

MIRROR IDENTIFICATION AND CORRECTION OF 3D POINT CLOUDS

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ABSTRACT:

In terrestrial laser scanning (TLS), the surface geometry of objects is scanned by laser beams and recorded digitally. This produces a discrete set of scan points, commonly referred to as a point cloud. The coordinates of the scan points are determined by measuring the angles and the time-of-flight relative to the origin (scanner position). However, if it comes to mirror surfaces laser beams are fully reflected, due to the high reflectivity. Mirrors do not appear in the point cloud at all. Instead, for every reflected beam, a incorrect scan point is created behind the actual mirror plane. Consequently, problems arise in multiple derived application fields such as 3D virtual reconstruction of complex architectures. The paper presents a new approach to automatically detect framed rectangular mirrors with known dimensions and to correct the 3D point cloud, using the calculated mirror plane.

1 INTRODUCTION

Scanning reflective surfaces with a 3D laser scanner yields incorrect 3D point clouds, since the emitted laser light is reflected by the surface and a wrong distance is determined. Fig. 1 presents an example, which has won the LiDAR-as-art-contest in 2013. The problem has impact on many post processing steps, e.g., automatic scene modeling and object recognition. In the area of mobile robotics, laser scanners are commonly used for system navigation and robotic mapping or simultaneous localization and mapping (SLAM), i.e., mobile robots have to be able to locate themselves and to identify obstacles. Faulty sensor values of the environment lead to unwanted behavior of the robot and to inconsistent maps.

The scientific contribution of this paper is the implementation of a new approach of solving this problem for the special case of framed rectangular mirrors whose dimensions are known. Thereby, an identification criterion is created, which allows to break down the problem of mirror detection into several subproblems, which are solved by methods of image processing and mathematics. Up to our knowledge, for the first time, a tool has been created to identify mirrors in 3D laser scans and to correct the corresponding 3D point clouds. Throughout the paper, we will demonstrate

the algorithms using 3D data acquired with a pulsed Riegl VZ-400 3D laser scanner in multiple mirror situations. The evaluation shows, that the resulting algorithms are applicable without modification to 3D scans acquired using the phase-shift principle. First, we describe the detection of potential mirror contours in a 2D panoramic representation of the point cloud based on a jump edge detection and 3D contour extraction algorithm. Second, we show how actual mirror contours are identified, how the mirror plain is calculated using the Principal Component Analysis (PCA) and also how the point cloud is corrected.

2 RELATED WORK

Not much research has been done dealing with the problem of faulty laser scanner measurements on mirrors and windows. There is only one approach by Yang and Wang (2008, 2011). In their work, problems of both mirrors and windows are addressed and integrated into the robot's localization, mapping, and navigation framework. They introduced a sensor fusion technique to detect potential obstacles using sonar sensors and a laser scanner. However, their approach works in 2D only. Mirrors are finally described as obstacles in a 2D occupancy grid map. In contrast to that, this paper describes more a tool to find the exact 3D mirror

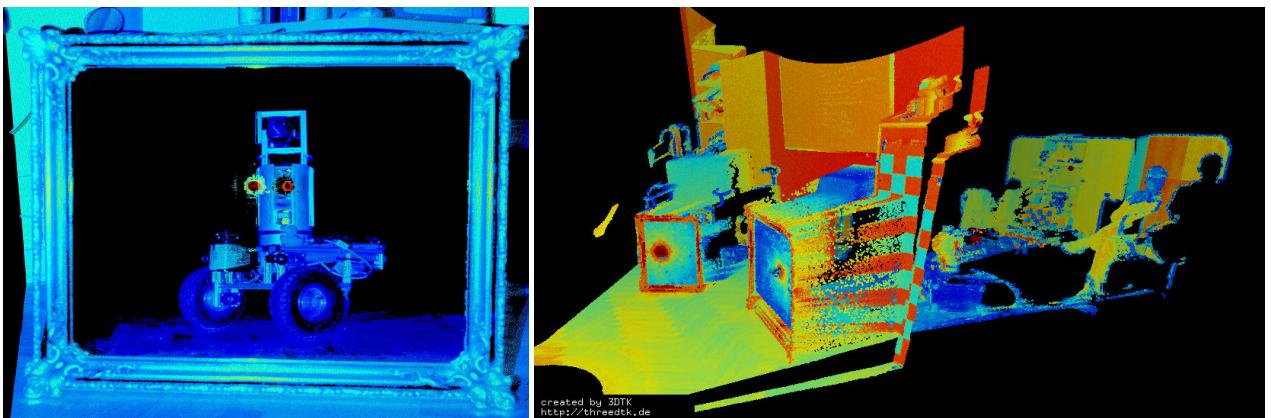


Figure 1: Left: The image depicts how our robot Irma3D sees itself in a mirror. The laser looking into itself creates distortions as well as changes in intensity that give the robot a single eye, complete with iris and pupil. Thus, the image is called "Self Portrait with Duckling". Image courtesy Jan Elseberg. Right: Scanned scene with two mirrors.

position and to correct 3D point clouds after the recording of the laser scan.

