# An improved web-based height map for the Netherlands using AHN2

**MSc Geomatics Final Graduation Plan**
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Kees Jonker
1528416

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## Personal information

Name: Kees Jonker
Student number: 1528416
Adress: Veluwemeer 10
Postal code: 2729PC
City: Zoetermeer
Phone: 06-49094041
Email: c.jonker@student.tudelft.nl

## Support and supervision

Graduation Professor (main mentor): Prof. dr. J.E. Stoter
Daily Supervisor (second mentor): dr. H. Ledoux

# 1 Introduction

The recent emergence of LiDAR (Light Detection And Ranging)) scanning technology has resulted in the availability of very large three dimensional point cloud data sets. For the Netherlands, the AHN2 (Algemeen Hoogtebestand Nederland) is a country-wide high-resolution dataset comprising nation's terrain by measuring height obtained by LiDAR, using airborne laser scanning (ALS). The average point density of the dataset is between 6 and 10 points per square meter (Van der Zon, 2013)). Such a high point density makes the AHN2 dataset quite large; it contains almost 640 billion laser points (Kadaster, 2014). In practice it appears that collected data on a local scale deviates from the predefined specifications Van der Zon (2013) gives different causes for this problem:

- Lower point density on different types of surface;
- Missing data next to high buildings;
- Ridges (on farmland);
- Puddles on grass land and;
- Data below trees.

Since collection of the AHN2 dataset was already finished in 2012 and made publicly available as Open Data since March 2014, research has been done on the development of (geo-)products based on the AHN2 dataset. Two groups of products can be distinguished:

- Vector-based (point-based) and;
- Raster-based.

Where the first group of products focuses directly on visualization of the point cloud data itself (Wouda, 2011; Geonext, 2014), the last group of products use spatial interpolation to calculate continuous (or non-discrete) data out of the discrete vector samples. This thesis research will focus on the latter strategy, a raster-based approach.
Since raw point clouds are not acquired on a uniform grid but can be seen as a set $S$ of $n$ (arbitrary) points in $R^2$ with an associated elevation function $h : S \to R$. To construct a grid DEM (Digital Elevation Model), $h$ has to be extended via interpolation to a uniform grid $G \subset R^2$ at the desired resolution (Beutel, 2011).
By applying this strategy, a reconstruction will take place of the surface that has been recorded. When looking to existing raster-based products, it becomes clear that the used methodologies to apply such a reconstruction are far from good. Products contain errors, for example, holes (no-data areas) and also dynamic objects (cars, animals) are still represented in the data. Cause for these errors can be found in the deviations during the collection of the point cloud data as described by Van der Zon (2013) as well by the used methodologies to process the point cloud data. Additional, the way the raster data is represented can be qualified as unclear. This research will investigate the possibilities to decrease or even solve such problems in order to develop an improved web-based height map for the Netherlands based on the AHN2 dataset.

# 2 Objectives, scope and deliverables

## 2.1 Objectives

The objective of this thesis is to developed a methodology that automatically generates a raster map based on AHN2 point cloud data. As stated in chapter 1, compared to existing products, I think there are potential improvements possible for the production of a better AHN2 raster map. The feasibility of this statement will be researched in this thesis and therefore, some objectives and research questions are defined. The main research question is:

- Is it possible to design and prototype algorithms to automatically generate a digital raster height map for point cloud samples (retrieved by LiDAR techniques) that performs better than existing ones?

The research of the main objective can be divided into the following (sub-) research questions:

- Given raw point cloud data, is filtering needed in order to detect and remove noise and/or outliers?
- Which interpolation technique(s) is/are most appropriate to calculate/estimate a height at a given location (that is assigned to a grid cell) from (LiDAR) raw point cloud data?
- In extent to which is it possible to create a raster height map from raw input data without usage of external 2D geodata (TOP10NL, BGT)?
- The AHN2 dataset can be qualified as a large-scale data set ("big data"), what (automatic) methodology is best to process such large raw point cloud samples (retrieved by LiDAR techniques) and generate new (raster) data out of it for usage in a web-map?
- In what order can the visual representation of raster data help to improve the understanding of a map?

