Object Extraction from Terrestrial Laser Scanning Data

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Key words: Terrestrial Laser scanning, Object extraction, Segmentation

SUMMARY

Terrestrial laser scanning emerges as a leading technology for direct 3D documentation of natural scenes irrespective of their complexity. The detailed level of description comes however at the cost of huge volume of data in form of unorganized, unevenly spaced, three-dimensional points. The cloud of points provides a geometric description of the scanned scene but carries no semantic information regarding the objects within. Consequently, direct extraction of objects turns a challenging task. So far, research has focused on the extraction of well-defined objects with clear geometric characterization (e.g., plane, cylinders). Objects were extracted using segmentation algorithms which led to heavy computational efforts and were sensitive to scanning resolution and to artifacts. Effective working schemes for the extraction of objects require efficient and more general point-cloud processing methodologies. Such schemes are instrumental if aiming towards turning laser scanners into actual 3D mapping tools, and not only as means for characterization of surface geometry.

We present in this paper a model for the extraction of objects in natural and cluttered scenes. The proposed approach is predominantly based on using a panoramic representation of the individual laser scans. We discuss the advantages of this representation for a direct scene interpretation and a clear definition of point connectivity it provides. Our focus is on means for identifying and detecting objects appearing in different shapes, sizes, depths and locations within the scene and relatively to the scanner. Results show that the proposed model is applicable for complex 3D point clouds that depict natural scenes without heavy computational effort.

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1. INTRODUCTION

Laser scanning is an emerging technology with great prospects for three-dimensional surveying. Differing from conventional techniques like classical surveying, or photogrammetry, laser scanners provide rapid and direct description of 3D geometry that is independent of lighting conditions, weather, and without a need for manual collection of data. Furthermore, the point-cloud provided by high-resolution laser scanners is both dense and accurate, thereby allowing a detailed description of objects irrespective of their shape complexity. As a result, a growing number of applications make use of laser-scanning technology as a means for modeling 3D scenes. A partial list of such applications include: cultural heritage recording (Barber, 2005; Stenberg, 2006; Vistini, 2006), architectural modeling (Levoy, 2000; Akca, 2006), building reconstruction (Alshawabkeh, 2005), structural engineering (Gordon, 2004), and autonomous reverse engineering of 3D industrial scenes (Rabanni, 2006) as only a few examples. All these reports note the rapid way by which contextual information can be extracted from the data as the main reason for preferring laser data over alternative sources of information.

The ability to rapidly capture shape of three-dimensional objects, contrasts, to some degree, the complexity associated with the consequent phase of scene and object modeling. Operating within an unorganized set of 3D points requires suitable interaction techniques that are different than the standard raster-based. Additionally, diversity of objects and varying form complicate the analysis and modeling of the entities within the datasets. Therefore, modeling is hardly carried out on-site and is mostly performed back in the office, requiring considerable amount of time and resources.

The first stage in object analysis is their isolation from the rest of the data within point cloud. Once objects have been isolated they can be further probed, partitioned into object parts, and modeled by geometric primitives or surfaces. Realizing the important role of object extraction from laser scanning data we study in this paper the means for their identification. Our objective is to provide an efficient extraction strategy that is aware of objects form and scanning features. The studied data features a cluttered urban scene with objects of various forms which are scanned in different levels of detail. Shape diversity and varying representation make their detection a challenging task.

We begin the presentation with analysis of laser scanning data properties and their implication on object-extraction and scene modeling. Based on this analysis, we propose a feature extraction model that is attentive to the geometry of data acquired by terrestrial laser scanners. We then demonstrate the application of the model on a set of objects located within an urban scene. We conclude the presentation with analysis and point to avenues of future work.

2. REPRESNTATION OF 3D OBJECTS WITHIN A LASER SCAN

Scene representation is largely dictated by data acquisition features. With terrestrial laser scanners, spatial resolution is governed by angular spacing leading to objects being modeled in different scales. Distant objects will therefore have a lower resolution than those closer to the scanner. Figure 1 illustrates the direct effect of the varying resolution on the level of detail by which objects are described, showing poles with similar object-space dimensions appearing in different resolution, and consequently different forms. Their different representation suggests that their detection and separation from the surrounding must account for object distance from the scanner.

