Zeb-Revo Guide

Information on the use of the Zeb-Revo handheld laser scanner and the possible applications and processing of the Zeb-Revo point cloud data.

MADE

BY

Peter Haacke

Master Earth Sciences – University of Amsterdam

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Zeb-Revo + GeoSLAM Hub

The use of the Zeb-Revo and processing of Zeb-Revo data in GeoSLAM Hub is explained in detail in the Zeb-Revo manuals provided by GeoSLAM. Some additions can however be made concerning the application of this software in forestry and outside application. This section provides information on possible GeoSLAM Hub installation issues and simplified step by step walkthroughs of both Zeb-Revo systems.

Installation notes

The (black) USB stick that comes with the Zeb-Revo contains guides for the installation of the GeoSLAM Hub and GeoSLAM Draw. Geoslam Draw is mostly used for inside environments and applications. Considering the installation uses a virtual machine and requires specific processor requirements some errors might occur that are not described in the available guides.

The first error that might occur is that the GeoSLAM Hub software cannot initialize the processing engine via Oracle Virtual Box. This error will describe that there is something wrong with for example the file destination of the virtual machine. In some cases, that can be due to the GeoSLAM installation advising the installation of an outdated or incorrect version of Oracle Virtual Box (v5.1.22). If this error occurs, first uninstall Virtual Box (v5.1.22) and install the most recent version of the v5.1 series (v5.1.36). After installation restart your pc and GeoSLAM Hub should recognize the virtual machine and this start the processing engine.

The second error that might occur is that your pc does not have hardware virtualization enable which is necessary for GeoSLAM Hub. This setting has to be change in the BIOS settings as follows:

1. Reboot the computer and open the system's BIOS menu. This can usually be done by pressing the **Delete** key, the **F1** key or **Alt** and **F4** keys depending on the system.
2. Select **Restore Defaults** or **Restore Optimized Defaults**, and then select **Save & Exit**.
3. Power off the machine and disconnect the power supply.
4. **Enabling the virtualization extensions in BIOS**

Note: BIOS steps

Many of the steps below may vary depending on your motherboard, processor type, chipset and OEM. Refer to your system's accompanying documentation for the correct information on configuring your system.

  a. Power on the machine and open the BIOS (as per Step 1).
  b. Open the **Processor** sub-menu The processor settings menu may be hidden in the **Chipset**, **Advanced CPU Configuration** or **Northbridge**.
  c. Enable **Intel Virtualization Technology** (also known as Intel VT) or **AMD-V** depending on the brand of the processor. The virtualization extensions may be labeled **Virtualization Extensions**, **Vanderpool** or various other names depending on the OEM and system BIOS.
  d. Enable Intel VTd or AMD IOMMU, if the options are available.
  e. Select **Save & Exit**.

5. Power off the machine and disconnect the power supply.
6. Run **cat /proc/cpuinfo | grep vmx svm**. If the command outputs, the virtualization extensions are now enabled. If there is no output your system may not have the virtualization extensions

or the correct BIOS setting enabled. In some cases, the command is not recognized in which case it is best to start GeoSLAM Hub and check if the error still occurs.

With these fixes the software should initialize correctly if the license dongle is inserted when requested by GeoSLAM hub during the start-up of the processing engine.

Original Zeb-Revo

The original version of the Zeb-Revo uses a black box for data collection. This means that data is first collected onto the hard drive of the black box and must then be copied to a computer. The data can then be processed in GeoSLAM Hub. The process of data collection and processing for the original Zeb-Revo can be found in detail in the *"ZEB-REVO User Guide V3.0.0"*. The following explanation is a short walkthrough of the steps necessary to successfully collect and process data, including a list of the equipment available. For a quick start up GeoSLAM also provides a guide, namely: *"ZEB-REVO – Quickstart guide v1.1.1"*

Measurement accessories

- Bag
- Data Logger
- Battery for data logger (inside the frame of the data logger)
- Handheld scanner (Zeb-Revo)
- Cable which connects the handheld scanner and camera to the data logger
- Cable which connects the data logger to an external data storage
- USB stick
- Dongle (for the GeoSLAM software license)
- USB mini cable (to connect GoPro camera to the computer + charging (white))
- Charger/Adapter for battery for data logger
- GoPro camera attached to Zeb-Revo

In practice

Start-up:

- Find a stable point where you can put the device on its back
- Connect the Zeb-Revo to the data logger (white cable to white connector and Zeb-Revo, blue cable to the blue connector)
- Connect the camera by plugging in the mini USB cable in the port on the Zeb-Revo (it is sensitive!)
- Plug the data logger into the battery (short black adapter cable)
- Switch on the data logger by pushing the button once and wait until it is blinking red.
- Turn the head of the scanner once (>360°) then wait until it turns green (don't move it!)

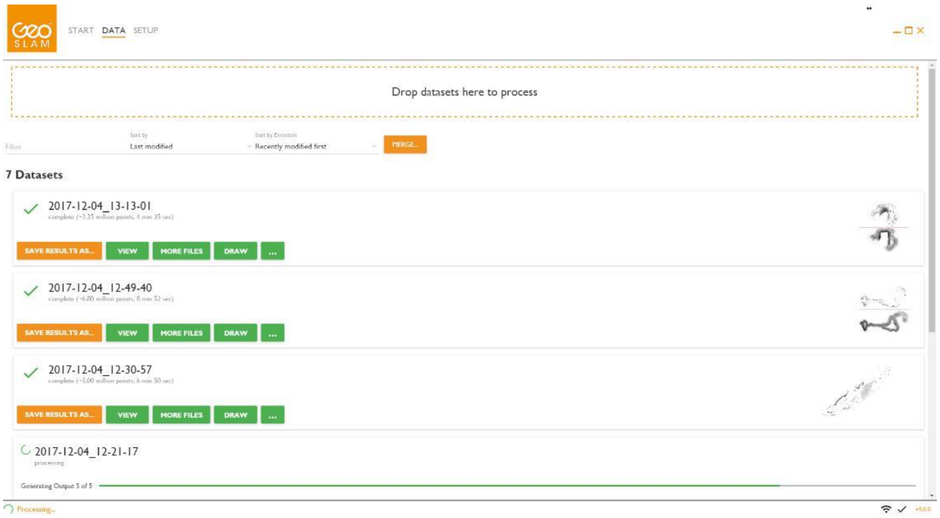
Data collection:

- Switch on the camera by pressing the button on the top of the GoPro (once for immediate recording, hold for power on but no recording)
- Switch on the scanner by pressing the button on the side of the Zeb-Revo
- Pick up the Zeb-Revo measure the area while avoiding moving objects and staying behind the back panel
- Finish recording by going back to the starting point and put the Zeb-Revo in the same starting position.
- The data will now be transferred from the Zeb-Revo to the data logger. Wait until the light on the side of the Zeb-Revo is blinking red and then unplug the Zeb-Revo.

