3D Topography Modeling from Integrating Bathymetric and Aerial Imagery for Sermo Reservoir Monitoring

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Abstract. Reservoir monitoring is important in maintaining water retention and controlling volume changes as well as sedimentation rates. Reservoir monitoring usually uses conventional means such as recording the pole leveling height at a certain time, using large ships with the sounding method and determining the position and depth by utilizing total stations with intersection method measurements. However, such conventional methods require a lot of manpower, a significant period of time, a lot of equipment, and, more often than not, yielding in results that cannot be used to depict the real condition of the corresponding reservoir. This paper uses bathymetric and aerial photographic data to construct land and water topography, the state of the reservoir, and a 3D model of the reservoir, which later can be used as the basis for volume and sedimentation analyses. An effective way of merging the aforementioned data is by utilizing point cloud data generated from bathymetric surveys and UAVs. The point cloud data was then used as the basic material for creating DEM, land, and water contours. The bathymetric data quality test results meet the SNI 7647:2010 standard tolerance with a 1.96*standard deviation of 0.191. It passes the SNI 8202:2015 photo quality test with CE90/LE90 values of 0.325 and 0.285, respectively. Merging bathymetric and aerial photographic data in the regular reservoir monitoring or shallow waters is proven to be a more efficient, effective, and optimum method compared to the existing conventional means.

1. Introduction
Sermo Reservoir is a building structure filled with water that is on the ground surface and started operating in 1997 in Sermo Hamlet, Special Region of Yogyakarta, Indonesia [1],[2]. Sermo Reservoir has various functions and benefits for the community around the reservoir, such as a reservoir for water used as clean water, irrigation water, and flood prevention. However, the Sermo reservoir building experienced changes in depth caused by sedimentation over time. As a result, the Sermo reservoir can no longer perform the primary functions they were designed for, such as water retention, flood control, recreational purposes, etc. Dams accumulate transported sediments, reducing their operating capacity and water storage capacity [3]. To monitor the condition of the bottom surface of the reservoir, which has a vital function, one of them is by doing three-dimensional (3D) modeling, which aims to get a real picture of the bottom surface of the reservoir and display the situation around the reservoir area in detail.

Reservoirs are manufactured waters whose conditions need to be monitored and maintained properly not to cause disasters in the area around the reservoir. One of the reservoir maintenance problems is sedimentation, as is the case with Sermo Reservoir. Sedimentation causes the water reservoir to decrease, causing the reservoir life to be shorter than planned [4]. Lack of information about the bottom surface of the reservoir causes monitoring and maintenance of the reservoir not to run optimally and can
cause a new problem to occur, namely the reduced function of the reservoir itself [5]. One way to obtain complete information about the condition of the reservoir is to carry out survey activities using the acoustic method such as bathymetric measurements and photogrammetric methods were carried out by measuring aerial photographs.

These two alternative measurement methods are required and integrated for monitoring the condition of the Sermo Reservoir to obtain results in a 3D Point Cloud and DEM model so that reservoir's bottom surface condition can be used as a reference for reservoir management and maintenance. This applicative activity is expected to meet the need for spatial data in a DEM model required to keep Sermo Reservoir in good condition.

2. Related Work
The measurement combines photogrammetric and bathymetric methods, which refers to the GNSS coordinates. However, before the GNSS data is used as a georeference, it must ensure the horizontal and vertical position (elevation) data. The elevation value that refers to the geoid is called the orthometric height (H). The determination of orthometric height can be done by using spirit level equipment to level the method. In addition to using the conventional or levelling method, the orthometric method of determining height (H) or height difference (ΔH) can be obtained based on observational data from GPS (Global Positioning System) or also known as the GPS Heighting method. Determination of height using the GPS method, in principle, is to use the component data of the ellipsoid height (h) and the value of the geoid undulation (N) to determine the orthometric height (H). The geoid undulation value used to calculate the orthometric height is the undulation value to the EGM2008 datum [6]. The following is the equation used to calculate the orthometric height value;

\[ H = h - N \]  

Where H is the geoid referenced orthometric height, h is the ellipsoid referenced height, and N is the geoid undulation.

