Analysis of Bathymetry Data for Calculating Volume of Water in a Reservoir

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***Abstract*—Analysis of bathymetry data is a challenging task due to several reasons. The data is collected remotely which is enormous in size. Bathymetry data contains the depth values of water body at various locations. This data is processed to generate a 3D plot by interpolating the intermediate values of the plot. The bathymetry data consists of Multipath noise which is removed by applying noise removal algorithms and finally the volume of water is predicted. This paper presents a comparative analysis of different interpolation techniques and implements various noise removal techniques on bathymetry data to predict the volume of water in a reservoir. Results indicate that Natural interpolation and median filter are more accurate reservoir bottom surface plot generation and noise removal techniques, respectively.**

***Keywords*—bathymetry data, gridding, multipath noise, interpolation**

I. Introduction

Bathymetry includes the detailed examination of the bottom of a water body like a reservoir, a lake or an ocean. It is one of the remote sensing [1] methodologies to study and analyze the bottom of water bodies. Bathymetry analysis is essential for many important reasons like, carrying out hydrographic survey, determining the shape of the bottom surface of the water body, investigating the geological properties of the bed of the water body, finding the volume of water in it, finding the nature of sedimentation beneath etc. [2]. Depending on the depth of the water body, the bathymetry is divided into shallow water (5m - 300m) and deep water (beyond 300m) [3].

Traditionally, the bathymetry data was collected using simple methods. These involved measuring the depth of the water body using sticks suspended from the boat till it touches the bottom surface. This method was time consuming since it took many days to cover the entire water body surface. Moreover, the depth ranges measured were short. The introduction of SONAR based bathymetry systems enabled to collect the bathymetry data without any direct contact with the floor of the water body. It helped to collect data using single-beam echo sounding technique along the bath of the ship. The single-beam echo sounding had limited coverage with the beam width of 30-60 degrees. For higher resolutions, narrow beam widths of 3-5 degrees were introduced.

Recently, multi-beam echo sounders have replaced single-beam echo sounders, which provide higher resolution, higher depth accuracy and coverage.

The bathymetry data obtained using multi-beam echo sounders is a part of Geographical Information System (GIS) [4] that collects the data in X, Y, Z format. The X and Y values are the geographical co-ordinates obtained from Global Positioning System (GPS) and Z is the depth value received from the echo sounder. The depth values are calculated by finding the time duration between the transmission and reception of the sonar waves in water. The X and Y co-ordinates are generally not regularly spaced due to the difficulty in acquiring bathymetry data. Moreover, the reflection of sound waves in water results in reception of received signal from different directions. This results in addition of noise in the data. This demands a need for developing a system to predict the noise model in bathymetry data. Also the X and Y co-ordinates are spaced at sufficiently large distance and are irregular in spacing. This demands obtaining a regular spaced co-ordinate system and interpolation [5, 6] technique to obtain the intermediate values of depth. Finally, the volume of water can be calculated from the interpolated data. This paper does a comparative analysis of various interpolation and noise reduction techniques implemented on the bathymetry data of a reservoir, for calculation of volume of water in it.

The rest of the paper is organized as follows. Section II describes the proposed system design. Section III presents the results and discussion and Section IV discusses the conclusion of the proposed system design.

II. Bathymetry Data Analysis System

The components of a bathymetry data analysis system are depicted in Fig. 1. The system first receives the bathymetry data, followed by interpolation and noise removal stages. In the final step, volume of water is calculated.

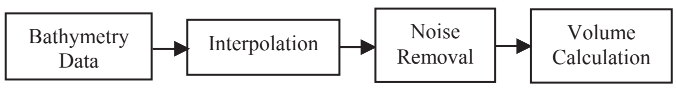


Fig. 1. Bathymetry data analysis system.

The following section discusses each system component in detail.

A. Bathymetry data

In this paper, the system designed is based upon the data of a hydropower reservoir near Bhopal, Madhya Pradesh in India. The volume of water in this reservoir is measured for power house situated there. The data collected is irregularly spaced at a distance of around 1m. It consists of X, Y and Z values. The Z i.e. the depth values are measured between up to 30m dimensions. The sample of the data obtained from the echo-sounder based data logger system is indicated in Table 1.

