CHANGE DETECTION VIA TERRESTRIAL LASER SCANNING

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ABSTRACT:

We present in this paper an algorithm for the detection of changes based on terrestrial laser scanning data. Detection of changes has been a subject for research for many years, seeing applications such as motion tracking, inventory-like comparison and deformation analysis as only a few examples. One of the more difficult tasks in the detection of changes is performing informed comparison when the datasets feature cluttered scenes and are acquired from different locations, where problems as occlusion and spatial sampling resolution become a major concern to overcome. While repeating the same pose parameters is an advisable strategy, such demand cannot always be met, thus calling for a more general solution that can be efficient and perform without imposing any additional constraints. In this paper, we propose a general detection strategy based on terrestrial laser scanning data. We analyze the different sources of complexity involved in the detection of changes and study their implication for terrestrial laser scans. Based on this analysis we propose a detection model, which is both aware of these hurdles and is efficient. We show that by finding an adequate representation of the data, efficient solutions can be derived. We then demonstrate the application of the model on several natural scenes and analyze the results.

1. INTRODUCTION

Differing from conventional mapping techniques like photogrammetry, laser scanners provide rapid and direct description of 3D geometry independent of lighting conditions, and without the need for a manual collection of the 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. It is therefore, not surprising that laser-scanning technology is rapidly becoming the popular alternative for modeling 3D scenes, for site characterization, cultural heritage documentation and reverse engineering, as only a few examples.

A key application where terrestrial laser scanning technology offers great use is monitoring of changes that occur over time. One example is the need to update geographic information by comparing the existing information with current state; another, which is more extreme, follows disastrous events where comparison of pre- and post- events is required, preferably in an efficient manner. Change detection should not necessarily be related to large-scale events. Behavior of small size natural phenomena or changes of specific objects are of great importance for analyzing deformations or objects evolution, and require a more subtle analysis of the measured scene. We point that the detection of changes can find its use in the elimination of moving objects within a static scene; such application can find use when reconstructing static landmarks, while avoiding irrelevant objects in the scene.

To date, detecting changes is mainly performed via images, usually by using object to background separation or a simple subtraction between images. Such models are limited and usually impose rigid constraints like static mounting of the camera, recognizable (usually artificial) landmarks, and are sensitive to shadows and local illumination problems. With 3D data arriving from airborne laser platforms, change detection is mainly applied in the form of a Digital Surface Models (DSMs) subtraction, where the DSMs are created from the raw laser point cloud (e.g., Vu et al., 2004). Murakami et al. (1999) also add to this intensity images as an additional information layer to help revising GIS databases. Vogtle and Steinle (2004) propose a methodology for detecting changes in urban areas following disastrous events. Instead of solely computing the difference between the laser-based DSMs, a region growing segmentation procedure is used to separate the objects and detect the buildings; only then, an object-based comparison is applied. Hofton and Blair (2001) propose waveforms correlation of coincident footprints between different epochs to study vertical or elevation changes in LIDAR data.

As for change detection via terrestrial laser scans, most works focus on deformation analysis for designated objects. Comparison can be performed by the subtraction of a resampled set of the data (Schäfer et al. 2004), or adjustment to surface models like cylinders (Gosliga et al., 2006) or planes (Lindenbergh and Pfeifer, 2005). For the comparison of a complete scene, Hsiao et al. (2004), propose an approach that combines terrestrial laser scanning and conventional surveying devices such as total station and GPS, in order to acquire and register topographic data. The dataset is then transformed into a 2D grid and is compared with information obtained by digitization of existing topographic maps. Such approach has very appealing use in practical applications, but is very limited in scope and cannot be generalized into a change detection scheme for 3D data. Girardeau-Montaut et al. (2005) discuss the detection of changes in 3D Cartesian world, and point to the possibility of scans comparison in point-to-point, point-to-model, or model-to-model manners. The authors then use point-to-point comparison with some adaptations and make use of an octree as a data structure for accessing the 3D point cloud. Comparison is carried out by using the Hausdorff distance as a measure for changes.

The review demonstrates the great potential of change detection via laser scanning data that allow assessing variations within the physical scene without resorting to interpretation of radiometric content, as is the case with images. It also shows that in most cases where terrestrial laser scanning is being applied, some constraints on the studied objects or on the scanner pose are being imposed. Since, the assessment of the actual change, and the ability to quantify and measure it (e.g., size, volume), offer great assets, we study in this paper the detection of changes without the imposition of external constraints (other than having some overlap) and propose a model for the assessment of changes. Our goal is not only to develop a methodology for the detection of changes, but also to propose an efficient solution, aware of the unique characteristics of terrestrial laser data.