The bathymetric survey work provides information on the depth of the waters and provides information on the topographical conditions of the bottom surface of the waters that it can visualize [11],[13]. The sounding method utilizes acoustic waves in its measurement and utilizes echosounder technology. The echosounder is used to obtain optimum depth data that covers the entire deepest depth of the survey area. Generally, there are 2 types of echosounder systems: Single beam echosounder and Multi beam echosounder [7],[8]. These technologies operate on the same fundamental principle that uses acoustic waves as a medium to calculate the depth of the sounding point emitted by the transducer using an equation;

\[ d = \frac{1}{2} \cdot (v \times t) \]  

Where d is the measured sea depth at the time of measurement (m), v is the speed of acoustic wave propagation in water (m/s), and acoustic wave travels time (dt).

Standardization of reference for bathymetric survey activities is required in the measurement. This standardization serves to maintain the quality of the output data from the measurement activities carried out so that the quality of the measurement can be accounted for. The national standard used in bathymetric surveys using a single beam echosounder in Indonesia is SNI 7646 of 2010. The SNI 7646:2010 was prepared concerning the international standard for hydrographic surveys, namely SP-44 of 2008, published by the International Hydrographic Organization (IHO).

A Single beam echosounder is a water depth measuring instrument that uses a single sound wave signal sender and receiver. The working principle of SBES is to use the principle of measuring pulse phase difference, which is to calculate the time difference between transmitting and receiving acoustic pulses. SBES is also quite accurate, where SBES can provide accuracy of up to 0.1 meters at a depth of fewer than 100 meters [9]. When collecting depth data, it is necessary to consider single-beam echosounder calibration by correcting bar checks and reducing the depth of single beam echosounder with the formula;

\[ d_c = \left\lfloor \left( \frac{bari - bar_{i+1}}{reci - rec_{i+1}} \right) \cdot (d_0 - rec_{i+1}) \right\rfloor + bari \]  

Where i is the bar check number, \( bari \) is the bar check value, \( reci \) is the receiver value, \( d_0 \) is the depth of sounding at time zero, and \( rec_{i+1} \) is the receiver value at the next bar check.

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Where, \(d_c\) is corrected depth, \(d_0\) is any observed/record depth to be corrected for speed of sound and index error, \(bar_i\) is bar depth at checkpoint \(i\), \(bar_{i+1}\) representing bar depth recorded at point \(i + 1\), \(rec_i\) is recorded depth at bar depth \(i\), \(rec_{i+1}\) is recorded depth at point \(i + 1\), \(i, i + 1\) is any two successive calibration depth points and \(rec_i > d_0 > rec_{i+1}\).

The noise data accuracy test using a single beam Echosounder is carried out in overlapping lane areas. The depth value of the overlapping area between the main and cross lanes will generally be the same. The patch data quality test refers to the SNI 7646:2010 standard with a 95% confidence level. The equation used to calculate the fault tolerance limit can be seen in Eq (4)

\[
\pm \sqrt{a^2 + (b \times d)^2}
\]

(4)

Where \(a\) is an independent error, \(b\) is the depth-dependent error factor, \(d\) is mean depth, and \(b \times d\) is the depth-dependent error. The values of \(a\) and \(b\) in the equation are adjusted to the order of the survey conducted in SNI7646:2010.

The depth value quality test is carried out by assuming that the main lane depth (\(H_{lu}\)) is the same as the cross lane depth (\(H_{ls}\), which coincides with each other (at the same x and y positions). Then look for the difference between \(H_{lu}\) and \(H_{ls}\), from the difference, the average value and absolute average are sought, then the standard deviation value. In equation (5), the mean equation is presented, and equation (6) is the standard deviation equation[10], as follows:

\[
\bar{H} = \frac{\sum (H_{lu} - H_{ls})}{n}
\]

(5)

\[
\sigma = \sqrt{\frac{\sum (H - \bar{H})^2}{n - 1}}
\]

(6)

Where, \(H_{lu}\) is the main lane depth, \(H_{ls}\) is the cross lane depth, \(\bar{H}\) is the average value, \(H_i\) is the difference between the main lane and cross lane depth values, \(\sigma\) is the standard deviation and \(n\) is the number of samples.