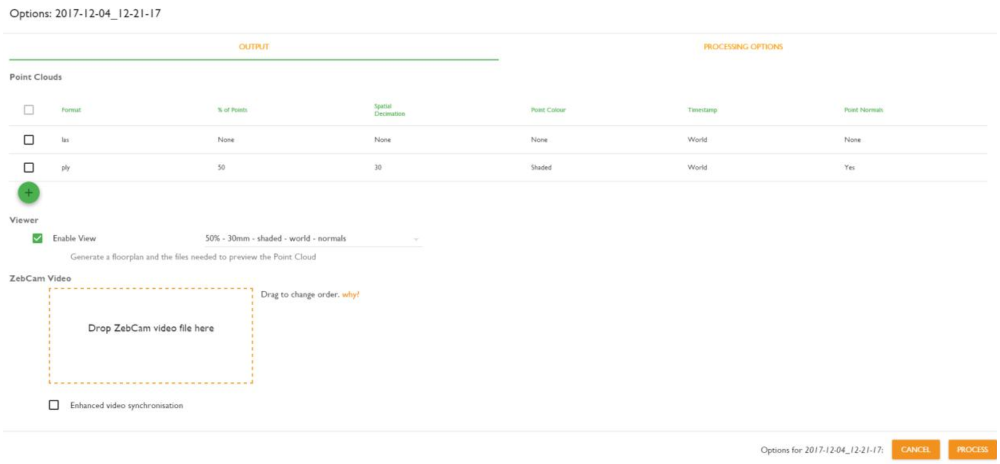
- The data will still be processing inside the data logger. Wait until the AUX light on the data logger stops blinking orange and the Zeb-Revo light on the data logger is blinking red and then remove the white and blue cable from the data logger.
- Connect the external data export cable to the data logger (blue AUX connection) and to a USB stick. Wait until the green AUX light on the data logger is gone and only the Zeb-Revo light on the data logger is blinking red. This means the data has been transferred onto the USB stick.
- Unplug the external data export cable and switch off the data logger by pushing the button once.
- Disconnect the data logger from the battery (unplug the adapter cable)
- Pack it back into the bag.

Data processing

1. Copy all the data from the USB and camera onto your local computer
2. Drag and drop the zip file (measured data) from the local computer and the matching camera file (mp4).



3. Set what kind of output files you would like to get (las, laz, ply, etc.). It is also possible to reduce the number of points randomly (max 50% recommended) and to define the attributes of the extraction (colorized by time, SLAM condition or GoPro camera)



4. Then start the process with the process button.
5. After the processing is finished, save your data by clicking Save results. You can immediately view your data by clicking on view or open in the final prompt.

If the resulting point clouds do not yield reliable results, there is unfortunately no way of changing the outcome due to fact that the SLAM algorithm and software is a black box. Hence it is important to be very precise in your measurements when using the older version of the Zeb-Revo.

Real-Time Zeb-Revo

The real-time (RT) version of the Zeb-Revo uses a mini-computer for data collection that is instantly processed and visualized. Due to the high computional requirements this over the shoulder computer is ventilated and therefore much more susceptible to wet conditions. The RT Zeb-Revo should only be used in dry conditions, for all other applications it is best to use the original Zeb-Revo. The process of data collection and processing for the RT Zeb-Revo can be found in detail in the *"ZEB-REVO RT User Guide V1-0-2"*. The following explanation is a short walkthrough of the steps necessary to successfully collect and process data, including a list of the equipment available.

Measurement accessories

- Flight-Case
- Real-Time Data Logger
- 2 Lithium Ion batteries
- Handheld scanner (Zeb-Revo)
- Cable which connects the handheld scanner and camera to the data logger
- Cable which connects the data logger to an external data storage
- USB stick
- Dongle (for the GeoSLAM software license)
- USB mini cable (to connect GoPro camera to the computer + charging (white))
- Charger/Adapter for battery for real-time data logger
- GoPro camera attached to Zeb-Revo
- Magnetic back attachment

In practice

Start-up and data collection:

- Find a stable point where you can put the device on its back
- Connect the Zeb-Revo to the real-time data logger (white cable to white connector and Zeb-Revo)
- Connect the camera by plugging in the mini USB cable in the port on the Zeb-Revo (it is sensitive!)
- Turn on the real-time data logger
- Connect your phone or tablet to the Zeb-Revo network:
    - Wifi: geoslam-rt
    - Password: zebedee12
- Open a browser and go to http://192.168.102.2
- Before starting a new scan start the GoPro by clicking the top button once
- Once connection has been made, press **new scan/start** and enter a name for the dataset
- Once the initializing is done, power on the Zeb-Revo with the side button on the handheld scanner.
- The scan has started and data can now be collected safely.
- When done place the handheld scanner in the same location as the start point and click the **end scan/stop** button.
- After global optimization is done turn of the GoPro by clicking the top button once

While scanning the coloured dot in the top right of the screen will show the SLAM conditions. A red dot will indicate poor slam conditions. This means during processing the scan data may come out distorted or not process. An Orange dot will indicate satisfactory slam conditions. Data collected in this region should process acceptably. A green dot indicates good slam conditions. Data collected in this region should process acceptably. Where possible scanning should be conducted in the orange and green regions to ensure data processing.

Data Processing

Unlike the original scanner the RT Zeb-Revo has already processed all the data and is now available for download or viewing on the GeoSLAM network. Download the. geoslam file and then drag it into GeoSLAM Hub. The data can then be unpackaged and viewed and saved in different formats. When using the *"save results as…"* option the data will be saved as. laz files. Other extensions and files that are colored according to time, height etc, or less dense point clouds can be downloaded by using the *"more files"* button. Other processing changes such as *"Conservative Outlier Pruning"* can be made by clicking *"…"* and reprocessing the point cloud.

Processing data notes

For Zeb-Revo data focusing on forestry data or outside locations, it is best to set the number of points to 100% and also check the *"Large range filter slope"* processing option. Although this option removes some outliers in the point cloud it is unclear what the algorithm behind this feature specifically excludes, due to the SLAM algorithm being a black box. Therefore, it might be more favorable to perform outlier removal within other software that specifies what are the boundaries of the outliers. Some point clouds, often ones with a low algorithm condition, fail to create a complete point cloud during processing with the *"Large range filter slope"* option checked. In those cases use the default ".las" output that is created during processing.

The merging tool available in GeoSLAM Hub does not offer many options in the alignment of different point clouds and it is therefore advised to use the merging methods specified within the CloudCompare section of the guide.

