ACCURACY OF MEASURING THE BOTTOM OF A POND BY AIRBORNE LIDAR BATHYMETRY (ALB)

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ABSTRACT:

Airborne Lidar Bathymetry (ALB) is a technology for characterizing the depths of shallow-water bodies in relatively transparent waters from an airborne platform using a scanning and pulsed light beam. A bathymetric LiDAR usually uses wo laser pulses: one is a near-infrared (NIR) laser pulse for land topography and the other is a green laser pulse for submarine topography. In recent years, ALB has become more popular in river and coastal surveying in Japan. The accuracy of ALB has been verified by comparison with the results of acoustic sounding or levelling. However, since the comparison with either acoustic sounding or levelling is limited to a partial comparison at a point or on a line such as a cross section, it is not suitable for overall verification for detailed terrain features. In addition, accuracy verification by comparison between the results of ALB's green laser scanning and those of NIR laser scanning has been performed in the past only on land, but not in water. As scattering of the green laser occurs when measuring in water, it is possible to affirm that the verification under actual operating conditions has not been sufficiently investigated. In this study, we conducted NIR laser scanning in a natural pond and an artificial pool when they had no water, and conducted green laser scanning when they were filled with water. Thus, the NIR laser scanning and the green laser scanning could be compared in terms of surface measurement for the same bottom of the water body. It was confirmed that the green laser in water has sufficient accuracy compared to the NIR laser in actual operation conditions.

1. INTRODUCTION

Topographic surveying under water started quite later than that of land did. In late 19th century, lead line was used to measure the water depth for navigation (Oshima, 2000). For the limitation of rope length and influence of water flow that slants a lead line could slant during navigation, the lead line technique has been replaced by acoustic sounding techniques. Both the lead line and acoustic sounding techniques were shipborne instruments that have the limitation of efficiency and time consuming (Ismart, 2015). It is also difficult to use shipborne sensors to acquire bathymetric data near coastlines with rocky shoreline and craggy terrain, as well as shallow rivers. Airborne LiDAR Bathymetry (ALB) is an effective technology for measuring water depth in relatively shallow rivers and nearshore coastlines. It can be a significant supplement of acoustic sounding to get seamless geospatial data from land to submarine topography, as well as riverbed topography.

ALB was mainly used to collect submarine topography, while in recent years, it has become more popular in river surveying in Japan. In Japan, one of the technical policy issue of river management is how to acquire cross section and longitudinal profile of riverbed efficiently and integrally. ALB was considered as a solution for its time and cost effectiveness. Researches on application of ALB technique to river surveying were conducted. The accuracy of ALB has been verified by comparison with the results of acoustic sounding or levelling (Unome et al., 2014. Ida et al., 2017). However, since the comparison with either acoustic sounding or levelling is limited to a partial comparison at a point or on a line such as a cross section, it is not suitable for overall verification for detailed terrain features. In addition, accuracy verification by comparison between the results of ALB's green laser scanning and those of aircraft LiDAR's near-infrared (NIR) laser scanning has been performed in the past only on land, but not in water (Ikema et al., 2016. Ooga et al., 2015). As scattering of the green laser beam occurs when measuring in water, it is possible to affirm that the verification under actual operating conditions has not been sufficiently performed since it is, as of now, limited to on-land measurements.

Accordingly, we conducted an experiment to investigate the measurement accuracy of ALB in a suburb of Tokyo. In the experiment, observation results of the bottom of the water with water by green laser scanning were compared with those without water by NIR laser scanning. The comparison was executed in two study areas. One of the study areas was Inokashira Pond selected as a natural pond, and the other was a swimming pool exposed on the rooftop of a building selected as an artificial pool.

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2. METHODOLOGY

2.1 Study Areas

Two sites were selected for evaluation of the accuracy of ALB. One is a natural pond named Inokashira Pond shown in Figure 1, located in the centre of Inokashira Park, Tokyo. The other one is an artificial swimming pool on a building's rooftop as Figure 2 shows. Its size is 25 m x 12.5 m. Inokashira Pond is drained regularly to keep from sludge accumulation, thus the terrain of its bottom can be measured by traditional NIR LiDAR to compare with ALB green LiDAR when it is filled with water. The artificial swimming pool was selected as its actual water depth is easy to confirm.