## 2.2 Scope

Focus will be on quality of the outcome of the algorithm, not on performance of the algorithm itself. Design of an efficient algorithm is something that comes secondary. Quality parameters to test outcome can be resolution, number of holes and presence of dynamic objects (cars, animals) and noise.

## 2.3 Deliverables

The deliverables of this thesis research will be the following:

- The thesis self;
- A (Python-)script to create automatically the input for a web-map;
- A server running a web-map containing the research results. Final goal is to come to a map for the Dutch province Zuid-Holland.

# 3 Scientific relevance and contribution of the project

The initiative for obtaining the AHN2 dataset for the Netherlands was taken by the 26 water boards and Rijkswaterstaat, the executive Directorate General for Public Works and Water Management of the Dutch Government. For the tasks both organizations perform, like constructing, managing and maintaining waterways, dikes and flood defenses, detailed information on the height of the terrain and dikes is important. With good quality (geographical) information it is possible to make better decisions (van Loenen and Zevenbergen, 2006). Next to the original purposes defined by Rijkswaterstaat and the Dutch water boards, usage of the dataset by other governmental departments is stimulated by Dutch government. Also, by publishing the data as Open Data, initiation and exploitation for additional purposes by the market is stimulated. Primary is thought of possibilities to use AHN2 for purposes like wind and air simulation, vegetation mapping, light and shadow simulation, and many more applications (Haarman, 2012).

Height maps, or Digital Elevation Models (DEMs) are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. While a Digital Surface Model (see chapter 4.2.3) may be useful for landscape modeling, city modeling and visualization applications, a Digital Terrain Model (see chapter 4.2.1) is often required for flood or drainage modeling, land-use studies, geological applications, and other applications (Environment Agency, 1998).

As stated in chapter 1, existing AHN2 products contain errors or have possibilities to be improved. The used methodologies to obtain raster maps from raw point clouds leaves space to errors, because of deviations during the collection of the point cloud data as described by Van der Zon (2013) as well by the used methodologies to process the point cloud data. The relevance of this project is that possible improvements in the processing phase could contribute to better input data for DEM applications.

# 4 Background information

In this chapter a overview will be given of the different AHN2 products provided as Open Data.

## 4.1 General information

Since the AHN2 dataset is large in size, it was decided to split up the whole dataset into smaller subsets in order to make it more user friendly to make use of the information. Therefore the information is distributed in tiles: in total 1372 tiles that cover an area of 5 x 6.25 kilometers (Figure 1).

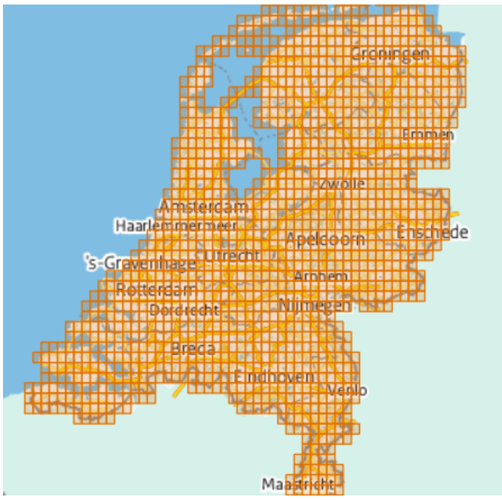


Figure 1: Tiles of the Netherlands containing AHN2 data (PDOK, 2014)

## 4.2 AHN2 point cloud data

The AHN2 point cloud data is available in two versions:

- One that includes only ground points (gefilterd) and;
- One that includes only non-ground points (ongefilterd).

### 4.2.1 AHN2 gefilterd

For the first product (gefilterd), producers developed a filtering procedure, based on the height, slope and multipath, in order to filter out all points that are classified as being non-ground points (Swart, 2009). This product could be used as input for the generation of a Digital Terrain Model (DTM, Figure 2). When visualizing the AHN2 data it becomes clear that only bare ground points (including slope-based objects like (infrastructural) dikes) and water are included. Quality of the data is good, the presence of noise seems to be low.