Lastly GeoSLAM Hub also offers the ability to combine the point cloud with the captured video footage as is also explained in the *"ZEB-REVO RT User Guide"*. This ability allows for visualization of the video footage along the trajectory of the Zeb-Revo recording. Furthermore, the point cloud can be colored according to the video, this option is however still very unreliable and not very useful for forestry or any classification attempts.

CloudCompare

The Zeb-Revo can collect roughly 20 minutes of data. This is often enough to retrieve a highly detailed dataset of the study area. However, some areas might be bigger or more complex in structure and require multiple Zeb-Revo scans. Considering the Zeb-Revo is only equipped with an inertial measuring unit (IMU) there is no simple way to overlap these dataset using GPS coordinates. There are three possible ways to merge these datasets, namely via spherical markers, merging via simple point pairs or automatic merging. This section will go through the steps necessary to perform all three merging methods in CloudCompare (CloudCompare v2.9.1, 2017). Furthermore, it will provide information on a few useful tools for Zeb-Revo data.

When recording multiple datasets that have to be merged later it is useful to have the same starting point so that the positioning of the point clouds becomes more clear. The merging of multiple point clouds is a less precise method of merging due to it depending on the selection of x, y, z points that overlap in the clouds in question. This method should therefore only be used if merging via spherical markers is unavailable. Furthermore, the purpose of the dataset has to be considered when deciding how to merge and if it is useful to merge. When using point clouds for precise measurements of for instance tree structure parameters, the use of simple pair merging might decrease the reliability of these measurable parameters and therefore be unfit. When using point clouds for classifications of objects the precise measurements might be less important and simple pair merging could provide more reliable data.

Visualization

Before merging can be done it is important to get familiar with a few visualization and navigation options in CloudCompare.

Open CloudCompare

Go to F**ile** > **Open**, and open "TutorialCloud01.las".

A window will appear concerning the characteristics and display of the point cloud.

Click **Apply** (default settings are correct)

To move the point cloud around use left click to rotate around the rotation center and use right click to move the point cloud in its entirety. The point cloud will appear colored by recorded time.

There are a few basic changes that can be made to change the visualization:

1) On the left you can set the view of the point cloud and change the rotation center

2) While zooming and rotating the automatic center can sometimes be in an unfavorable location leading to difficulties in navigation. To make sure the rotation center is correct set the **"Set pivot visibility"** to always visible.

With the point cloud selected, under the *Properties* window:

3) Under *Cloud*, you can change the point size

4) Under *Color Scale* you can change the color and type of visualization

5) Under *SF display params* you can change the visible points depending on parameters (The graph visible in SF display params can be examined further by using the show histogram button in the top bar)

With the visualization of time it is possible to see which data points were recorded at what time, however the path taken during the recording of TutorialCloud01 is not clear. The trajectory can also be added by going to **File** > **Open**, and opening "TutorialCloudtraj01.ply". Once again **Apply** the default settings.

Merging

Simple point pairs

Open TutorialCloud02.las

When loading both point clouds it becomes apparent that the initial start location overlaps but that any movement hereafter (while recording with the Zeb-Revo) does not line up correctly seeing as these point clouds should overlap for the most part. Merging these two clouds is difficult due to the fact that overlapping points are hard to find by hand. However, this will be necessary if spherical markers do not exist.

First it will be necessary to get TutorialCloud02 in roughly the right location compared to TutorialCloud01. To do this click on "**Set top view**" on the left. TutorialCLoud02 should first be rotated 180 degrees on the z axis. Click on the "**Translate/rotate**" button at the top. Then for **"Rotation"** select the **"Z"** axis. Rotate the point cloud and drag it so that the start locations line up once more. If you want to move the camera view point while using the translate/rotate tool use the "P**ause**" button.

See "MergingPositioning" video

TIP: Try to find bigger trees that are clearly visible in both point clouds to line up both datasets.

Once the point clouds are roughly lined up simple pair merging can be done. During this process TutorialCloud02 will be aligned to TutorialCloud02 which is the reference point cloud. First set the view to **“Set right sight view”** with TutorialCloud02 on. Zoom in to the left of the point cloud so that your screen resembles the left image in figure 1 (TutorialCloud02). The tree pointed out in this figure shows a tree with a high density point cloud that is present in both datasets. This will be the first object from which two points will be selected for merging.

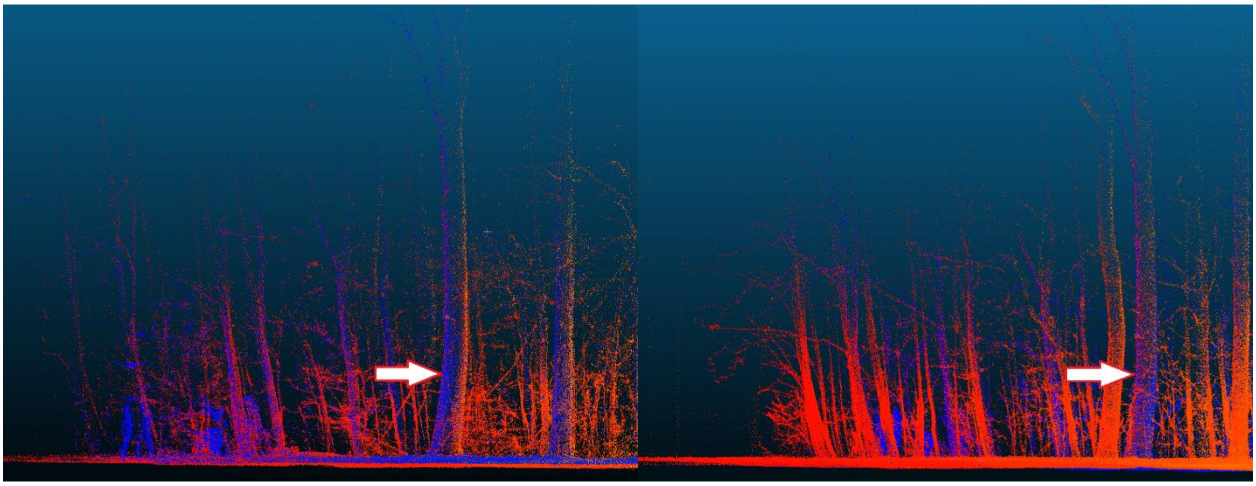


Figure 1: Left: Image showing the first reference tree in TutorialCloud02 Right: Same tree in TutorialCloud01

Select both the TutorialCloud01 and TutorialCloud02 layers and click the **“Align two clouds by picking (at least 4) equivalent point pairs”**  button at the top. Make sure that the point clouds are ordered as can be seen in figure 2.

