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Measurement and Computational Study of Underwater Topography

Satoshi Iwakami[1], Masahiko Tamega[1], Masahide Sanada[1], Michiaki Mohri[1], Yoshitaka Iwakami[1], Naoki Okamoto[1], Eishi Mitsui[1], Hidetaka Chikamori[2], Ryosuke Akoh[2], Shuji Jimbo[3*], Masaji Watanabe[3#]

[1]Earth Rise Company, Inc., Okayama, Japan
[2]Faculty of Environmental, Life, and Natural Science and Technology, Okayama University, Okayama, Japan
[3]Okayama University, Okayama, Japan
Email: watan-m@okayama-u.ac.jp

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Abstract

This paper reports previously obtained results concerning topographic change in a water area. Latitude-longitude components of positional data obtained from a GPS receiver were transformed to planar orthogonal coordinates, and vertical components of positional data were combined with depth data obtained from an echo sounder. A piecewise linear function defined on a triangular mesh represented a surface that fitted measurement results. This study applied those techniques to data obtained in measurement of November, 2021 and data obtained in measurement of September, 2022.

Keywords

Topographic Change, Water Area, RTK-GPS, Echo Sounder

1. Introduction

Human damages and materials damage due to heavy rain disasters in recent years include 119 fatalities, 29 injured people, 213 totally destroyed houses, 340 partially destroyed houses, and 290 damaged houses caused by 2018 Japan floods (Ministry of Land, Infrastructure, Transport and Tourism, 2018), 104 fatalities, 3 missing people, 43 severely wounded people, 341 minorly wounded people , 3308 totally destroyed houses, 30,024 partially destroyed housed , and 12510 damaged houses caused by 2019 Typhoon 19 (Hagibis, October 2019) and the subsequent heavy rain events (Cabinet Office, Government of Japan, 2020), 84 fatalities, 2 missing people, 23 severely wounded people, 54 minorly wounded people, 1621

*Visiting Researcher.
#Emeritus Professor, Specially Appointed Professor (Research).

totally destroyed houses, and 4504 partially destroyed houses caused by July 2020 heavy rain disaster (Cabinet Office, Government of Japan, 2021), and 26 fatalities, 1 missing person caused by July 2021 heavy rain disaster in Japan (Ministry of Land, Infrastructure, Transport and Tourism, 2021). One speculates that disastrous heavy rain events may increase in frequency and scale as the climate change progresses, and the preventive maintenance of rivers, reservoirs, and coastal areas as well as measurement and analysis for underwater topography are necessary.

This paper focuses on techniques for measurement and analysis of topography in a water area, and application of those to investigation of topographic change. The following sections describe our techniques to construct a surface from a given set of data points. Those techniques were developed in previous studies (Iwakami et al., 2019, Iwakami et al., 2020a, Iwakami et al., 2020b, Iwakami et al., 2021a, Iwakami et al., 2021b, Iwakami et al., 2023a, Iwakami et al., 2023b). Those techniques were applied to positional data and depth data obtained in measurement conducted in Kojima Lake, Okayama Prefecture, Japan. Some results shown in this paper were orally presented (Satoshi Iwakami, Masahiko Tamega, Masahide Sanada, Michiaki Mohri, Yoshitaka Iwakami, Naoki Okamoto, Eishi Mitsui, Hidetaka Chikamori, Shuji Jimbo, Masaji Watanabe, Development of techniques for measurement and analysis of underwater topographic change, SIMANTAP 2022, November 28th, 2022).

A real time kinematic-global positioning system (RTK-GPS) in virtual reference station (VRS) mode provided positional data. The latitude-longitude components of positional data were transformed to planar orthogonal coordinates, and vertical components were combined with depth data that an echo sounder recorded. A piecewise linear function defined on a triangular represented a topographic surface that fitted output results from measurement. Those techniques were applied to data obtained in measurement of November, 2021 and data obtained in measurement of September, 2022.