### 4.2.2 AHN2 ongefilterd

For the second product (ongefilterd), all remaining points are merged in one file. According to the definition of Weidner (1997) this can be seen as a normalized Digital Surface Model (nDSM). A nDSM is a model that only contains information about above ground points like buildings and vegetation (Figure 2). When visualizing the AHN2 data it becomes clear that all above-ground objects like buildings and vegetation are present, as well as infrastructural objects like bridges, but the data contains also a lot of noise which need to be filtered out in order to retrieve qualitative information.

### 4.2.3 Merging AHN2 gefilterd and ongefilterd

When merging the two products (gefilterd + ongefilterd), a product is created that contains both DTM and nDSM data. This raw point cloud defines a Digital Surface Model (DSM); an elevation model that includes elevation information about all ground and above ground objects like buildings and vegetation (Figure 2). When visualizing the data the same information as mention in the last sections. Focused need to be on the noise that the dataset contains because visualizing the raw data does give a lot of artifacts.

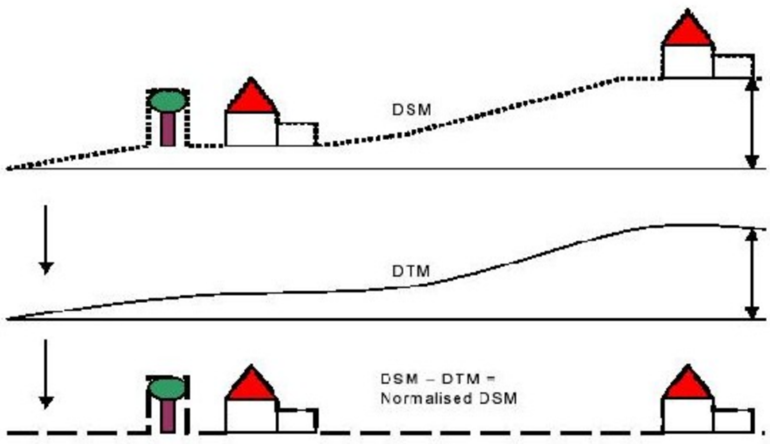


Figure 2: The difference between a DSM, DTM and a nDSM (Wichmann, 2012))

## 4.3 AHN2 gridded raster data

For both versions of the point cloud data as introduced in chapter 4.2, gridded versions of these data is provided in two resolutions:

- 0.5 meter and;
- 5.0 meter.

For the 0.5 meter grid, height values will be interpolated using Inverse Distance Weighting (IDW). Given a density between 6 and 10 points per square meter at least 1 raw point cloud point should be available for each grid cell. Calculated is that the average points distance at land even in the most pessimistic situation is 46 centimeters at maximum (Arcadis, 2012).
For the calculation of the height of a raster cell the function will only use the points that are located within the grid cell itself (Figure 3). In this way there won't be any smoothing of the data, this result in the visibility of small objects like speed bumps and curbs (van der Zon, 2013). Advantage of IDW is that it averages the stochastic error, by averaging a number of raw point cloud points to one raster cell. For the AHN2 dataset the stochastic error is calculated at 5 cm (Van der Zon, 2013).