The alignment box will now be open and points can be selected in the aligned and reference point clouds. With only the aligned point cloud turned on select a point at the base of the tree. Once selected turn of the aligned cloud and turn on the reference cloud and select a point in the same location at the base of the tree. Do the same for a location in the higher reaches of the tree. Continue to create reference points throughout the point clouds.

TIP: Do not put two reference points to close to each other and try to spread out the reference points along all axes.

TIP: When selecting a point make sure you did not select a point in front of it by checking the location of the point in 360 degrees.

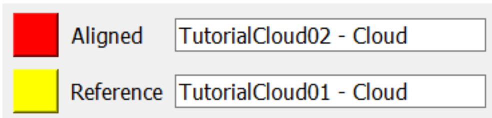


Figure 2: Settings for cloud alignment

Points can be deleted when misplaced by clicking the button next to that specific point. Once at least 3 reference points have been selected it is possible to align the point clouds. Make sure that before clicking on the **“align”** button the “*adjust scale”* and *“auto update zoom*” options are unselected. When clicking align the point clouds will attempt to align with the smallest error possible. Once the clouds are aligned with a small error click the  button to finish aligning the clouds. The *Console* will show what the Final RMS error is. If the clouds do not seem to align correctly or the Final RMS is too high, go through the same process and make sure to select reliable reference points. A Final RMS below 0.25 is a good aim.

Now that the clouds have been aligned they can be merged into one cloud. Go to **Edit > Merge** and click yes for *“generate a scalar field with the original cloud index”*. To save the final merged cloud go to **File > Save** with the merged cloud selected and make sure that you are saving the file as a “.las”.

See “MergingSimplePair” video

Spherical markers

A quicker and often more reliable way to merge point clouds is the use of spherical markers. These markers can be any spherical object as long as they are located in a fixed place during the collection of both datasets. This guide uses basketballs to show the possibility of using spherical markers for merging (Fig 3). The data used in this part of the guide is not particularly reliable but can still be used to show the potential of marker merging. Two spherical markers were used whereas datasets should normally include at least three markers for a reliable alignment.

Figure 3: Basketball used as spherical marker.

Go to **File** > **Open**, and open both TutorialCloud03 and TutorialCloud04. Unlike the clouds used in simple pair merging these clouds have been colored according to their height for a clearer visualization.

Change the view to **"Set top view"** and rotate TutorialCloud04 so it roughly aligns with TutorialCloud03.

See "SphericalMarkerPositioning" Video

With the clouds aligned it is now possible to locate the spherical markers. As can be seen in figure 4 on marker is out in the open on the right and the other marker is located underneath the canopy on the right.

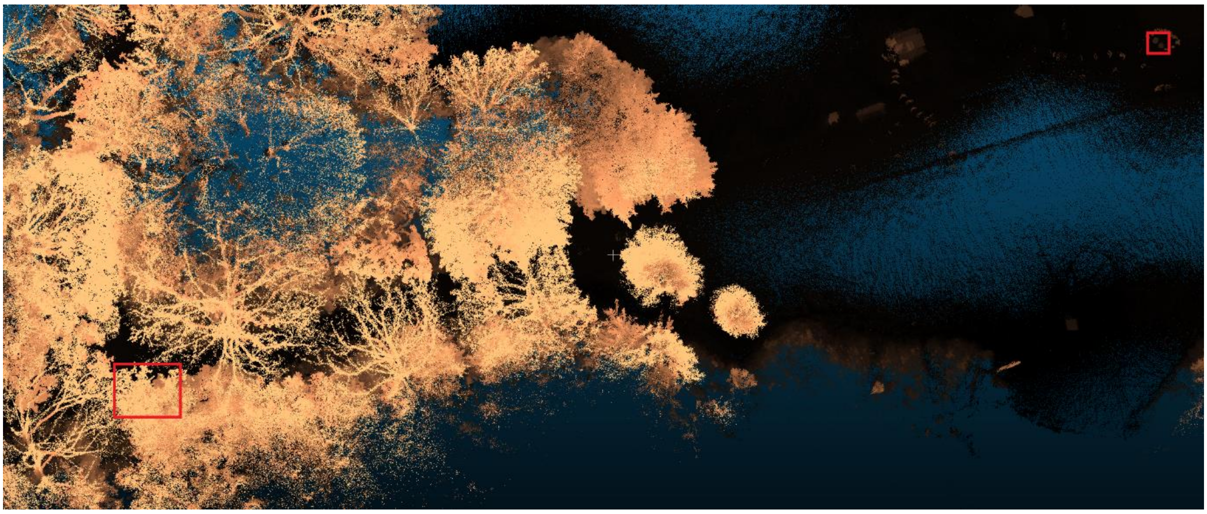


Figure 4: Top view of TutorialCloud03 and TuroialCloud04 roughly aligned with the markers location marked in red.

Once the spherical markers have been located zoom in on either one so it is clearly visible in both point clouds.

TIP: For better visualization of the spherical markers it might be useful to increase the point size of both clouds to 2.

Click the **"Align two clouds by picking (at least 4) equivalent point pairs"** button with both clouds selected. Make sure that the TutorialCloud04 is the aligned cloud and TutorialCloud03 is the reference cloud and press **Apply**. Click the **"Pick spheres instead of points (for clouds only)"** button and select the sphere in the aligned cloud first. Most likely an error will occur that says one of the following:

1. RMS is too high!
2. Failed to crop points around the picked point?!
3. Detected sphere radius (x) is too far from search radius!

(1) If the RMS is too high (10%) then the value needs to be change to a higher value so that the boundaries of the detection will be lower (25%). This can occur for the left sphere in TutorialCloud04 due to the spherical marker having a distorted point cloud. (2) If CloudCompare failed to crop points it might be that either the wrong point was selected or that there are not enough points in the spherical marker cluster to recognize a sphere. (3) If the detected sphere radius is to far the it is necessary to either increase or decrease the r value in the top right of the referencing window. In this case it will most likely be to big seeing as the spherical markers are quite small. The r value specifies the radius in which the tool searches for a spherical object. Furthermore, the r value is an implicit unit which means it is expressed in the same units as the data loaded into CloudCompare. A value of approximately 0.2 will yield a spherical recognition for TutorialCloud04.

TIP: Always try to create spherical markers with a high RMS limit if possible to increase the reliability of the alignment.

See "SphericalMarkerSelection01" video

Do the same for the second spherical marker and select a third simple point marker. Watch the video mentioned below if you are having difficulties locating the second spherical marker.

