

Detection of spikes in single-beam bathymetry data

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Abstract. *The process of detecting spurious depth (spikes) in bathymetric single beam data can be extensive depending on the quantity of data acquired on survey, because it is mostly executed manually during the processing phase. Another matter to be considered is the subjectivity of the process, because the surveyor must visually analyze the echogram of each probing line and decide, based on his experience, which data could be a possible spike. Therefore, this project intends to demonstrate a methodology for automation of the detection process and elimination of spikes, based on splinesinterpolators, applied on bathymetric single beam data.*

Resumo. *O processo de detecção de profundidades espúrias (spikes) em dados batimétricos monofeixe, pode ser demorado dependendo do volume de dados adquiridos no levantamento, pois é, na maioria dos pacotes de processamento, executado de forma manual. Outra questão a ser considerada é a subjetividade do processo, pois o hidrógrafo deve analisar visualmente o ecograma de cada linha de sondagem e decidir, baseado em sua experiência, qual dado configura um possível spike. Assim, este trabalho objetiva demonstrar uma metodologia para a automatização do processo de detecção e eliminação de spikes, baseada em interpoladores splines, aplicada sobre dados de batimetria monofeixe.*

1. Introduction

In several areas, the knowledge of the submerged relief is the major issue. Activities such as the establishment and maintenance of waterways (maritime and river), infrastructure works (construction and maintenance of bridges, ports, piers, etc.), leasing of cable networks and submerged pipelines, prospecting for mineral resources (oil, gas natural, etc.) and monitoring of silting of dams [Ferreira et al. 2016] are examples of activities that use this technology.

Nautical charts and Digital Elevation Models (DEM's) of aquatic surfaces called also as Digital Depth Model (DDM) are constructed from depths obtained by bathymetric surveys [IHO, 2005; Ferreira et al. 2015].

The bathymetric survey can be highlighted as the main activity in hydrographic surveys. Bathymetric information, which consists of depth and position data, is essential to know and represent submerged topographic features. These depths can be obtained directly, using rulers, plumb lines and probes, or through indirect methods, using echo sounders [Ferreira et al. 2013]. In these measurements, it is common to use acoustic systems, such as single-beam echo sounders (SBES – Single Beam Echo Sounders) and multi-beam (MBES – Multibeam Echo Sounders) and also interferometric sounders [IHO 2005] among others. Coupled to the echo sounder, a GNSS (Global Navigation Satellite System) receiver is usually installed, for georeferencing the collected depths. According to [IHO (2005); Ferreira et al. (2013)] the RTK (Real Time Kinematic) technique is commonly used.

It is known that the surface to be mapped must be properly divided into a mesh of almost equally spaced lines, called regular probing lines [Ferreira 2015]. According to [Martini (2007)], the way they will be defined must take into account the nature of the survey site.

In the processing of a bathymetric survey, the detection of spurious depths is the most time-consuming and subjective of the steps, because it is a manual process and the surveys have a large amount of data [Ware et al.1992; Calder and Smith 2003]. Softwares such as Hypack (2020) allows the user to analyze digital or analog echograms generated from the survey's bathymetric data, manually eliminating outliers. It is important to emphasize that it is necessary to attach these echograms generated during the survey to the Final Report SBES bathymetric surveys [NORMAM-25 (2017)]. Furthermore, studies are constantly being developed to enable the automatic detection of spikes, especially for multibeam surveys, such as SODA (Spatial Algorithm for Outliers Detection). [Ferreira et al. 2018].

The reason for the occurrence of these spikes is due, among others, to failures in the performance of the algorithms used for the detection of the bottom, the detection of multiple reflections, the presence of air bubbles near the transducer and reflections in the water column, typically caused by algae, fish, DSL-type layers (Deep Scattering Layer), thermal variations and suspended sediments [Miguens 2005; Jong et al. 2010]. These flaws or inconsistent observations are defined as outliers [Hawkins 1980]. More specifically, in hydrographic surveys, these outliers are commonly treated as spikes, however, the procedure for detecting these spurious depths must take into

account the vicinity of the discrepant point. If a given observation is very different from the observations immediately before and after it, then this observation has a great chance of being a spike [Ferreira 2018].