Based on SNI 7646:2010, the data quality test is continued by calculating the depth difference error value with a 95% confidence level, which is 1.96\(\sigma\). If calculating the depth difference value is still within the tolerance limit, then the data is declared to have passed the quality test. If the calculation result of the depth difference value is outside the tolerance limit, then the data is declared not to pass the quality test, illustrated in the following statement:

- Data is rejected, if \(1.96 \times \sigma > \sqrt{a^2 + (b \times d)^2}\)
- Data received, if \(1.96 \times \sigma < \sqrt{a^2 + (b \times d)^2}\)

(7) (8)

The geometric accuracy test was applied to the orthophoto mosaic to determine the accuracy and error of the horizontal position. In contrast, the vertical or elevation accuracy was tested on the Digital Elevation Model (DEM). The method used to test the accuracy of the data refers to SNI 8202:2015. The geometric test is based on a comparison between the coordinates (\(x, y, z\)) at the Independent Check Point (ICP) field measurement results using Geodetic GNSS, with coordinates (\(x, y\) orthophoto and \(DEM(z)\))[15],[16]. CE90 and LE90 values are obtained using the equation:

\[
CE90 = 1.575 * \text{RMSe}_r
\]

\[
LE90 = 1.6499 * \text{RMSe}_e
\]

(9) (10)

Where \(\text{RMSe}_r\) is Root Mean Square Error at position \(x\) and \(y\) (horizontal), \(\text{RMSe}_e\) is Root Mean Square Error at position \(z\) (vertical), \(CE90\) (Circular Error 90%) is a measure of horizontal geometric accuracy, \(LE90\) (Linear Error 90%) is the vertical geometric accuracy.

This study combines point cloud data generated from hydrographic and photogrammetric surveys into one coordinate system. The point clouds data is important because it has coordinated and semantics to provide information on the topographical situation of land and water optimally with equation (11). An illustration of these measurements can be seen in Figure 1.
Where $X$ is the GNSS as georeferencing, $PCDT$ is the Bathymetric-based point cloud, $PCDU$ is the UAV-based point cloud, and $PCDF$ is the fused Bathymetric and UAV-based point cloud.

![Figure 1](image1.png)

**Figure 1**. Hydrographic and photogrammetric surveys integration (Source: Author)

### 3. Data and methods

#### 3.1. Study Area

The research location is in Sermo Reservoir in Sermo Hamlet, Hargowilis Village, Kokap District, Kulonprogo Regency, Yogyakarta as shown in Figure 2.

![Figure 2](image2.png)

**Figure 2**. Location of the Sermo Reservoir (left) and the planning of the sounding (right)
The purpose of constructing the Sermo Reservoir is to increase the provision of irrigation, flood control, fishery business, tourism, and water sports infrastructure. Sermo reservoir was constructed to supplement irrigation in Clereng, Pengasih, and Pekik Jamal, particularly during the dry season. This dam will increase agricultural productivity by expanding irrigated agriculture, irrigation water efficiency, and the intensity of cropping patterns. In addition to agriculture, water from the Sermo Reservoir is also used by the community as a source of fishery water. The Sermo Reservoir improves water management, resulting in fewer flooded areas. The dam is also used by the Regional Drinking Water Company (PDAM) to serve raw water for the Kulon Progo community. The dam’s existence and surroundings also provide a place for fishing, hiking, camping, and cycling. Water sports, particularly rowing, are extremely popular in Sermo. The natural condition of the Sermo area is also a favorite site for lovers of off-road, two wheels and four wheels. This research is focused on monitoring the condition of the Sermo Reservoir with the bathymetric and photo aerial method approaches to obtain optimal data.