Only a small number of researchers have looked into the issue of detecting specular surfaces and correcting the errors automatically. A related problem is the detection of transparent or translucent objects. The related works in the area range from 3D point cloud processing of kinect data to environment perception and object reconstruction methods (Foster et al., 2011; Ihrke et al., 2010; Klank et al., 2011; Albrecht and Marsland, 2013).

3 PANORAMA CREATION

To find potential mirror contours we detect jump edges. First, a 2D panoramic range image of the point cloud is created using the *equirectilinear* projection method (Houshia et al., 2013). When creating panorama images from laser scans, each point of the 3D point cloud is projected onto a 2D array of a certain resolution. Therefore the scanned environment of the laser scanner is seen as the projection of a sphere around the scanner. Given the 3D point in spherical coordinates (θ, ϕ, r) the projection method determines on which 2D pixel with the coordinates (u, v) a 3D point is projected. If multiple 3D points fall into a pixel, e.g., by full-wave-analysis or resolution mismatches, they are stored in a vector. The distance r of one 3D point defines the value of a pixel in the range image version of the *equirectilinear* projection. While many projection methods are available (Houshia et al., 2013), for this work, the projection method *equirectangular* is used which is defined by the simple projection rule:

$$\begin{aligned} u &= \theta \\ v &= \phi \end{aligned}$$

with longitude θ and latitude ϕ .

Depending on the resolution of the panorama image, multiple points of the point cloud are usually projected on the same pixel (u, v) . If this occurs, there are two possibilities: The mapping method *FARTHEST* takes the point with biggest range r as represented pixel; the mapping method *NEAREST* the one with smallest range r . Depending on the point cloud and the mirror situation both methods have different effects, so it has to be chosen individually for each scan, cf. Fig. 2.

4 JUMP EDGE DETECTION AND CONTOUR EXTRACTION

Jump edges are detected in the panoramic range image and a corresponding jump edge image of same resolution is created. Between two adjacent pixels of an image, there is a jump edge if the difference in their value is greater than a certain threshold. The sign of the difference describes which of the two pixels is closer to the origin, i.e., scanner pose. A jump edge is only represented in the jump edge image, if the considered pixel is closer to the origin than the one compared to. This is important to ensure that the detected contour describes only the mirror frame and contains no pixels within the actual mirror plane. Otherwise 3D contours cannot be extracted properly.

Extracting the detected 2D contours of the jump edge image is a known problem of image processing and is done by using the corresponding OpenCV-function `findContours` in CvRetrExternal mode. Subsequently the corresponding 3D contours are extracted by testing which 3D point is projected onto the considered 2D contour pixel, which is the reverse process of creating the range image. Note: The chosen mapping method changes the outcome

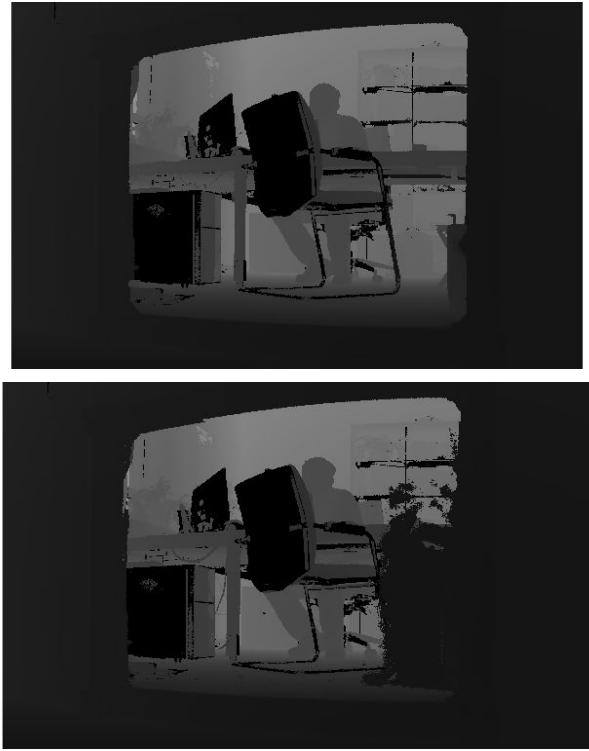


Figure 2: Part of a range image of a mirror. Undefined pixels appear black. Without `fillZero`-function. Top: Method *farthest*. Bottom: Method *nearest*. Not ideal case with 3D points on the mirrors plane.

of the extracted 3D contour. To get the frame point as 3D contour point, the mapping method has to be *nearest*.