TABLE I. SAMPLE BATHYMETRY DATA

X	*Y*	*Z (m)*
654591.1	2462581	9.19
654595.8	2462573	9.33
654599.9	2462564	8.8
654603.2	2462555	9.22
654606	2462545	10.63
654609.8	2462534	11.32

This data is converted into three-dimensional plot to model the earth's surface or terrain under water. This conversion is done using Delaunay triangulation algorithm [7].

B. Interpolation

The Delaunay triangulation algorithm generates a plot composed of triangles spaced irregularly. The X and Y dimensions need to be gridded in a regular manner. The gridded plot is a discontinuous terrain plot. A continuous surface plot is obtained using interpolation. Interpolation is a fundamental step in digital signal processing. It is a process of finding the intermediate values between known sample points. Interpolation techniques are generally classified into two types: statistical and deterministic. Statistical techniques predict the signal by minimizing the estimation error while deterministic techniques assume some variability between the points. Statistical methods are computationally expensive than deterministic techniques. In this paper, following deterministic interpolation methods [8] are applied on the discontinuous, three-dimensional plot.

- Nearest neighbor interpolation – it is one of the simplest interpolation [9] methods. The nearest sample value of the signal is assigned to the output interpolated value. The basis function for nearest neighbor interpolation is given by

$$g(x) = \begin{cases} 1 & -0.5 \le |x| < 0.5 \\ 0 & otherwise \end{cases} \tag{1}$$

- Linear interpolation – this method tries to pass a straight line through two consecutive sample points in the signal. It's basis function is given by

$$g(x) = \begin{cases} 1-|x| & 0 \le |x| < 1 \\ 0 & 1 \le |x| \end{cases} \tag{2}$$

- Natural interpolation [9] – this method is based on computation of weighted Voronoi tessellation of input sample points. The weights reflect the changes in the Voronoi tessellation points. The basis function is,

$$g(x) = \sum_{i=1}^{n} w_i x_i \tag{3}$$

- Cubic interpolation – it approximates a sinc function using third degree algorithm to give fairly smooth interpolated output. The equation for cubic interpolation basis function is

$$g(x) = \begin{cases} (a+2)|x|^3 - (x+3)|x|^2 + 1 & 0 \le |x| < 1 \\ a|x|^3 - 5a|x| + 8a|x| - 4a & 1 \le |x| < 2 \\ 0 & 2 \le |x| \end{cases} \tag{4}$$

C. Noise Removal

Bathymetry data collection using multi-beam echo sounding introduces multipath noise in the signal. This is due to refraction of the acoustic signal in water. Multipath noise is also added due to the reflection of the signal by rocks and sediments in water at the bottom of the reservoir. This noise results in impulses in the signal that appear as spikes in the surface plot. The multipath noise can be characterized by salt-and-pepper noise model [10]. The salt and pepper noise is removed by filtering operation. The filter mask of $\omega(s,t)$ is convolved with the interpolated plot $f(x,y)$ using,

$$\omega(s,t) * f(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} \omega(s,t) f(x-s, y-t) \tag{5}$$

Various noise removal algorithms are implemented to get rid of multipath noise in bathymetry data. In this proposed work following noise removal algorithms are implemented

- Low pass filter [10] – this filter mask computes the average R of the values in the neighborhood of the center pixel given in

$$R = \frac{1}{s \times t} \sum_{i=1}^{s \times t} \omega_i \tag{6}$$

This removes the impulses or sharp variations in the signal and gives a smooth plot.

- Gaussian filter – this is similar to low-pass filter but has a different basis function, whose coefficients decrease with increasing distance from the centre of the filter mask. The Gaussian filter function is given by

$$G(s,t) = \frac{1}{2\pi\sigma^2} e^{\frac{s^2+t^2}{2\sigma^2}} \tag{7}$$

Here σ is the standard deviation of the signal distribution.

- Median filter – it is non-linear filter obtained by sorting the values in the mask and replacing the centre value of the mask with the median of the sorted values [11].

The effect of noise removal algorithms on various interpolation techniques is analyzed by comparing the mean and variance of the surface plot after noise removal.