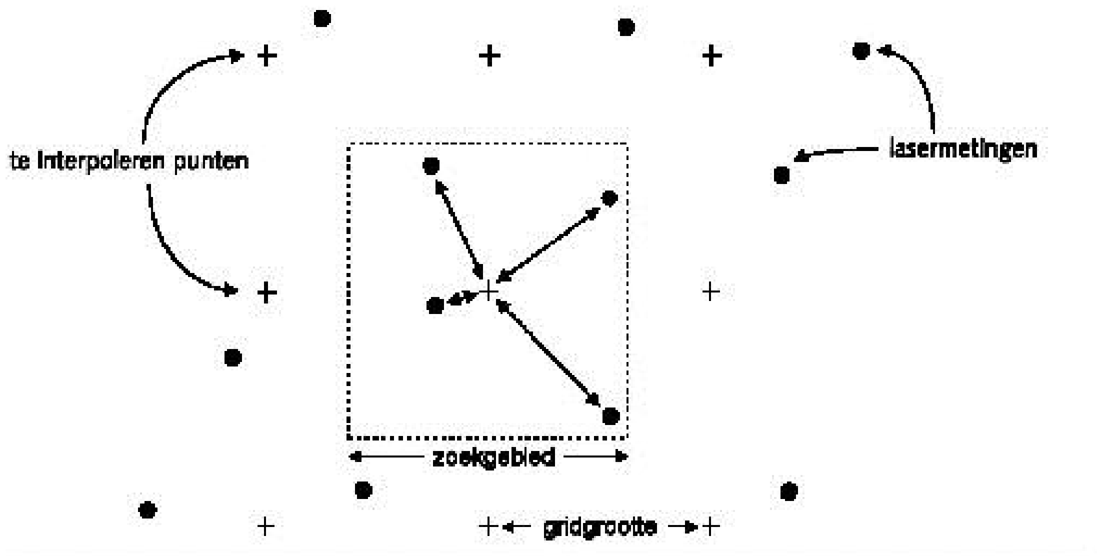


Figure 3: Inverse distance weighting (Rijkswaterstaat Meetkundige Dienst)

For the 5 meter grid the height will be calculated by averaging the 0.5 meter grid within each 5 meter grid cell (Van der Zon, 2013).

# 5 Related work

In this chapter related research will be introduced in order to support this thesis research in potential. First some related projects in the Netherlands will be highlighted. As second, related projects in other countries will be highlighted.

## 5.1 Netherlands

There exist at this moment three public available height web maps based on AHN2 LiDAR data at a resolution of 50 centimeters. Two are based on interpolation done by IDW (PDOK[1], Geodan[2]) and another one is assumed to be based on interpolation by Delaunay Triangulation (ESRI[3]).

### 5.1.1 PDOK / Geodan AHN2 web-map

Both the PDOK and Geodan AHN2 web-maps are based on IDW as described in Chapter 4.3. Because both maps more or less show the same data they will be treated together. When looking to both maps (Figure 4) it immediately becomes clear that the applied methodology is not able to cover the problems during the collection of the data as described by Van der Zon (2013). The data contains holes and artifacts appear which can, due to resolution, not good be explained. Next to this the representation of the data is not clear and filtering of dynamic objects is not applied.

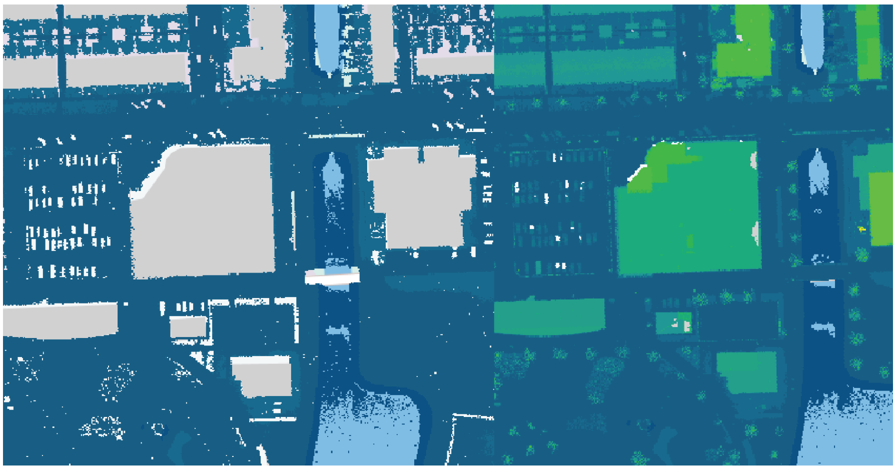

Figure 4: Impression of raster height map provided by PDOK, both gefilterd (left) and merged (gefilterd+ongefilterd) (right) (own image, based on (PDOK, 2014))