In the ideal case, all 3D mirror points are laser beam reflections and are therefore further away from the scanner and need to be corrected. However, in some cases 3D points occur that describe the actual mirror surface due to not perfect reflections or detection using the full-wave-analysis, cf. Fig. 2 bottom picture. The 2D contour will then be shifted to the inside of the mirror and will not describe the mirror frame anymore. Consequently, 3D contours might not seem to be connected what leads to the need of filtering these contours or an erroneously calculated plane. In those cases the mapping method *farthest* is chosen to avoid this problem (Fig. 2 top picture).

5 IDENTIFICATION OF MIRROR CONTOURS

So far we described how potential 2D and corresponding 3D contours are extracted. Now the actual mirror contours have to be identified among all detected ones.

In a first step a connectivity filter is applied on all detected contours. It calculates the distances of all 3D contour points towards their next neighbor. If the distance between two neighbored contour points is larger than a certain threshold, the considered contour is seen as unconnected and therefore removed. If a considered 3D mirror contour contains points that do not describe the mirror frame due to previous problems in detecting the jump edges, the efficiency of this filter decreases because the used threshold has to be increased to not filter the actual mirror contours. Consequently more non-mirror contours pass this filter. In a second step, for all remaining 3D contours, the dimensions as well as the best fit plane through the contour points, which is the



Figure 3: Top: Range image of scanned bathroom environment with five mirrors of same size and resolution of 3600×1000 . Middle: Corresponding jump edge image with a threshold of 0.1 m. Bottom: Extracted 2D contours of picture above.

