Figure 3: CAD model of Helipod

Figure 4: IMU results for 10 Sept. 2016 Flight

Figure 5: Height change 7 May - 10 Sept. 2016

Figure 7: Reference photo and DEM

Figure 8: Intensity-colored 10 Sept. 2016 point cloud

Figure 6: Height change 7 May - 10 Sept. 2016