Before turning to the analysis and methodology presentation, we note that the detection of changes between scans from different location requires the establishment of registration between the point-clouds. Since scans are acquired in local reference frames whose origin is at the scanner position, the relative transformation parameters between the datasets should be known a priori (in practice, estimated). Our work considers the transformation parameters as known. This assumption is based on the fact that the registration between the scans is a common practice that can be treated either by using artificial targets within the scene (spheres, or corner reflectors) or in an autonomous manner.

The change detection model is presented as follows, in Section 2, we discuss various geometric and scanner related features that influence the detection of changes in laser scanning data. Section 3 presents the proposed change detection model; we outline first the proposed model, analyze it, and then present a processing sequence that addresses scanning related problems. Section 4 presents results of the application and the model, and Section 5 offers concluding remarks and outlook.

2. CHANGES BETWEEN LASER SCANS

When studying the detection of changes between terrestrial laser scans, concerns like data characteristics, level of comparison, and scene complexity, are key factors that affect the detection methodology. Data characteristics relate here to the three-dimensionality, the irregular point distribution, the varying scale and resolution within the scene (depending on depth), and the huge data volume in each scan. Regarding the level of comparison, it may be applied at the point level by comparing a point to its surrounding, at the feature level via primitive based comparison (e.g., planes or conics), and the object level by comparing objects and their shape variation between epochs.

Since laser scans provide point-clouds embedded within 3D space, we study the realization of changes in that space. For an efficient model, we focus on the prospects of point-level based change detection. We opt towards efficient models that do not impose elaborated processes with added computational overhead. Since changes in the point level are based on a comparison of points to their surroundings, we analyze first the potential artifacts that may affect the detection, particularly with reference to cases that raise the level of false alarms. Because of the unorganized nature of the 3D data, it is clear that some form of data arrangement (or structure) must be used for efficient access and association between the sets of points. Gorte and Pfeifer, (2004) use a voxel based organization as a means to impose regularity in the data (though not for change detection), and Girardeau-Montaut et al. (2005) use octree representation, which is more efficient and more aware of the fact that most of 3D space has no information. In the analysis, we study their applicability to point based comparison.

2.1 Resolution and object pose

We begin our analysis with assessment of the varying resolution both within and between scans. As angular spacing dictates the resolution of the acquired data, distant objects will have a lower resolution than those closer to the scanner. The most direct effect of the varying resolution is the level of detail by which objects are described. However, the fixed angular spacing also means that distances between consecutive ranges will keep increasing the further the ranges from the scanner become. Figure 1 illustrates this effect, it also shows that the increasing point spacing is object-dependent – while the spacing of the ground points in the 'green' scan keeps growing, those related to vertical objects (poles, trunks, or standing people) are more or less fixed. Finding a point-to-surrounding comparison scheme that suits close and distant points is, therefore, hard. The use of volumetric arrangement models (that define surrounding by their nature) will fail covering both ends. Small size surroundings will lead to cells with no points from one scan but some from the other, and will therefore raise a "change" flag. Bigger size surroundings will lead to missed changes (e.g., accommodating for the decreasing ground resolution may cover complete vertical objects). Such effects will occur with both the voxel scheme and the adaptive, octrees based, partitioning.

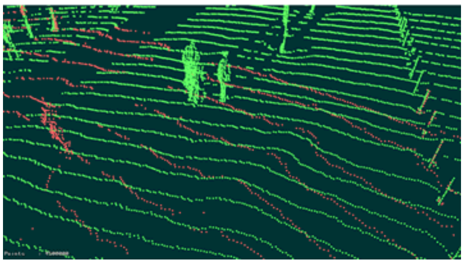

Figure 1. Overlaid scans from different positions, and the effect of the varying resolution.

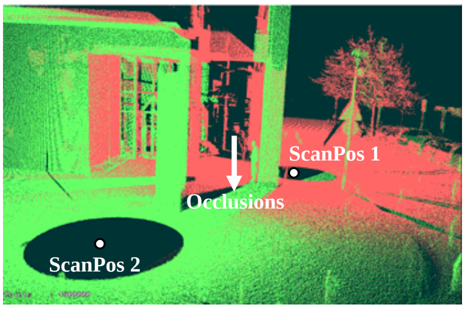

Figure 2. Occluded areas in one scan that are 'seen' from the other scan. Such regions will wear the form of a change by a plain point based comparison.

