THE FUNCTIONALITIES OF PROCESSING SOFTWARE

Point Clouds (1)

Whether based on Lidar, photogrammetry, radar, sonar or other remote sensors, systems for geodata acquisition create millions or even billions of 3D points. To be useful, the data needs to be organised, combined, georeferenced, measured and analysed, and that in turn requires software. This article first defines what point clouds are and identifies their sources. It then goes on to examine software functionalities such as visualisation and editing. The July 2014 edition of *GIM International* will be a themed issue covering collection and processing of point clouds and hence will include a selection of the many software packages currently available.

A point cloud is a set of data points represented in a preferred coordinate system. The dataset consists of measurements taken at discrete points of a curved 2D surface in 3D space. This 2D surface may be smooth or it may contain discontinuities such as facades of building. The number and density of the points should be such that the 2D surface can be reconstructed, i.e. at every point on the surface a value can be calculated from the measured values in the vicinity. This process is called 'interpolation'. The initial data is unorganised; processing software is needed to organise the unorganised into a point cloud and extract information from it.

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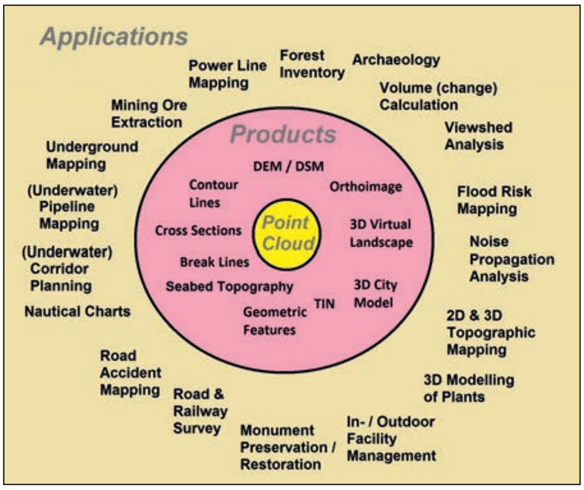
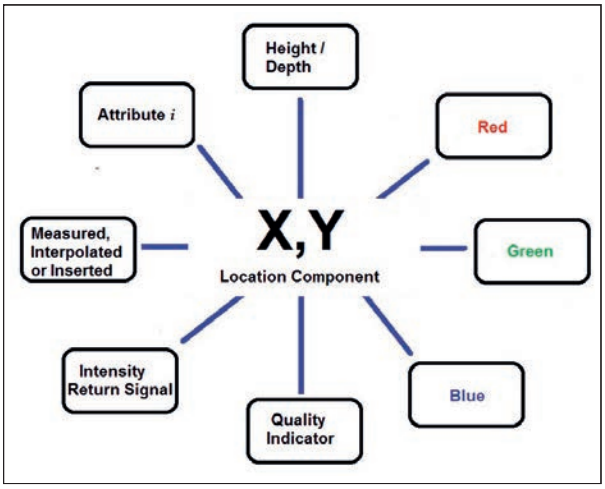
POINT CLOUDS

In principle, the curved 2D surface can represent any instance such as soil pollution, forest biomass, rainfall, terrain elevation or the seabed. In the field of geomatics, the phenomenon will usually be the terrain surface or the seabed in the form of a digital elevation model/digital surface model (DEM/DSM). The tools used to acquire the point cloud can include: levelling; GNSS; terrestrial laser scanning (TLS); airborne Lidar; airborne or spaceborne radar; terrestrial, aerial or spaceborne photogrammetry; or multibeam sonar. Another source can be contour lines digitised from maps. This article focuses on point clouds from which DEMs or DSMs can be created and products can subsequently be derived (Figure 1). These products can then be used in a variety of applications. For forest inventory, for example, the height of individual trees, the density of the canopy, biomass and the stand volume can be calculated, while in road construction volumes and masses can be calculated from a DEM to support earthworks. By comparing time series of DEMs, ore extraction of an open-pit mine can be determined as well as erosion and accumulation of sand in dunes to support flood risk management. The point cloud data consists of a set of x,y coordinates to which height/depth values have been assigned: one value per x,y location. Added to height or depth, other attributes may be attached to