Within this perspective, the importance of studies in the area of automation of spike detection in single-beam bathymetry data is notorious. The reduction of time used in the process tends to reduce the costs of the products generated and the elimination of the subjectivity of the manual process brings more reliability to the results obtained. In this context, this work seeks to present a methodology developed for automated spike detection in single-beam bathymetry data. The algorithm was implemented in open-source software.

2. Methods

2.1. Study area

The data that served as the basis for this study were collected in 2020. The study area comprises the reservoir located in the city of Viçosa, Minas Gerais, Brazil (Figure 1).

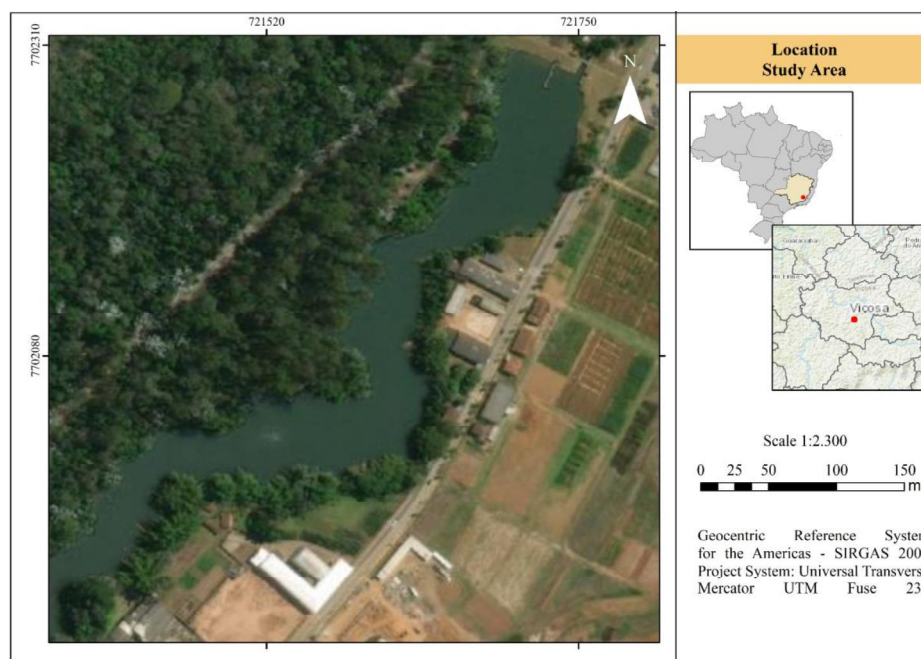


Figure 1. Geographic location of the study area

The Echotrac CV3 MKIII [Teledyne 2018] dual-frequency single beam echo sounder and a pair of GNSS RTK (Real Time Kinematic) receivers, model Triumph1 from JAVAD®, were used. Were probed 55 lines, being 2 of check lines.

Among several probed lines collected, those that showed spikes were processed manually, with due care by an analyst experienced in the Hypack software, where the visualization and editing of digital echograms was performed to remove inconsistent depths. Thus, aiming to meet the objectives of the work, an algorithm was developed to

automate this process. And these data were then used as a reference for evaluating the developed algorithm.

2.2. Methodological proposition

The flowchart in Figure 2 demonstrates the functioning of the methodology applied in the study.

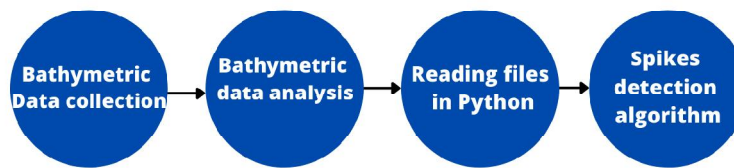


Figure 2. Methodology flowchart

After the collection, the bathymetric data were analyzed to verify the occurrence of holidays, in addition to the reduction of depths to the local reference level, however, there was no considerable variation in the water level and not even any holidays present in the data. In that way, a first algorithm developed in Python was used to generate the data input file, just to read the data that came from the survey and to edit this files, letting just with the depths, time, and ID for the algorithm developed in the Scilab software to detect the spikes in the bathymetric data automatically.