[1]http://pdokviewer.pdok.nl/
[2]http://ahn.geodan.nl/ahn/
[3]http://www.arcgis.com/home/webmap/viewer.html?webmap=6b3beecbd02b4a838c7f785ba07b0fd9

### 5.1.2 ESRI AHN2 web-map

The ESRI AHN2 web-map is assumed to be based on Delaunay triangulation (DT) from a set of points by creating a triangular mesh, surface or triangular planes connecting the data points. DT is considered to be a desirable approach for creating natural-looking surfaces because minimum interior angles of all triangles are maximized and triangles are as equiangular as possible, thus avoiding long, thin triangles (Pearlstone, 2010). In Figure 5, samples of rasterization AHN2 data after what is supposed to be DT are showed. The same holes, and errors are visible as in the example after performing IDW. It can be assumed that the same sources are used as in the example in chapter 5.1.1, and that there are no further processing steps (filtering) made before interpolating the data.

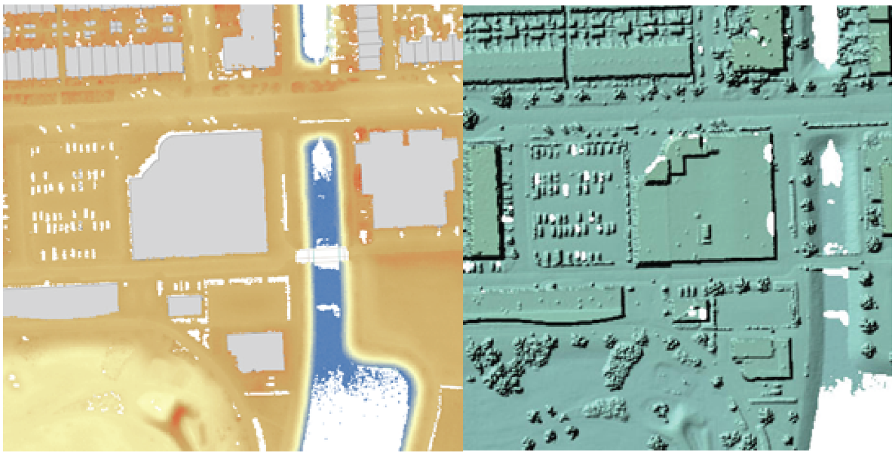

Figure 5: Impression of raster height map provided by ESRI, both gefilterd (left) and merged (gefilterd+ongefilterd) (own image, based on (ESRI, 2014))

### 5.1.3 Filling holes

In (Kramer et al., 2014) a method is proposed for flling holes (no-data areas). In this method an approach is described on filling nodata for DTMs, DSMs and nDSMs (see chapter 4), based on the gridded data as introduced in chapter 4.3. By making use of external 2D geodata it is possible to design a set of rules in order to gain external knowledge. For a DTM the followig rules are defined:

- For water surfaces, the height value is set equal to the lowest point that intersects a certain waterbody in the TOP10NL dataset;
- For building footprints, the height is set equal to the average of the buffer of each polygon in the BAG dataset and;
- All other points are filled by using IDW.

For a DSM the following rules are defined:

- For no nodata areas on buildings the average height for the nearby area is used that intersects with the building footprint as defined by the BAG dataset and;
- Vegetation will be detected by calculating a vegetation-index (NVDI) based on aerial photography. Based on the average height of the detected vegetation nodata will be filled.

Both methodologies are based on the idea of filling holes that are in the provided raster data after interpolation with IDW, by PDOK[4]. Because of this, the introduced approach is somehow limited in its possibilities. Filtering of (erroneous) data that is not supposed to be in one of the products is not possible (cars and other dynamic registered objects in a DSM, for example). To do so, it is needed to start at the beginning, at the raw point cloud data self. Another problem is the difference in source date when combining different (2D) geo-datasets. Because the data is a representation of a dynamic world, its state might differ when two geo-datasets have a different source date.