Figure1. Study area of Inokashira Pond as a natural pond

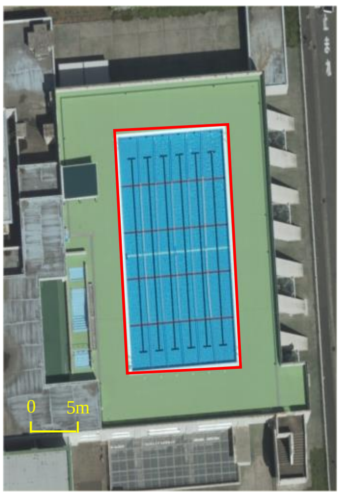


Figure2. Study area of a swimming pool as an artificial pool

2.2 LiDAR System Specifications

Aerial laser scanning was performed by using Trimble Harrier 68i installed on helicopter AS350 B1 and Leica Geosystems Chiroptera II installed on helicopter AS350 B. Harrier 68i, released in 2010, can generate dense 3D point cloud with high position accuracy. It is known as a topographic LiDAR with a NIR laser scanner. NIR laser scanning is difficult to measure terrain under water. This is due to that most of the laser pulses are not able to penetrate the water to reach the bottom. For this reason, Chiroptera II uses a NIR of wavelength 1064 nm for topographic surveying and a green of wavelength 515 nm for bathymetric surveying. Specifications of these two LiDAR systems are shown in Table 1.

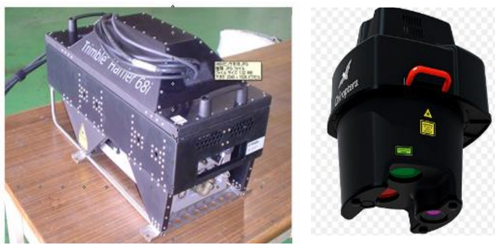


Figure 3. LiDAR sensor of Harrier 68i (left) and Chiroptera II (right)

	Harrier 68i	Chiroptera II	
	NIR laser	NIR laser	green laser
Scanner pattern	Parallel lines	Oblique scanner	
Laser wavelength	1,550nm	1,064nm	515nm
Pulse repetition rate	up tp 400kHz	up to 500 kHz	35kHz
Field of view	45~60°	±14°front/back,±20°left/right	
Operation altitude	up to1,600m AGL	up to 1,600m AGL	400-600m AGL
Scan Frequency	10~200Hz		
Beam divergence	≦0.5mrad	≦0.5mrad	≦4.5mrad
Eye safety class	class 3R	class 4	

Table 1. Specifications of utilized LiDAR systems

Besides laser scanners, both the two LiDAR systems are also equipped with a camera, an inertial measurement unit (IMU), and a GPS receiver. The offsets between its platform reference frame and each equipment are accurately calibrated. Internal errors of scanning angle and boresight, caused by the movement or impact of the system are also calibrated. The distance from the ground GPS reference stations are less than 10 km and the measurement time interval of ground GPS reference station is 1 second.

2.3 Data Collection

Four data sets were collected by Trimble Harrier 68i and Chiroptera II. They are listed in Table 2. As for Inokashira Pond as a natural pond, Data-A was collected by Harrier 68i on February 9, 2018 after drainage of water. Although Chiroptera II has NIR laser scanner, Data-A was acquired by Harrier 68i because Chiroptera II was under airworthiness check at that time. On April 27, 2018, when the pond was fully filled with water, the measurement was performed by Chiroptera II. Data-B measuring the water bottom of the pond was acquired by Chiroptera II's green laser scanner. Table 3 shows more details of the flights to measure the bottom of Inokashira Pond.

As for the artificial swimming pool, laser scanning of Data-C was performed by Chiroptera II on April 26, 2018 when the water of the pool was drained. The bottom of the pool was acquired by the NIR laser scanner of Chiroptera II. In addition, laser scanning of Data-D was performed on August 25, 2018, when the pool was filled with water. The bottom was observed by the green laser scanner of Chiroptera II. Table 4 shows more details of the flights to measure the bottom of the pool.

Type	Harrier 68i	Chiroptera II	
	NIR laser	NIR laser	green laser
Inokashira pond without water	A		
Inokashira pond filled with water			B
Artificial pool without water		C	
Artificial pool filled with water			D

Table 2. Data collected by NIR and green laser scanning

	Harrier 68i	Chiroptera II	
	NIR laser	NIR laser	green laser
Flight date	2018/2/9	2018/4/27	
Flight line/course	5	5	
FOV	60°	±14°front/back,±20°left/right	
Operation altitude	500m	500m	
Flight speed	50kt	60kt	
Pulse repetition rate	200kHz	500kHz	35kHz
Scan rate	77.5Hz	70.0Hz	23.7Hz
Point Density	8.88pt/m2	33.48pt/m2	2.34pt/m2
Data	A		B