Subsequently, two experiments were performed using this algorithm in two bathymetric lines, comparing the amount of spikes identified at different tolerances and the profile generated from one of the experiments with a profile generated using the Hypack (2020) software. Some experiments were also carried out using interpolation by cubic splines in bathymetric lines and with this, it is possible to analyze the behavior of these interpolations.

2.3. Algorithm processing for automatic spike detection

The flowchart demonstrates the operation of the tool developed in Scilab software for data processing [Scilab 2015] (Figure 3).

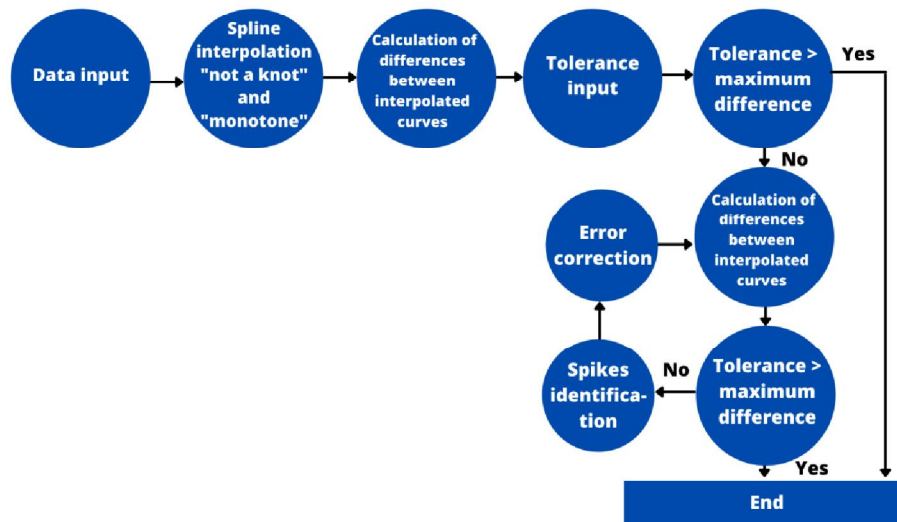


Figure 3. Flowchart of the algorithm developed for the detection and elimination of spikes

The algorithm created starts from the reading of the file containing the identification number, the time of data collection in hours and the depth in meters. In this first part, the time from (hour:minutes:seconds) is converted to decimal hours and the length of the probed line, the greatest depth observed and the total time of the line are determined. Then, the interpolation interval and the number of interpolation points are defined, as well as the discretization for data evaluation, the abscissa and the ordinate of the interpolation points.

From the data input, the algorithm automatically proceeds by performing two types of spline interpolation: one “not a knot” and the other “monotone”. The first is used as a standard by Scilab, whether the derivatives of the edges are unknown, the second is used to limit oscillations, as it has an asymptotic error behavior [Scilab 2015]. The program will generate a range for values that can be entered in the console and that will only depend on the values from the file read for the tolerance input, in millimeters for the spikes. It will be checked if the tolerance entered is within the allowed range, if not, it will be informed that a new value must be imposed and thus the detection and elimination of spikes starts through iterations, which will check in which places the difference vector of depth between the interpolations have already been corrected, attributing the value zero in these places so that a new correction does not occur in them. This elimination occurred from the biggest error to the smallest, until the tolerance is greater than the remaining spikes.