3.2. Data Used
The data used is primary data from GNSS Javad Triumph, Dji Phantom 4 Pro, and Single-beam Echosounder Odom Hydrotrac to obtain bathymetric data. Geodetic measurements resulted in 10 control points that have been undulated with geoids as tie points for reservoir monitoring, which can be seen in Table 1.

| No | GCP & ICP | X (m)       | Y (m)       | Z (m)      |
|----|-----------|-------------|-------------|------------|
| 1  | BMS2      | 403482.211  | 9135020.061 | 168.046    |
| 2  | ICP1      | 403075.791  | 9135615.034 | 169.292    |
| 3  | ICP2      | 402584.06   | 9136312.12  | 169.791    |
| 4  |           |             |             |            |
| 5  | GCP5      | 402274.732  | 9134057.091 | 231.781    |

Coordinate data for Ground Control Point (GCP) and Independent Check Point (ICP) from GPS survey results using the static method and using the WGS 1984 UTM Zone 49S reference system with elevation referring to the Sermo Reservoir palm water level. Bathymetric measurements were carried out for two days concerning the same water level of 124.5 on the peil scale of the Sermo Reservoir. This reservoir water level elevation is used as a depth reference. Google Earth image is used as the Sermo reservoir inundation area boundary. Figure 3 describes the distribution of control points of GNSS at various locations in the Sermo reservoir.

Figure 3. Distribution of GCP Data obtained from GNSS
3.3. Processing Data
The material used to design the sounding line is a google earth image of the Sermo Reservoir or an aerial photo of the Sermo Reservoir. The criteria for designing the sounding line are to make the mainline perpendicular to the land boundary and the distance between the lines according to the map's scale to be made. The sounding line must also contain a cross-lane design that is perpendicular to the orientation of the main lane, and the distance between the cross lanes is ten times the distance between the main lanes. In processing bathymetry data, a vertical reference equation is needed. The vertical reference equation combines depth data and detailed elevation data of the situation around the Sermo reservoir area. The vertical reference refers to the reservoir's water level elevation in the Palm Automatic Water Level Recorder (AWLR) located in the Sermo. The results of the sounding or bathymetric can be seen in Figure 4 (left). In the form of points containing the position and depth.

Aerial photo measurements were carried out using the DJI Phantom 4 Pro. Measurements are divided according to the flight path and photo overlaps that have been determined at the time of measurement preparation; aerial photo overlap is 75%, while aerial photo side lap is 65%. Before taking measurements, make sure that the control point (GCP) has been installed and marked to be visible at the shooting time. Aerial photo data processing is carried out by combining all the resulting photos according to the flight path, then proceeding with the orthorectification process. The process of making orthophotos is carried out with aerial photo data processing software and includes control points and adjustment calculations. This process results in an ortho aerial photo with coordinates according to the coordinates in the field. The exported data are point cloud, DEM and orthophoto. The point cloud data is shown in Figure 4 (right).

After finishing aerial photos processing using Agisoft Software, generating Dense Cloud and extracting DEM from the point cloud, after getting the DEM data from the Sermo reservoir, then merging the DEM with bathymetric data, the process of merging the DEM data using GIS Software, resulting in a DEM of the entire Sermo reservoir, to display the resulting DEM model using GIS Software. To display point cloud data using AutoCAD Recap Software and identify important buildings around the Sermo reservoir.

![Figure 4. Sounding data (left) and dense cloud data from aerial photography (right).](image)

Then the point cloud process is to be able to form a DEM using the TIN method approach. After getting the DEM in .tiff format, then export the contour lines from the DEM to be merged with the contour lines from the bathymetry data.

4. Results and discussion
4.1. Single Beam Echo Sounder Data Quality Test Results
The depth data quality test employs the primary and cross lanes overlapping sample points. The depth data was tested using the SNI standard to determine the measurement order. In this depth data quality test, 31 samples of depth point that overlap in the primary and cross lanes were used. These points have varying depths, which will be tested using the SNI data quality standard. Based on the depth data in the table above, the total depth difference is 0.288 meters, the average depth difference is 0.009 meters, the
standard deviation value for the depth difference is 0.098, and the value is 1.96 * Standard deviation is 0.191. The standard deviation of SNI 7646:2010 is obtained from variables a and b on order 1, where the value of a = 0.5 meters and b = 0.013 meters produces a tolerance value of 0.574. From the 31 overlapping points, it can be stated that 31 entry points are in a particular order and meet the tolerance limits of the data quality test based on SNI standards because the depth difference value is less than the tolerance limit that has been set.