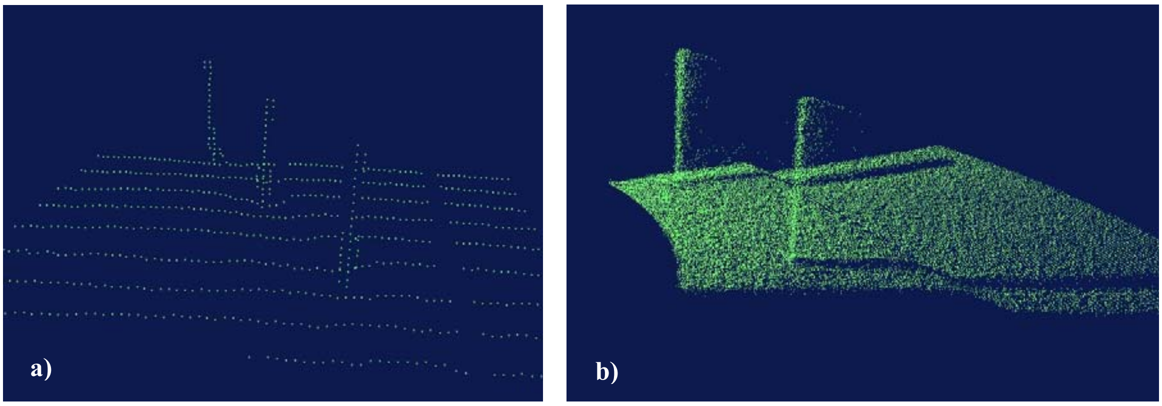

Figure 1: representation of similar objects located at different depths within the scan (25 and 2 m respectively).

To feature objects within unstructured 3D data, it is necessary to build neighborhood relationships as a means to estimate local surface properties. Rabbani (2006) proposes selecting the k-nearest neighbors for this purpose. This approach is computationally expensive but can be optimized by using space partitioning methods. As Figure 1 shows, the k-nearest neighbors may cover different spatial extents as a function of object distance from the scanner and therefore may lead to an uneven distribution of neighboring points. Gorte and Pfeifer, (2004) use a voxel based arrangement as a means to impose regularity in the data. However, voxels are uniform partitioning units and are insensitive to the existence (or absence) of data and to the varying resolution. Alternatively, an octree representation offers a better awareness to data distribution within 3D space. It also ensures a good ratio between memory usage and extraction speed and provides the ability to rapidly identify the points lying within a specific cube (Weiss, 1992). Basing point arrangement on density considerations, both voxels and octree arrangements are unaware of the varying object representation as a function of scale.

3. OBJECT EXTRACTION MODEL

Extracting objects from a cluttered scene requires separating them from their surroundings. Points belonging to the same object usually share some common properties and changes in these properties reveal their boundary. To efficiently compute such features and establish neighborhood that is aware of variations in scale, the 3D laser scanning data is represented as a range panorama whose axes are the latitudinal and longitudinal scanning angles, and the ranges are the intensity values. As the angular spacing is fixed (defined by system specifications), regularity is an established property of this representation and incurs no data loss (Zeibak and Filin, 2007). Neighborhood is established in this representation based on pixel arrangement within the raster data irrespective of the change in point density and depth (Figure 2).

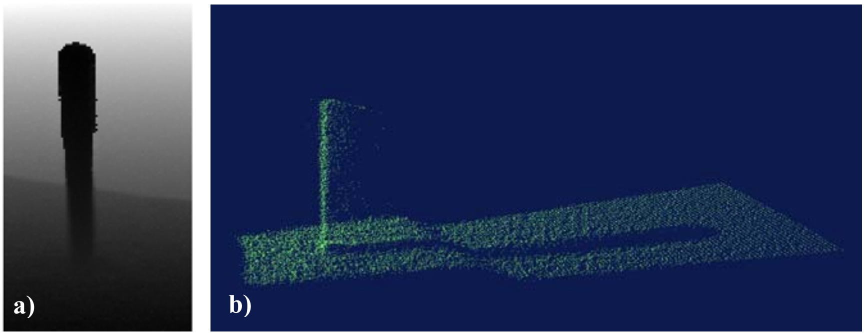

Figure 2: Object appearance in the range panorama and its equivalent representation in the 3D point cloud. Neighborhood for any point in the scan can be easily drawn from the image by directly accessing its neighboring pixels.

