Leonarda Rusan ◆MASTER THESIS ◆2021.

UNIVERSITY OF ZAGREB
FACULTY OF GEODESY

Leonarda Rusan

INTERPOLATION OF WATER DEPTH DATA CAPTURED BY A MULTIBEAM ECHOSOUNDER SYSTEM TO ELEVATION MODELS

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SVEUČILIŠTE U ZAGREBU
GEODETSKI FAKULTET

Na temelju članka 19. Etičkog kodeksa Sveučilišta u Zagrebu i Odluke br. 1_349_11 Fakultetskog vijeća Geodetskog fakulteta Sveučilišta u Zagrebu, od 26.10.2017. godine (klasa: 643-03/16-07/03), uređena je obaveza davanja „Izjave o izvornosti“ diplomskog rada koji se vrednuju na diplomskom studiju geodezije i geoinformatike, a u svrhu potvrđivanja da je rad izvorni rezultat rada studenata te da taj rad ne sadržava druge izvore osim onih koji su u njima navedeni.

IZJAVLJUJEM

Ja, **Leonarda Rusan**, (JMBAG: 0007179885), rođen/a dana 11.01.1998. u Zagrebu, izjavljujem da je moj diplomski rad izvorni rezultat mojeg rada te da se u izradi tog rada nisam koristio drugim izvorima osim onih koji su u njemu navedeni.

U Zagrebu, dana _____________ ________________________

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Interpolation of Water Depth Data Captured by a Multibeam Echosounder System to Elevation Models

Abstract: *With the help of The Department of Geodesy of Bochum University of Applied Science, measurements of underwater topography at the lake in Haltern, using a multibeam echosounder system, were conducted. Collected 3D point cloud is described and its characteristics are listed and explained. Four types of interpolation methods were applied on the data, Inverse Distance Weight (IDW), Triangulated Irregular Network (TIN), Ordinary Kriging (OK) and Cubic Spline interpolation. For application of interpolation on the measured data, QGIS software was used. The question of which interpolation methods are suitable with regard to the special properties of the measurement data was investigated. For each interpolation method, one raster as a result was created. With the help of histograms that belong to each resulting raster, and the statistical data, conclusions were made. Interpolation method that best suits the measured data used in this thesis work is Ordinary Kriging. Resulting raster is the smoothest without no-data cells.*

Keywords: *interpolation, multibeam echosounder system, Ordinary Kriging, QGIS software*

Interpolacija podataka dobivenih mjerenjem Multibeam Echosounder sustavom u svrhu kreiranja elevacijskog modela

Sažetak: *Uz pomoć Odjela za Geodeziju Sveučilišta primijenjenih znanosti u Bochumu, provedena su mjerenja podvodne topografije na jezeru u Halternu pomoću Multibeam Echosounder sustava. Prikupljeni 3D oblak točaka je opisan i navedene su njegove specifične karakteristike. Izvršene su četiri vrste interpolacija nad podacima, Metoda inverzne udaljenosti (IDW), Mreža nepravilnih trokuta (TIN), Obični Kriging (OK) i Kubični spline. Za izvršavanje interpolacijskih metoda nad mjerenim podacima korišten je QGIS softver. Provedeno je istraživanje kako bi se dobio odgovor na pitanje koja metoda interpolacije najbolje odgovara mjerenim podacima s obzirom na njihove posebne karakteristike. Rezultati istraživanja su četiri rastera kreirana uz pomoć četiri interpolacijska algoritma. Uz pomoć histograma koji pripadaju svakom nastalom rasteru, te statističkih podataka, izvedeni su zaključci. Interpolacijska metoda koja nabolje odgovara izmjerenim podacima je Obični Kriging. Raster dobiven tom interpolacijom je najglađi i nema ćelija bez podataka.*

Ključne riječi: *interpolacija, multibeam echosounder sustav, Obični Kriging, QGIS softver*

CONTENT

1. INTRODUCTION

Bathymetry is the study of the underwater depth of the ocean, rivers or lakes. What is hypsometry and topography on the ground that is bathymetry under the water.

The department of Geodesy of Bochum University of Applied Sciences is concerned with the measurement of underwater topographies using mainly multibeam echosounder system. There is still a need for the presentation of the resulting 3D models to customers or the interested public and to provide interactive data exploration and analysis tools to surveying experts. In this context, one of the main tasks is to use a suitable data interpolation method of the scattered measurement data and derivate the elevation model where the Z value gives bathymetric depth data.

Data collected with the multibeam echosounder system is specific. Resulting 3D point cloud has special characteristics. The main thing is the shape of the data. Every measured point belongs to one of the virtual lines of points. For that reason and many others that are listed and explained in this work, the problem of choosing an interpolation method for this type of data is still not resolved.

In the thesis work, it will be investigated which interpolation methods are suitable concerning the special properties of the measurement data.

The problem of which interpolation method should be used will be possibly resolved with the help of QGIS, a free and open-source software. This software is offering many different interpolation methods that are easily accessible. After performing selected interpolations, results should be analyzed and scrutinized to get an optimal solution. The differences in the results will be shown and discussed.

The research question, which interpolation method is recommended to set up the elevation grids, probably can only be answered partially. At the end of the work, the corresponding scientific discussion will be held.

2. BATHYMETRY

The term „bathymetry“ most simply refers to the depth of the seafloor relative to the sea level, but the concepts involved in measuring bathymetry are far from commonplace. The mountains, shelves, canyons, and trenches of the seafloor have been mapped with varying degrees of accuracy since the mid-nineteenth century. Today, the depth of the seafloor can be measured from kilometer- to centimeter-scale using techniques as diverse as multibeam sonar from ships, optical remote sensing from aircraft and satellite, and satellite radar altimetry (Dierssen and Theberge, 2014).

Even though more than 70% of the Earth’s surface is covered with the undersea landscape, bathymetry has been taken seriously only within the past century due to advances in technology for measuring the depth of the ocean.

As already listed above, there are three main types of depth-measuring techniques:

- near-bottom remotely operated vehicles,
- ships on the sea surface,
- satellites high above the Earth.

Depending on vehicle and mission, these systems utilize acoustics, optics, or radar altimetry to either directly measure or infer bathymetry. Each method provides different spatial resolutions and can probe depths ranging from shallow coastlines to the deepest trenches (Dierssen and Theberge, 2014).

In the process of collecting the data for this thesis the second depth-measuring technique was used. The ship with all the necessary instruments and equipment was used.

Bathymetric data, in essence, information about the water depth and underwater topography of oceans, seas and lakes, are important in many aspects of marine and lacustrine research, administration and spatial planning of marine and coastal environments and their resources (Hell et al., 2012).

Bathymetric data, which includes information about the depths and shapes of underwater terrain is used for many different things. Some of them are:

- nautical charts,
- studying changing coastline features,
- hydrodynamic models,
- studying marine life.

Nautical charts that are based on bathymetric data are used for guiding mariners the same way that road maps guide drivers. For safe maritime transportation, especially for large ships, it is essential to have accurate information about the depth of the water and potential underwater hazards.

Bathymetric data is used for studying the effects of climate change and to monitor beach erosion, sea-level rise and land sinking.

Scientists use bathymetric data to create models that can calculate currents, tides, salinity in an area and water temperature.

Studying marine life is important. Scientists create maps from bathymetric data to monitor and study habitats of benthic organisms (URL 1).

3. INTERPOLATION

Geodesy depends on measuring and measuring is providing a big amount of data. If we want to get a quality final product from that data, whatever it may be (e.g. maps, models…), we must pick very critically and carefully which interpolation method we use. In the mathematical field of numerical analysis, interpolation is a type of estimation, a method of constructing new data points within the range of a discrete set of known data points (Sheppard, 1911). Process of interpolation helps fill the gaps in measurements for final results (Figure 3.1) and provides worthy results. Interpolation is a method often used in engineering and science. It is a very important method in geodesy because of the nature of geodetic observations. Surveyors are always trying to find new, better ways of approximating and interpolating data. Not all methods are suitable for all types of data. In the following paragraphs interpolation methods will be described which were used on the data collected in the practical part of this thesis.

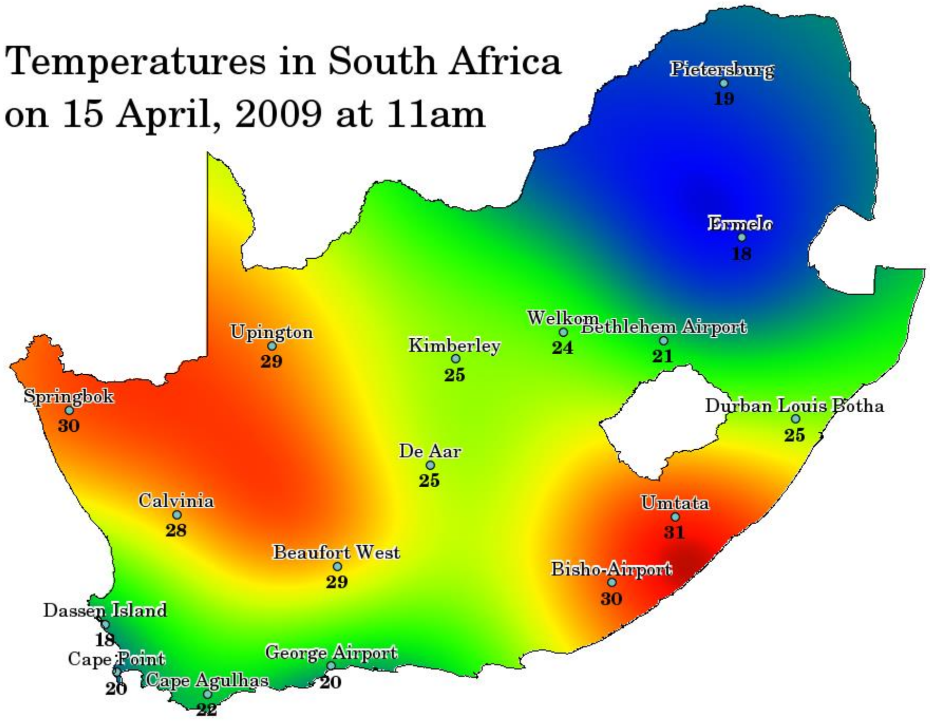


Figure 3.1 Temperature map, interpolated from South African Weather Stations, as a result of interpolation process (URL 2).

3.1. Interpolation methods

Today, there are a lot of different types of spatial interpolation methods (Figure 3.2). Spatial interpolation methods use point measured data to estimate unknown values at unsampled locations. There are a large number of interpolation methods, from simple to complex, which are available for use (Lam et al., 2015).

Spatial interpolation can be divided into two forms, the interpolation of point and areal data.

Point interpolation combines exact and approximate methods. Exact methods include most distance-weighting methods, Kriging, spline interpolation, interpolating polynomials and finite-difference methods. Approximate methods include power-series trend models, Fourier models, distance-weighted least-squares, and least-squares fitting with splines (Lam, 1983). Exact interpolator produces values equal to observed values at all measurement locations. Approximate interpolator accounts for uncertainty in the data by allowing the model to predict values at sampling locations that are different from the exact.

Areal interpolation methods are classified according to whether they preserve volume. Traditional areal interpolation methods which utilize point interpolation procedures are not volume-preserving, whereas the map overlay and pycnophylactic methods are. Methods that possess the volume-preserving property generally outperform those that do not (Lam, 1983).

