Analysis of the green light penetration from Airborne LiDAR Bathymetry in Shallow Water Area

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Abstract. An Airborne LiDAR can be used to map the depth of the water. This system is called an Airborne LiDAR Bathymetry. In order to measure the water depth, an Airborne LiDAR is utilized with the green light sensor beside the near-infrared light sensor. However, water condition affects the capability of the green light penetration. The clarity of the water and the vegetation are some of the restriction for green light to penetrate the water especially in inland water areas. The research examined the penetration capability of the green light of the Airborne LiDAR Bathymetry in shallow water areas. A comparison of depth values derived from the LiDAR system and the direct measurements was performed to asses the penetration accuracy of the green light. The depth comparison is derived from eleven channels in the research area. The direct measurement was conducted by using a tape to measure the depth, and the RTK GNSS to measure channel’s dimension. A Secchi Disk also used to measure the turbidity of the water. The vertical reference for the depth is Earth Gravitational Model 2008 (EGM 2008). Based on the research, the depth difference between LiDAR Bathymetry and the direct measurement ranges from 0.02 m to 0.22 m. The vertical accuracy of the LiDAR Bathymetry is 0.239 m within 95% of confidence level.

1. Introduction

Based on Constitution Number 6 of 1996 concerning on Indonesian water, Indonesia’s water are consist of territorial sea, island water, and inland water. The inland water consists of inland sea and inland water. Shallow Water mapping is not an easy thing to do in Indonesia. There are several methods for determining depth, they are mechanical method (using rope), the acoustic method (using echo sounder), and the optical method (using electromagnetic waves) [1][2]. Mapping with using the acoustic method has the difficulty to reach inland waters, one of which is shallow water. Besides the acoustic method, an optical method can be used to determine depth. Depth determination by using an optical method uses electromagnetic waves called LiDAR. LiDAR is one of the active remote sensing sensor.

LiDAR (Light Detection And Ranging) is a part of the sensor system that uses an active sensor (using its own energy source, not from reflected sunlight) [3]. A laser beam on LiDAR can be used to obtain physical map features with very high resolution [4]. There are 2 many type of LiDAR, namely Airborne Laser Scanner (ALS) and Airborne LiDAR Bathymetry (ALB).

Airborne LiDAR Bathymetry (ALB) is an advanced technology that effective in mapping and measuring water depth in the coastal zone, shallow water and inland freshwater bodies, such as river and lake [5]. Airborne LiDAR Bathymetry in the United States known as Airborne Oceanographic
LiDAR (AOL) and Hydrographic Airborne Laser Sounder (HALS) systems, while in Australia it is known as the Laser Airborne Depth Sounder (LADS) system [6]. The LiDAR sensors emit a laser beam to an object and re-record the reflected waves after reaching the object. In general, waves emitted by sensors consist of two parts, namely green light waves and infrared waves. Green light waves has the function to penetrate in water area. Green light waves has the function to measure depth data, while the function of infrared waters is to measure topographic data. The NIR (Infrared) wavelength is 1.064 µm for topographic mapping and the wavelength of the green light waves is 0.515 µm for bathymetry mapping [7]. LiDAR sensor has the ability to measure multiple returns. Multiple returns are used to determine the shape of an object or vegetation that covers the surface of the ground [8]. However, several factors that affect the penetration of airborne’s green light waves in measuring water bodies, including water turbidity (turbidity of water), composition of the water base (sediment, vegetation, etc.), and weather [9].

In this research, validating data in shallow water areas measured using Airborne Hydrography AB. Validating data is using direct measurement in shallow water area. The direct measurement was conducted by using a tape to measure the depth, the RTK GNSS to measure channel’s dimension, and the Secchi Disk measurement to measure water turbidity. The measurement of water’s turbidity is to determine how the penetration of airborne green light waves in shallow water measurements. The output of this research is analysis of penetration airborne green light waves in shallow water measurements.

2. Methodology

2.1. Study Area and Data

The location of this research took place in Kebumen Regency of Central Java Province at the coordinates of 7° 27’-7° 50’ LS and 109° 22’-109° 50’ BT[10]. Kebumen Regency is located with the northern border of Banjarnegara Regency, in the southern border is the Indian Ocean, in the western border is Banyumas Regency and Cilacap Regency, and in the eastern border is Wonosobo Regency and Purworejo Regency. Data that used in this research are point cloud Airborne Hydrography AB (AHAB) from PT. Map Tiga Internasional, depth validation, and turbidity validation.

Figure 1. Study area map.
2.2. Data Survey
The data survey used to support this research are:

1. Point Cloud Airborne Hydrography from PT. Map Tiga Internasional.
2. GPS Data for positioning validation data.
3. Turbidity Water (Measured using Secchi Disk).