▲ *Figure 1, Point clouds, derived products and fields of application.*



▲ *Figure 2, Diagram representing the nucleus of a point cloud consisting of location and attributes.*

the x,y component, such as reflection intensities of the laser/sonar pulse or RGB of a colour image recorded by a camera at the same time (Figure 2). Hence, the x,y component and its attributes forms the nucleus of the point cloud and the number of nuclei may run into billions.

SOURCES

The vast majority of point clouds stem from the output of active systems, including airborne Lidar, TLS, radar or sonar, with the latter mainly being used for mapping seabeds and riverbeds. Thanks to advances in the underlying technologies over the past two decades, it is now easy to produce high-resolution terrain data at very high rates. For seabed mapping, for example, the shift from singlebeam to multibeam echosounders has increased the amount of data that can be acquired to billions of echo returns per day. Returns from Lidar and sonar are first stored in the form of range, angle and time. These are then integrated with 3D location data (latitude, longitude and altitude) collected by on-board GNSS and pose data (roll, pitch and heading) measured by an IMU, which is usually integrated with the GNSS, and if applicable compasses, barometers and odometers. The integration of the raw data is largely automated and results in a georeferenced 3D point cloud which often needs editing to remove outliers and other improper points. Usually the point cloud is transferred to a 2.5D surface in the form of regular grids or triangulated irregular networks (TIN). These products often act as the basis for input in CAD, BIM and other tools for the creation of a variety of products, such as contours, nautical charts, volumes or 3D landscape models. Added to this, the output should be in a format which is readable by CAD, hydrological and other application-oriented software. Point clouds may also stem from overlapping imagery, captured by nadir-looking or oblique cameras, using photogrammetric image-matching software. The cameras may be mounted in manned or unmanned airborne systems. Lidar point clouds are captured either in the air or from ground / mobile stations whereas radar sensors are either mounted on aircraft or are orbiting.

FUNCTIONALITY

The functionalities of processing software differ widely. To understand types of use, it is key to gain insight into the ins and outs of the different packages. The functionality may start at the creation of the point cloud itself, as is the case for image-matching software which creates a DSM from overlapping imagery. The functionality can be tagged into eight groups (Figure 3). A first challenge in the use of point clouds is the huge file size: a 32-bit operating system can only handle files of up to a few gigabytes, and most computers are not designed for such large datasets. The amount of data produced by today's sensors is growing faster than the processing and storage capacity of database management systems (DBMS). An important aspect of point-cloud creation is the removal of unwanted points, which is called 'filtering'. Key for specific, industrial use is not only the manual measuring of length, height, distance, angle, area and volume, but also the extraction of geometric features such as lines and planes and the fitting of solid models through a set of points. The solid models may include cubes, spheres, cylinders or user- ▶

specified objects such as valves and elbows. Vendors often offer plug-in modules, which provide a sequence of functionalities adapted to particular needs, while others provide 'lite' versions aimed at users who do not need all the functions. The sequel to this article will focus on the following: georeferencing; visualisation and editing; interpolation; and the filtering aspect of point-cloud creation.