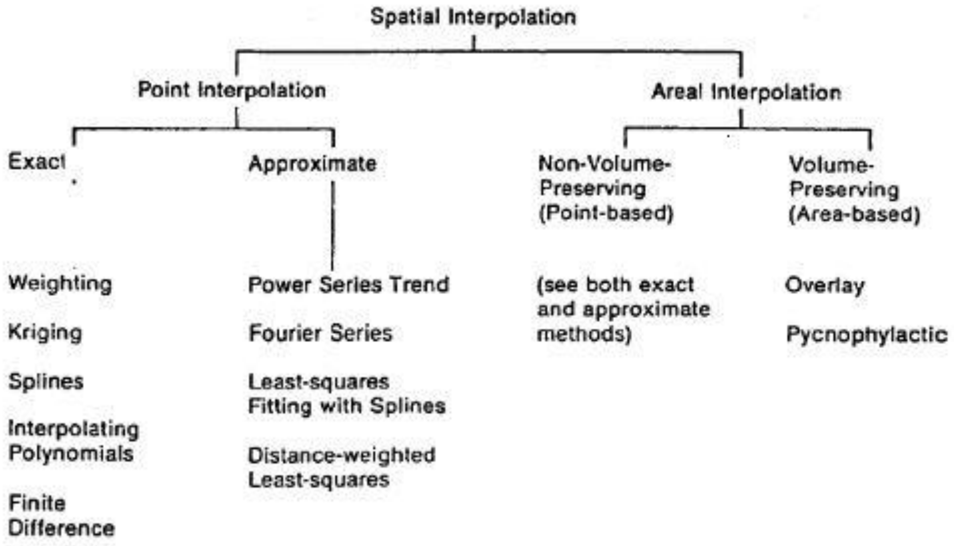


Figure 3.2 Types of spatial interpolation methods (Lam, 1983).

All interpolation methods used in this thesis belong to the Point interpolation group. Some of them are Exact and others are Approximate interpolation methods.

An appropriate interpolation model depends largely on the type of data, the desired degree of accuracy and the amount of computational effort afforded. Some of the methods are too time-consuming and expensive to be justified for certain applications even with computers available.

3.1.1. Inverse Distance Weight (IDW)

Inverse Distance Weighting (IDW) is a simple deterministic interpolation method. It is also exact interpolation with very few decisions to make regarding model parameters. It assumes that things that are closer are more similar than farther ones and uses measured values surrounding an unmeasured location to predict its value. Those measured values closest to the prediction location will have more influence on the predicted value and were given more weight than those further apart (Lam et al., 2015).

This interpolation method is one of the most common interpolation methods available in software QGIS. This interpolation estimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell. The closer a point is to the center of the estimated cell, the more weight it has in the averaging process. A specified number of points, or all points within a specified radius (Figure 3.3) can be used to determine the output value of each location (URL 3).

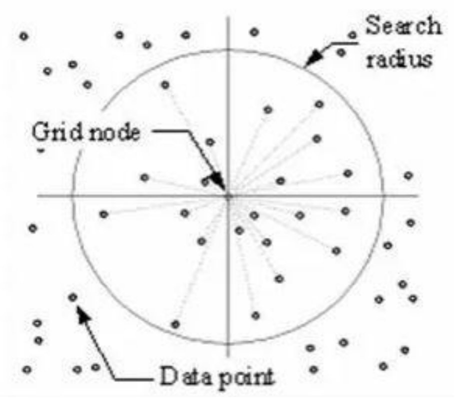


Figure 3.3 Radius around points created to determine the output value of each location (URL 3).

Every point has a weight and with the weighting coefficient it is controlled how the weighting influence will drop off as the distance from the new point increases. The bigger the weighting coefficient is, the less of an effect the points will have if they are far from the unknown point during the interpolation process. When the weighting coefficient increases, the value of the unknown point approaches the value of the nearest observation point.

The IDW algorithm is usually applied to highly variable data. There are some advantages of this interpolation method, such as the possibility to estimate extreme changes in terrain like cliffs, fault lines. Dense, evenly spaced points are well interpolated e.g. flat areas with cliffs. With this interpolation method it is possible to increase or decrease the number of sample points to influence cell values.

Every interpolation method has its minuses and so does this one. The quality of the interpolation result can drop off if the distribution of sample data points is uneven. Also, minimum and maximum values in the interpolated surface can only occur at sample data points. It cannot estimate above maximum or below minimum values. Because of that, there are often small peaks and pits around the sample data points in the results, so it is not good for peaks or mountainous areas (URL 3).

The resulting output of this method is a continuous surface on a raster map because interpolation results in QGIS are usually shown as a two-dimensional raster layer.

3.1.2. Triangulated Irregular Network (TIN)

The Triangulated Irregular Network (TIN) is an interpolation technique that calculates the elevations of the surface by digitally creating ridgelines from height point data (Jordan, 2007).

This interpolation method, together with IDW, is one of the most common interpolation methods. Delaunay triangulation is a common TIN algorithm that tries to create a surface formed by triangles of nearest neighbour points. It works by creating circumcircles around selected sample points and their intersections are connected to a network of non-overlapping and as compact as possible triangles (Figure 3.4).

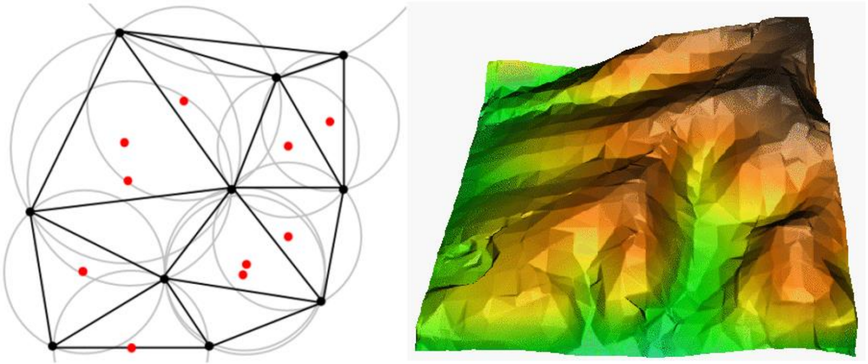


Figure 3.4 Delaunay triangulation with circumcircles around the red sample data on the left. The resulting interpolated TIN surface created from elevation vector points is shown on the right. (Matas and Matasova, 1999).

Problem with Triangulated irregular network is that the surfaces are not smooth and it may give a jagged appearance. This is caused by discontinuous slopes at the triangle edges and sample data points. Triangulation is generally not suitable for extrapolation beyond the area of collected sample data points.

While a TIN provides an effective representation of surfaces useful for various applications, such as dynamic visualization and visibility analyses, interpolation based on a TIN, especially the simplest, most common linear version, belongs among the least accurate methods (Franke and Nielson, 1991). It is commonly used for elevation data, and not like the IDW method for interpolating data such as mineral concentrations and populations.

Accuracy of the method is strongly dependent on the number of observations within the field, and also on the density of observations. When samples are clustered, neighbouring observations will be given a relatively good prediction. On the other hand, for isolated samples the constructed triangle will be much larger and the prediction will be even more imprecise or flawed. It is important to understand that each predicted value only depends on the three apexes of a triangle. This method does not give good results when small scale variations are present.

The TIN technique is available on many softwares, not just in QGIS, and is efficient from a computation time point of view. It might be applied when lots of observations are available without requiring important memory storage (URL 4).

3.1.3. Ordinary Kriging (OK)

Kriging is perhaps the most distinctive interpolation methods. The term is derived from the name of D. G. Krige, who introduced the use of moving averages to avoid systematic overestimation of reserves in the field of mining (Lam, 1983).

It is a geostatistical interpolation technique that considers both the distance and the degree of variation between familiar data points when estimating values in unknown areas (URL 3). It is a weighted linear combination of the known sample values around the point to be estimated. Kriging interpolation method generates an estimated surface from a scattered set of points with z-values. It is working with the assumption that the distance or direction between sample points reflect a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to all points within a specified radius or to the specified number of points, to determine the output value for each location.

Kriging process can be separated into more multi-steps:

- exploratory statistical analysis of the data,
- variogram modelling,
- creating the surface,
- exploring a variance surface (optional).

When there is a spatially correlated distance or directional bias in the data, Kriging gives worthy results. It is often used in geology.

Kriging has some similarities with IDW (Inverse Distance Weighted). For example, it weighs the surrounding measured values to derive a prediction for an unmeasured location. Also, the general formula (1) (URL 3) for both interpolators is formed as a weighted sum of the data:

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \tag{1}$$

where:

Z(S_i) is the measured value at the i-th location,

λ_i is an unknown weight for the measured value at the i-th location,

S_0 is the prediction location,

N is the number of measured values,

$\hat{Z}(S_0)$ is the interpolated value at the prediction location.

The weights λ_i are not based only on the distance between the measured points and the prediction location, but also on the overall spatial arrangement of the measured points.

There are several types of Kriging: Ordinary, Simple, Universal, Indicator, Probability, Disjunctive kriging, etc.

Ordinary Kriging is the most widely used Kriging method. It is an estimation technique known as the Best Linear Unbiased Estimator (BLUE) that has the great advantage of using the semivariogram information (Cressie, 1993).

The advantage of Kriging interpolation method is the possibility to show directional influences such as soil erosion, lava flow, siltation flow and winds. The good side of Kriging is that it exceeds the minimum and maximum point values.

Problem with the Kriging interpolation method is that it does not pass through any of the point values and causes interpolated values to be higher or lower than real values.

3.1.4. Cubic spline

Cubic spline interpolation is a mathematical method commonly used to construct new points with the boundaries of a set of known points (URL 5). New points are function values of an interpolation function (referred to as spline), which itself consist of multiple cubic piecewise polynomials.

The concept of the spline originated from the drafting technique of using a thin flexible strip (called spline) to draw smooth curves through a set of points (Ajao, 2012).

The equation (2) (Ahmad and Deeba, 2017) of the cubic spline in the i^{th} interval $[x_{i-1}, x_i]$, is:

$$f_i(x) = a_i + b_i\, x + c_i\, x^2 + \; d_i\, x^3;\; i = 1,2, \dots, n \tag{2}$$

where:

a_i, b_i, c_i, d_i is the 4n coefficient for i = 1, 2, …, n.

The goal of cubic spline interpolation is to get an interpolation formula that is continuous in both the first and second derivatives, both within the intervals and at the interpolating nodes (Ahmad and Deeba, 2017). That way we will have a smoother interpolating function. The continuity of the first derivative means that the graph will not have sharp corners and the continuity of the second derivative means that the radius of curvature is defined at each point.

Cubic spline is a special type of spline interpolation which is usually used to avoid the problem of Runge’s phenomenon. Interpolating the polynomial of the cubic spline method is smoother and has smaller errors than some other interpolating polynomials such as Lagrange polynomial and Newton polynomial.

Just like other interpolation methods that are explained in the previous chapters, cubic spline is one of the deterministic methods available in QGIS software. It is a powerful data analysis tool because splines correlate data efficiently and effectively, no matter how random the data may seem.

Cubic spline is a popular interpolation method because it is easy to implement and produce a curve that appears to be seamless. Straight polynomial interpolation of evenly spaced data tends to build in distortions near the edges of the table. Cubic splines can avoid that problem, but they are only piecewise continuous. It means that a sufficiently high derivative (third) is discontinuous. If the application is sensitive to the smoothness of derivatives higher than the second, cubic splines are not the best choice.

4. DATA COLLECTION

To do something in geodesy you have to have spatial data. In order to collect spatial data you have to carry out the procedure of measurement. On Monday (May 31st, 2021) measurements took place at a lake (sandpit “Silbersee II”) in Haltern (North Rhine Westphalia region of Germany) with help and provided equipment from the Department of Geodesy at Bochum University of Applied Sciences. Participants were prof. Benno Schmidt, Sebastian Michels, Rouven Borchert, Petra Pokrovac and Leonarda Rusan. A group of people from the Department of Geodesy at Bochum University of Applied Science is often doing the surveying and subsequent modelling of underwater topographies for regional inland waters, e.g., water reservoirs, sand pits, shipping canals, or medium-sized rivers. For collecting the data mainly a multibeam sonar system, which is installed on a small boat as a measuring platform, is used. More detailed explanation of the boat and equipment is given in the next chapter of this thesis.