The range panorama representation emphasizes objects due to the difference in range value between object and its surrounding background (Figure 2a). Sharp changes in the depth map can therefore be applied for detecting discontinuities. However, as Figure 3 shows range discontinuities not always represent actual object boundaries and do not form closed curves around objects. As detection of the actual boundaries in places where they are absent is a complex task, we make use of surface normals for the extraction.

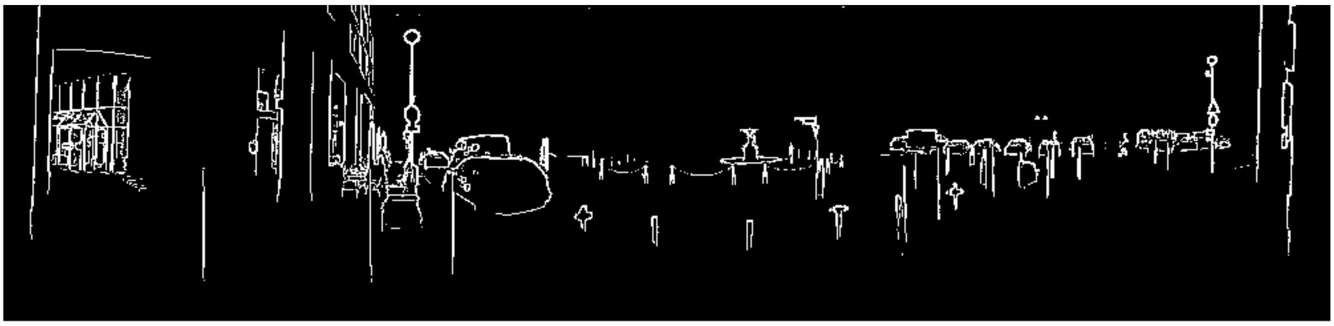

Figure 3: Edge detection using the application of the LoG operator on the range panorama.

3.1 Surface normal analysis

Computing surface normals for each scanned point requires at least two vectors on the surface. The normal is their cross-product.

$$\vec{N} = \vec{v}_1 \times \vec{v}_2 \tag{1}$$

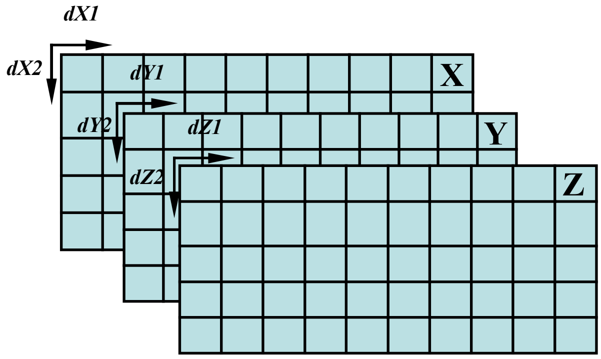

Figure 4: Organizing points' Cartesian coordinates into three individual panoramic.

Using the panorama representation, normals can be computed efficiently. This is achieved by storing the *x*, *y*, and *z* ordinates of each point in three individual matrices with dimensions similar to those of the panoramas (Figure 4). Local derivatives in the horizontal and vertical directions can then be computed within each ordinate panorama by differencing neighboring pixels (equivalent to applying a gradient operator). The differencing provides two gradient vectors $\vec{\nabla}_1 = \begin{bmatrix} dX_1 & dY_1 & dZ_1 \end{bmatrix}^T$, $\vec{\nabla}_2 = \begin{bmatrix} dX_2 & dY_2 & dZ_2 \end{bmatrix}^T$ whose normalized cross-product at each pixel provides the normal to the point.