2. Acquisition and Processing of Positional Data and Depth Data

The transducer of an echo sounder was fixed to a boat with the lower end submerged underwater. A GPS antenna was attached to the upper end of the pole that led to the transducer. As the boat traveled, positional data from the GPS receiver unit and depth data from the echo sounder were recorded. **Figure 1** shows GPS tracks in an xy-plane based on data recorded in measurement of September 12th, 2022, and the outline of Kojima Lake based on data obtained by an online softwares (Latitude-Longitude Map, Geospatial Information Authority of Japan). **Figure 2** shows output data from the echo sounder obtained in the measurement of September 12th, 2022.

The positional data were combined with depth data according to time stamps, and three dimensional topographic data were constructed. The vertical component of topographic data (x_j, y_j, z_j) was defined by the expression

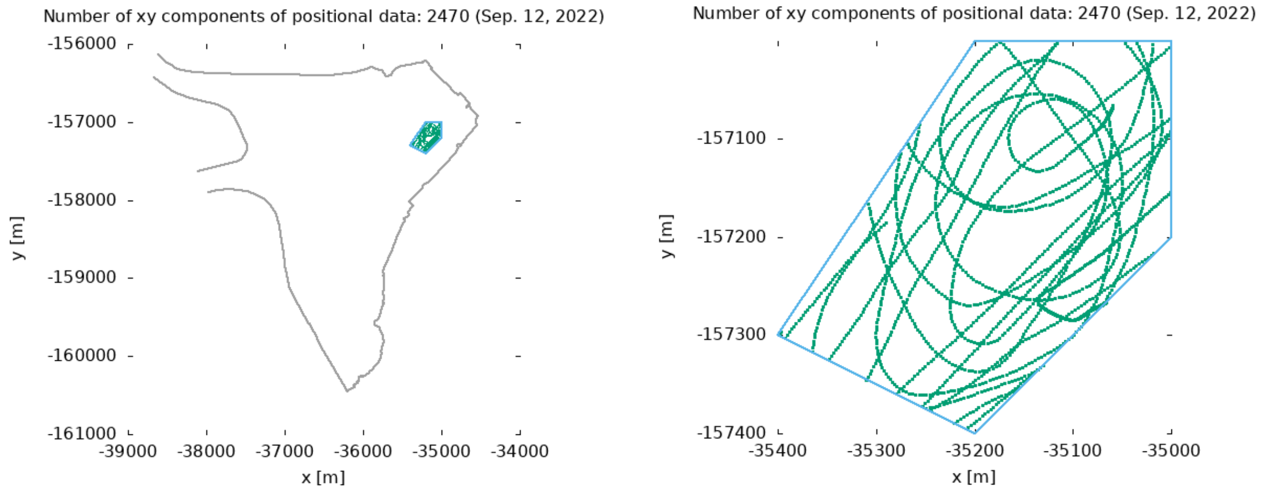

Figure 1. The figure on the left shows a part of GPS tracks recorded on September 12th, 2022, and the outline of Kojima Lake based on data obtained by an online softwares (Latitude-Longitude Map, Geospatial Information Authority of Japan 1). The figure on the right is an enlarged figure of a part of the figure on the left.

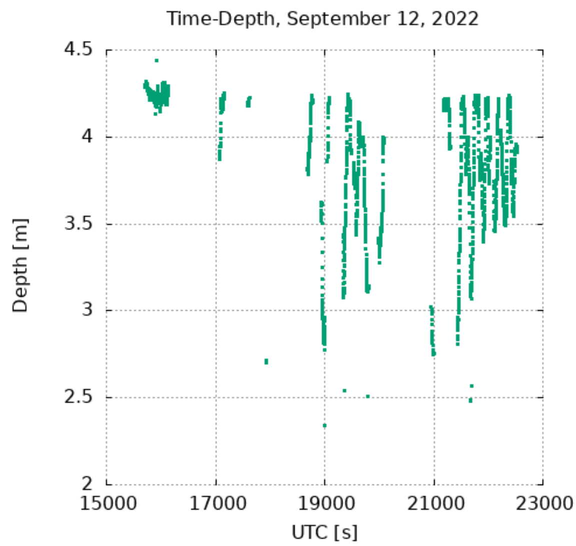

Figure 2. Output data from the echo sounder (September 12th, 2022).