The weather on that day was very nice and sunny with a few clouds. Temperatures were around 22 °C. Survey work on the lake that was carried out by Rouven Borchert and Sebastian Michels started at 8:30 a.m. The lake (“sand-pit”) is a place for mining quartz sand which is later used for 3D printing, glass making and other things.

4.1. The measuring boat as multi-sensor system

The Department of Geodesy at Bochum University of Applied Sciences is using a small boat (Figure 4.1) equipped with a multibeam (Figure 4.2) echosounder for data acquisition in the hydrographic survey of inland waters. Hydrographic surveying with mobile multi-sensor systems requires a complex measuring and evaluation process in order to create georeferenced 3D point clouds from the measurements of the individual sensors and then to create models of the water bed (Schmidt et al., 2021).

The system contains many integrated sensors such as a multisensory echo sounder, a water sound velocity probe (SVP) (Figure 4.5), an inertial measurement unit (IMU) (Figure 4.3) and GNSS (Global Navigation Satellite System) (Figure 4.4). The last two are used as navigation sensors. The simple small boat is used as a platform that carries all those sensors.

For correct and precise hydrographic survey individual sensors, which are integrated, must be synchronized and calibrated. It is also important to calibrate the overall system, especially the position and orientation of the reference systems of the sensors and the sensors in relation to the platform as well as the so-called lever arms.

The process of measuring is performed with the fan-shaped echo sounder which sends out ultrasonic impulses in the direction of boat movement. The direction of emission, i.e. the position of the beam within the fan and the correspondingly measured surface to the surface of the water is recorded for each emitted measuring beam.

The water sound velocity value, which has been measured using an SVP (Figure 4.6), has a relevant influence on the distances delivered by the multibeam echo sounder. These distances are determined based on the signal delay method. The water sound speed value is determined both permanently near the echo sounder and along the water column in the form of a water sound speed profile (Borchert et al., 2020).

The measurement is not complete until the position and orientation of the measuring boat are determined. To determine it IMU and GNSS (the navigation sensors) are being used. RTK (Real-Time Kinematic) is used for precise GNSS positioning on inland waters. The GNSS correction data is received from the high-precision real-time positioning service of the satellite positioning service of German land surveying (SAPOS-HEPOS) via mobile radio. This method has an accuracy of 2 to 3 cm and heights are given concerning ETRS89 (European Terrestrial Reference System 1989). The data from GNSS and IMU are evaluated together in a Kalman filter (Marchthaler and Dingler, 2017). By both the low-frequency GNSS positions and heading angle, the high-frequency IMU data is obtained. The navigation and detection sensors are synchronized with the PPS signal (pulse per second) from the GNSS. Three-dimensional position (geographical longitude and latitude, ellipsoidal height) and the orientation (roll, pitch and course angle relative to the navigation system) are available. The relative observation of the multibeam echo sounder is connected with the trajectory. Three-dimensional coordinates of the water bed are computed in the course of georeferencing. A common time system for navigation and multibeam echo sounder equipment is the prerequisite for this.

It is advantageous to have available in real-time or near real-time three-dimensional georeferenced point clouds and models. So, in post-processing, the recorded water sound velocity profile of the water body is used to correct the depths measured with the multibeam echo sounder. Measured data have to be cleaned and improved with different techniques, which is usually done in post-processing.

The ellipsoidal height should be transformed into normal heights of the DHHN 2016 (German Main Height Network, 2016) with the help of the quasigeoid undulation (Bundesamt für Kartographie und Geodäsie, 2016). The accuracy of the transformation is specified by the Federal Agency for Cartography and Geodesy (BKG) and it is approximately 1 cm in the lowlands, approximately 2 cm in the high mountains and 2 cm to 6 cm in the sea area.

Specifications of the measuring boat, the multibeam system, the IMU, the GPS (Global Positioning System) and the antenna, the SVP-Boot and the SVP were given in the tables 1-6.

Figure 4.1 Small boat from Department of Geodesy at Bochum University of Applied Sciences (Gundlich and Borchert, 2020).

Table 1 Specifications of the measuring boat form Department of Geodesy at Bochum University of Applied Science (Gundlich and Borchert, 2020).

MEASURING BOAT	
Description:	Swiss-Cat 15
Length:	4.60 m
Width:	2.15 m
Internal dimensions:	1.62 x 0.46 m
Weight:	around 300 kg
Max. payload:	490 kg (6 people)
Permissible engine power:	37 kW
Drive motor:	15 PS, 11kW
Measuring system:	Multibeam echosounder Hydrobat Composite
Crew during measurement:	Max. 5 people
Design category:	C (coastal waters)

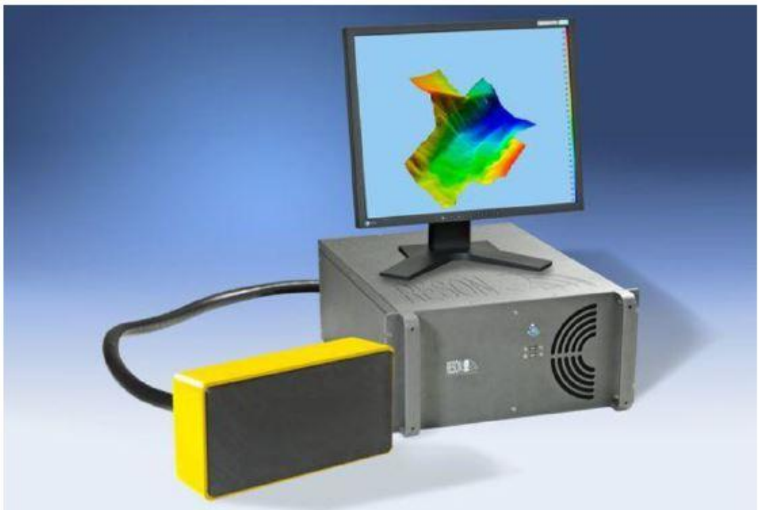


Figure 4.2 Multibeam system (Gundlich and Borchert, 2020).

Table 2 Specifications of the multibeam (Gundlich and Borchert, 2020).

MULTIBEAM	
Description:	Hydrobat Composite
Frequency:	160 kHz
Opening angle:	120°

Number of rays:	112
Min. range:	1 m
Max. range:	200 m
Ping rate:	≥ 20 Hz
Weight (air):	18 kg
Integrated software:	PDS2000
Profile width, spacing between points:	17 m, 16 cm (depth 5 m) 35 m, 31 cm (depth 10 m) 69 m, 62 cm (depth 20 m) 173 m, 156 cm (depth 50 m) 346 m, 312 cm (depth 100 m) 693 m, 624 cm (depth 200 m)
Spacing between profiles:	4 cm (3 km/h), 7 cm (5 km/h), 14 cm (10 km/h)

Figure 4.3 IMU (Inertial measurement unit) (Gundlich and Borchert, 2020).

Table 3 Specifications of the IMU (Gundlich and Borchert, 2020).

IMU	
Description:	IMU-108R-30 Motion Sensor
Registration:	roll, pitch, heave, motion

Angular accuracy:	0.02° (static), 0.03° (dynamic)
Resolution angle:	0.001°
Resolution Heave/Surge/Sway:	0.01 m
Range roll/pitch:	+/- 30°
Measuring range Heave/Surge/Sway:	+/- 99.99 m
Accuracy of acceleration:	0.01 m/s^2

Figure 4.4 GPS device and antenna (Gundlich and Borchert, 2020).

Table 4 Specifications of the GPS and the antenna (Gundlich and Borchert, 2020).

GPS	
Description:	Trimble SPS461 Modular GPS Heading Receiver Precise RTK
Corrections:	DGPS RTCM 2.x
Accuracy of location:	± 1-2 cm
Accuracy of height:	± 2-3 cm
Accuracy of heading:	0.04° RMS
ANTENNA	
Description:	Trimble GA530 Antenna
Frequencies:	GPS L1/L2

Figure 4.5 SVP-Boot (Gundlich and Borchert, 2020).

Table 5 Specifications of the SVP-Boot (Gundlich and Borchert, 2020).

SVP-BOOT	
Description:	RESON SVP 71
Measuring range:	1350-800 m/s
Resolution:	0.1 m/s
Accuracy:	± 0.15 m/s (0-50 m), ± 0.25 m/s (until 2000 m)

Figure 4.6 SVP (Gundlich and Borchert, 2020).

Table 6 Specifications of the SVP (Gundlich and Borchert, 2020).

SVP	
Description:	RESON SVP-15 T
Speed of propagation	
Measuring range:	1350-1600 m/s
Resolution:	0.1 m/s
Accuracy:	± 0.25 m/s
Depth	
Max depth:	200 m (in 0.5 m steps)
Accuracy:	± 0.10 m + 0.2% the measured depth
Accuracy of temperature:	± 0.4 °C
Recording:	By time or depth
Storage capacity:	400 values

4.2. Factors influencing the quality of the resulting 3D point clouds

Measured data is “raw data” that is influenced by many different factors. As a product of measurement, a 3D point cloud is available and it needs to be cleaned from different influences.

Influences are coming from the inside of the measuring system and from the outside of the system. Some of the influences are easier to fix than others. The boat has different properties that influence measuring. For example, the relative position of the different sensors in the platform system have a significant influence on the quality of the result data. Everything that is surrounding the measuring system is also influencing the measured data. The environment, such as the air, temperature, pressure, weather and everything about water, like salinity, have a direct influence on the measurement with a hydroacoustic measuring system. Also, things inside the water, like plants growing in the water body can negatively affect the depth measurements. The other thing that can influence the results are characteristics of the water bed.

For determining the position of the measuring boat, GNSS is used. When the measuring boat is going closer to some bigger vegetation or under some structures on the water or above the water like bridges, it is expected that the GNSS signal is lost or shaded. The speed of the measuring boat affects the point density of the resulting 3D point cloud. Also the ping rate, the number of profiles measured per second, significantly influences the point density of the resulting 3D point cloud. The outer measuring beams of the multibeam echosounder are problematic because they have a flat angle of incidence, especially on a level body of water. Those beams should be discarded by using different filter techniques.

All enumerated and many other factors influencing the quality of the resulting 3D point clouds should be somehow eliminated with different techniques if it is possible.

4.3. Bathymetric surface generation

In the process of measuring, enormous amounts of data points have been collected. A regular two-dimensional grid is computed from the irregular 3D point cloud to reduce the number of data points. A simple ASCII (American Standard Code For Information Interchange) file which gives the set of (x_k, y_k, z_k) tuples ("XYZ file") is used as an input source. Grid data are stored in a matrix referring to a defined coordinate reference system (CRS). The matrix elements cover the geographical area under investigation and each vertex identifies a specific location and contains a z-value that is representing the water depth at that location.

There are two types of approach, the so-called *lattice approach* (vertex-based interpretation) and the *grid approach* (cell-based interpretation) (Figure 4.7). The first approach is used for visualization purposes because it gives smooth visual representations. This smooth visual representation is achieved by assuming that the grid points are the resulting mesh representation's vertex points. The other approach, so-called *grid approach*, is used for data-processing where the depth value z refers to an entire grid cell. It is referred to as the cell-based view for data processing and analysis purposes.

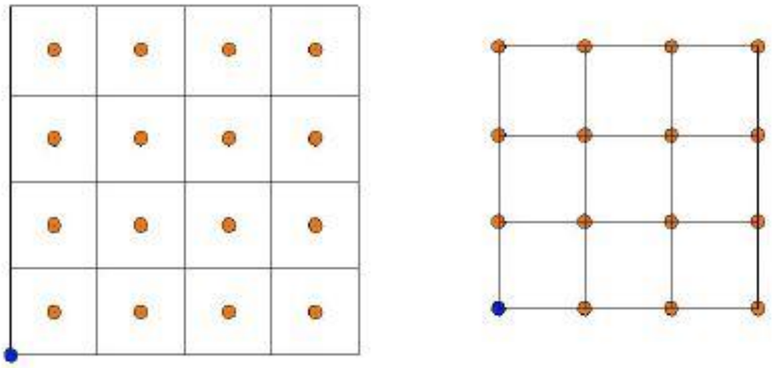


Figure 4.7 Cell-based „grid" interpretation (left) and vertex-based „lattice" interpretation (right) of the same point-set (Schmidt et al. 2021).