$$\vec{N} = \frac{\vec{\nabla}_1 \times \vec{\nabla}_2}{\left\| \vec{\nabla}_1 \times \vec{\nabla}_2 \right\|} = \begin{bmatrix} Nx \\ Ny \\ Nz \end{bmatrix} \tag{2}$$

Because of ranging noise and high point-density near the scanner, gradients there are more sensitive to noise (Figure 5). To reduce noise effect on the normal estimation, we smooth the range panorama. Smoothing is performed adaptively in order to avoid blurring of objects that are distant from the scanner and less affected by ranging noise. Adaptive smoothing is performed by varying the window size as a function of the point distance from the scanner. The Gaussian filter variance is set as follows,

$$\sigma(\rho) = \left| \frac{\max(\rho) - \rho(x, y)}{\max(\rho)} \right| \tag{3}$$

with ρ the range, leading to a Gaussian function defined as

$$g(x, y) = \frac{1}{2\pi\sigma_{(\rho)}^2} e^{-\frac{x^2 + y^2}{2\sigma_{(\rho)}^2}} \tag{4}$$

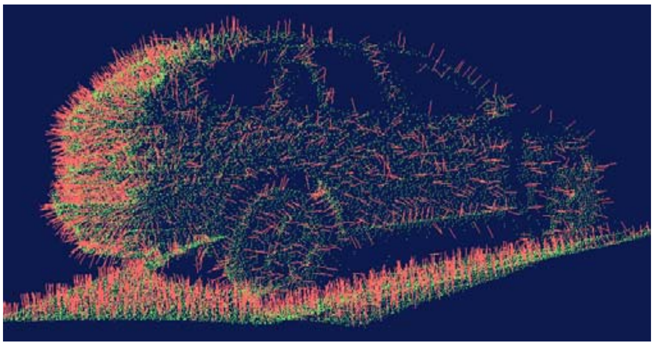

Figure 5: Normal vectors results on surfaces with different level of complexity.

3.2 Object-to-background separation

Transition between objects and the background is identified by a change in the normal direction. Normal direction of the background can be user defined; however, it can be learnt from the data when the background is the dominant feature there. Since ground (which generally acts as the background) is usually the dominant scanned object, we derive its direction by means of identifying the most dominant normal direction within the data. This is carried out by computing all surface normals, as defined in Section 3.1, and analyzing them in a three-dimensional feature space. Surface normals will be distributed on a sphere of unit radius, and the analysis will seek there the most dominant cluster. Once the background has been defined, objects are isolated by evaluating the angle, α, between each normal and the dominant direction, N^*

$$\cos(\alpha) = \left|\left\langle N_{i,j} \cdot N^* \right\rangle\right| \tag{5}$$

Strong changes in normal direction relative to the background, indicate in this scheme an object boundary. Points with an absolute value lower than a specified threshold are classified as belonging to an object. Finally, to isolate individual segments from the classified data, the points are grouped into clusters. Objects are grouped via a region-growing scheme where connectivity is established by a distance criterion which is adaptively set as a function of the range from the scanner. This way different objects that are linked to one another in the panorama can be separated (Figure 6). Small clusters (as a function of the range) are eliminated to remove noise. This way, spurious joints are eliminated and objects are separated.

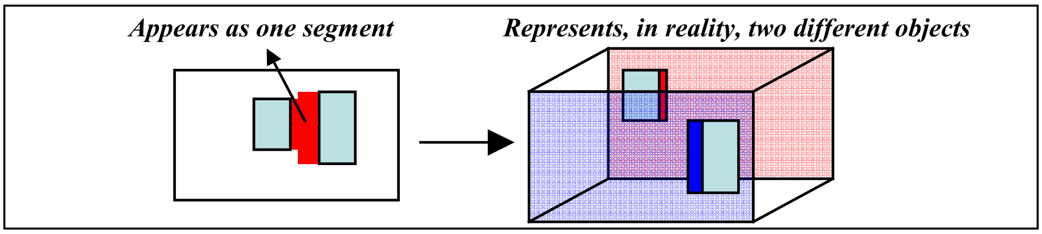

Figure 6: Checking spurious joints within a spatial surrounding.