Then, a vector identifying the error locations in the observation data is generated by replacing the spike point by an average value of its adjacent ones. Again, the interval and the number of interpolation points will be determined, together with the discretization for data evaluation, the abscissa and the ordinate of the interpolation

points. Promptly, “not a knot” and “monotone” interpolations will be performed, generating corrected vectors and all possible spikes are reduced from their location in the error vector. The corrected line is saved to a text file with the output file being determined by the operant. The number of detected spikes, the corrected bathymetric profile and two columns containing decimal hour and depth in meters will be displayed.

Finally, two graphics will be generated, the first containing the raw profile and the corrected profile and the second containing the information from the first graphic together with the interpolations used during the process.

Based on the results of these interpolations, the discrepancies of the interpolated curves are calculated, considering the position of the primitive data. In sequence, a message is printed on the Scilab console with the limits in millimeters of the calculated differences.

In this way, a tolerance value is requested. After, the maximum value among the discrepancies is compared with the established tolerance value. If the tolerance exceeds this maximum value, the algorithm is terminated, as there are no spurious depths for this tolerance. Otherwise, the program will identify each of the spikes by an iterative search method and apply a correction, which consists of replacing the value by the average of the points immediately before and after the spike. Then, the identified spike position is replaced by the zero value, making the discrepancies vector when recalculated not to find the same error.

Finally, a graph containing the corrected profile and the old bathymetric profile is generated, in order to compare the results, as well as a file with the corrected data.

3. Results and discussion

The algorithm was developed so that probe lines, in the input data format mentioned above, can be filtered according to the arbitrated tolerance. Thus, some lines were selected to demonstrate and analyze the errors.

Figure 4 shows the results of splines “not a knot” (black) and “monotone” (pink) interpolations, compared with the raw profile (blue), in the first test line, this specific experiment was called “test 1” and was adopted a tolerance of 2 mm.

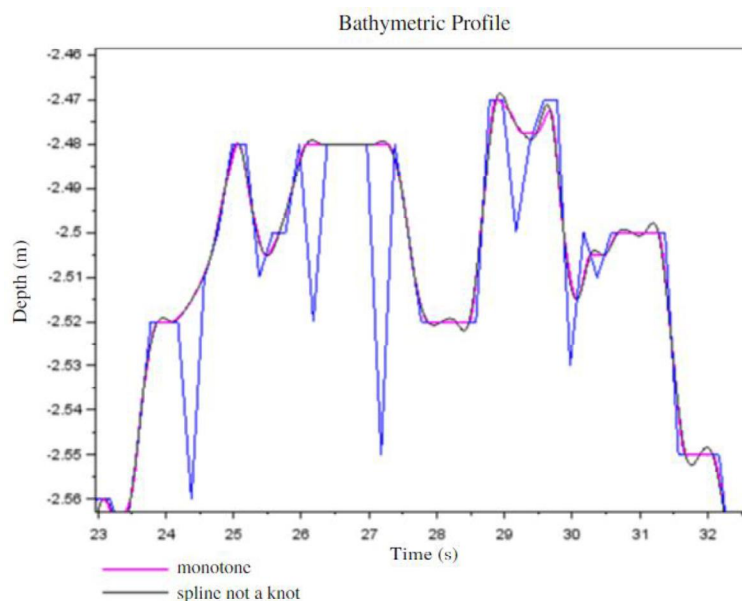


Figure 4. Raw bathymetric profile of test 1 and spline interpolations, generated by the algorithm.

Still for test 1, using a tolerance of 2 mm, Figure 5 shows the results regarding the correction of the spikes, where the blue line represents the raw bathymetric profile and the green line the corrected profile. In this way, the graphic and visual comparison of the corrections of the bathymetric profile without correction with the corrected one by the created algorithm is carried out.

