自动物体检测在点云中是通过将点分离到不同的类中来完成的，这个过程通常称为‘分类’或‘过滤’。物体的类型，以及因此而产生的类，主要取决于点云收集的应用领域。例如，用于电力线维护项目的类与用于道路维护或城市建模项目的类将不同。本文讨论了两种分类方法：点基分类和组基分类。点基分类意味着软件一次查看一个点，并分析点的属性、它与周围点的连接，或它与参考元素的关系。对于组基分类，点首先被分配到组中，这是一个有时也称为‘分割’的过程。然后，软件查看组，并分析组的几何和属性，与样本组的相似性，或与其他组或参考元素的关系。

**点基分类**

点基分类基于单个点的属性，这些属性为每个点收集并存储，如坐标值、强度、时间戳、扫描角度或返回类型和数量。额外的属性可能在处理工作流程中推导出来，例如到地面的距离值、法线向量、从图像提取的颜色值，或植被指数。在更高层次的分类过程中，点之间的几何连接是考虑的。分析点到点的关系决定一个点是否属于表面结构，如地面，或线性结构，如架空线。单个孤立点也可以通过将点与最近环境进行比较来检测。

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**图1**：组基分类用于检测树木高度，最高点的组表示树木（洋红色点在树尖）。

不同的参考元素类型可以支持点云过滤任务。轨迹确定扫描器在点云中的位置。
a certain point in time, which enables the classification of points based on their range or angle from the scanner. Cross sections of tunnels or clearance areas are used for detecting points falling inside or outside a section. Finally, vector data representing topographic objects allows a detailed classification of point clouds. Examples are boundary polygons for classifying points inside or outside of a specific area (e.g. water areas), and centre line elements of corridors for classifying points within a buffer area around the linear element (e.g. points along power lines, railways or roads).

**Group-based Classification**

The group-based classification approach goes further by analysing not only point-to-point relationships but also geometrical characteristics within and between point groups. The distance above the ground of a group, the planarity of points in a group, the shape and width-to-height ratio of a group, the point density and distribution within a group, and the distance between point groups all determine whether the group most likely represents a lamp post, a tree crown, a car, a building roof, a wall or another object of interest. The statistical analysis of point attribute values in a group leads to additional information for classification tasks. Specific object types may be represented with typical attributes in point clouds, such as dominating colour channel or intensity values. A common example is the separation of coniferous and deciduous trees by using near-infrared colour values.

The detection of objects in a point cloud can be supported by the use of group samples. The sample represents a typical entity of an object type, such as a street lamp or a pole. In the detection process, the software compares a group with samples stored in a library and assigns the corresponding class.

![Figure 2: In an image matching point cloud, often only the outer layer of a tree is represented without clear information about the tree shape and structure.](http://www.terrasolid.com/download/presentations/2017/classification_using_groups.pdf)

Reference elements can be used for the classification of point groups in a similar way as for single points. There are more options for defining the relationship between a group and the reference element. For example, inside a boundary polygon may be the entire group of points, the majority of them or just a number of points. The classification of key points in groups, such as the highest, lowest and/or centre point of a group, can be useful for analysis tasks. A typical example could be the detection of tree heights, which are mapped by the highest points of groups representing trees (Figure 1).

**Method Comparison**

The group-based classification approach has clear advantages for the automatic detection of above-ground objects in point clouds. Point groups provide information about the geometry and other characteristics of an object. By analysing the information, automatic filtering routines can directly assign a group to a specific object class. In addition, the comparison of groups to group samples enables the discovery of objects of the same type in the point cloud.

In contrast, the point-based classification approach seldom relates the points directly to an object type. Attributes of a single point are most often not object-specific due to the diverse and random nature of point clouds. Thus, the approach is suitable for the detection of isolated points, surface-like and linear structures, but very limited for automatic above-ground object detection.

The processing effort is lower for point-based classification. It can be started directly after internal positional errors are corrected in the point cloud. The group-based approach relies on group assignment before the classification of the point cloud starts. Therefore, the classification result depends mainly on the quality of the grouping.

**Challenges**

Point clouds collected with different scanner systems or created by image matching software represent the same object type in different ways regarding point density, viewing angle, sharpness and so on. For example, in an airborne point cloud a tree is mainly represented by its crown seen from above. Points from inside the tree crown and the ground around the tree may be included if the point cloud is dense enough and if the laser beam was able to penetrate the crown. In a mobile point cloud, a tree is seen from the side and from below the tree crown. Therefore, much more information is available about the tree trunk, limb and crown structure, but not necessarily about the top of the tree crown. In an image matching point cloud, most often only the outer layer of a tree is represented without clear information about the tree shape and structure (Figure 2). The smaller or thinner an object is, the more dependent the detection ability is on the point cloud density and viewing angle of the scanner. While poles along roads and railways are easy to detect in dense mobile point clouds, they are hardly detectable in less dense airborne point clouds where the scanner does not always capture the vertical part of a pole (Figure 3).

![Figure 3: Poles are hardly detectable in less dense airborne point clouds where the scanner does not always capture the vertical part, as this example of street lamps along roads shows.](http://www.terrasolid.com/download/presentations/2017/classification_using_groups.pdf)

Another challenge for automatic object detection is the variety of object types that are present in point clouds of different application fields. Furthermore, the same object type may look very different in different countries and regions of the world. This applies not only to natural objects, such as trees, but also to man-made objects like buildings, road and railway furniture, power line towers and so on. Automatic detection algorithms therefore have to be flexible to cope with many different object types in various point cloud types. Predefined libraries with sample objects can only provide a starting point for country-specific, region-specific and application-specific extensions. Machine learning and artificial intelligence methods seem to be promising for improving the automatic object detection in point clouds in the future.

**Further Reading**