2.3. Data Processing
In the research that will be conducted to compare Z bottom surface measured using Airborne Hydrography AB with measurements using the lead line method and GPS Geodetic. Firstly, collect Airborne data and GPS data. The GPS measurements is done by using the RTK method. The Airborne acquisition can be seen in Figure 2.

![Figure 2. LiDAR Acquisition [11]](image1)

The RTK method is a GPS measurement method using one base and one rover. The RTK method used is absolute, where this method does not require a reference point where the position is known and simply uses one receiver. The RTK using measurement marking point. The RTK method measurement can bee seen in Figure 3.

![Figure 3. RTK Method Measurement [12]](image2)

In advance to compare both data, they have to be in the same geoid reference. The geoid model used in this research is EGM2008 geoid model. To obtain the EG2008 geoid model from the ellipsoid are as follows:

\[ H = h - N \]  \hspace{1cm} (1)

Where H is the geoid elevation, h is the ellipsoid elevation and N is the undulation [13].

The geoid value is obtained from the ellipsoid height minus the undulation value. This geoid undulation value is determined to model the actual geoid shape. The value of geoid undulation is not the same in all places, this is due to the uneven distribution of the mass of the earth.
Figure 4. Illustration Geoid Height [13].

After that, the Airborne Hydrography AB Processing. It aims to classify the airborne point cloud. There are 2 stages in conducting a classification, automatic classification and manual classification. The result of these classification is used to identify topographic point cloud and bathymetry. Where point cloud will be compared with the results of validation data. The point cloud processing can be seen in Figure 5.

Figure 5. Point Cloud Bathymetry Processing.

Then, do the validation measurements and process the validation measurement. Validation that has been carried out was measuring shallow water depths using mechanical method and measuring water turbidity using a Secchi disk. Secchi Disk is shaped like a disc with black and white, where black and white has a good brightness when exposed to sunlight [14][15].

After processing Airborne point cloud and validation measurement, Airborne data will be overlaid with the results of validation measurements carried out in the field to determine the result of measurement comparison

Turbidity analysis also done, because turbidity is one of the factors that affects the penetration of green waves. Turbidity analysis is obtain from the measurement using a Secchi disk. This is to discover the penetration that can be reached by airborne through turbidity of water. It can be expressed through the equation below,

\[ D_L = (1.5 - 3)D_S \]  \hspace{1cm} (2)

Where \( D_L \) is the airborne depth and \( D_S \) is the Secchi disk depth [7]. To find out the green light penetration in shallow waters using the \( D_L = (1.5)D_S \), while for the depth water using the equation \( D_L = (3)D_S \) [16]. The Secchi disk depth can be obtained by measuring the depth of the water surface until the tool cannot be seen from the surface water.
Besides depth comparison and turbidity analysis, we also done the vertical accuracy test. A vertical accuracy test conducted to determine the vertical accuracy of airborne measurements. Vertical accuracy test can be done by calculating the RMSE\(_Z\) according to the equation below,

\[
RMSE_Z = \sqrt{\frac{\sum (Z_{\text{data}}(i) - Z_{\text{check}}(i))^2}{n}}
\]

(3)

From the calculation of RMSE\(_Z\) then calculate the vertical accuracy test such as the equation below,

\[
\text{Vertical Accuracy Test} = 1.96 \times RMSE_Z
\]

(4)

Vertical accuracy determined comparing the coordinates of \(Z_{\text{data}}(i)\) and \(Z_{\text{check}}(i)\) (data with reference altitude truth) [18][19].

3. Result and Discussion

3.1 Result and Analysis Bottom Surface

Water turbidity is used to determine the penetration of green light waves in Airborne Hydrography AB (AHAB) in depth measurements. To discover the penetration of green light waves first compare the \(Z\) value the bottom surface water from the results field validation measurements with measurements of Airborne Hydrography The \(Z\) bottom surface Airborne Hydrography using geoid model EGM2008 references. The result \(Z\) value bottom surface of the Airborne Hydrography can be seen in Table 1.

| No | \(Z\) Value Bottom Surface (Meter) |
|----|-----------------------------------|
| 1  | 36.304                            |
| 2  | 14.569                            |
| 3  | 10.852                            |
| 4  | 12.626                            |
| 5  | 12.123                            |
| 6  | 5.942                             |
| 7  | 10.496                            |
| 8  | 10.088                            |
| 9  | 7.971                             |
| 10 | 7.501                             |
| 11 | 8.011                             |

From Table 1, we can draw a graph for \(Z\) value bottom surface of Airborne Hydrography. The graphic \(Z\) value of the Airborne Hydrography can be seen in Figure 7.
The Z minimum value 5.942 m in sixth location and the Z maximum value 36.304 m in first location. The Z bottom surface validation is measured using rope and GPS Geodetic for positioning. The Z value Airborne Hydrography using geoid model EGM2008 references. The result Z value bottom surface validation can be seen in Table 2.