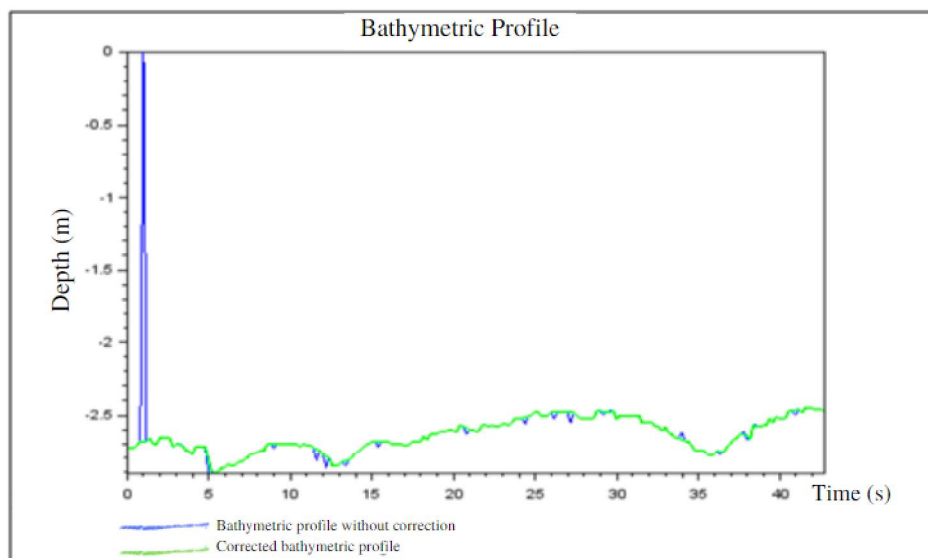


Figure 5. Results from test 1 using a tolerance of 2 mm.

For test line 1, presented above, the following variation of spikes was obtained in relation to the different adopted tolerances presented in Table 1.

Table 1 – Variation in the number of spikes in test 1.

Test 1	
Tolerance (mm)	Spikes
2	28
5	5
10	1
20	1
260	0

It can be observed that as tolerance increases, the number of spikes decreases, this happens because larger values of discrepancies between the interpolated lines are accepted, and as a consequence, fewer observations are considered spikes.

The same was observed for the bathymetric line of test 2. Table 2 presents the results obtained for the tested tolerances and figure 6 shows the corrected errors for a tolerance of 2 mm.

Table 2 – Variation in the number of spikes in test 2.

Test 2	
Tolerance (mm)	Spikes
2	14
5	2
10	1
100	1
369	0

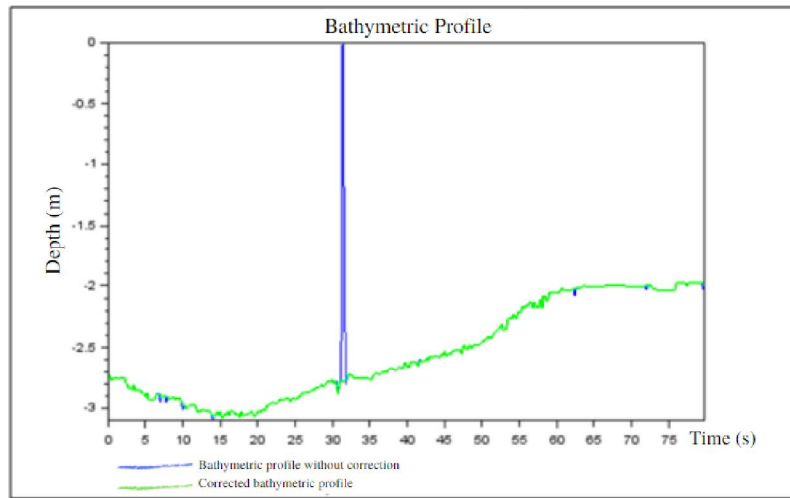


Figure 6– Results from test 2 using a tolerance of 2 mm.