4. RESULTS AND DISSCUSION

The application of the proposed algorithm is tested on a scan acquired by the Riegl LMS Z360i laser scanner (angular resolution of $\Delta\theta$=$\Delta\varphi$=0.12º). The scan contains 2.25 million points (creating a 750×3000 pixels image) spanning 360° horizontally and 90° vertically. It describes a wide variety of objects (buildings, cars, poles and others) with different levels of complexity. The data covers a courtyard-like square and offers a typical urban environment that is dominated by man-made objects and is cluttered (Figure 7).

Figure 7: The studied scan in panoramic view.

Figure 8a shows a color coding of the surface normals as computed in a naïve manner and Figure 8b shows those normals after applying the adaptive smoothing procedure. Notice the effect of ranging noise in the area near the scanner (lower part of the figure) that is featured in this representation by the non-uniform colors. Following the smoothing, colors are more constant while objects appearance does not change.

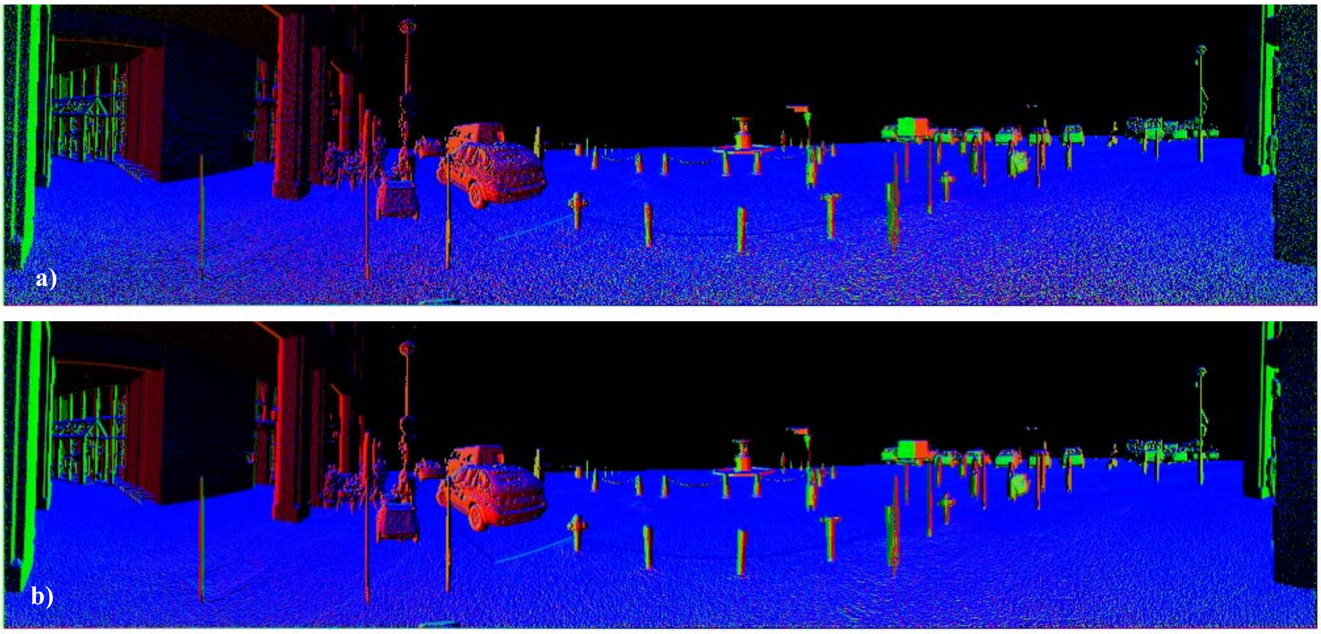

Figure 8: Normal vectors' direction, **a)** before and, **b)** after applying the adaptive smoothing procedure.