D. Volume Calculation

Finally the volume V (cubic units) of the 3D plot is calculated by Simpson's rule [12] given by

$$V = \frac{d}{3}\left[O_1 + O_n + 4(\sum O_{even}) + 2(\sum O_{odd})\right] \tag{8}$$

Here O_n are the segments in which the 3D plot is divided. O_1 is the first segment, O_n is the last segment and d is the distance traversed by all the segments. It is a well known method for calculating volume of irregular shaped surfaces.

III. Results and Discussion

The bathymetry data base consists of over 5000 values of three-dimensional data of the reservoir mentioned earlier. The entire plot or region is divided into 500 non-overlapping regions and processed using Python software. The output of three-dimensional data values after applying Delaunay triangulation algorithm is shown in Fig. 2.

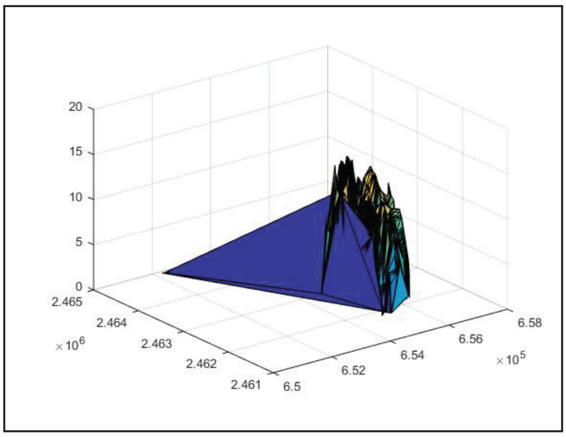
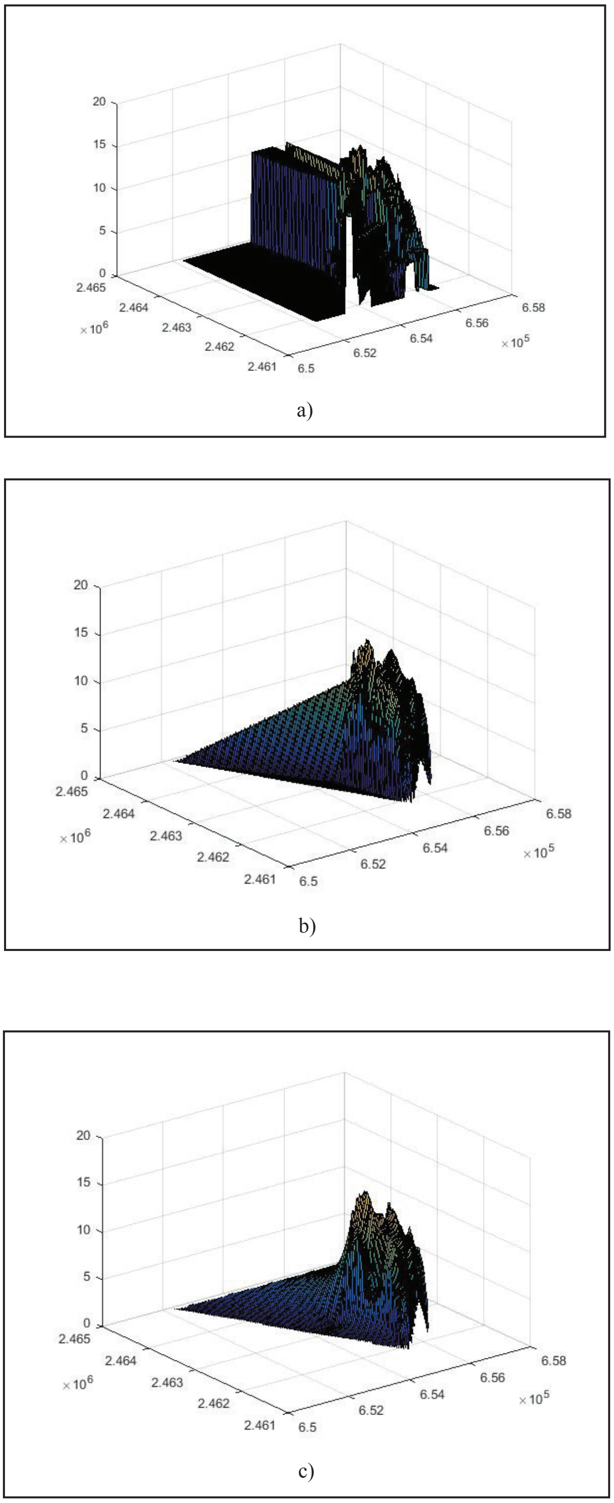
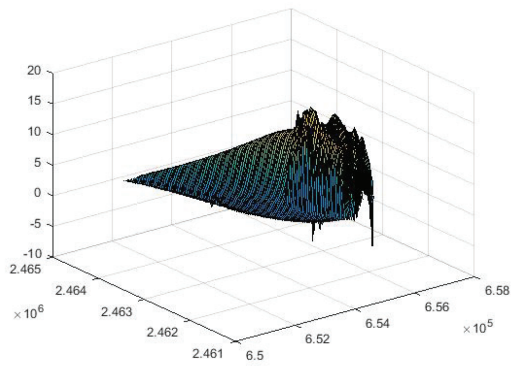