See "SphericalMarkerSelection02" video

When both spherical markers have been turned into reference points and a third point has been selected click **Align**. The Final RMS value should be around 0.15. With more reliable point clouds and multiple spherical markers this Final RMS can be decreased even further. The aligned clouds can then once more be merged via **Edit > Merge**.

See "SphericalMarkerAlign" video

Automatic alignment

Another method to merge clouds is to use the automatic alignment feature of CloudCompare. This tool aligns already roughly aligned point clouds. This is however a more difficult tool to use for forested areas considering the amount of spatial variability in both point clouds. Furthermore, considering the point clouds used in the last two merging methods do not completely overlap, this tool cannot be applied seeing as it tries to overlap/align the entire point clouds. Moreover, these point clouds contain 9 to 14 million points which leads to a very high computational time. This tool can provide a higher reliability in merging with a lower RMS if the point clouds in question are suitable. Therefore, before this method will be explained a specific tree will be extracted from both datasets.

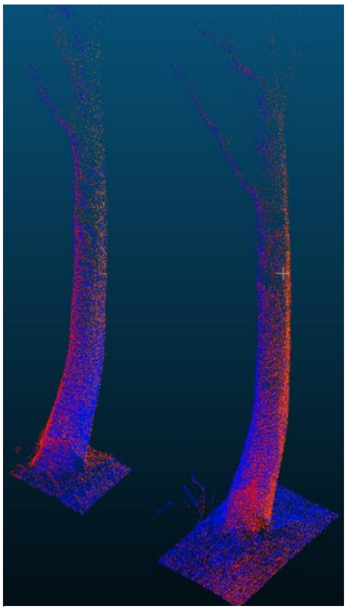


Figure 5: Extracted tree from both point clouds using the cross section tool.

CloudCompare provides a simple tool to create cross sections of point clouds and extract these sections. First, Open both TutorialCloud01 and TutorialCloud02 and rotate TutorialCloud02 180 degrees once more so that the datasets are roughly aligned. Now focus the view again as specified in figure 1. With the cross section tool, you will extract the tree pointed out in figure 1 in both point clouds. Select TutorialCloud01 and click the cross section  button. Use the arrows on the sides of the box to decrease the size of the point cloud until only the specified tree is left. To extract this tree as an independent point cloud click the **"Export selection as a new cloud"**  button. Do the same for TutorialCloud02 so that you are left with two points clouds of a single tree as can be seen in figure 5.

See “CrossSection” Video

Now that only this single tree is left use the “**Translate/rotate**” button again to align both point clouds of the tree. Once they are aligned click the **“Finely registers already (roughly) aligned entities (clouds or meshes)”** button. In the *Cloud registration* window settings can be left at default values. If the point clouds have more than 50000 (default) points a higher accuracy can be achieved by increasing the *Random sampling limit* under the *Research* tab. Click **OK**. The aligned point clouds should have a much lower Final RMS than the RMS value seen in simple point pair merging. A good aim is a RMS value below 0.025. The aligned clouds can then once more be merged via **Edit > Merge**.

This method could also be applied after using simple point pair merging to increase the reliability of the already aligned point cloud. However, this is once again dependent on the amount of overlap of the two point clouds.

Additional CloudCompare tools

There are many more possibilities in CloudCompare, the following is a short overview of a few possibly useful tools for scientific application.

CloudCompare has the ability to display the density of a point cloud based on a certain defined radius. This can show where a dataset is the densest and can give an indication of which areas of the point cloud are most reliable. Furthermore, it can provide a histogram of the volume density distribution for a specific radius. To do this go to **Tools > Other > Density** with the point cloud in question selected. For a histogram click the show histogram button at the top. The higher the precise radius the longer the computational time. An example of a point cloud (TutorialCloud05) colored by density and its related histogram can be seen in figure 6.

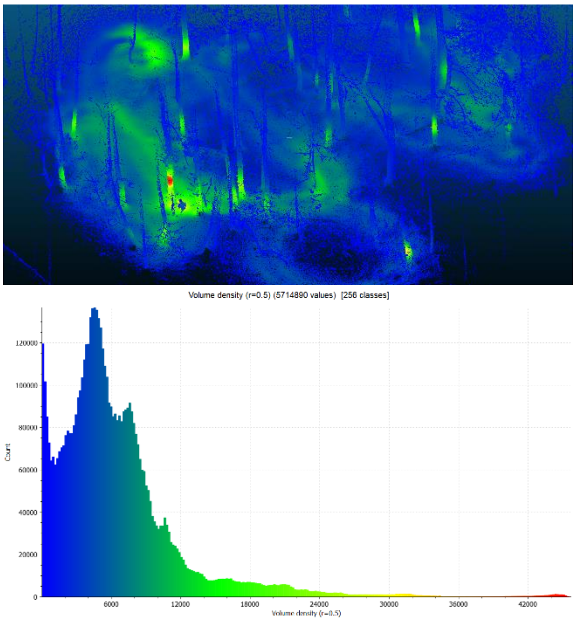


Figure 6: Top: Point cloud colored by density with a radius of 0.5, Bottom: Histogram of the point density.

In some cases, a high point cloud density could lead to high computational times. Furthemore the goal of certain analyses might not be dependent on a high point cloud density. Decreasing the density of the point cloud can therefore be favorable considering the computational time. This can be done in GeoSLAM Hub but is much more reliable in CloudCompare considering the control over the methods of subsampling CloudCompare provides, such as min. space between points. To use this tool click the “**subsampling**” button at the top.

Lastly sometimes it’s useful to calculate the distance between two points. To do this click the **“Point picking”** button at the top and then select .

LAStools

LAStools can be used for many different things concerning point clouds such as, extension conversion, clipping, ground point extraction and classification (Isenburg, 2014). This part of the tutorial will focus on the capabilities of LAStools in extracting ground points from Zeb-Revo point cloud data and the different parameters this is dependent on.

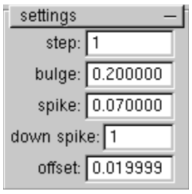
Open the *"lasground_new"* application in the bin folder of LAStools. Browse to the tutorial folder and select *"TutorialCloud05.las"*. There are some default settings on the right such as wilderness, nature and town or flats. These settings and LAStools are aimed more on aerial laser scanning (ALS) data and parameter values are therefore somewhat large for Zeb-Revo data. However, lasground_new can still classify ground points reliably by changing the custom settings.

There are five settings namely the step, bulge, down spike, spike and offset.