In the course of the rasterization, the value z of each grid cell, that is representing the water depth at that location, is determined from the 3D coordinates of the points in the input point cloud that is in the immediate vicinity of the cell. To generate an axially parallel, regular grid with constant cell sizes, some steps have to be done. As an input, point cloud consisting of N data points $\{(x_k, y_k, z_k), k = 0, \ldots, N-1\}$ is used. The next step is to create an envelope $(x_{min}, y_{min}) \ldots (x_{max}, y_{max})$ giving the spatial location of the target grid. Grid size is given by the numbers N_x and N_y. N_y are rows and N_x are columns that create the target grid matrix. Output is a grid consisting of N_y rows and N_x columns. Z value should give a good estimation of the real bathymetry. As the last step, optionally, meta-data which will allow us to evaluate the quality of the interpolation results could be given.

5. CHARACTERISTICS OF MULTIBEAM DATA (3D POINT CLOUD)

Characteristics of the data influence the results of the interpolation, so not every interpolation method is suitable for every data. If you know what type of data you are dealing with, it will be easier to choose an interpolation method that will give satisfying results.

Characteristics of the multibeam data are (Schmidt et al., 2021):

- huge data sets,
- statistical measurement noise,
- filtering of obvious statistical outliers,
- overlapping swaths,
- irregular point distribution,
- missing data near shallow waterfronts,
- “summit overhang” effect
- time dependency of data,
- meaningful data.

Raw-data point cloud collected with the multibeam echo sounder system is usually quite huge. A big amount of data has its advantages and disadvantages. More points will give more detailed and more precise results. The problem with huge data sets is the time-consuming computation. A data set that is collected in this work contains 31 846 617 points.

Observational errors are a normal thing in measurement processes. If you measure the same point or distance two times in the same conditions, the results would not be the same. Variability is an inherent part of the results of measurements and the measurement process. There are two types of measurement errors, random error and systematic error. In the process of computing a 2D grid to represent the bathymetry, it has to be assumed that there is statistical measurement noise in the data. Another type of error, systematic error is difficult to fix or eliminate. An example of a systematic error is an error depending on the direction of travel of a tilted boat. Systematic error is in the opposite direction of travel. This type of error is rooted in the measurement and it is usually hard to detect and remove (Schmidt et al., 2021).

It is expected to have obvious statistical outliers in the measurement. Those statistical outliers should be removed from the XYZ source file before generating the grid model. The reason for their existence is for example too shallow water depths. Also, one of the obvious outliers is the Nadir filter.

A specific characteristic of measurements collected with measuring boats is overlapping swaths. Often the boat drives over the same location more than once, so as a result there are more data points XYZ at the same location. Measurements have strip-shaped point sequences recorded by the “beams”.

Data points have irregular spatial distribution. Points are close to each other for a swath and neighbour strips are a little further apart. The point density is lower in deep waters than in shallow waters. For the target raster file, it can be generated different metadata like “hit count” (number of XYZ points that fall within a single cell of the target raster), a maximum value of Z, a minimum value of Z, standard deviation. “Hit count” is looking into point density (Schmidt et al., 2021).

6. INTERPOLATION PROBLEM OF THE MEASURED DATA

After measurement, the final product is the point cloud. The next step is to create a grid and preform an interpolation method on the data. In the previous chapter, all the specific characteristics of the data are enumerated. Since the data has a specific line shape (Figure 6.1), there is no regular point distribution. Lines consist of points that have a value. Choosing which interpolation method to perform on this type of data is not easy. When distribution of the data is regular it is easier to find a suitable interpolation method.

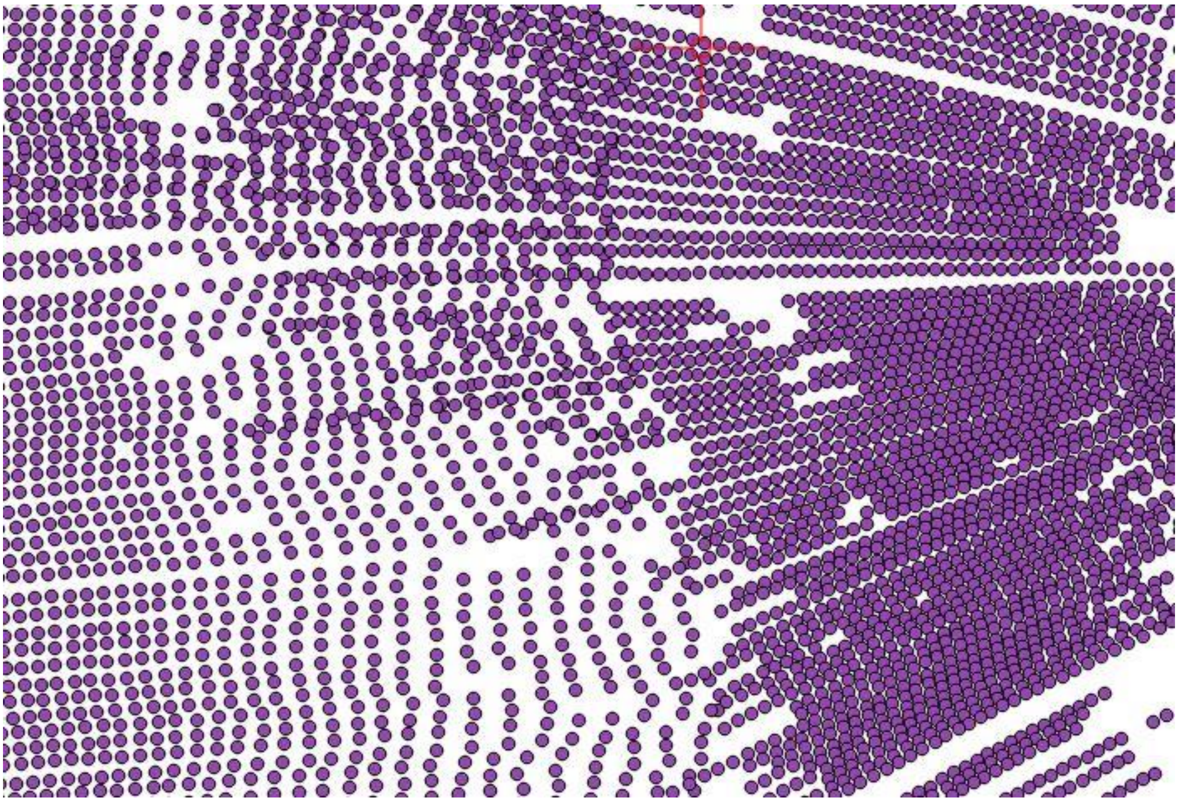


Figure 6.1 Line shaped type of the data.

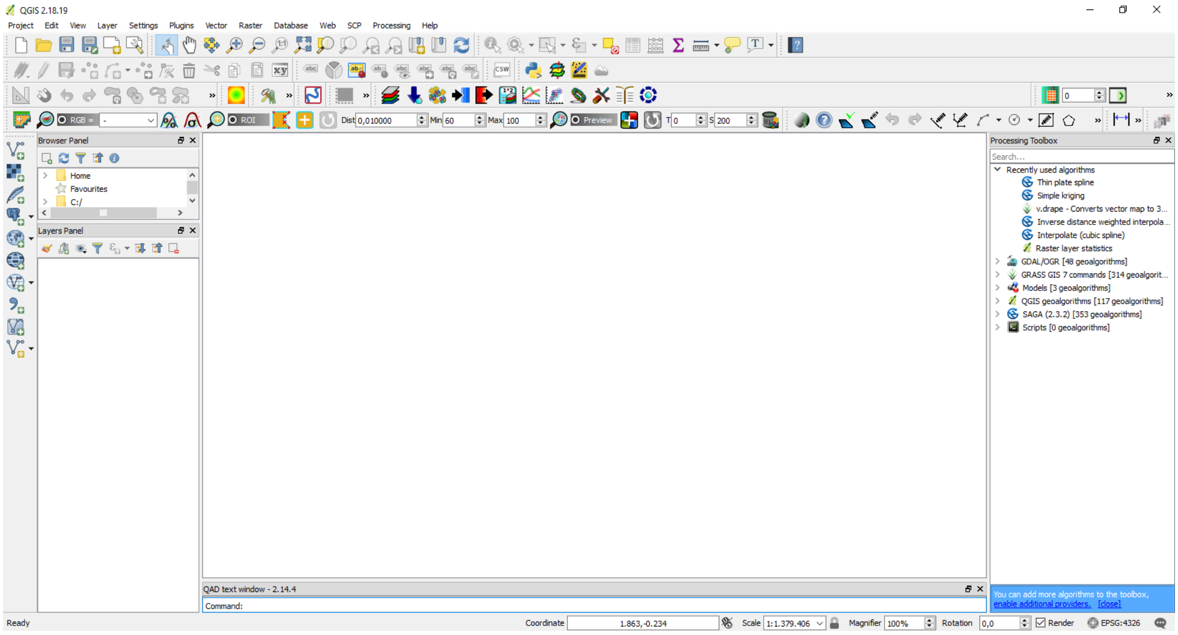
When creating a two-dimensional grid from the irregular 3D point cloud, grid data is stored in a matrix referring to a defined coordinate reference system (CRS). The spatial resolution of the target grid is 1 m x 1 m. The question is to what extent the use of higher resolutions is justifiable (Schmidt et al., 2021).

The computed z-values each represent a depth assumed for the entire area covered by a grid cell and sometimes give a wrong impression about the accuracy that is not actually given. The problem of finding a suitable interpolation method for the measured data will be solved in the further text.

7. QGIS

QGIS, also known as Quantum Geographic Information System is a free, open-source, cross-platform and callable geographic information system (GIS) tool with plugins that are developed in Python and C++ languages. QGIS integrates the geospatial data abstraction library (GDAL). This library allows reading and processing a large number of geographic images. It is distributed under the GNU/general public license (GPL) version 2. It can be used on most platforms such as GNU/Linux, Unix, Mac OS X and Windows (Moyroud and Portet, 2018).

QGIS is a useful software for analysing and editing different spatial information and composing and exporting graphical maps (Figure 7.1). QGIS supports both raster and vector layers.



You can add more algorithms to the toolbox, enable additional providers. [close]

Figure 7.1 QGIS graphical user interface.

In this thesis the slightly older version QGIS 2.18.19. is used.