2.2 Occlusion

Occlusion of objects, or object parts, offers another type of "interference," with a likely consequence of false detection. Figure 2 shows a scene part in 3D space, which is seen in the 'green' scan but is occluded in the 'red' one due to the supporting pillar. Those points appearing in one scan but not in the other are natural change candidates. An additional related effect arises when the same object is partially visible in both scans, either with a region mutually seen by both scans, or when the visible parts are exclusive one to the other. To handle occlusion effects, the application of z-buffering must be applied. However, z-buffering considers by its nature a sense of surfaces, and therefore requires a level of interpretation that either involves data segmentation or the definition of connectivity among the points. With the varying resolution, such definition becomes hard, and in order to be applied properly, a sense of objects must be inserted.

2.3 Scanner related artifacts

The scanning system itself offers several features to consider when dealing with the detection of changes. Among them are the "no-reflectance" regions, range limits, and noisy ranges. Artifacts related to regions of **no-reflectance** refer to areas towards which pulses have been transmitted, but due to absorption or specularity, not enough energy (if any) is returned to trigger a range measurement (objects like, windows, and low reflectance surfaces are some example to that). When data from the other scan exists in those "hole" regions they will be considered a change while not being so.

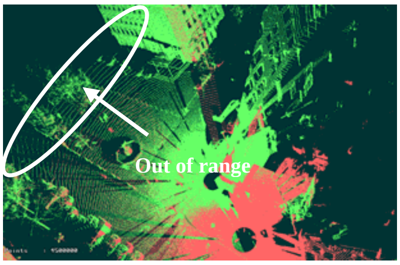

Figure 3. Regions covered by only one scan. By the simple comparison, it is impossible to distinguish between a "no data" area and an actual change.

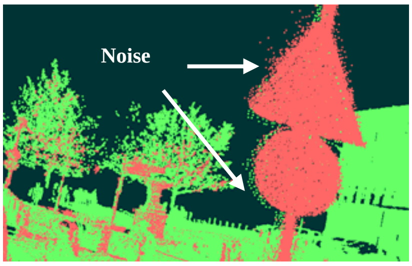

Figure 4. Noisy laser returns around object borders that can be interpreted as changes.

With **ranging limits,** the different scanning positions will leave areas seen in one scan uncovered by the other (see Figure 3). This relatively trivial fact suggest that the lack of information cannot be attributed only to actual changes (or geometric constraints that the scene imposes) but also to the lack of range measurements in a region. Therefore, the consideration of the range limits should be handled appropriately. Finally, we point to **noise** in the data (see Figure 4) which usually accompanies laser data, especially around object edges and corners. Unless treated properly, noise will be interpreted as changes in the scene.

All those features suggest that detection of changes between laser scans cannot be decimated into a mere point-to-surrounding comparison problem if such artifacts are to be resolved. In the following Section, we present a model for change detection that accommodates those features of the scan.

3. CHANGE DETECTION MODEL

The essence of point-level change detection in 3D space is comparing a point from one scan to its surrounding in the other. Change detection between scans can be approached however, from a different direction by asking whether a point that was measured in one scan can be seen in the other. For this question, three answers can be given, i) yes, but there is no object in the reference scan, namely a change, ii) yes, and it is lying on an object, namely no change, and iii) no, as there is an item hiding it, and due to lack of any other information we mark it as no change. In the rest of this Section we show that under an adequate data representation a decision among the three alternatives can be easily and efficiently made.

3.1 Data representation

3D laser scans can be seen as range panoramas 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 becomes an established property of this representation. Relation between the Cartesian and the polar data representation is given in Eq. (1).

$$(x, y, z)^T = (\rho\cos\varphi\cos\theta, \rho\cos\varphi\sin\theta, \rho\sin\varphi)^T \qquad (1)$$

with x, y and z the Euclidian coordinates of a point, φ and θ are the latitudinal and longitudinal coordinates of the firing direction respectively, and ρ is the measured range. $\Delta\theta$, and $\Delta\varphi$, the angular spacing, define the pixel size. Figure 5.a shows range data in this representation where the x axis represents the θ value, $\theta \in (0,2\pi]$, and, the y axis represents the φ value, with $\varphi \in (-\pi/4,\pi/4]$ for this scan.