Ground Control Point (GCP) data from GPS measurements are required for photo processing and orientation in Agisoft Photoscan software. Position errors in the orientation process reveal the results of GPS precision calculation. In the Agisoft Photoscan software, the geometric quality of the orientation process output is RMSe X = 7.20 mm; Y = 3.50 mm; Z = 0.758 mm, and total error = 8.04 mm. The accuracy of the GCP point marker placement on the pre mark in the photo influences the RMSe value. If the GCP point marker placement varies, it can cause a change in the value (RMSe) of the picture coordinate position, which is used in the image matching process. The process has an average error of 0.150 m.

Based on these results, it can be seen that the comparison value of ICP coordinates from geodetic GPS observations with orthophoto produces an RMSe value of 0.214 m for horizontal accuracy and an RMSe value of 0.172 m for vertical accuracy. Horizontal accuracy is expressed in Circular Error 90% (CE90), while vertical accuracy is described in Linear Error (LE90). This means that 90% of the defined points tested must be within the specified tolerances. The results of the above accuracy test are 0.325 m for horizontal accuracy (CE) and 0.284 m for vertical accuracy (LE90). Based on the SNI Base Map accuracy, the horizontal accuracy is on a scale of 1:2,500 for class 1, and the vertical accuracy is on a scale of 1:1,000 for class 2.

4.2. Single Beam Echo Sounder Data Quality Test Results
Bathymetry data collection in the Sermo reservoir was carried out as the reservoir receded, resulting in a gap or unmeasured area in the data collection process, the unmeasured area being in the western part of the reservoir and the reservoir edges because the tool is no longer capable and has stuck or has been maximized in data collection, as shown in figure 5.

Figure 5. There is a gap on the west side and the edge of the reservoir

The 3D Point Cloud model is obtained based on the results of the previous aerial photo processing and the bathymetry data processing, which was received by the DEM model and then processed using QGIS software and CloudCompare software. AutoCAD Recap software created point clouds from aerial
and bathymetry data. Figure 6 depicts the visualization of the 3D Point Cloud model. The visualization results place the two Point Cloud data in the same coordinate reference system.

From the results of the formation of the Digital Elevation Model (DEM), which is already in a coordinate reference system (X, Y, Z), it has an elevation value that has been represented by colour. The deeper the elevation value, it will show a dark blue colour, while the higher the elevation value, it will show a red colour. From the DEM in the middle, it offers a blue colour that indicates that the area's elevation value is low, with an elevation value reaching 79,948 meters. The orange colour around the reservoir is hills with an elevation value above 200 meters.
5. Conclusion
Based on the research that has been conducted and explained in the preceding subchapters, the following conclusions can be drawn: (a) The results of the 3D DEM model of the reservoir bottom surface use the bottom surface elevation value of the reservoir, which is obtained from the reservoir water level elevation, which refers to the palm water level elevation value obtained at the time of bathymetry data measurement. The water level elevation data is reduced with the depth value resulting from bathymetric measurements; (b) The results of the 3D DEM model of the Sermo reservoir from aerial photo measurements have a maximum elevation value of 250 meters and a minimum elevation value of 90 meters; (c) The results of the combined DEM model have the highest elevation value of 250 meters and a minimum elevation value of 79,948 meters; (d) The bathymetric data quality test results meet the standard tolerance of SNI 7647:2010 with a value of 1.96*standard deviation of 0.191. For the photo quality test using ICP, it meets the tolerance of SNI 8202:2015 with CE90/LE90 values of 0.325 and 0.285, respectively. The bathymetric data quality test results are included in the excellent category because all test points do not exceed the tolerance limit based on the SNI 7646:2010 standard. The aerial photo quality test results are included in the superb category because the horizontal accuracy and vertical accuracy values meet the tolerance based on SNI 8202:2015 Accuracy Base Map; (e) The accuracy test result is 0.325 for horizontal accuracy (CE) and 0.284 for vertical accuracy (LE90). Based on SNI 8202:2015 Accuracy Base Map, the horizontal accuracy is included in the 1:2,500 scale, and the vertical accuracy is in the 1:1,000 scale. Subsequent research will combine the USV developed by Suhari et al [11],[12],[13],[14] and the UAV to determine the ease of conducting surveys, budget errors, and level of accuracy.

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