7.1. Interpolation in QGIS

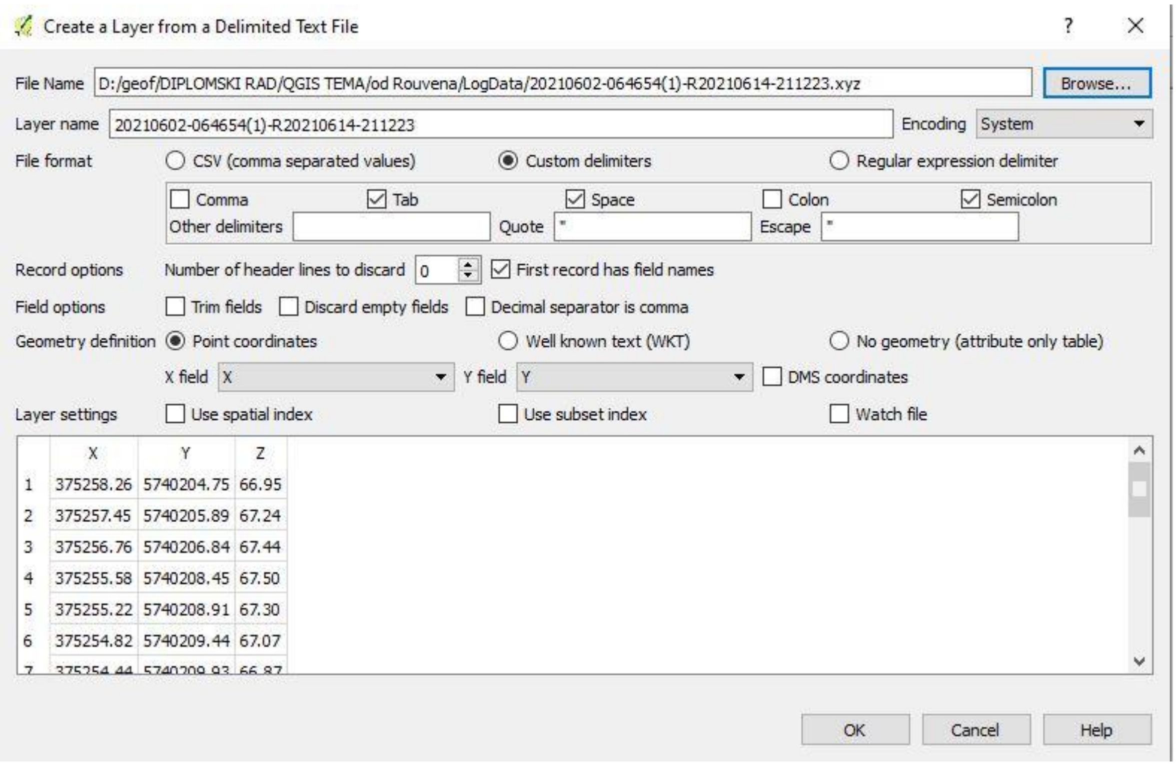
One of the functions available in QGIS is an interpolation. Since there are a lot of things that are continuous, such as elevations, soils, temperatures, rainfall, chemical concentrations, noise levels etc. it is worthy to be able to do interpolation and model these surfaces for analysis because it is impossible to take measures throughout the surface. If you want to create a continuous surface from discrete points you can easily achieve that with QGIS tools for interpolation which are accessible from the Processing toolbox.

The interpolation process in QGIS is achievable in a way of using vector points with known values to estimate values at unknown locations to create a raster surface covering an entire area. The result of the interpolation is typically a raster layer. It is very important to find the best interpolation method to optimally estimate values for unknown locations.

There is a wide range of spatial interpolation techniques. The two most used ones in QGIS are Inverse Distance Weighting (IDW) and Triangulated Irregular Network (TIN). Apart from common ones, there are also many other interpolation methods available in QGIS.

8. APPLICATION OF INTERPOLATION ON THE DATA IN QGIS SOFTWARE

After downloading and running QGIS 2.18.19., data is loaded. The collected data is in XYZ File type with the .xyz extension. Loading data is done by using commands *Layer ⇨ Add Layer ⇨ Add Delimited Text Layer*. After selecting the parameters (Figure 8.1) and clicking OK, the data is uploaded and ready for processing.



Create a Layer from a Delimited Text File

File Name: D:/geof/DIPLOMSKI RAD/QGIS TEMA/od Rouvena/LogData/20210602-064654(1)-R20210614-211223.xyz

Layer name: 20210602-064654(1)-R20210614-211223

Encoding: System

File format: ○ CSV (comma separated values) ● Custom delimiters ○ Regular expression delimiter

☐ Comma ☑ Tab ☑ Space ☐ Colon ☑ Semicolon

Other delimiters: Quote: " Escape: "

Record options: Number of header lines to discard: 0 ☑ First record has field names

Field options: ☐ Trim fields ☐ Discard empty fields ☐ Decimal separator is comma

Geometry definition: ● Point coordinates ○ Well known text (WKT) ○ No geometry (attribute only table)

X field: X Y field: Y ☐ DMS coordinates

Layer settings: ☐ Use spatial index ☐ Use subset index ☐ Watch file

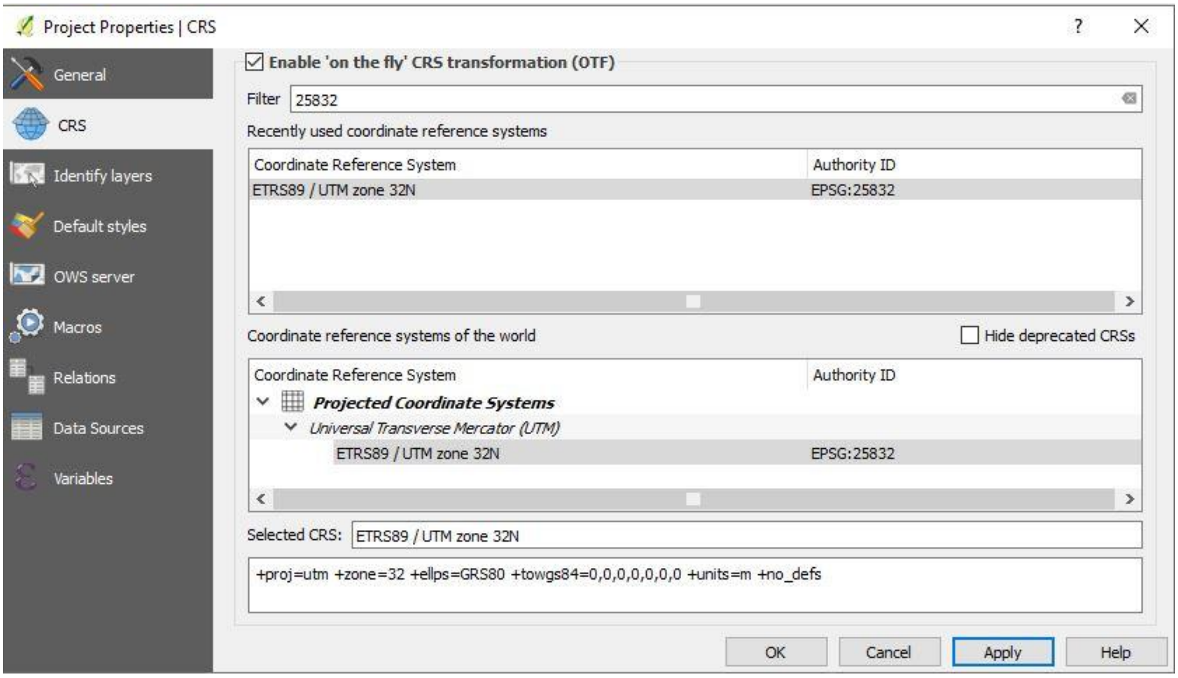
	X	Y	Z
1	375258.26	5740204.75	66.95
2	375257.45	5740205.89	67.24
3	375256.76	5740206.84	67.44
4	375255.58	5740208.45	67.50
5	375255.22	5740208.91	67.30
6	375254.82	5740209.44	67.07

Figure 8.1 Parameters chosen while importing the measured data in QGIS.

The procedure was repeated for all 91 .xyz files that contain the data. As a result, multiple vector layers that contain points are created in QGIS.

Next step is selecting the right Coordinate reference system (CRS). Used CRS is ETRS89/ UTM (Universal Transverse Mercator) zone 32N. The EPSG code (European Petroleum Survey Group code) is EPSG:25832. The zone number “32” is omitted for EPSG:25832, the value 500 [km] has been added to the central meridian value.

The right coordinate reference system should be set in the QGIS project by clicking on the lower right corner. The Project Properties (Figure 8.2) is opened. Option “*on the fly*” (OTF) should be enabled, then the Coordinate reference system (CRS) with the EPSG code 25832 should be selected. After that, all vector layers should be transformed into the CRS of the project. This is done by clicking on the right button on the mouse on the layer in Layers Panel and then choosing *Set Layer CRS ⇨ Coordinate Reference System Selector*. In the opened dialog box, the right CRS should be selected.



☑ Enable 'on the fly' CRS transformation (OTF)

Filter 25832

Recently used coordinate reference systems

Coordinate Reference System	Authority ID
ETRS89 / UTM zone 32N	EPSG:25832

Coordinate reference systems of the world ☐ Hide deprecated CRSs

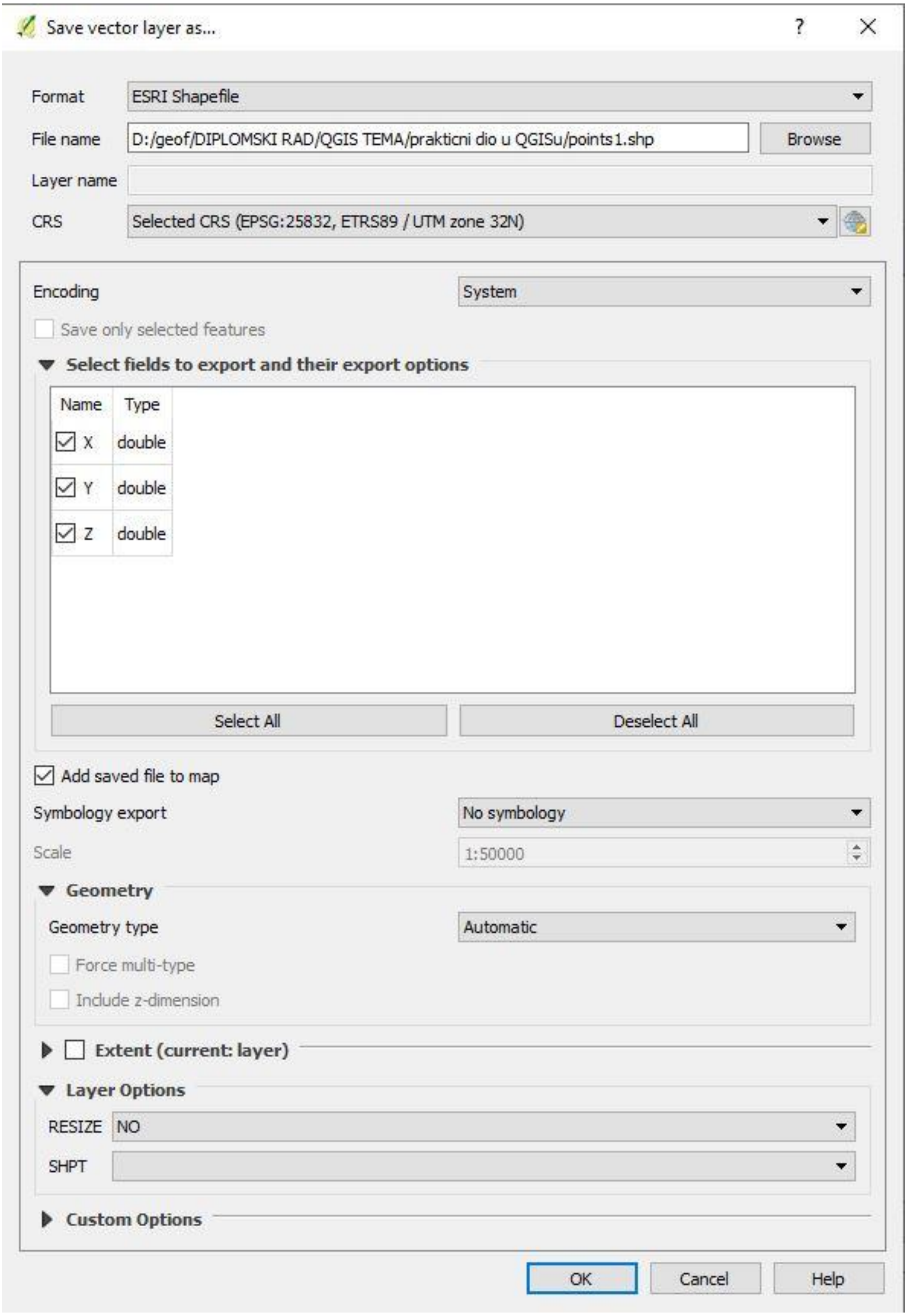
Coordinate Reference System	Authority ID
Projected Coordinate Systems	
Universal Transverse Mercator (UTM)	
ETRS89 / UTM zone 32N	EPSG:25832

Selected CRS: ETRS89 / UTM zone 32N

```
+proj=utm +zone=32 +ellps=GRS80 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs
```

Figure 8.2 Project properties for selecting the right CRS for project.