### 5.1.4 Tree detection

In (Volkove, 2014), a methodology is described where a tree database is developed based on the AHN2 dataset. This database included information about tree locations, tree crown projection parameters, and several tree shape parameters. Aim of the study was to find a new way of delineating trees and deriving their parameters using Terrestrial Laser Scanning (TLS) and ALS. The quality of tree parameters derived from ALS raster and point data was assessed using parameters derived from TLS point data. Based on the results of validation, the tree location calculation from ALS raster data was not as precise as urban tree managers may be requiring, producer's accuracy was 0.23 meter and user's accuracy was 0.15 meter. However, this result is not very much reliable, as only in 63.07 percent of cases tree locations derived from TLS point data were correct. This could be explained by the fact that the accuracy of ALS raster data is much lower, which is caused by the low density of points and averaging these points during the transformation of point data into 0.5 x 0.5 meter raster cells. In general, validation showed that extraction of parameters using ALS point data rather than ALS raster data gives more precise result.

### 5.1.5 Roof detection and analysis

Geodan (2014), developed a web viewer containing the AHN2 raster data called Dynamic Holland Shading Map (Figure 6). By calculating the slope and its direction it can show for each moment of the day the light intensity for each raster cell, by a technique called 'dynamic hillshading'. The map does not really provide shadows. Since the algorithm calculates the light intensity for each grid cell it does not take heights into account relative height differences of neighboring grid cells. Because of this there is no 'real' shadow presented on the map. There seems to be space for implementation of a better shadow analysis map.

[4]http://pdokviewer.pdok.nl/

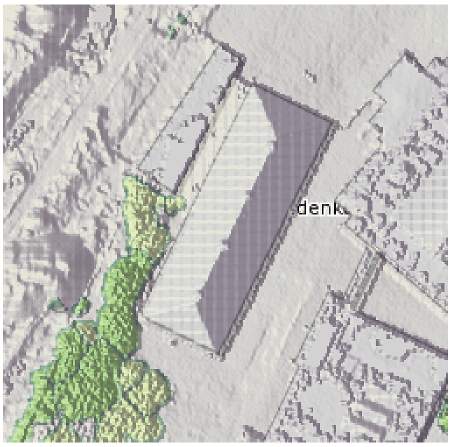


Figure 6: Impression of Dynamic Holland Shading Map (Own image, based on (Geodan, 2014))

## 5.2 Denmark

In Denmark, Geodatastyrelsen, the Danish Geodata agency is in the process of gathering raw point cloud data for the generation of a new and better elevation model since spring 2014 (Geodatastyrelsen, 2013). The point cloud has a density about 4 points per square meter. This density is lower than the Dutch AHN2 dataset. Nevertheless, this dataset contains information that is missing in AHN2:

- For each point is the RGB colors (Red, Green and Blue) is detected of the returned laser signal for each point. The registered RGB colors can be used for enhanced visualization and improving the automation process for object identification and point classification;
- Full waveform data is available, not only the first and last return of the laser pulse is registered, but the entire waveform (full waveform). Currently, full waveform data is mainly used in scientific studies such as forestry (Geodatastyrelsen, 2013).

A part of the raw point cloud is available as open data for free. Based on this dataset, Septima (2014) took initiative to produce a raster map with a grid cell 40 centimeter resolution based on gridded DT. Claimed is that the map is just a representation of the raw point cloud data errors are not filtered (Septima, 2014). This resulted in artifacts, like holes (Figure 7). Cause of this is the presence of noise in the data which can be filtered out by the use of filtering algorithms.

### 5.2.1 Carthograpy

Interesting about this map is the more realistic cartography used. Compared to the AHN2 raster grid the data is represented in a more eye-friendly way using a higher resolution, while the input does have a lower point density than the Dutch web-map.