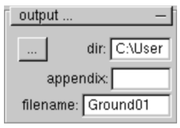
- Step = Changes step size of las analysis (min = 1)
- Bulge = The bulge affects how the triangle that the point under consideration falls into is interpolated at this points x/y coordinate to compute its z_int. A bulge of zero means that the facet is planar and z_int lies "in the triangle". A bulge of non-zero means that the three normals of the triangles are used to "bulge" the triangle either up or down (depending on the normal direction) so that z_int can lie "above" or "below" the triangle.
- (Down) Spike = Spike defines the threshold of ground classification.
- Offset = The offset decides how high the real z of the considered point is allowed to lie above the interpolated z_int to be considered a ground point, namely no more than the offset. For an offset of zero, the real z of the considered point must be equal or lower than the interpolated z_int to become part of the ground. For an offset of 0.05, the real z of the considered point is allowed to lie up to 5 cm above the interpolated z_int to become part of the ground.

To create a ground point classification of the TutorialCloud05 las tile, it is important to understand the parameters mentioned above and set them to the right level for a reliable return. For this dataset values should be set as follows:

- Step = 1
- Bulge = 0.2
- Spike = 0.07
- Down Spike = 1
- Offset = 0.02



To save the output select the correct directory and choose a filename at the top right, also change the output extension at the right bottom to las. Check *"compute height"* for easier further classification. Do not check "*replace z"* because it will move higher elevated z values to the average z point value. For areas with steeper elevation it could prove useful to intensify the search for initial ground points by setting it to fine, extra fine etc.



Click **RUN** to classify the ground points. Use either ArcScene or CloudCompare to visualise the new point cloud (Ground01).

To extract the ground points from the new point cloud, use the *"lassplit"* application in the bin folder of LAStools. This application can split point clouds based on their classification. Select the *"Ground01.las"* file under *browse*. Then select *by classification* on the right side and once again choose a directory, filename (Split01) and las extension for your new point cloud. Click **RUN.** LAStools will automatically name your split point clouds (Split01_0000001, Split01_0000002). Split01_0000002 contains the extracted ground points which can be used later when classifying trees or creating a DEM.

3D Forest

There are many applications that can be used to segment, analyze and classify forestry point cloud data. 3D Forest is an open source program that has the capability of automatically segmenting vegetation using two point clouds, namely a terrain and vegetation point cloud (Trochta et al., 2017). In the last section both these point clouds were created (Split01_0000001, Split01_0000002). These point clouds will be used as example within 3D forets to shortly display the automatic segmentation of the software. However, the resulting segmentation is very unreliable because the vegetation point cloud includes a lot of outlying points and ground points. Due to the fact that 3D forest has limited option concerning data processing and analyses this guide will not elaborate further then the basic principle of 3D forest. Other applications might be able to rely more on the possibilities within 3D forest.

Start 3D Forest and go to **Project** > **New Project**. Select a name and location for your project. For *"Choose transform matrix"* choose *"NO_MATRIX"*. Click **Next** and **Finish**. If a prompt appears, click **Yes**.

Go to **Project > Import > Import Terrain Cloud**, and select Split01_0000002.

Go to **Project > Import > Import Vegetation Cloud**, and select Split01_0000001.

Once the data has loaded go to **Vegetation > Automatic Tree Segmentation**.

In the *"Automatic segmentation"* window make sure that Split01_0000001 is the vegetation cloud and Split01_0000002 is the terrain cloud. Leave the input distance at default but change the *"minimal points in cluster"* to 400 and click **Okay**. This yields 35 new segmented point clouds. When turning of the original and vegetation-rest layer it becomes clear that the presence of ground points has made the classification somewhat incorrect. However, when unselecting these ground points, the resulting selection shows a quick visualization of the biggest trees in this dataset (Fig 7). The reliability can be increased by first using the outlier removal option, 3D forest offers minimal noise removal options compared to other software such as CompuTree. Furthermore, no adjustments, such as size, can be made to the automatic tree segmentation of 3D Forest. 3D forest might provide more possibilities in tree structure parameter extraction, such as diameter breast height and crown delineation, which should be further explored.

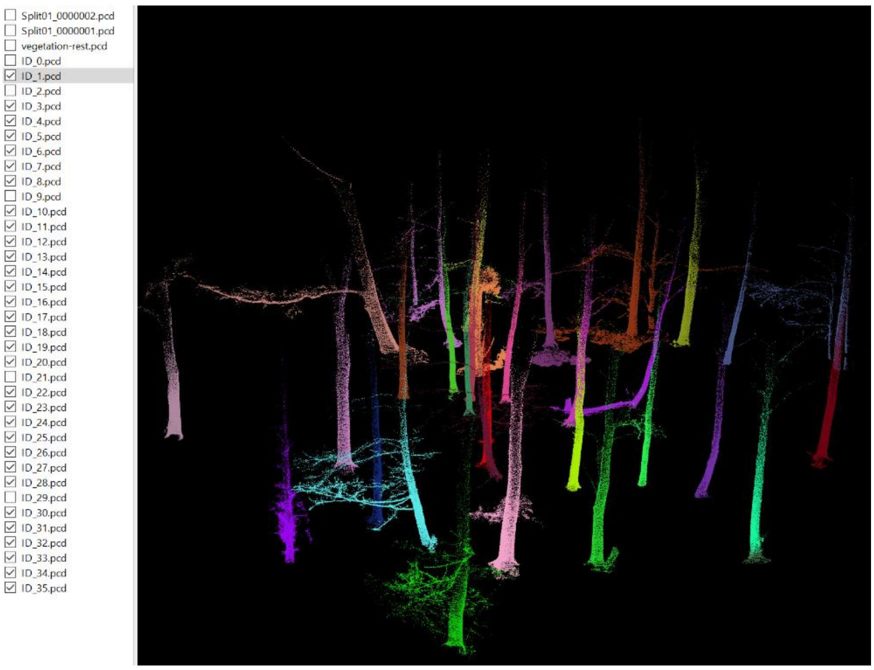


Figure 7: Image displaying the tree segmentation capability of 3D Forest, with a visualisation of the layers that are turned on.

CompuTree

Another open source program that can segment, analyze and classify forestry point cloud data is CompuTree (Othmani et al., 2011). This section will give a step by step walkthrough of a some of the tools that can be used to create tree inventory data based on a Zeb-Revo point cloud. Each step is numbered according to the amount of steps present in the eventual workflow.

Initialization

1. Loading and visualization

Open CompuTree, go to **Window > Steps (F2)** to open the steps window which will be used to access the necessary tools. Click on **Load > Points > Points, format LAS** and select TutorialCloud05. The first step should now be visible in the steps workflow on the right. To load and visualize the dataset right click the step and click on **Execute** . Once CompuTree is done loading the point cloud, check the **Results** box so that the results show up in the *"Model manager"* window. Check the box next to **Scene** to visualize TutorialCloud05.