GEOREFERENCING

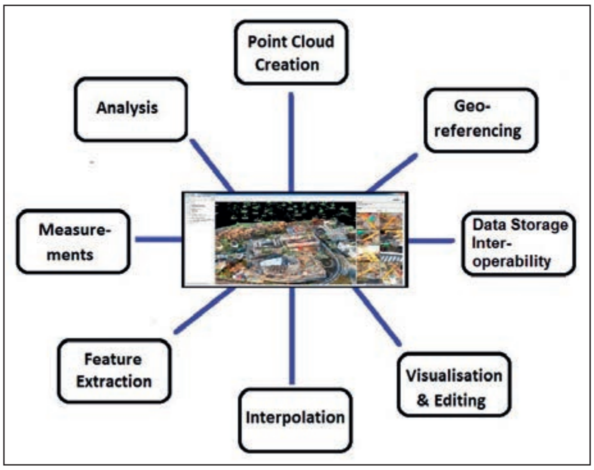
3D patches of point clouds – i.e. individual scans – must be transformed to a single coordinate system to enable georeferencing or registration, which involves identifying common points in the overlaps. As a geometric transformation model, the 3D similarity (Helmert) transformation is usually applied (three translation parameters, three rotation parameter and one scale parameter). This process requires at least seven coordinates, i.e. two 3D ground control points (GCP) and one height GCP. To obtain redundancy and thus the ability to detect outliers and to compute precision through error propagation, seven or more GCPs that are evenly distributed along the border of the site are measured, usually with differential GNSS or a total station. The stitching of the single point clouds requires tie points in the overlaps. These are distinctive points in the scene or consist of targets placed, marked or painted in the overlaps. The latter requires a more thorough planning of the survey to ensure that the marks are placed in the overlaps. Of course, the GCPs should be clearly identifiable. In addition to the indirect method described above, direct georeferencing can also be conducted in some cases. For example, a TLS can be centred over a known point and levelled as if it were a total station. The position can also be determined using a GNSS antenna mounted on top of a TLS.

FILTERING

Airborne Lidar, TLS, sonar as well as the DSM generated from automatic matching of overlapping imagery capture all objects present on the site, including vegetation, cars, bikes, dogs, fish, shipwrecks and suchlike, all of which are irrelevant for the survey at hand and are thus 'noise' from the surveyor's point of view. The software should therefore be able to remove such points, either through manual editing or by automatic filtering. Most software contains tools to quickly and easily reduce such noise. Ground filtering is a specific method aimed at the removal of points reflected from vegetation when creating a 3D city model, or from vegetation and buildings when creating a bare-ground DEM (Figure 4). Many methods have been developed, which is a token of the complexity of the filtering problem. A broad overview of Lidar ground-filtering methods to guide users in selecting the optimal method for their specific applications is given by Meng et al. (2010).

INTERPOLATION

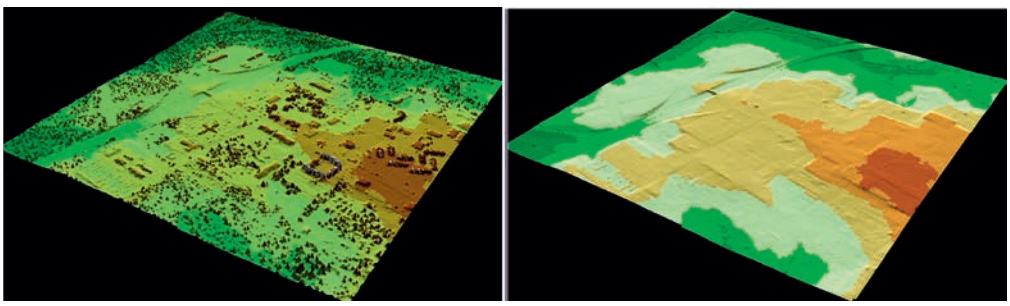
The value of an unknown point is usually computed from measured points in the vicinity using a weighting scheme. The closer a known point lies to the unknown point, the more similar the behaviour will be. Hence, it is feasible to use the inverse of the distances as weightings. The inverse distance weighting (IDW) weights the known points in a search area around the unknown point using distance (Figure 5). The search area may be a circle, a square or any other shape. The result is a distance-weighted mean. Nearest neighbour (NN) uses area as the weighting criterion. IDW and NN both compute values which are within the range of those of the known points and thus do not generate peaks, pits, ridges or valleys if they are not present in the input. No action from the user is needed and the output is smooth while the values of the known points are preserved. Another often-used method is Kriging whereby the weighting function is not based on distance or area, but rather on the covariance of the measured points. In general, the quality of the computed value of the unknown point of any interpolation method mainly depends on whether the points in the vicinity belong to the same type of points. For example, if the measured points are partly located on a building roof and partly on the street, the height of an unknown street point will be computed somewhere between street and roof level. Figure 6 shows this effect for a point located in a valley.