Fig. 2. Plot after applying Delaunay Triangulation Algorithm.

As seen from the plot, the output of triangulation needs to be interpolated to give a smooth plot. The plot is gridded regularly before interpolation with spacing of 30 between two consecutive points. The result of gridding and interpolation using nearest neighbor interpolation, linear interpolation, natural interpolation and cubic interpolation is shown in Fig. 3 a) through Fig. 3d) respectively.





d)

Fig. 3. Interpolation results: a) Nearest neighbor interpolation, b) Linear interpolation, c) Natural interpolation, d) Cubic interpolation.

The smooth plots obtained are further passed to various filtering operators for removal of salt and pepper noise. The values of mean and variance obtained after applying noise removal filters are given in Table II. As indicated in the results, the median filter is best at removing salt and pepper noise with least variance value. Also, the Natural interpolation technique gives a smooth bottom surface plot. The surface plot is finally used to calculate the volume of water in the reservoir by applying Simpson's rule.

TABLE II. COMPARISON OF INTERPOLATION AND NOISE REMOVAL TECHNIQUES

Interpolation Technique	Noise Removal Technique	Mean (m)	Variance (m^2)
Nearest Neighbor	Noisy data	8.15830	16.82715
	Low-pass filter	4.29642	18.55965
	Gaussian filter	4.33758	19.20592
	Median filter	4.32350	18.91467
Linear	Noisy data	8.15830	16.82715
	Low-pass filter	6.19099	15.99577
	Gaussian filter	6.30429	16.49370
	Median filter	7.31403	15.23608
Natural	Noisy data	8.15830	16.82715
	Low-pass filter	5.81287	14.67928
	Gaussian filter	5.90954	14.98333
	Median filter	6.84380	14.48932
Cubic	Noisy data	8.15830	16.82715
	Low-pass filter	5.97338	21.24691
	Gaussian filter	6.09035	21.96681
	Median filter	7.17503	20.47985

The comparison of calculation of volume by Simpson's rule with various interpolation techniques is given in Table III. The volume is calculated in m^3.

TABLE III. VOLUME OF WATER

Interpolation Technique	Volume using Simpson's rule (m^3)
Nearest Neighbor	242762205.00
Linear	119918579.88
Natural	114249523.22
Cubic	123315557.02

The value of volume is computed for all 5000 data points. The results when compared with the Surfer software indicate that the volume obtained using Natural interpolation technique gives more accurate results. The volume obtained using Surfer software is 107243787 m^3.

IV. CONCLUSION

Accurate prediction of volume of water is essential for reservoir water management. This paper presents a comparative study of various interpolation and noise removal techniques that are applied on bathymetry data of a reservoir. The techniques are evaluated on the bathymetry data with salt and pepper noise model generated due to multipath noise added while data collection. Four different interpolation techniques namely nearest neighbor interpolation, linear interpolation, natural interpolation and cubic interpolation and three noise removal techniques, namely, low-pass filter, Gaussian filter and median filter are evaluated. Results indicate that median filter with Natural interpolation technique is the best combination for multipath noise removal and accurate reservoir bottom surface plot prediction, finally resulting in accurate water volume calculation.

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