CompuTree also includes a few basic coloring capabilities. To change the colour of a specific layer in the *"Model manager"* right click the layer and then choose one of the available coloring options. A clear visualisation for this layer would be **Colorize points of each element by > 1 > Z**, which shows the height from red to yellow.

NOTE: CompuTree is open source software that is not entirely stable, this can lead to issue with colorization changing when turning layers on and off. Furthermore, high computational steps could lead to the program overloading and crashing without any displayed error. To avoid loss of data or steps be sure to save your workflow regularly via **File > Save the steps tree**. Most commonly after the crash the program will load the most recent version of your steps workflow.

Next it is important to classify the ground points. As shown during the LAStools section this can be done using the lasground_new application. However, the method in which ground points are selected in CompuTree is different than the method provided in LAStools. CompuTree uses a ground point selection based on the *"Minimum density"* of a point cloud (cluster), *"Ground thickness"* and neighbouring points in a specific point cluster. Furthermore, one of the shortcomings of LAStools is that it is mainly designed for large scale/highly spatial data, which means it can only select ground points in grids of 1 meter. CompuTree provides a higher detail selection that can create a grid selection of ground points up to 1 cm. However, depending on the aim of the study or data analyses either software could provide beneficial features. For forestry data the use of CompuTree is advised.

2. Ground point classification

In the **Steps** menu got to **Points > Classify > Classify ground points**. In the *"Configuration"* window leave the values at default settings (Fig. 8). For a more precise classification the *"Grid resolution"* can be decrease to for instance 10 cm. For areas with a very steep or diverse ground profile it is also advised to decrease the *"Grid resolution"*. So that the effect of height differences on the classification of ground points is diminished. Keep in mind that a smaller grid resolution means a longer computational time. For point clouds of relatively flat areas with little ground disturbance, *"Ground thickness"* can be decreased as well. Considering Zeb-Revo contains highly dense data the choice can also be made to increase the *"Minimum density"*. However, for the purpose of this tutorial default settings will yield satisfactory results while keeping the computational time to a minimum. Click **Apply**. The result can once more be visualized by checking the **Results** box and turning on the **Ground points** layer. The classification tool also yields a rasterized version of the point cloud which can be found in

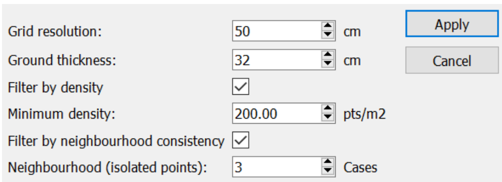


Figure 8: Default settings for the classification of ground points

the **Classification raster**. This result also automatically contains a ground point density layer which can be useful to determine the reliability of the dataset.

NOTE: To change values within any of the already established steps in the workflow, right click on the step and click on **Config. parameters** . For a more detailed description of the step click on **Step documentation**.

The Zeb-Revo contains some erroneous data in the form of floating points above or next to objects and also above the ground. Furthermore, the classified ground points currently include objects such as fallen tree logs and the start of tree trunks. These points and other noise should, of course, not be part of the ground point data and should be removed to create a cleaner ground point dataset.

3. Ground point noise removal

In the **Steps** menu got to **Points > Filter > Removes noise from detected ground points**. A window will come up which asked for the input data. Select **Results_ONF_StepClassifyGround** and make sure that **Ground points** is selected in the input data selection. Click **OK**. The noise removal will show in which a value can be set for the angle of deviating points that need to be removed can be set. Considering most tree trunk albeit fallen or upright do not start at an angle of 45 degrees the value should be decreased to at least **40 Degrees**.

NOTE: Always be sure to check that you have the correct input layer selected which is the results of the step prior. Furthermore, after each step don't forget to execute the step in the steps workflow and visualise the data so that you can be certain that the results are correct.

Although ground points have already been classified, to further classify the point clouds displaying the vegetation it will be necessary to create a DTM based on these ground points.

4. DTM

In the **Steps** menu got to **Raster/Images > Digital elevation models > Create DTM (simplet…)** and set the **Raster resolution** to **0.50 m**. Once again the raster resolution can be decreased for a more detailed DTM. However, this is not necessary for the purpose of examining forest structures and will increase he computational time immensely. For studies focussing on elevation changes or anything reated to the DTM the choice can also be made to use another tool namely: **Raster/Images > Digital elevation models > Create DTM (onf)**. This tool also allows for changes to the amount of smoothing and the size of the interpolation.

Now that the ground points have been classified, cleaned up and transformed into a DTM it is possible to start cleaning the vegetation point cloud and segmenting individual trees. To do this the vegetation will be divided into two point clouds based on height compared to the DTM, so that different methods of noise removal can be applied on the lower ranges and higher ranges of the vegetation.

Lower vegetation slice

5. Extraction

In the **Steps** menu got to **Points > Extract > Smooth extraction of a point slice parallel to the DTM** and select the **Vegetation points [Point scene]** under **Scene > Results** and the **DTM_ST [Raster<float>]** under **MNT (Raster) > Results**. Click **OK** and in the next window set the **H minimum** to **0.30 m** and the **H maximum** to **2.30 m**. Depending on the height of the vegetation and the structural characteristics of the trees that are meant to be classified, this value can be changed. For example, to eventually only be left with larger tree trunks that are straight and perpendicular to the DTM and have little branches in the lower ranges (conifers), the H maximum can be increased.

6. Noise removal

In the **Steps** menu got to **Points > Filter > Removes noise from the stem slice** and select both **Slice above DTM [Point scene]** and **Denoised ground points [Point scene]** under **Results_In > Results ST_StepExtactSliceAboveDTM**. Before continuing change the searched data behind **Denoised ground points [Point scene]** to **Ground cloud**. Click **OK** and in the next window leave the angle at the default value (45 Degrees). This will remove point clusters that do not have perpendicular directionality compared to the DTM.

7. Euclidian clustering denoising

The current **Denoised Stem Slice** still contains a lot of point clusters that are not part of any tree or clear vegetation and can thus be considered noise. To remove these clusters, it will be necessary to use Euclidian clustering denoising which divides the cloud into the **smallest clusters** (noise) and the **largest clusters** (trees/vegetation).

In the **Steps** menu got to **Points > Filter > Euclidian clustering denoising** and select **Denoised stem slice** under **Results_In > Results ST_StepFilterStems**. Consideirng we are looking to eventually segment and extract larger trees the **clustering distance** should be increased to **0.10 clusterTolerance m**. For research aiming to analyse smaller objects which can be closer to each other the cluster distance can be left at the default value or further decreased. **The number of clusters** should not be a limiting factor and should therefore be increased to a safe margin of **1000 numCluster**. **The number of points a cluster needs to contain** can be left at the default value of 1 due to the fact that cluster size will be defined in the next parameter. If clear information is available on the amount of points for each tree this value could be changed to the value of the smallest tree cluster. **The number of points a cluster needs to contain in percentage of total size** should be set to **0.2 min percentage** to secure that the largest clusters (mostly trees) will be left. Make sure the parameters are set correctly as can be seen in figure 9 before clicking **Apply**.

clustering distance	0.10	clusterTolerance m
The number of clusters	1000	numCluster
The number of points a cluster needs to contain	1	minPts
The number of points a cluster needs to contain in percentage of total size	0.2	min percentage

Figure 9: Settings for Euclidian clustering denoising that yields reliable results.