Another improvement is made by adding a visual effect called hillshading. Hillshading is a hypothetical illumination of a surface according to a specified azimuth and altitude for the sun. Hillshading creates a three-dimensional effect that provides a sense of visual relief for cartography, and a relative measure of incident light for analysis. Coloring is done by tranforming grayscale intensity values to a color according to a table or function, this leads to a pseudocolor image.

Figure 7: Holes in the ground (left) due to noise in the data and artifacts due to applied interpolation technique (right) (Own image, based on (Septima, 2014))

## 5.3 Finland

The national survey of Finland published in 2012 their LiDAR dataset for the whole country as Open Data. The point cloud has a density about 0.5 points per square meter (Figure 8). In Korpela et al. (2008), the potential for combined use of airborne discrete-return LiDAR and digital imagery in the classification and measurement of common seedling stand vegetation was examined in southern Finland. From a broader perspective such a strategy might be interesting, next to the ones already mentioned strategy where is made use of (2D) geo-datasets (Chapter 5.1.3).

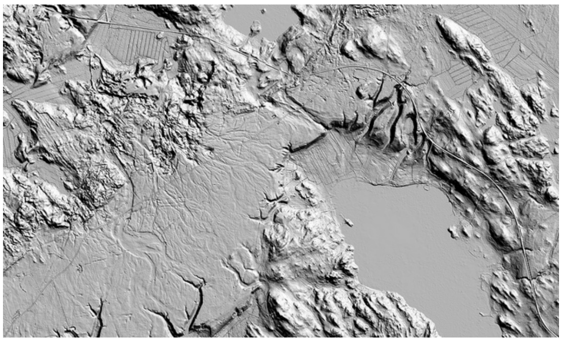

Figure 8: DTM sample, created with the Finnish LiDAR dataset (Own image, based on (Korpela et al., 2008))

# 6 Methodology

In this chapter the expected methodology will be treated to come to an answer for the research (sub)question(s), objectives and deliverables as introduced in chapter 2.

## 6.1 Data acquisition

As mentioned already in chapter 4, the needed AHN2 point cloud products are available as Open Data as download at the website of PDOK[5]. The province Zuid-Holland consists of 117 tiles with each an average of 500 million points. In total an amount of around 58.5 billion points will be used as input. Research on most relevant questions can be done with a maximum of four tiles in order to do research how to process data near the borders of a tile best.

## 6.2 Data processing and interpolation

The AHN2 point cloud data is provided as LAZ-files, this is a compressed LAS file. A LAS file is an industry-standard binary format for storing LiDAR data (ASPRS, 2013). A method to read these files, as provided by Isenburg (2013), is with a command line utility named LASzip[6]; this utility can decompress the LAZ-files to their original LAS-format. Given two LAS-files for each tile (gefilterd and ongefilterd) a look will be given at buffering, filtering, classification, and generation of a raster image out of the raw point cloud. For the generation of raster images, a look will be given to most well-known existing interpolation techniques:

- Inverse Distance Weighting (IDW);
- (rasterized) Delaunay Triangulation (DT);
- Natural Neighbor interpolation (NNI) and;
- Spline.

The results of the different interpolation techniques will be compared to each other and based on their outcome the technique(s) that give the most accurate representation of the truth will be used for the creation of the AHN2 height map.
Massive point clouds can be processed with LAStools[7] as described in (Isenburg et al., 2006). Processing can be done by e.g. data thinning, splitting, merging, buffering and rasterization. The unique selling point of LAStools is that it is able to generate Raster DEM from mass points via TIN streaming. In this way it is possible to process data without having memory problems. Since all other mentioned interpolation techniques are available in SAGA GIS[8], this program will be used for the creation of raster data by using the other interpolated techniques as mentioned in this chapter.

[5] https://www.pdok.nl
[6] http://www.laszip.org/
[7] http://www.cs.unc.edu/ isenburg/lastools/
[8] http://www.saga-gis.org/

## 6.3 Data processing and interpolation

GDAL[9], a library for reading and writing raster geospatial data formats, can be used for further processing of the data:

- Interpolate data (remaining holes):
  - Inverse Distance Weighting (IDW);
  - Average and;
  - Natural Neighbour interpolation;
- Georeferencing the raster data or transform coordinates;
- Interpolate no data regions;
- Create contours from DEMs;
- Analyze DEMs and;
- Visualize DEMs.