All layers with the correct CRS should be saved in the same file where the project is saved. Saving vectors is done by clicking on the right button on the mouse on the vector layer and then choosing *Save As…* In the dialog box *Save vector layer as…* (Figure 8.3), all the parameters (Format, File name, CRS, Select fields to export and their export options, Add saved file to map) should be correctly selected. By clicking OK, the new vector layer is created and imported into the QGIS project. The procedure is repeated for all 91 vector layers that contain points. The option “*on the fly*” (OTF) can now be disabled.



Format: ESRI Shapefile

File name: D:/geof/DIPLOMSKI RAD/QGIS TEMA/prakticni dio u QGISu/points1.shp

Layer name:

CRS: Selected CRS (EPSG:25832, ETRS89 / UTM zone 32N)

Encoding: System

☐ Save only selected features

Select fields to export and their export options

Name	Type
☑ X	double
☑ Y	double
☑ Z	double

☑ Add saved file to map

Symbology export: No symbology

Scale: 1:50000

Geometry

Geometry type: Automatic

☐ Force multi-type

☐ Include z-dimension

☐ **Extent (current: layer)**

Layer Options

RESIZE: NO

SHPT:

Custom Options

Figure 8.3 Dialog box for saving vector layer with correct CRS chosen.

To simplify operations on points from created vector layers, it is recommended to combine all vector layers in one. This is done with operations *Vector ⇨ Data Management Tools ⇨ Merge vector layers*. This algorithm combines multiple vector layers of the same geometry type into a single one. If attribute tables are different, the resulting table will contain the attributes from all input layers. Attribute tables of all vector layers in this work have the same structure. After the merging process, all layers from the Layers panel are removed apart from the merged one and only the merged layer is used in the further proceedings.

Merged vector layer (Figure 8.4) contains in total 31 846 617 points.

Figure 8.4 Representation of merged vector layer.

Due to a large number of points, problems are expected during the interpolation process, so only a specific area from the middle of the lake (Figure 8.5) was used.

After clicking on the button *Select Features by area or single click*, it is necessary to select the area of interest with the mouse to create a new layer. In the Layers Panel, click the right button of the mouse on the merged layer and choose *Save As…* Dialog box *Save vector layer as…* is opened. In this dialog box, select ESRI Shapefile as Format (Environmental Systems Research Institute), preferred File name and right CRS. It is important to put a tick in the square next to the *Save only selected features*. A new vector layer containing only selected points is created and contains 153 940 points.

Figure 8.5 Yellow points belong to the selected area of the lake that will be used for performing interpolation methods.

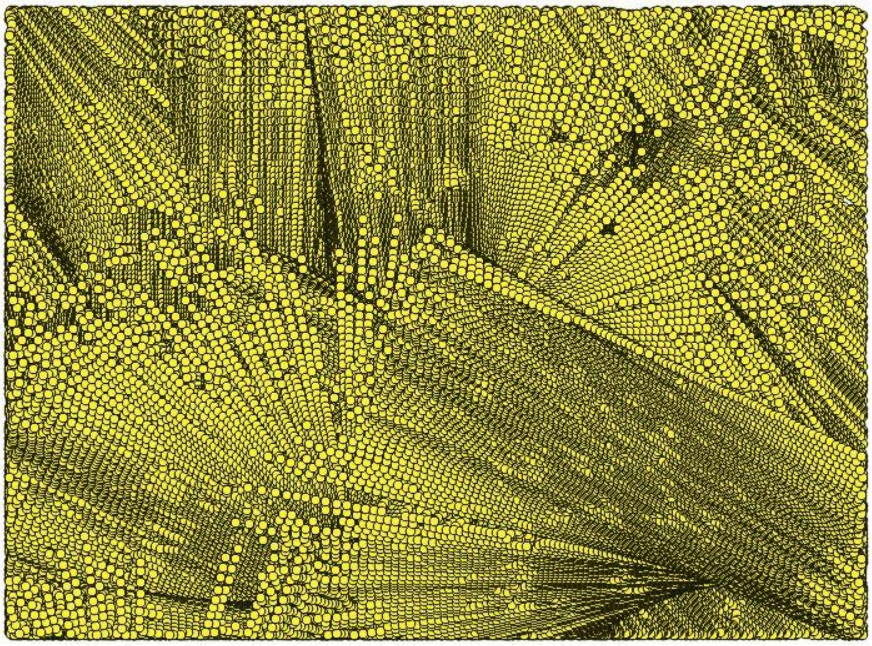


Figure 8.6 Representation of vector layer containing only selected points that will be used in the interpolation process.

The process of performing interpolation methods on the vector layer with selected data (Figure 8.6) is described below.

8.1. Inverse Distance Weight (IDW) interpolation method in QGIS

Inverse distance weight interpolation is available in QGIS software by using the Interpolation plugin. This plugin can be used to generate a TIN or IDW interpolation of a point layer. Installation of plugins in QGIS is done by choosing the option *Plugins ⇨ Manage and Install Plugins*. In the opened dialog box, select the plugin of choice and click on the *Install plugin* button.

To access the Interpolation plugin, click on *Raster ⇨ Interpolation ⇨ Interpolation*. In the opened Interpolation plugin window, choose a Vector layer that contains selected points, then for the Interpolation attribute put a column from the attribute table that contains values for elevation. The next step is to click on the *Add* button and then select Inverse Distance Weighting (IDW*)* as an Interpolation method. Parameters Cellsize X and Cellsize Y should be changed to value 1. This value is the size of each pixel in the output grid. Since the source data is in a projected CRS with metric units, based on the selection, the grid size will be 1 meter. After choosing the location and the name of the output file, a raster is created.

8.2.Triangulated Irregular Network (TIN) interpolation method in QGIS

Triangulated Irregular Network is available in QGIS by using the Interpolation plugin just like Inverse Distance Weighting interpolation. This plugin for TIN interpolation is available by clicking on *Raster ⇨ Interpolation ⇨ Interpolation*. In the opened Interpolation plugin window, choose all settings just like for IDW interpolation. The only difference is the interpolation method, which in this case is a TIN interpolation.

8.3. Ordinary Kriging (OK) interpolation method in QGIS

Ordinary Kriging is available in QGIS and it is accessible in the *Processing Toolbox*. In the opened window, select a vector layer with selected points. The attribute parameter is elevation data from the attribute table. Just like for IDW and TIN interpolation, Cellsize should be set as 1.

8.4. Cubic spline interpolation method in QGIS

Cubic spline, just like many other interpolations, is also available in QGIS in the *Processing Toolbox*. In the Interpolate (cubic spline) window, select all the parameters like for an Ordinary Kriging interpolation. By clicking on Run, raster as a result of Cubic spline interpolation is created.

9. RESULTS

The result of interpolation is a raster that should be styled for a better representation of the results. The style of the created layer can be modified in the *Layer Properties* dialogue box.

The render type is Single-band pseudocolor. To have a more credible display, since we are dealing with water depth data, a Blue range of color (white pixels present the shallowest water and dark blue the deepest) is used. The resulting rasters are displayed in figures 9.1 – 9.4.

The minimum value of depth (Z column in the Attribute table) in the vector layer containing selected points is 52,579 and the maximum value is 57,130. It is not a surprise that in different interpolation rasters there is different minimum and maximum value because different interpolation algorithms work differently and interpolate data on a different way. It can be seen in the legends of rasters that are representing different interpolations (Figure 9.5).

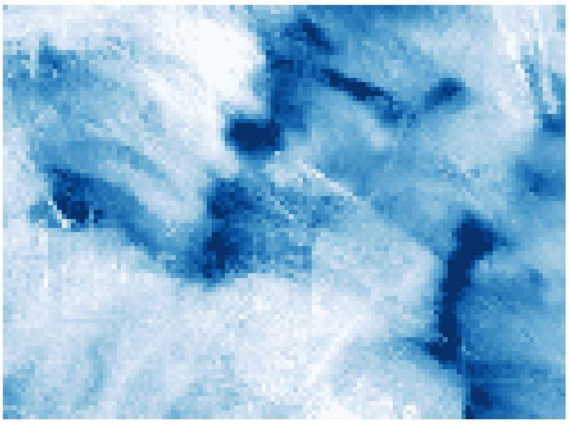


Figure 9.1 Result of IDW interpolation.

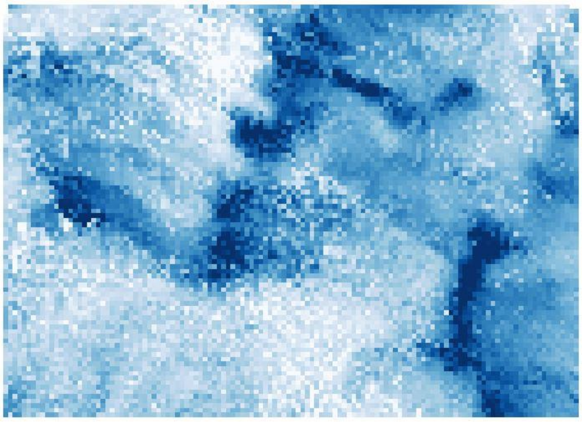


Figure 9.2 Result of TIN interpolation.

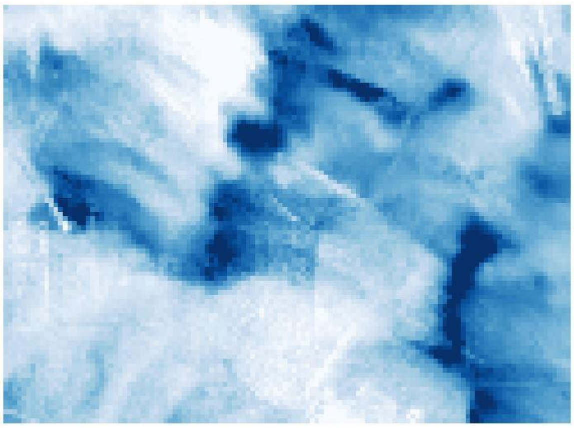


Figure 9.3 Result of Ordinary Kriging.

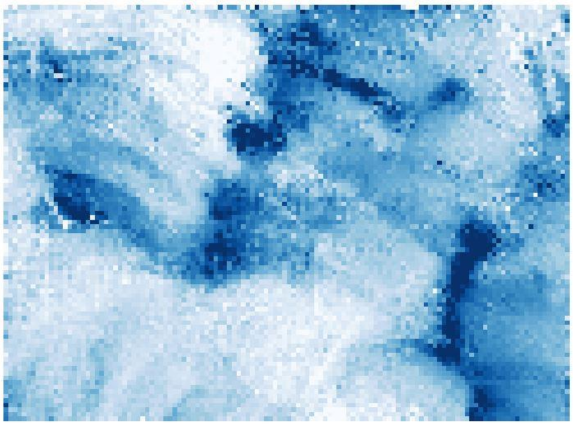


Figure 9.4 Result of Cubic spline.