$$z_j = h_j - d_j - z_0 - L\left(j = 1,2,3,\ldots\right),$$

where h_j [m] is the antenna height, d_j [m] is the output from the echo sounder, z_0 [m] (z_0 = 36.23), based on an output result from an online software (Geospatial Information Authority of Japan 2) is the geodetic height of mean sea level, and L [m] (L = 2.3356) is the distance between the antenna and the lower end of the transducer. **Figure 3** shows three dimensional topographic data based on data obtained in the measurement of September 12th, 2022.

3. Construction of Topographic Surface in Water Area

A piecewise linear function defined on a triangular mesh represents a topographic surface of a water area. A previous study developed a method to generate

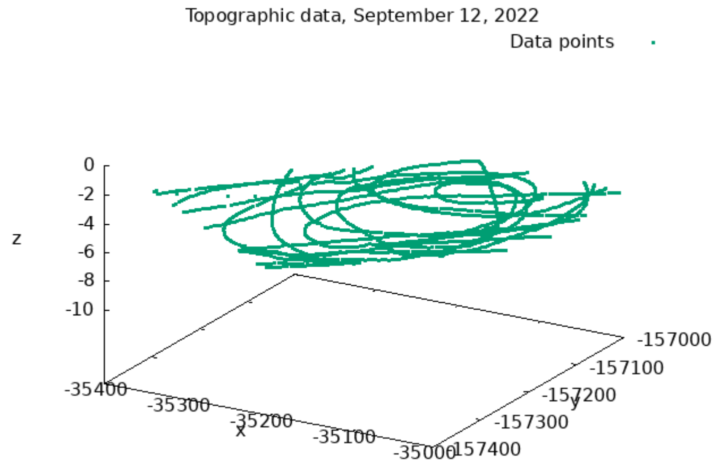

Figure 3. Three dimensional topographic data based on data obtained in the measurement of September 12th, 2022.

a sequence of triangular meshes from an initial mesh. An element in a triangular mesh is associated with data density, which is the number of *xy* components of topographic data per unit area. An element is divided into two triangles, three triangles, four triangles, or undivided depending on its data density and data densities of elements that shares the sides with the element as common sides. **Figure 4** shows an initial mesh M_0 and mesh M_5 obtained after five times applications of data adaptive division.

A piecewise linear function over a triangular mesh represents an underwater topographic surface. Consider a triangular mesh consisting of *m* elements $E_1, E_2, \cdots, E_m$, and *n* nodes $N_1(x_1, y_1), N_2(x_2, y_2), \cdots, N_n(x_n, y_n)$. Suppose that the elevation z_i at node N_i is given ($i = 1, 2, \cdots, n$). Suppose also that $V_1(x_{i(1)}, y_{i(1)})$, $V_2(x_{i(2)}, y_{i(2)})$, and $V_3(x_{i(3)}, y_{i(3)})$ are vertices of element E_k. Note that $i(1) = q(1 \le q \le n)$, $i(2) = r(1 \le r \le n)$, and $i(3) = s(1 \le s \le n)$ for some *q*, *r*, and *s*. Suppose also that element *k* contains (x, y) components of the *p* data, $(x_1, y_1, z_1), (x_2, y_2, z_2), \cdots, (x_p, y_p, z_p)$. Note that those data include $(x_1, y_1, z_1), (x_2, y_2, z_2)$ and (x_3, y_3, z_3) whose x, y components are coordinates of the vertices, and that z_1, z_2, and z_3 are elevations at nodes V_1, V_2, and V_3, respectively. Consider a linear function $z = ax + by + c$ such that the values of coefficients *a*, *b*, and *c* are those that minimize the square sum $\sum_{i=1}^{p} \left[z_i - (ax_i + by_i + c) \right]^2$. Once those coefficients are evaluated, values of z_1, z_2, and z_3 are updated.