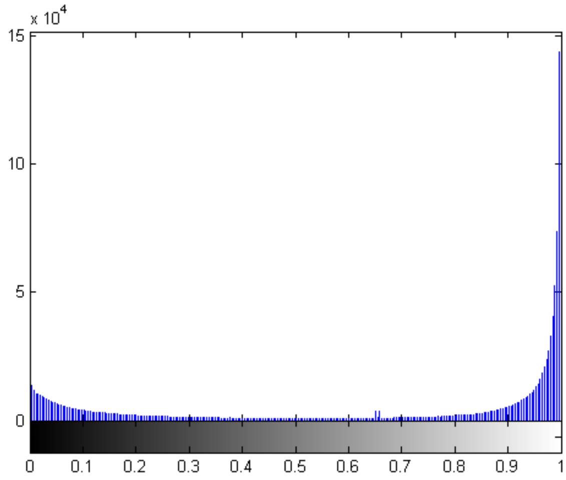

Figure 9: Histogram of z component of normal direction.

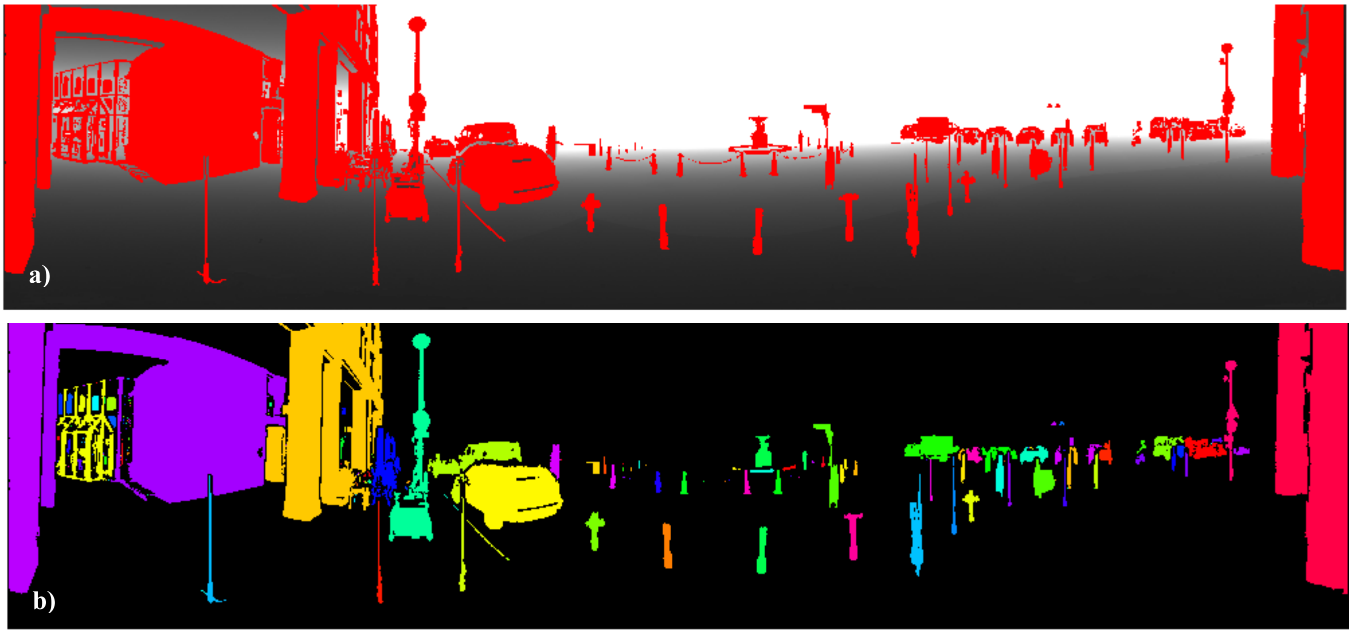

Figure 10: a) Object extraction results. **b)** Objects separation according to changes in depth.

Figure 9 shows the distribution of the z value of the surface normals. It shows a very clear maxima in this data which is at direction $N^* = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$. For simplicity of presentation only the z component is presented. Using the derived direction and applying the dot product based analysis, points are classified as objects (Figure 10a). Separation of the classified entities into objects is presented then in Figure 10b. Notice how the individual entities were well separated this way into individual objects appearing in different and consistent color. Such separation alludes to the attractiveness of the proposed approach. Some artifacts that relate to present limitations of the proposed approach can be noted however, referring mostly to objects that are in close proximity to one another. Examples to such occurrences can be seen with the pram located next to the lamppost (left part of the scene in Figure 10), both merged into a single object. Similar effect can be seen in Figure 11a where a person leaning on a supporting pillar was grouped with the pillar. Further analysis of the extracted objects will introduce shape related measures for surface modeling and for further separation of objects.