Table 3. Flight details of Inokashira Pond

	Chiroptera II	
	NIR laser	gree laser
Flight date	2018/4/26	2018/8/25
Flight line/course	6	
FOV	±14°front/back,±20°left/right	
Operation altitude	500m	
Flight speed	70kt	
Pulse repetition rate	200kHz	35kHz
Scan rate	61.1Hz	25.6Hz
Point Density	11.53pt/m2	2.02pt/m2
Data	C	D

Table 4. Flight details of artificial pool

2.4 Ground Control

Ground control points (GCPs) were surveyed to ensure the LiDAR data accurately corresponds the actual ground elevations. In this study, two GCPs were used for elevation adjustment of Inokashira Pond, and four GCPs were used for artificial pool. Usually it would be better to set at least four GCPs for ground control in one flight. However, in this study, the target area Inokashira Pond is quite small and covered by vegetation, there is no sufficient position for GCP settings, so two GCPS were set on the diagonal line of the target area Inokashira Pond. Laser points within the circle of 1.0 m radius from each GCP were compared with the elevation of the GCP. The comparison results were summarized in Table 5. Both RMSEs of the Inokashira Pond and the artificial pool were smaller than 0.08m. It would suggest that proper ground control was conducted.

Study area	Sensor	Mean.	Std.Dev.	RMSE
Natural pond	near-infrared laser (1,550nm)	-0.023	0.005	0.023
	green laser (515nm)	0.072	0.022	0.075
Artificial pool	near-infrared laser (1,064nm)	-0.007	0.011	0.013
	green laser (515nm)	-0.004	0.023	0.023

Table 5. Elevation comparison of GCPs and LiDAR points

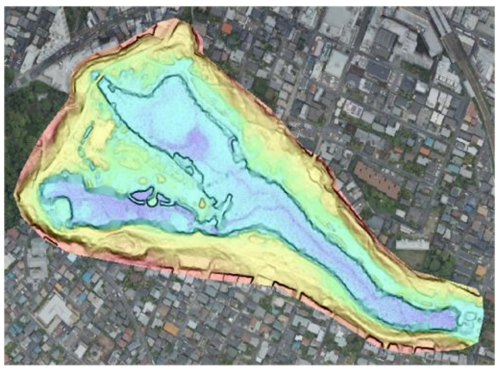
3. RESULTS AND DISCUSSIONS

All the flights of Data-A, B, C, and D were conducted with 50% overlapping ratio of adjacent flying courses, so the actual point density was much higher than planned point density.

3.1 Natural Pond

The point density of NIR laser scanning was 25 pt/m^2, while that of green laser scanning was 2 pt/m^2 where water surface and noise in the water was filtered. The water depth of Inokashira Pond was about from 1.3m to 1.8m. Figure 4 was a colour shaded relief map created by using ground laser points. As for Data-A, the water in the pond was drained, thus NIR laser scanning would be able to measure the bottom of the pond. According to Figure 4, the exposed water passage at the bottom of the pond can be clearly seen by both NIR and green laser scanning.

(a) NIR laser scanning



(b) green laser scanning

Figure 4. Colour shaded relief map of Inokashira Pond

Comparing with the NIR laser scanning, the green laser scanning did not observe waterside of the pond well as Figure 5 shows. This is due to vegetation spread above the water. Green laser pulses were partially or even wholly reflected by the vegetation. On the other hand, there are two reasons that the NIR laser scanning was able to observe the bottom without water around the waterside of the pond. One reason is the observation date. The NIR laser scanning was conducted in February, when the trees were bare of leaves. The other reason is the pulse repetition rate. The NIR laser scanner emitted nearly six times pulses of that of the green laser scanner per second as shown in Table 3, leading to high possibility of penetrating the trees to reach water.

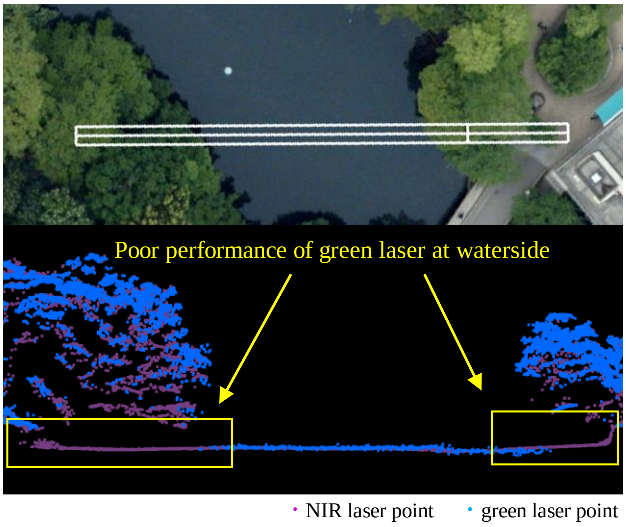
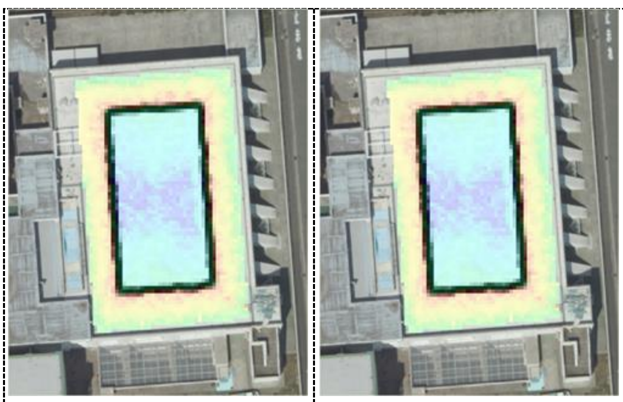