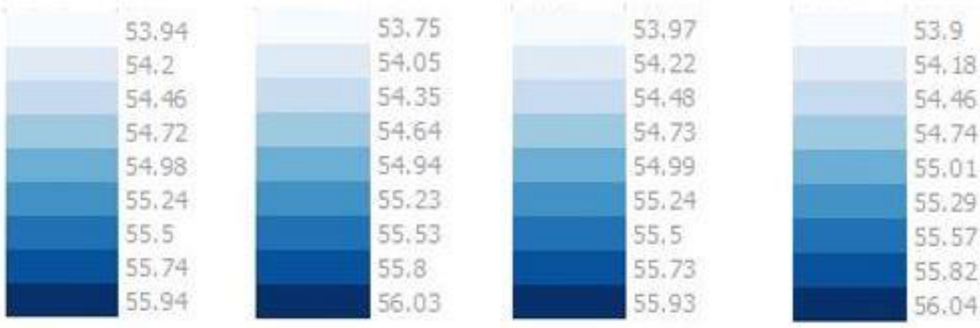


Figure 9.5 Legends for resulting rasters for IDW, TIN, Ordinary Kriging and Cubic spline interpolation, from left to right.

Histograms can be made for every interpolation method (Figures 9.6 – 9.9). The histogram provides the most common graphical summary of a random sample, as well as an estimation of the underlying probability density function (Scott, 2008).

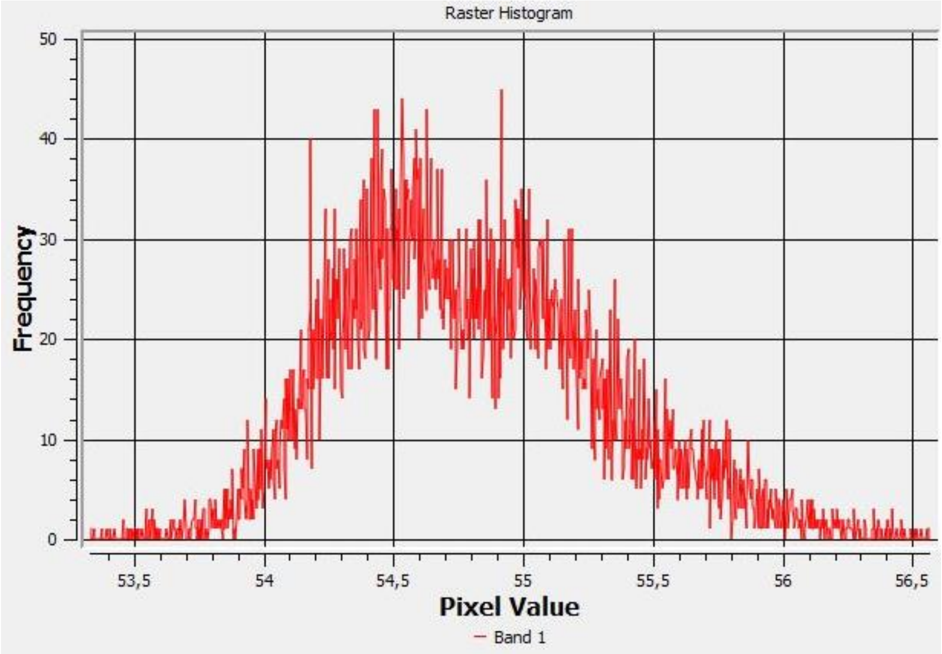


Figure 9.6 Histogram for IDW interpolation.

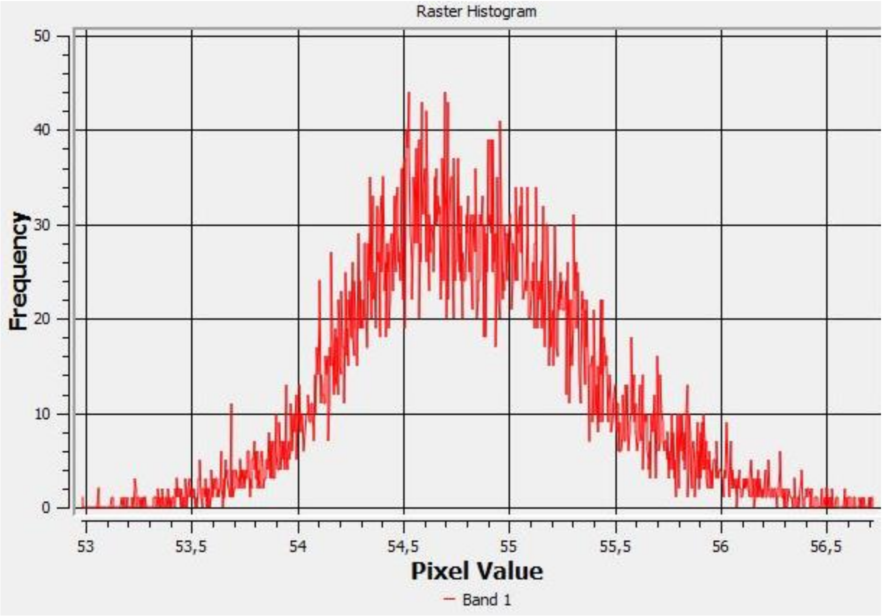


Figure 9.7 Histogram for TIN interpolation.

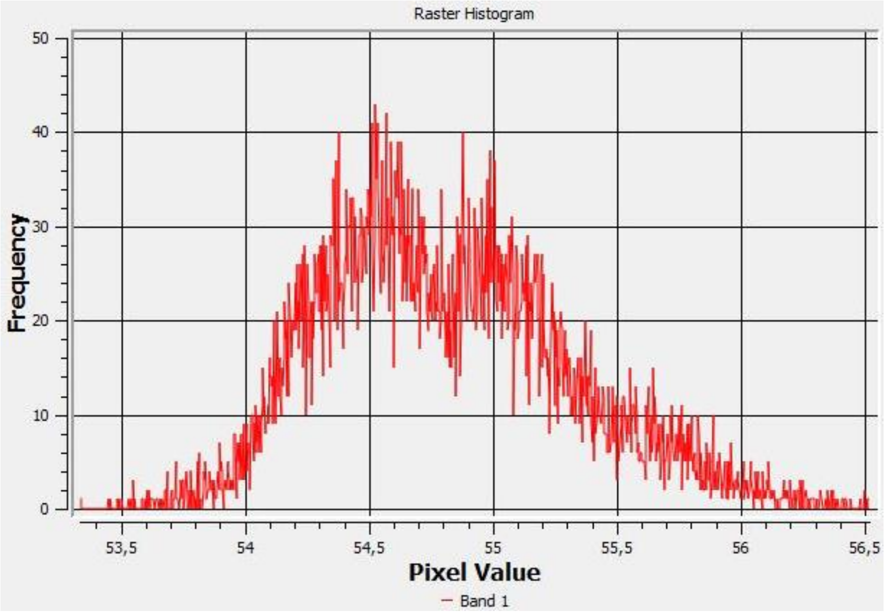


Figure 9.8 Histogram for Ordinary Kriging interpolation.

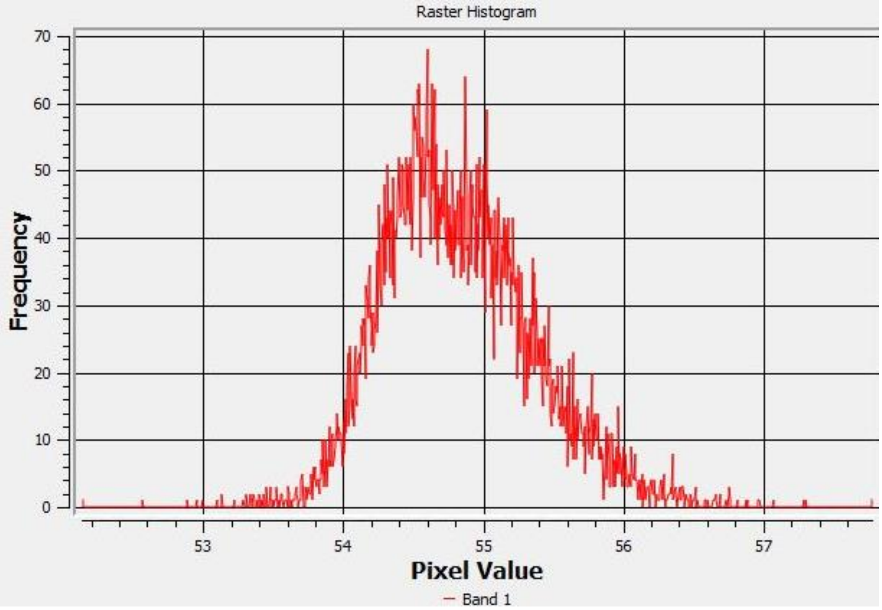


Figure 9.9 Histogram for Cubic spline interpolation.

In order to easily determine the quality of a particular interpolation that is performed over the measured data, table 7 was created.

Table 7 Statistical data on bathymetrically collected points.

Interpolation method	Inverse Distance Weight (IDW)	Triangulated Irregular Network (TIN)	Ordinary Kriging (OK)	Cubic Spline
Number of points	153 940	153 940	153 940	153 940
Use time	11 sec	10 sec	4 min	9 sec
Valid cells	11 284	11 032	11 284	11 282
No-data cells	0	128	0	2
Min value [m]	53,3320	52,9824	53,3352	52,1351
Max value [m]	56,5670	56,7196	56,5219	57,7825
Sum [m]	618 457,7720	604 792,4926	618 440,7122	618 550,8999
Mean value [m]	54,8084	54,8217	54,8069	54,8264
Standard deviation [m]	0,5017	0,5465	0,4965	0,5326

10. ANALYSIS AND INTERPRETATION OF THE RESULTS

After performing four types of interpolation methods (Inverse Distance Weight, Triangulated Irregular Network, Ordinary Kriging and Cubic Spline) that are available in QGIS software, four rasters were created as a result. Just from observing rasters, it can be concluded that Ordinary Kriging is the smoothest interpolation method. There is no big jump between adjacent pixels on the raster. After the Ordinary Kriging interpolation raster, the second smoothest is a raster created with the IDW interpolation method. Cubic spline and especially TIN are visibly the worst interpolation methods for measured data.

As already pointed out above, different interpolation methods have different algorithms by which they operate. None of them has kept the same min and max value of the points from the selected vector layer. The minimum Z value from the vector layer containing selected points is 52,579 m and the interpolated value is close to 54 m for all interpolation methods. The maximum Z value from the vector layer containing selected points is 57,130 m and the interpolated value is around 56 m.

From the IDW interpolation histogram it can be seen that most pixel values have a Z value around 54.5 m. That means that most of the selected area of the lake has that elevation. Histogram created for TIN interpolation has most of the values between 54.5 and 55 m. The Ordinary Kriging interpolation method has a very similar distribution to TIN interpolation. Cubic spline interpolation histogram has values around 54.5 m.

Deciding which interpolation method is the best for the measured data can be simplified with the help of statistical data such as mean value, standard deviation, max and min value and others.

For all interpolation methods the same sample with 153 940 points is used, but different time is needed for the interpolation algorithm to finish a job and give the results. The cubic spline is the fastest one needing only 9 seconds to create a raster. For TIN interpolation user should wait 10 seconds, and for IDW 11 seconds. The big difference is the time of Ordinary Kriging interpolation. It took 4 minutes for a raster to be created.

Cubic Spline and TIN interpolations have some empty cells, which means that IDW and Ordinary Kriging are better interpolation methods for this dataset.

The mean value for all interpolation methods is around 54.8 m. For this parameter, there are no big oscillations between interpolations.

The smaller the standard deviation, the more accurate the interpolation method is. Knowing this, it can be concluded that the most accurate interpolation method is Ordinary Kriging with a standard deviation of 0.4965 m. The worst interpolation method for measured data is TIN interpolation with a standard deviation of 0.5465 m.

From visually observing resulting rasters and taking a look into statistical data of interpolated rasters the same conclusions were made.