In order to verify the operation of the program, manual processing of raw data related to test 1 was carried out, editing the echogram and removing the spikes, using the Hypack software. Figure 7 shows the raw and manually corrected bathymetric profile data

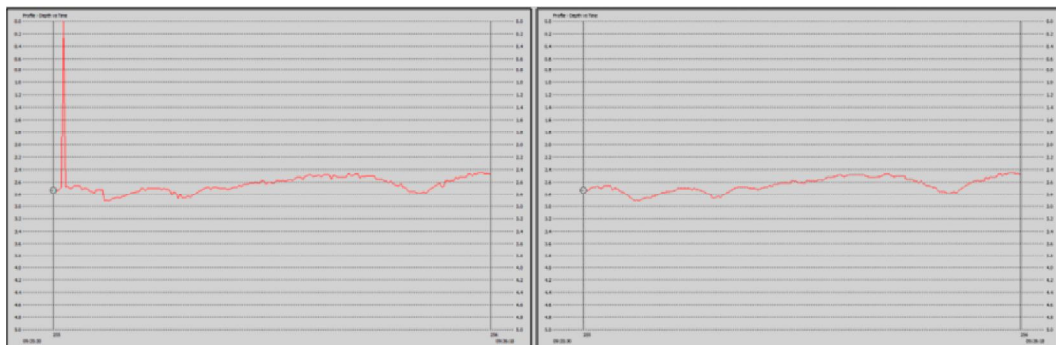


Figure 7 - “Raw” bathymetric profile (on the left) and bathymetric profile manually corrected (Hypack) (on the right).

Figure 8 shows a comparison of the profile obtained with the processing of test 1 was performed, for a tolerance of 2 mm, with the profiles resulting from the manual processing in the Hypack software, visually demonstrating that the method achieved the purpose of correcting the spikes.

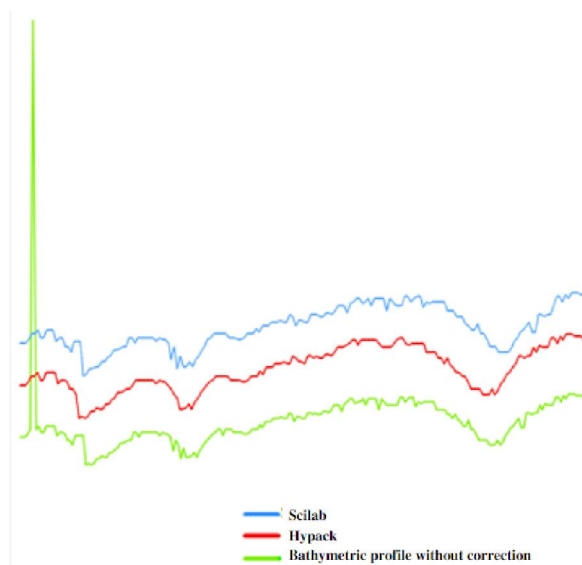


Figure 8 - Graph comparing results of semi-automatic processing (Scilab), manual processing (Hypack) and raw survey data.

It is also noteworthy that the average discrepancy between the depths of the lines processed by Hypack and those processed by the algorithm was 0.17 meters, showing the applicability of the methodology.

4. Conclusions

The proposed method achieved its goals, detecting spikes based on an established tolerance and semi-automatically correcting these errors quickly and simply. The developed algorithm managed to automatically eliminate the spikes, but the detection still requires the interference of the analyst, who must define a tolerance value. Thus, the method can be considered a semi-automatic solution for the detection and correction of spikes. The subject of automatic detection and elimination of spikes is still little explored by researchers in the field of hydrography.

It is also important to emphasize that the submerged floors of rivers, lakes and seas do not have a regular bottom. Thus, the bathymetric profiles for these environments present natural oscillations. Therefore, the use of this methodology requires prior knowledge and common sense from the user in the step of defining the tolerance used, as very small values can detect terrain features such as spikes. It is suggested that the algorithm be applied with caution, aiming not to overly smooth the submerged bottom.

As a suggestion, the methodology used can be adapted for the multibeam system and for interferometric sonars. Application tests should be performed on larger datasets and with a high volume of spikes in order to identify potential limitations of the methodology. Furthermore, future experiments in deeper and more turbid waters should also be carried out.

It is also suggested the use of another softwares in later works, so that it is not necessary to use a tolerance, completely automating the process.

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