The arrangement of the irregular 3D point cloud into a panoramic form offers not only a compact representation (which is less of a concern here) but more importantly an organization of the ranges according to their viewing direction. To some degree, this representation can be viewed as tiling of the data, where the pixel size in angular terms defines a region where the measured range is the best information source. This contributes to the connectivity notion as featured in Figure 5.a. Since size is defined here in angular terms, the varying distance between consecutive points and scan-lines cease being a factor.

To assess if a point that was measured from the other scan can be seen by the reference one, the evaluated scan should be transformed into the same frame as the reference scan. Even though the range dataset are assumed registered, each range panorama is given in a local scanner frame. This transformation has the notion of asking how the scan will look from the reference scanner position. This transformation involves rotation and translation, according to the pose parameters of the scanners, and is given by Eq. (2).

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = R_{12} \cdot \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} + t_{12} \qquad (2)$$

$$\text{where:} \quad R_{12} = R_1 \cdot R_2^T \quad \text{and,} \quad t_{12} = \begin{bmatrix} t_{1x} - t_{2x} \\ t_{1y} - t_{2y} \\ t_{1z} - t_{2z} \end{bmatrix} \cdot R_2$$

t_1, R_1, t_2, R_2 are the position and orientation matrices of the two scanners, respectively, and $[x_1, y_1, z_1]^T$, $[x_2, y_2, z_2]^T$ are the 3D coordinates in the individual scanners reference frames. Figure 5.c shows the analyzed scan, while Figure 5.b shows the same scan as transformed into the viewing point of the reference scan in Figure 5.a.

3.2 Detection of changes

When transformed, comparison between the scans can be reduced, with some adaptations, into a mere image subtraction. This image subtraction in the range panorama representation has some appealing properties: i) when a scan is transformed into the view point of the reference scan, occluded areas of the analyzed scan become "no-information" (or void) regions, as Figure 5.b shows, and therefore, have no "change-like" effect,