For the implementation of GDAL within the deliverable Python script as mentioned in chapter 5.3, the software packages Rasterio[10] and Fiona[11] are promising for implementation of OGR and GDAL implementation within Python itself.

## 6.4 Representation of the (raster) web-map

For a correct representation of the web map and the processed output data the program Mapbox[12] will be used. This program has functions to build up custom maps and is therefore very interesting for the cartography of the web-map. Additional the program has also additional libraries to support for example rasters, this method can help to load the final result faster on a users' browser. The methodology behind this is by applying a raster pyramid. A pyramid is a series of reduced resolution representations of the dataset, mainly used to improve the display performance of rasters when one is not working with the pixel information at full resolution. It contains a number of layers, each resampled at a more generalized level. Thus, each level of the pyramid is a resampled representation of the raster at a coarser spatial resolution. With the software package GeoServer[13], the (final) research results can be shared and displayed by using the Web Map Service (WMS) via the Internet in order to show the data that is stored on an external server.

## 6.5 Quality assessment

The goal of this thesis research is to investigate the possibilities to make a 'better' web-based height map for the Netherlands based on the AHN2 dataset. To compare the quality of the results, it is needed to design parameters to make comparison possible. Quality parameters to test outcome can be resolution, the presence of noise and dynamic objects (cars, animals) and the number of holes.

[9] http://www.gdal.org
[10] https://github.com/mapbox/rasterio
[11] https://github.com/Toblerity/Fiona
[12] https://www.mapbox.com
[13] http://geoserver.org/

# 7 Preliminary results

In this chapter a view will be given in the results achieved already. Because it is not the purpose of this proposal, result will be treated globally:

- Thinning of raw point clouds based on multiple point at the same xy-coordinatr led to a reduction of 8.3% drop in filesize for DSMs and 5.3% for DTMs without lose of quality;
- Filtering noise out of raw point cloud data, using LAStools classification method led to a reduction of 14.8% for DSMs and 0% for DTMs;
- Using DT setting a maximum value for the longest edge of each triangle of 1.0 meter gives 'smooth' values, even at 10 centimeter resolution but increases the number of nodata areas;
- Filling nodata areas using the method as provided by (Kramer, et al., 2014) gives reasonable output fot both DSMs and DTMs. Errors appear at places where AHN2 differs with information in the TOP10NL and/or BAG dataset;
- Merging tiles and splitting them up, taking into account buffers, seems a valid strategy to handle objects spanned in more than one tile and/or near the edge of a tile;
- Setting up the separate steps as described in Chapter 6 is done for all individual steps succesful already.

# 8 Activities and planning

## 8.1 Activities

The thesis work should correspond with 45 ECTS; this is equal to 158 days of 8 hours. A draft version of the planning to do the thesis is described below:

From P2:

- Further research on point filtering, thinning, buffering, classification and interpolation for raw point cloud data;
- Further research on interpolation of nodata areas (holes) and;
- Further research on carthograpy and presentation.

From P3:

- Write a script to automate the process from raw point cloud to raster data;
- Set up the webserver to present web-based height map and;
- Start writing thesis.

From P4:

- Prepare P5 presentation and;
- Finish thesis report.

## 8.2 Planning

In the course of the graduation process two obligatory progress reviews (P1 and P3) and three formal assessments (P2, P4, and P5) take place (TU Delft, 2014). The planned dates for these presentations are:

- P1: 11 November 2014
- P2: 22 January 2014
- P3: Week 10/11, 2015 (TBA)
- P4: Week 17/18, 2015 (TBA)
- P5: Week 21/22, 2015 (TBA)

For guidance and feedback during the project the student will have meetings every week with the Daily Supervisor.

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