Table 2. Z Value Bottom Surface Validation.

| No | Z Value Bottom Surface (Meter) |
|----|--------------------------------|
| 1  | 36.170                         |
| 2  | 14.483                         |
| 3  | 10.793                         |
| 4  | 12.470                         |
| 5  | 12.119                         |
| 6  | 5.788                          |
| 7  | 10.465                         |
| 8  | 10.060                         |
| 9  | 7.898                          |
| 10 | 7.388                          |
| 11 | 7.884                          |

From Table 2, we can draw a graph for Z value bottom surface validation. The graphic Z value of the validation can be seen in Figure 8.

The Z value minimum 5.788 m in sixth location and the z value maximum 36.170 m in first location. First location is located in highland. It has a higher altitude then other location validation.
The comparison surface Z values of the validation waters and Airborne Hydrography AB (AHAB) can be seen in Table 3.

Table 3. Z Value Bottom Surface Comparison.

| No | Z Value Bottom Surface Validation (Meter) | Z Value Bottom Surface Airborne (Meter) | Difference (Meter) |
|----|------------------------------------------|-----------------------------------------|--------------------|
| 1  | 36.170                                   | 36.304                                  | 0.134              |
| 2  | 14.483                                   | 14.569                                  | 0.086              |
| 3  | 10.793                                   | 10.852                                  | 0.059              |
| 4  | 12.470                                   | 12.626                                  | 0.156              |
| 5  | 12.119                                   | 12.123                                  | 0.004              |
| 6  | 5.788                                    | 5.942                                   | 0.154              |
| 7  | 10.465                                   | 10.496                                  | 0.031              |
| 8  | 10.060                                   | 10.088                                  | 0.028              |
| 9  | 7.898                                    | 7.971                                   | 0.073              |
| 10 | 7.388                                    | 7.501                                   | 0.113              |
| 11 | 7.884                                    | 8.011                                   | 0.127              |

The graphic comparison surface Z values of the validation and Airborne Hydrography AB (AHAB) can be seen in Figure 9.

Figure 9. Z Value Bottom Surface Comparison.

Results of the Z value obtained a minimum difference of 2 cm in eighth location and a maximum difference of 22 cm in first location. From the figure 9 and table 3, it can be seen that the green light waves of Airborne Hydrography AB (AHAB) cannot penetrate to the bottom of water, the maximum difference of 22 cm occurs due to the 0.533 meter Airborne Hydrography depth measurement. In measuring water turbidity using secchi disk at location 1 the depth that can be reached by airborne is 0.795 meter.

3.2 Result and Analysis of Turbidity Measurement

Water turbidity is measured using a Secchi disk tool. Turbidity water is done by measuring the depth of the Secchi disk from the surface of the water until the Secchi disk cannot be seen from the surface of the water by the observer. To discover the penetration of airborne green light waves, it is calculated by using equation 2. The result can be seen in Table 4.

Table 4. Result Green Light Waves Penetration.
| No | Secchi Disk Depth (Meter) | Airborne Depth (Meter) |
|----|--------------------------|------------------------|
| 1  | 0.265                    | 0.397-0.795            |
| 2  | 0.320                    | 0.480-0.960            |
| 3  | 0.300                    | 0.450-0.900            |
| 4  | 0.150                    | 0.225-0.450            |
| 5  | 0.235                    | 0.352-0.705            |
| 6  | 0.230                    | 0.345-0.690            |
| 7  | 0.160                    | 0.240-0.480            |
| 8  | 0.220                    | 0.330-0.660            |
| 9  | 0.150                    | 0.225-0.450            |
| 10 | 0.160                    | 0.240-0.480            |
| 11 | 0.200                    | 0.300-0.600            |

By following the calculation of water turbidity in equation 2, it is showed that Airborne Hydrography AB (AHAB) can reach a depth of 0.225 meters up to 0.960 meters from the water surface in validation measurement. From Figure 9 the difference of Z value known, it showed that the penetration of airborne green light waves cannot reach the surface of bottom waters. Turbidity is one of the factors that affect penetration green light waves Airborne Hydrography.

3.3 Vertical Accuracy Test

From the results of airborne data and validation data measurement, a vertical accuracy test is conducted to determine the vertical accuracy of Airborne Hydrography AB (AHAB). Vertical accuracy test calculated according to equation 3 and equation 4. From the calculation according to equation 3 and equation 4, the RMSEz result are 0.122 meters and the vertical accuracy test results in 11 location are 0.239 meters in confidence interval 95%.

4. Conclusion

1. The results comparison of the bottom surface’s Z value show the different value on watershed surface from validation and airborne measurements. A minimum difference of 2 centimeters in location eight and a maximum difference of 22 centimeters in location one.
2. From measurements of water turbidity using Secchi disks, penetration of airborne green light waves can only reach a depth of 0.225 meters up to 0.960 meters.
3. Vertical Accuracy Test from airborne measurements and validation measurements in 11 location obtained the value of 0.239 meters in confidence intervals 95%.

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