Figure 5. Cross section of LiDAR point cloud
*water surface and noise in the water of green laser point cloud were removed.

Figure 5 suggests that the cross-sectional shapes of NIR laser scanning and green laser scanning were almost the same. However, compared with the NIR laser scanning, points acquired by the green laser scanning were with relatively big variation.

3.2 Artificial Pool

The actual point density of NIR laser scanning was 30 pt/m^2, while that of green laser scanning was 4 pt/m^2. The water depth of the artificial pool was approximately 1.3m. Fine uneveness of the bottom was be able to be seen in Figure 6. Elevation in the centre was a little lower than the edge of the pool.



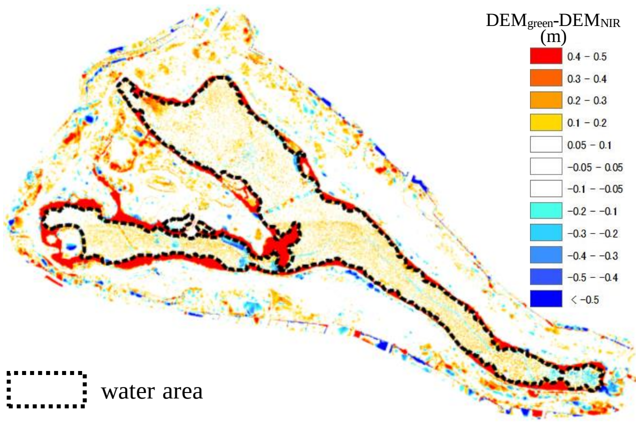
(a) NIR laser scanning (b) green laser scanning

Figure 6. Colour shaded relief map of the artificial pool

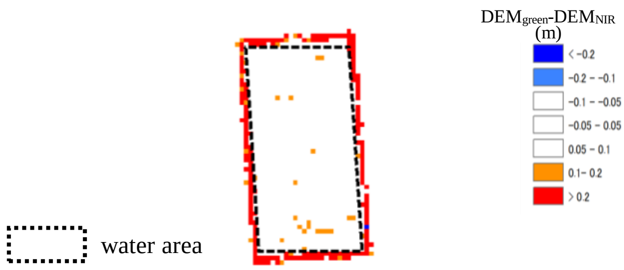
3.3 Accuracy Evaluation

Compare of elevations was executed at each grid. LIDAR data were interpolated into a 0.5m-meter grid through triangulated irregular network (TIN) interpolation. TIN interpolation is a standard method used to create LiDAR-derived DEMs according to the 2020 revised version of Japan Public Survey Work Regulation (Ministry of Land, Infrastructure, Transport and Tourism of Japan, 2020). TIN interpolation is also used by the Federal Emergency Management Agency (FEMA, 2010) to create DEM. The reason to use TIN interpolation is that TIN interpolation is proven to be isomorphic (Hu et al., 2009). This means that if a point A is higher than a point B on the ground, the TIN-interpolated elevation of point A is also guaranteed to be higher. Similarly, if the point A is higher than point B in a TIN-interpolated DEM, A is guaranteed to indeed be higher in the field. Isomorphism is important because it preserves the elevation order and sequence among terrain points (Liu et al., 2015). This is necessary for accuracy evaluation with interpolated LiDAR data.

Figure 7 shows the elevation differences between NIR laser scanning and green laser scanning results. The relatively big differences at the edge of the pond is due to the limited performance of green laser scanning to penetrate vegetation as shown in Figure 5. Excluding these pond edges and land around the pond, the difference values of the pond bottom, which is surrounded by dashed lines as shown in Figure 7, were evaluated. According to the histogram of the differences of the pond bottom as shown in Figure 8, 86.6% of the difference values are within -0.10m ~ +0.1m. 98.4% of the difference values are within -0.20m ~ +0.2m. 99.9% of the difference values are within -0.30m ~ 0.3m as well.