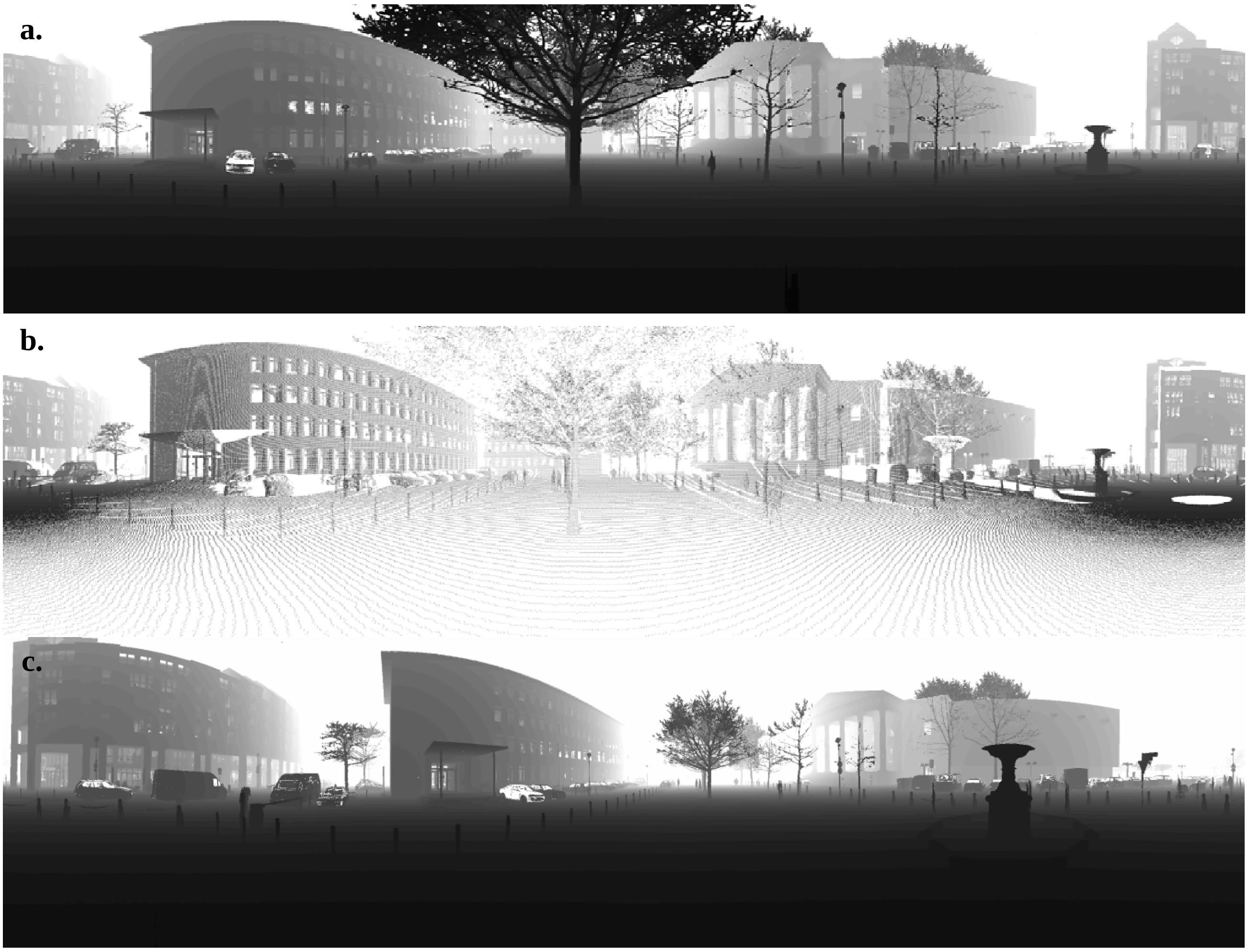

Figure 5. a. Reference scan. **b.** Analyzed scan transformed into the reference frame. **c.** Analyzed scan in its original local frame (not transformed).

ii) regions seen from the analyzed scan but not from the reference scan (occluded by the reference) will fall behind the occluding objects. As such, they will have bigger range values than those of the occluding objects and, therefore, a "no change" status, and iii) scale – since objects close to the scanner position occupy more pixels and far objects occupy less, the need to characterize multi-scale comparison arises. However, as objects from the analyzed scan are transformed into the reference scan frame, object scale differences will be resolved in large.

For the detection of changes, we apply the following rule:

$$d_{i,j} = \begin{cases} \text{change} & R_{i,j} - A_{i,j} > \varepsilon \\ \text{no change} & \left| R_{i,j} - A_{i,j} \right| \leq \varepsilon \\ \text{occlusion (no change)} & R_{i,j} - A_{i,j} < -\varepsilon \end{cases} \quad (3)$$

with d_{ij} pixel in the difference image, R_{ij} pixel in the reference image, A_{ij} pixel in the analyzed one, and ε an accuracy threshold. As can be noticed, the change detection is directional, namely negative differences, which are due to occlusion, cannot be described as changes. Additionally, "no-data" (no-information) regions in the transformed scan cannot be interpreted as a change (for consistency with the above definition and for implementation purposes, we assign "max-range" values there). So, in order to assess the overall difference between two epochs, changes should be mutually detected between the different scans, with the comparison between the reference scan and the analyzed scan telling what appears in the analyzed but not in the reference, and the reverse comparison telling what appears in the analyzed scan but not in the reference. Their union comprises the overall change; their exclusion reveals the static objects in the scene.

3.3 Pre and post processing

With the outline of the proposed differencing approach, we turn to discuss the pre- and post- processing phases that handle the additional scan characteristics that were pointed out, particularly no-return regions and ranging errors around corners and edges.

Correction for no-data regions – As Figures 5.a, c show, the range panorama has no-return regions due to reflecting surfaces or in open areas such as the skies. No-information regions have zero ranges there, and therefore will not be able to show changes (having negative distance and therefore considered occluded). To avoid this effect, no-reflectance regions in the reference scan are being filled by their neighboring values. These regions are detected by their "hole" appearance in the data (hole size is defined by a preset value). Figure 6 shows the filling effect, with Figure 6.a showing the raw laser data and highlighting two no-reflectance regions among many others that are seen around windows and car shields, and Figure 6.b showing the filling effect. For the background (skies etc.) regions, a "max-range" value is assigned. This way, not only no-reflectance regions are filled but also the different extent of both scans is handled.