After those operations are completed for the element *k*, the operations are repeated for the element *k* + 1. The iterations is completed when *k* reaches *m*. Forgoing operations update the *z* value at a typical node as many times as the number of elements which share the node as one of vertices, and define a mapping of *z* values, which gives rise to equations to be solved for the *z* values. Those processes were carried out for the sequence of triangular meshes M_0, M_1, M_2, ...

Those techniques were applied to topographic data obtained in measurement of September 12th, 2022. **Figure 5** shows some numerical results.

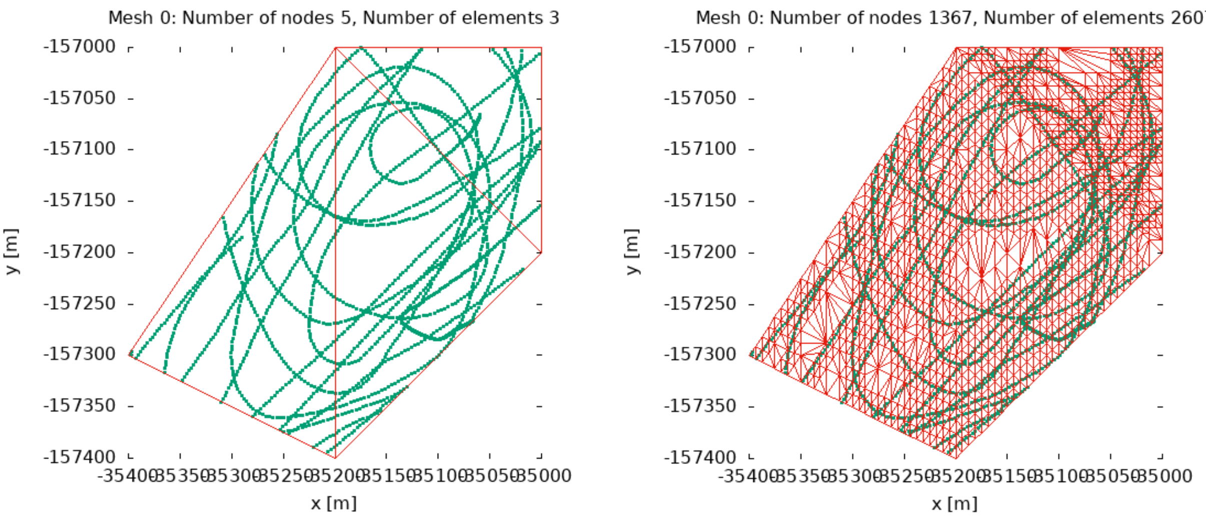

Figure 4. Adaptive meshes M_0 (4 nodes and 2 elements) (left), and M_5 (908 nodes and 1713 elements) based on the positional data obtained in the measurement of September 12th, 2022. GPS antenna tracks are also shown. The outline of Kojima Lake was based on data obtained by an online softwares (Latitude-Longitude Map, Geospatial Information Authority of Japan).