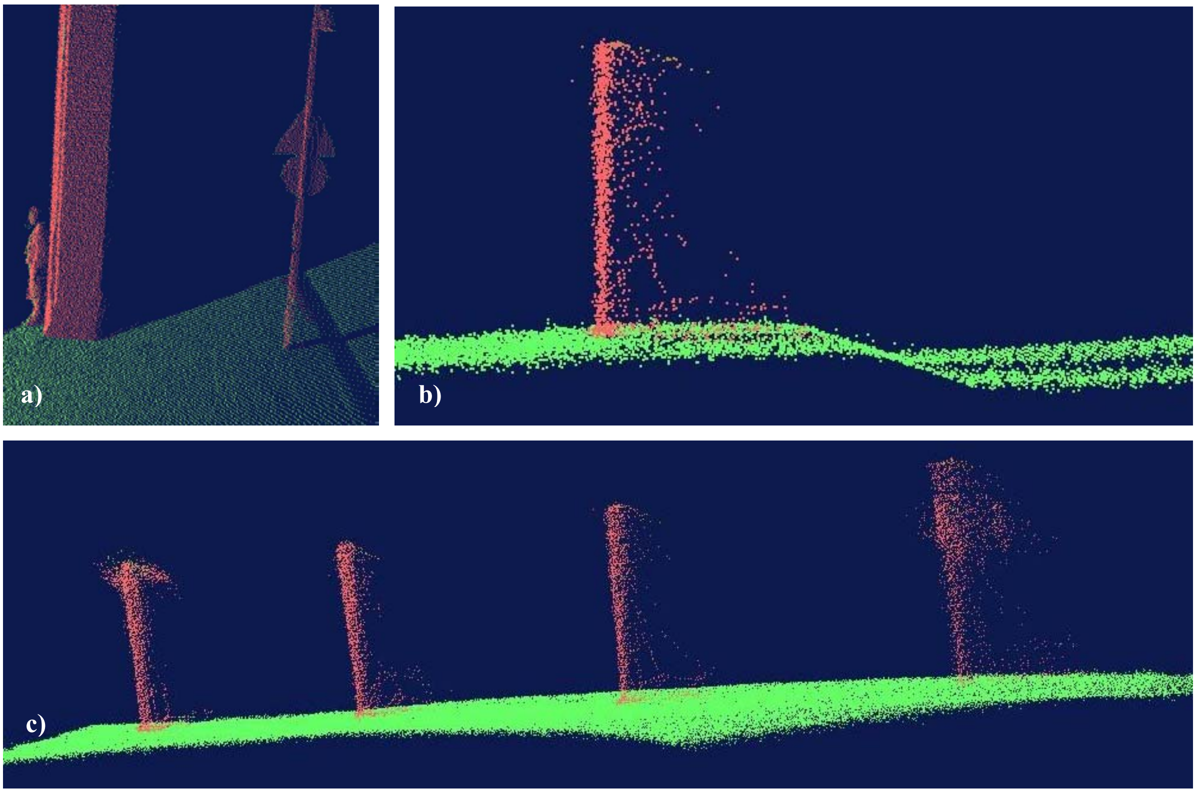

Figure 11: Results shown in a three dimensional form.

5. CONCLUSIONS

This paper presented a method for detection of objects within laser point clouds. It demonstrated how choice of data representation allowed for a relatively simple approach for object extraction and required only limited knowledge about the imaged scene. Therefore, it required little computational efforts. Using normal discontinuity analysis, it is capable extracting objects rapidly and can be applied for on-site data analysis and modeling without requiring much processing power. As the results show, the proposed approach managed extracting objects irrespective of their complexity and distance from the scanner. Using the polar representation and applying adequate methodologies, such as the normal computation strategy and the adaptive smoothing, a solution that is aware of the scanning features and varying scale has been derived.

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