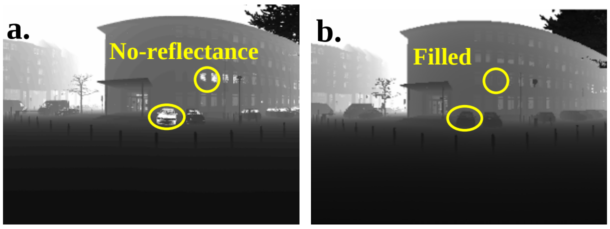

Figure 6. Filling no reflectance regions

Reduction of noise and edge effect – to eliminate the effect of edges and corners in the image that oftentimes result in noisy ranges, dilation-like operation is performed. The idea is to use a filter to locally dilate close object and erode its background. This way, we emphasize close objects and make the comparison between corresponding pixels more secure. Figure 7 shows the effect of the order filter operator.

Figure 7. Results of applying the order filter**.**

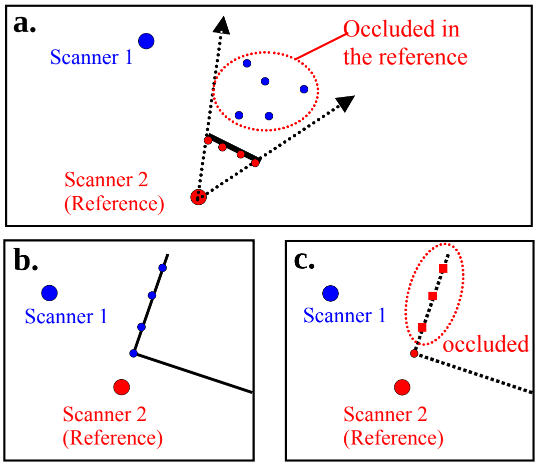

Figure 8. Occluded points and the effect of object co-aligned with the scanner

Multiple objects per viewing direction – one feature of the transformation into the reference scan coordinate system is that ranges in the analyzed frame that are co-aligned with the reference scanner viewing direction will all fall on the same image pixel. If those ranges are occluded this effect will go unnoticed (see Figure 8.a), however when they fall on a new object in the scene, only a single point (the closest) that depict the object will be considered a change while the rest will be ignored (Figures 8.b, c illustrate this effect). Therefore, instead of assessing a single laser point, the complete sequence should be evaluated.

Post processing - Following the detection of changes, which we perform pixel/range-wise, regions are formed. Further than the elimination of small regions, the grouping, which is performed in image space, is indifferent to the depth variation of the points. Therefore, spurious changes that are not connected in 3D space should be detected and eliminated. For such elimination, we study the neighbors of each detected point in 3D space. Such evaluation is relatively simple to perform as it involves defining a window around the point in image space and then truncating ranges that are further to the point than a given distance. If within this box, the number of points with change status is smaller than a given value, the point is not considered a change. This way, spurious changes are eliminated. We point that a window around the point, which is a simple definition, offers in fact a scale aware definition of the surrounding.

4. RESULTS AND DISSCUSION

The application of the change detection model is demonstrated in Figure 9 on a complete scene (the analyzed scan is compared here with the reference). The detection threshold, ε, was set to 5cm. Due to space limitation, we do not extend this comparison into multiple scans, and point that the extension of this approach is fairly straightforward. Changes in this scene between the two epochs are mainly passerbys and parking vehicles. They indicate the level of detail that can be noticed at various ranges (consider again Figure 5). As an example, we point to the two sitting persons on the distant building with the neo-classical front. On a larger scale, in Figure 10.a a bus that crosses the scene can be noticed. Manual inspection of the scene in reference to the detected changes shows that all the actual changes between the two scenes were indeed detected. Considering the very different views from which the two scenes were acquired, the ability to detect walking persons shows the great potential of the proposed approach to detect changes of various size and within a cluttered natural environment. Since comparison is performed by image subtraction, the detection of difference is almost immediate, requiring mostly the transformation of the analyzed scan into the reference scene, and if the total change is sought, applying the same transformation in the reverse order.