(a) DEM differences of the natural pond



(b) DEM differences of the artificial pool

Figure 7. DEM differences between NIR laser scanning and green laser scanning

As for the artificial pool, the elevation differences at the edge of the pool also tends to be larger than others. It is probably due to that the beam divergence of the green laser scanning is 9 times of the NIR laser scanning, which means the footprint diameter of green laser beam is 9 times of that of NIR laser beam when the flight was conducted at same operation altitude. It might make an elevation of a point on the pool wall recorded as an elevation of a point on the pool bottom. By excluding these edge points, 98.1% of the differences are within -0.10m ~ +0.1m. All differences are within -0.20m ~ +0.2m as Figure 8 shows.

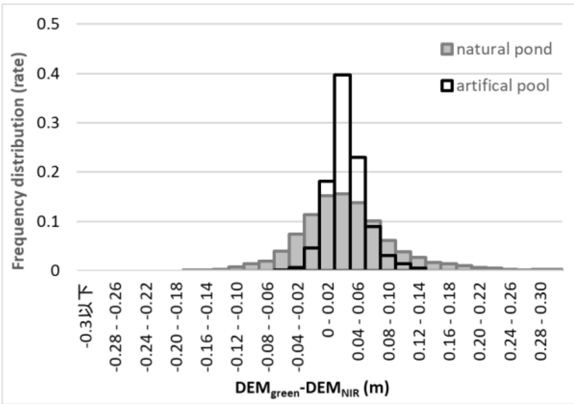


Figure 8. Frequency distritution of DEM differences between NIR laser scanning and green laser scanning

The statistics of elevation differences between green laser scanning and NIR laser scanning are summaried in Table 6. Table 6 indicates that the elevation differences of the natural pond is larger than the artificial pool.

	Min.	Max.	Mean.	Std.Dev.	RMSE
Natural pond	-0.174	0.330	0.035	0.062	0.071
Artifical pool	-0.017	0.020	0.009	0.009	0.013

Table 6. Statistics of elevation differences between green laser scanning and NIR laser scanning (unit: metre)

3.4 Discussions

According to the evaluation results of DEM differences between the green laser scanning and the NIR laser scanning, the differences tended to be large at the waterside of both the natural and the artificial ponds. Contrarily the experiment results indicate that the measurement accuracy of the green laser scanning excluding the waterside of the pond would be high enough. We consider that the measurement accuracy of the green laser scanning in the water body is nearly equal to that in the land under actual operation conditions.

As for the natural pond, the cause of the inaccuracy would be that the green laser scanning was unable to observe the bottom of the water body at the waterside sufficiently due to the spread vegetation above the water. Green laser scanning in the experiment was conducted in April with vegetation blooming. Green laser pulses were partially or even wholly reflected by the vegetation spread over the water.

As for the artificial pond, the cause of the inaccuracy would probably be that the beam divergence of the green laser scanning is 9 times of the NIR laser scanning, which might make an elevation of a point on the pool wall occasionally recorded as an elevation of a point on the pool bottom.

The experiment results show that the accuracy in the artificial pool tended to be higher than that in the natural pond. We consider that the following features of the test sites would influence the measurement accuracy:

(1) Difference of water quality
We consider that tap water used in the artificial pool contains less suspended solids and its quality is better than the water of the natural pond, which is a closed water area where water pollution tends to diffuse more easily.

(2) Change in the shape of the water bottom
Construction works had been being conducted in the natural pond. The transfer of mud from the bottom of the water body to shallow areas where it is used for embankment would have affected the measurement accuracy. Moreover, the changes in the shape of waterways at the bottom of the pond may be the cause of the low measurement accuracy as well.

(3) Unevenness of the water bottom
The water bottom of the artificial pool is almost flat because it is a human-made construction, but in the natural pond, it is considered that the water bottom is uneven because the groundwater is welling up at several locations. The small irregularities in the water bottom may have affected the experiment results.

4. SUMMARIES

We conducted an experiment to investigate the accuracy of ALB in a suburb of Tokyo. In the experiment, observation results of the bottom of the water with water by green laser scanning were compared with those without water by NIR laser scanning.

The experiment results show that the accuracy of green laser scanning in water would be nearly equal to that of NIR laser scanning without water. We concluded that the accuracy of ALB would be sufficient under actual operation conditions. Moreover, the experiments results indicate that ALB would be able to survey overall micro-topography that is difficult to be surveyed by conventional method such as acoustic sounding or levelling

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