11. CONCLUSION

Bathymetry is an important topic and this research should continue for many reasons, such as safe maritime transportation and calculation of currents. Global warming is a really serious topic and bathymetric data can be used for monitoring beach erosions, sea-level and studying the effects of climate change. For all those reasons, it is advantageous to measure underwater terrain and interpolate those measured data.

Data captured with a multibeam echosounder system has specific characteristics. The one that stands out the most is the shape of the data. Resulting 3D point cloud has line-shaped points. After collecting data, a series of interpolation methods, available in QGIS software, were performed on the data. Inverse Distance Weight, Triangulated Irregular Network, Ordinary Kriging and Cubic Spline interpolation were used. All used interpolation methods are easy to use. Four rasters were created as a result of four interpolation methods. An appropriate interpolation method depends on the amount of computational effort afforded, the degree of accuracy desired and largely on the type of data. Some of the methods are too expensive and time-consuming on a big amount of data to be justified for certain applications, even with computers available. Even in this thesis, the 3D point cloud has a total 31 846 617 points which is too big set of data for some of the QGIS interpolation algorithms. For that reason, a selected area of the lake is used. Selected area contains only 153 940 points.

From all four preformed interpolation methods, the one that suits the measured data the best is Ordinary Kriging. From the resulting rasters, it can be seen that this interpolation method is the smoothest. This claim is also confirmed by statistical data. The Ordinary Kriging is an interpolation method that has, from all four interpolations, the lower standard deviation, but the biggest use time. Raster for cubic spline interpolation has the worst standard deviation, but the best use time. The smaller the standard deviation, the more accurate the interpolation is. Knowing that Ordinary Kriging is giving the best results for this line-shaped data, it is logical to use it even though it will take more time to create the resulting raster. The results will be more worthy than the ones created with for example Triangulated Irregular Network interpolation. It is important to point out that Ordinary Kriging, just like Inverse Distance Weight interpolation, has zero cells with no-data. That means that these interpolation methods have better algorithms for this type of data than Triangulated Irregular Network and Cubic spline interpolation.

The resulting rasters come with belonging histograms. Distribution of the data is seen on them. Histograms for TIN, IDW and Ordinary Kriging interpolation are similar. The one for Cubic spline is a little bit different which means that this interpolation algorithm has a different distribution of the data.

Even though IDW and TIN are the most common interpolation methods available in software QGIS, they are not the best interpolation method for the data used for this thesis. Ordinary Kriging, the most widely used Kriging method, is giving the best results. It is the most distinctive interpolation method, so it has qualities that other interpolation methods do not have.

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LIST OF FIGURES

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LIST OF ABBREVIATIONS

2D - two-dimensional

3D - three-dimensional

ASCII - American Standard Code for Information Interchange

BKG - Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie)

BLUE - Best Linear Unbiased Estimator

CRS - Coordinate reference system

DHHN 2016 - German Main Height Network 2016 (Deutsche Haupthöhennetz 2016)

EPSG code - European Petroleum Survey Group code

ESRI - Environmental Systems Research Institute

ETRS89 - European Terrestrial Reference System 1989

GDAL - Geospatial Data Abstraction Library

GIS - Geographic Information System

GNSS - Global Navigation Satellite System

GPL - General public license

GPS - Global Positioning System

IDW - Inverse Distance Weight

IMU - Inertial measurement unit

OK - Ordinary Kriging

OTF - “on the fly”

PPS - Pulse per second

QGIS - Quantum Geographic Information System

RTK - Real-Time Kinematic

SVP - Sound velocity probe

TIN - Triangulated Irregular Network

UTM - Universal Transverse Mercator

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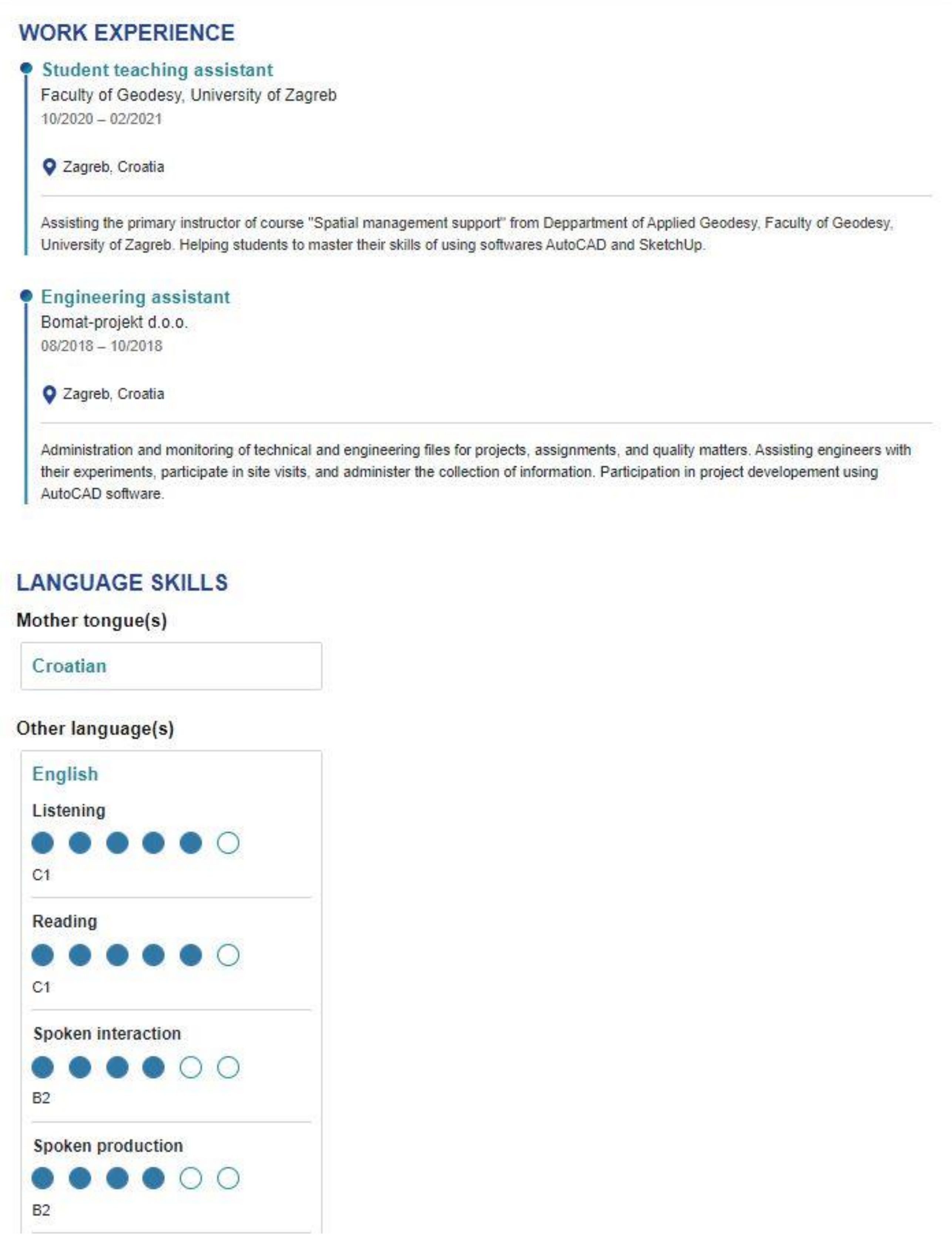

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Student teaching assistant

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Assisting the primary instructor of course "Spatial management support" from Deppartment of Applied Geodesy, Faculty of Geodesy, University of Zagreb. Helping students to master their skills of using softwares AutoCAD and SketchUp.

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Administration and monitoring of technical and engineering files for projects, assignments, and quality matters. Assisting engineers with their experiments, participate in site visits, and administer the collection of information. Participation in project developement using AutoCAD software.

LANGUAGE SKILLS

Mother tongue(s)

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Other language(s)

English

Listening

● ● ● ● ● ○

C1

Reading

● ● ● ● ● ○

C1

Spoken interaction

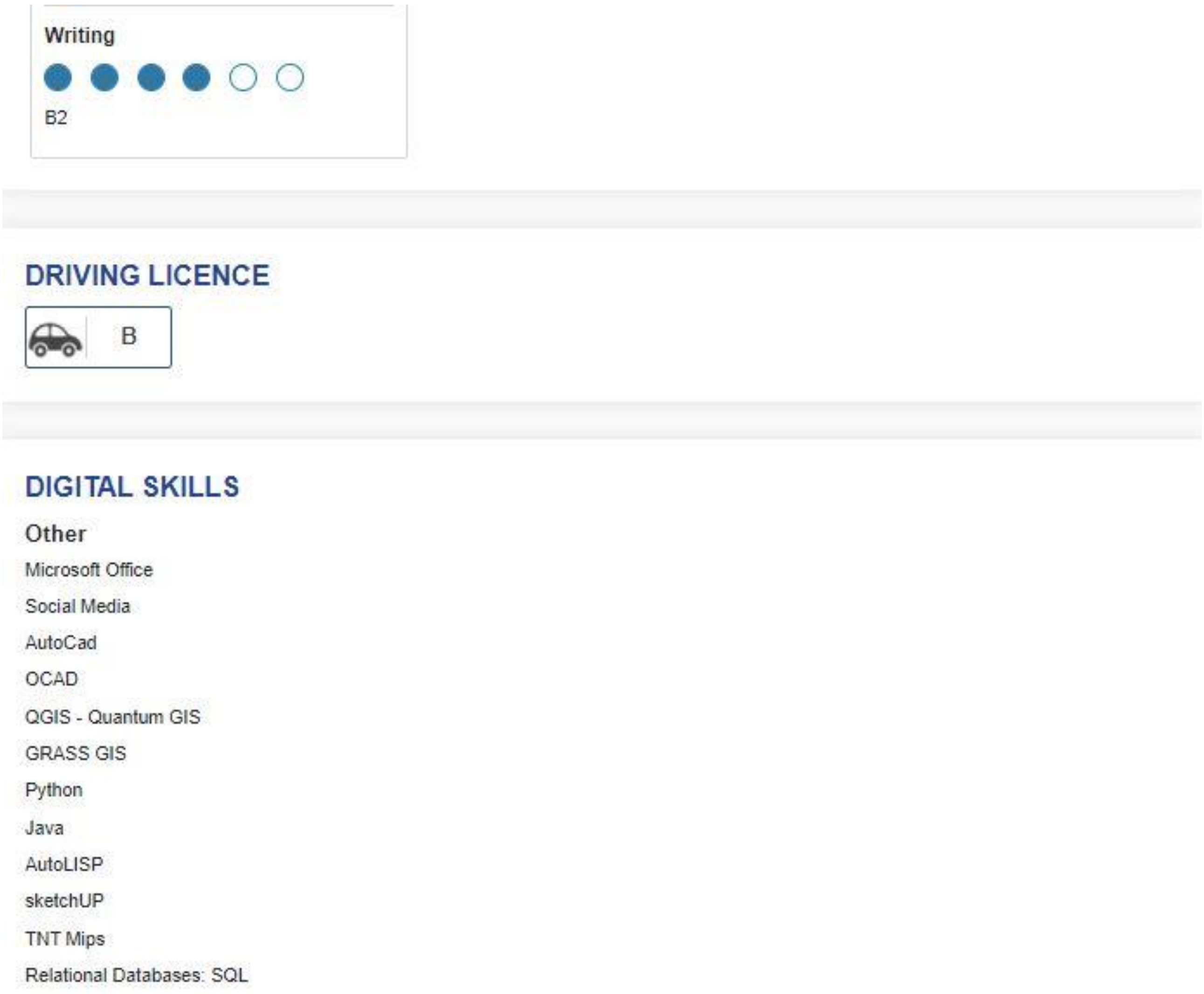
● ● ● ● ○ ○

B2

Spoken production

● ● ● ● ○ ○

B2



Writing

● ● ● ● ○ ○

B2

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Microsoft Office

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