The Figures show that a clutter of spurious changes has fallen on trees. The lack of structure in trees and the vegetation penetration property are some reasons for such changes to appear. Additionally, the ranging mode (first return or last

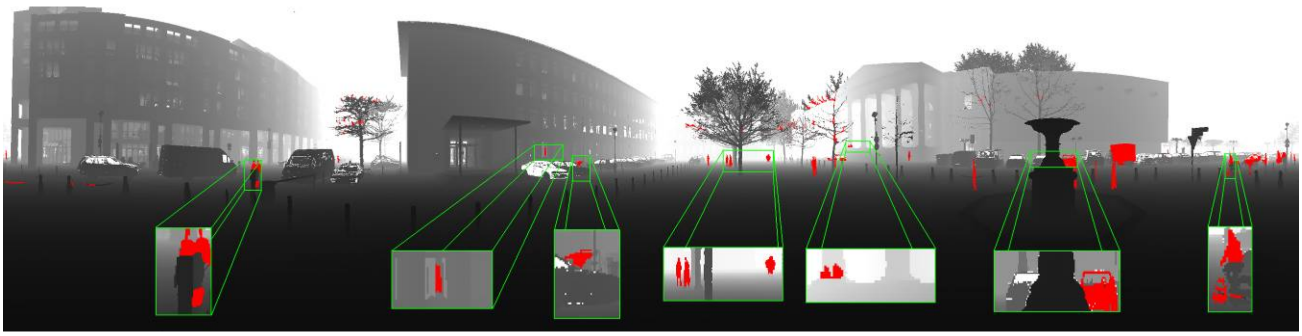

Figure 9. changes detected in the analyzed scan when compared to the reference one.

return) has an impact on non-solid objects and therefore affects the detection. The results indicate that for change detection applications, preferences for a first-return mode (namely, the closest object) are of reason and need. In terms of false alarms, chains between poles have also been detected as changes due to lack of information on them in the other scan, most likely for similar reason or due to noisy ranges that measurement of such objects is prone to.

While the differentiation between occluded areas and actual changes is a natural feature of the proposed model, it has interesting consequences regarding partially occluded objects. Being point-based, the comparison methodology holds no objects notion in it. Therefore, partially occluded objects will be partially marked as a change (see Figure 10.b and the bicycles highlighted in Figure 9). Linking (or reintegrating) such object parts can be performed via graph methods. We point out that adding object notion to the detection at the current stage when changes have been identified already is a more efficient (and to some degree natural) way than a comprehensive study of all objects in the scene, only as a means to identify which of them were changed.

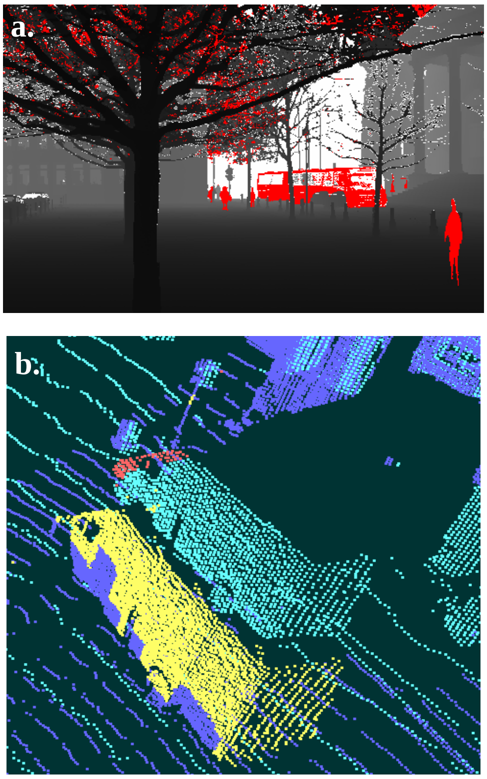

Figure 10. Detection of changes, **a.** large and small moving objects in the scene with false detection around trees. **b.** under occlusions (described in 3D); blue and cyan: two registered scans; yellow and red: changes detected in the two scans respectively.

5. CONCLUSIONS

This work has demonstrated the feasibility of change detection with no imposition of external constraints. It has shown that efficient solution to such complex features as varying scale across the scene, occlusion, and laser scanning artifacts exist. As was shown, the transformation of the data to the viewing setup of the reference scan, and the polar representation that was used, solve scale and occlusion problems in a natural way. Additionally, morphologic operators that were applied on the range data managed solving such problems as ranging limits, noise and no reflectance regions. The range subtraction of the points in the organized angular space provided a multi-scale analysis, not affected by the scanner position and the varying scanning resolution. The results show that not only major changes are detected, but also minor ones like passerbys in different size.

Future work on this proposed methodology will focus on methods for the elimination of false detection, particularly around vegetated objects and on adding object notion into the detection process (so that no two parts of the same object will be defined as change while the rest of it not). However, the current state of the results makes such analyzes and extensions much narrowed and focused compared to a complete analysis of the whole scene.

6. ACKNWOLEDGEMENT

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