NOTE: While adding different step of denoising and point cloud extraction don't be afraid to change the values to see how each tool works and to create a cleaner and more reliable dataset. Trial and error!

Upper vegetation slice

The same process will be applied to the higher ranges of the vegetation but without the use of **the removes noise from stem slice** tool. This is due to the fact that any smaller branches in the higher ranges of the vegetation must be left in. Using this tool could remove important data cluster concerning the structure of the trees.

8,9. Extraction and Euclidian clustering denoising

In the **Steps** menu got to **Points > Extract > Smooth extraction of a point slice parallel to the DTM** and select the **Vegetation points [Point scene]** under **Scene > Results** and the **DTM_ST [Raster<float>]** under **MNT (Raster) > Results (ST_StepComputeDTM)**. Click **OK** and in the next window set the **H minimum** to **2.30 m** and the **H maximum** to **50 m**. For the upper slice always make sure it continues where the lower slice ends and it has a maximum value that exceeds the range of the maximum z value of the point cloud. For the Euclidian clustering denoising set all values as displayed in figure 9.

Segmentation

10. Merging vegetation

Before segmentation can be performed it is first necessary to merge the lower and upper ranges of the vegetation again. In the **Steps** menu got to **Points > Clusterize > Merges multiple clouds** and select both **Largest_Clusters [Point scene]** layers under **Results_in > Result ST_StepExtractLargestCluster**. Click **OK** and the clouds will be merged yielding a single vegetation layer.

11, 12. Marker slice and sub clouds

To segment each individual into an independent point cloud it is first necessary to create a marker for each tree by creating a small slice above the DTM from the new merged vegetation data. This marker can then be aligned with the rest of the point cloud cluster it is attached. This secures that trees that might come in contact in the upper ranges of the vegetation are not clustered into the same segment when applying individual tree segmentation.

In the **Steps** menu got to **Points > Extract > Smooth extraction of a point slice parallel to the DTM** and select the **Merged_Cloud [Point scene]** under **Scene > Results** and the **DTM_ST [Raster<float>]** under **MNT (Raster) > Results**. Click **OK** and in the next window set the **H minimum** to **0.20 m** and the **H maximum** to **0.5 m**.

Now to add the rest of the point clouds from each tree to the cluster clouds go to **Points > Extract > An Euclidean clustering operation. Produces sub clouds of the clusters.** and select (the lowest/latest) **Slice above DTM [Point scene]** and click **OK**. For this Euclidean clustering keep the settings at default values and click **Apply**.

13. Segmentation into tree clouds

If the steps prior were executed correctly a new segmentation tool should now be available. In the **Steps** menu got to **Points > Clusterize > Segmentation into tree clouds** and select the **Clusters [Point scene]** and **Merged_Cloud [Point scene]** under **cloud_in > Results** and click **OK**. In the next configuration window leave the settings at default values. In case you have a computer with a fast CPU (16gb RAM, quad-core) you can increase the **Speed of computation** to **5**. If you are working with a slower CPU or this step takes too long to compute or CompuTree crashes while trying to complete this step, decrease the **Speed of computation.** Click **Apply**.

Once executed the resulting **Isolated Tree** layer can be best visualized by right clicking and changing the color to **Automatic color > 1**. This way each tree is visualized with a separate color resulting in a Point cloud as can be seen in figure 10.

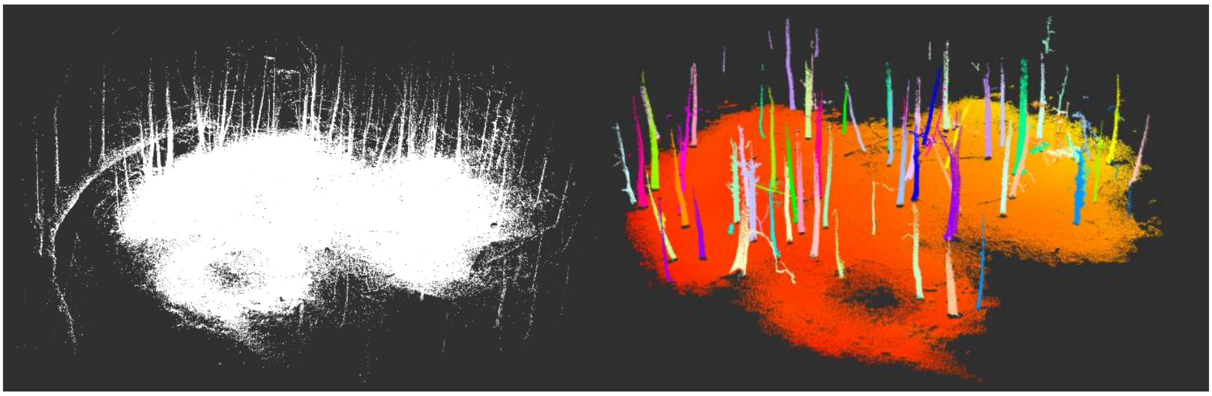


Figure 10: Left: TutorialCloud05 before CompuTree processing, Right: TutorialCloud05 after CompuTree processing

Lastly during these steps and after the segmentation it is possible to apply multiple **Statistical Outlier Filters**. To do this go to **Points > Filter > Statistical Outlier Filter** and select which ever layer you want to apply the statistical outlier filter to. Values for this filter depend on the intent of the filter and the point cloud you are executing it on. A quick walkthrough of the steps describe in this CompuTree guide can be found in the movie mentioned below.

See "CompuTreeAnalysis" video

Installation/Download links

The following links directly forward you to the installation site for all software used in this guide, excluding GeoSLAM Hub.

CloudCompare

LAStools

3D Forest

CompuTree

References

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Isenburg, M. (2014). "LAStools - efficient LiDAR processing software" (version 141017, academic), obtained from http://rapidlasso.com/LAStools in 2017

Othmani, A., Piboule, A., Krebs, M., Stolz, C., & Voon, L. L. Y. (2011, October). Towards automated and operational forest inventories with T-Lidar. In *11th international conference on LiDAR applications for assessing forest ecosystems (SilviLaser 2011)*.

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