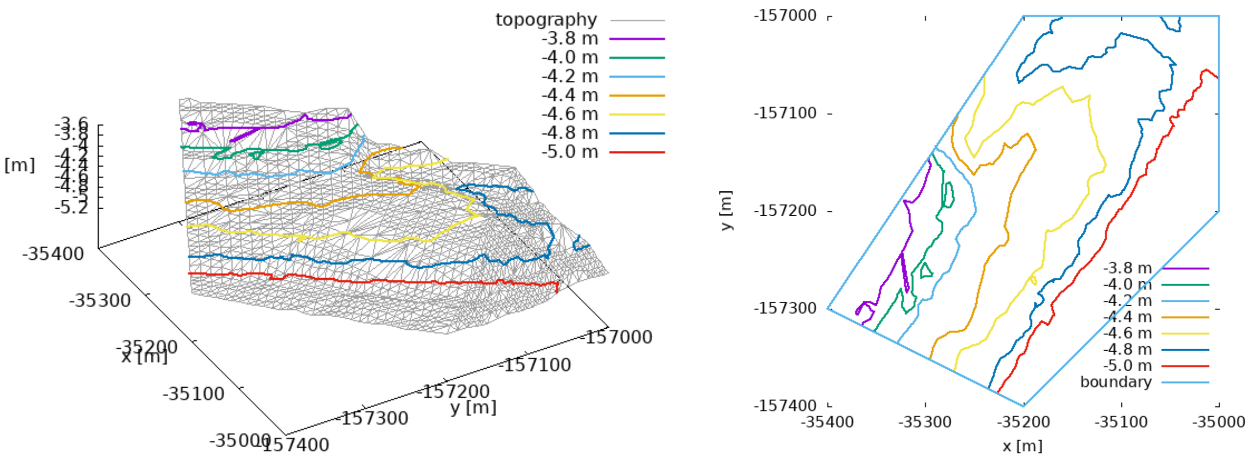

Figure 5. Topographic surface over M_5 based on the data obtained in the measurement of September 12th, 2022 (Left figure). Figure. Contour lines of the topography based on the data obtained in the measurement of September 12th, 2022 (Right figure).

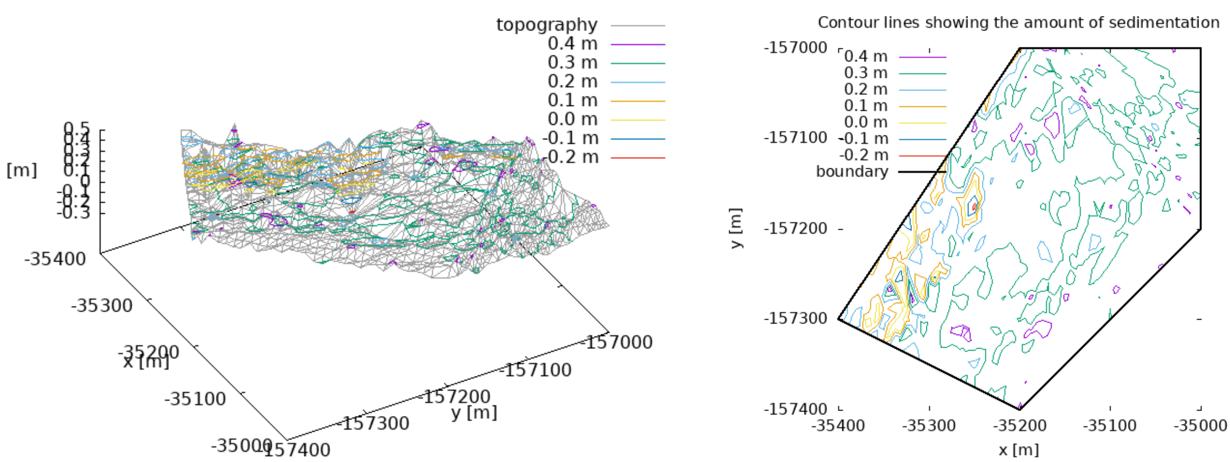

Figure 6. Sedimentation during period from November, 2021 to September 2022.

Our numerical techniques were applied to topographic data obtained in measurement conducted on November 22nd, 2021 (Iwakami et al., 2023a) and September 12th, 2022. **Figure 6** shows the change of the topography during period from November, 2021 to September 2022.

4. Discussion

This paper demonstrated numerical techniques for construction of a topographic surface in a water area with positional data and depth data. Our numerical techniques were applied to data obtained in the measurement of November 22nd, 2021 and September 12th, 2022. Our numerical results show notable sedimentation over the area. They indicate that deeper the depth of a region is, more sedimentation is accumulated.

Future issues concerning our study include consideration for correction of errors due to movement of boat such as pitch, roll, and yaw, establishment of hardware-software system for reliable measurement, and development of methods to compare numerical results and measurement results.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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