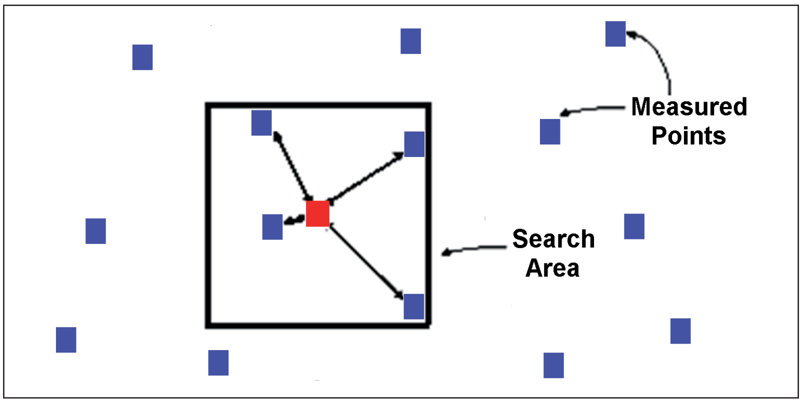
▲ *Figure 3, Functionalities of point-cloud processing software categorised in eight main groups.*

VISUALISATION AND EDITING

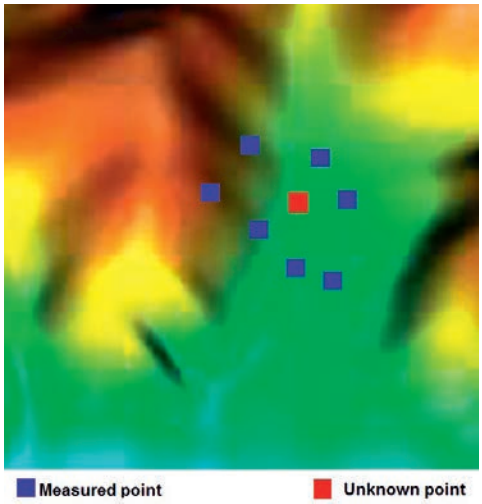
The software should be able to visualise and edit clouds with many billions of points at a reasonable rate; it should not take hours before a view appears on the screen. All the points may be depicted in a single colour and size, but a colour code may also portray the strength of the return signal, the elevation or the RGB values of the same point in an image. Inspection of the point cloud requires zooming, panning, rotating, fly-through and adjusting point size. Editing operations include the ▶



▼ *Figure 4, Original DSM (left) and its bare-ground representation after ground filtering.*



▲ *Figure 5, Interpolation using inverse distance weighting in a square search area.*



▲ *Figure 6, Points on the hill are used to compute an unknown point in the valley leading to an incorrect value.*

mouse-clicking of individual points for the removal of outliers or a group of points, addition of missing points or calculation of distances, angles, areas and volumes. The boundary of the group may be identified by drawing a cube, a rubber surface or other volume shape. Selection of a group of points allows geometric primitives such as planes, spheres, cylinders or NURBS (non-uniform rational basis spline) to be fit using an optimisation method – usually this will be least squares. Selection of a group of points also allows the manual removal of unwanted points such as those reflected on vegetation and buildings if one wants to create a bare-ground DEM. Staking out a baseline enables the extraction of a cross section. ◂

FURTHER READING

- Lemmens, M. (2011) *Geo-information – Technologies, Applications and the Environment*, Springer, ISBN 978-94-007-1666-7.
- Lemmens, M. (2013) Massive point clouds, *GIM International*, 27:2, p. 13.
- Meng, X., Currit, N., Zhao, K. (2010) Ground filtering algorithms for airborne Lidar data: a review of critical issues, *Remote Sensing*, vol. 2, no. 3, pp. 833-860.