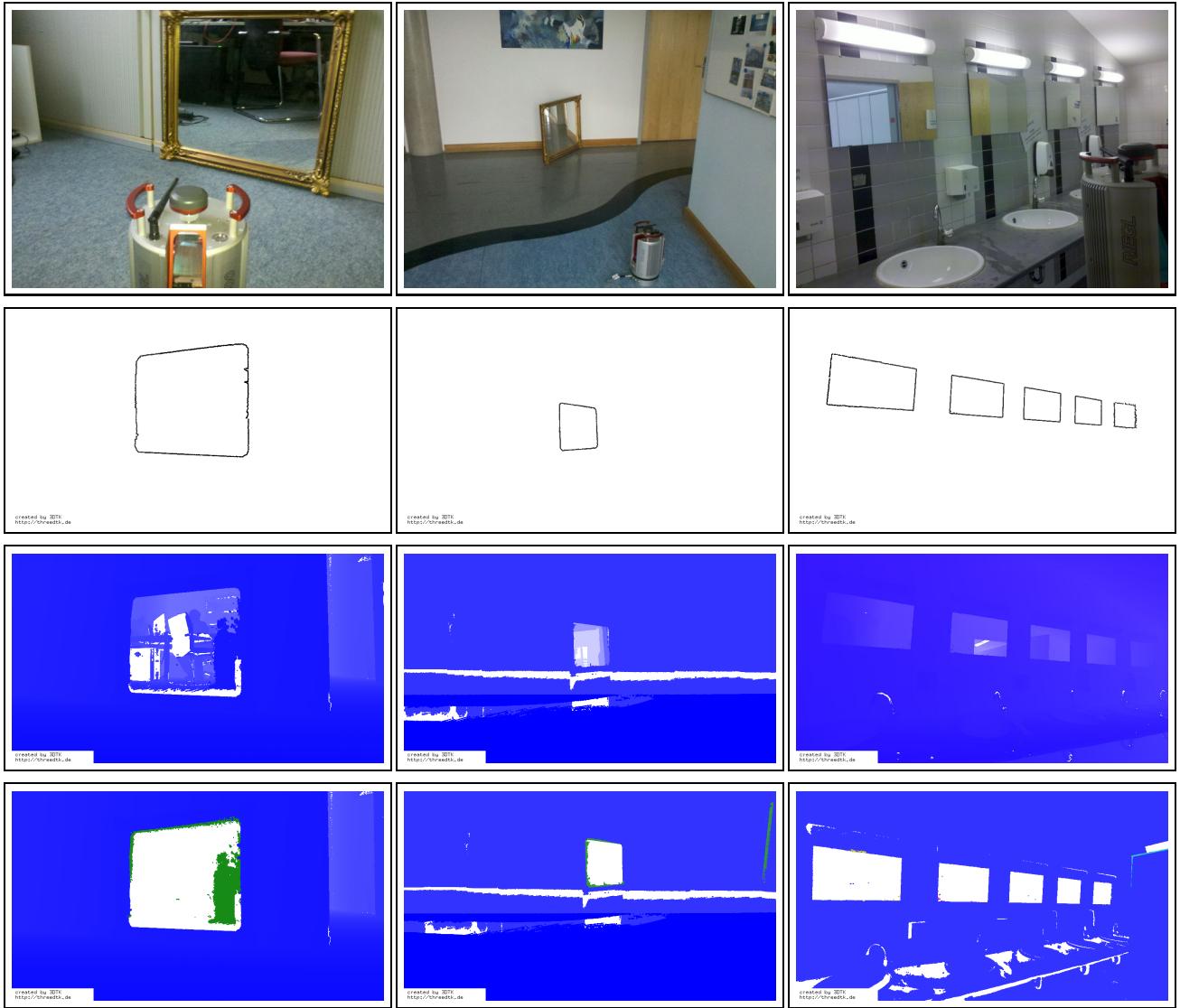


Figure 4: Left: Mirror of size 56×64 cm in an office environment. Middle: Same mirror placed in an office corridor. Right: 5 mirrors of size 40×60 cm in a bathroom. Top row: Photo of the scenes. Second row: Extracted 3D contours. Third row: Screenshots in a 3D point cloud viewer without mirror correction. Bottom: Corrected 3D point clouds.

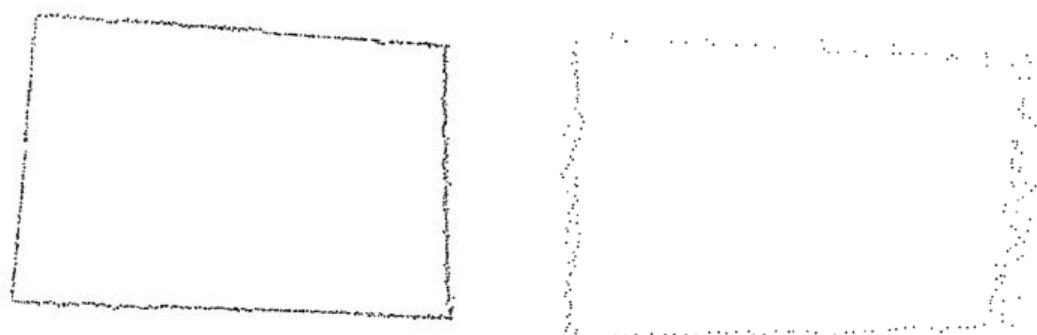


Figure 5: Two extracted mirror contours as 3D point clouds of mirrors. The right side features more noise, since the incidence angle is much smaller there.

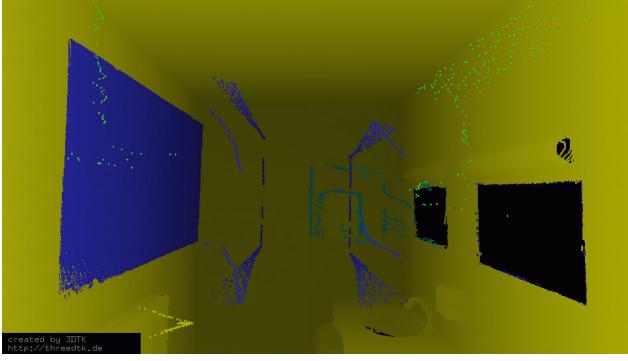


Figure 6: Screenshot of a corrected point cloud acquired by a Z+F 5006 Scanner in a bathroom environment.

mirror plane for a mirror contour, are calculated using the Principal Component Analysis (PCA) (Pearson, 1901).

In a second filtering process, contours having the specified mirror dimensions within a certain margin of error are identified. For an identified mirror contour, the original point cloud is corrected using the corresponding 2D contour as well as the calculated mirror plane. To this end, the OpenCV function `pointPolygontest` is used to find all 3D points which are projected within the 2D mirror contour. Those are then reprojected onto the mirrors plane, stored in a separate 3D point cloud and deleted from the original one.

6 DEALING WITH UNDEFINED PIXELS

There are many challenges in dealing with real-world data, such as dealing with undefined pixels in the panoramic image. High reflective surfaces, e.g., when scanning water, cause undefined pixels in when creating the panoramic image. This means there are pixels in the panoramic image onto which no 3D point is projected and therefore do not posses a range value.

Since these undefined pixel cause false jump edges and so lead to incorrect contours, a method for dealing with those has been developed. Therefore a `fillZeros` function assigns values to undefined pixels by copying the closest properly measured pixel from top-left in the 2D image coordinates. This algorithm often leads to shifting of the 2D mirror contour either towards the inside of the mirror or towards the outside. The second case is not a problem because normally the contour will still describe the frame or at least the mirror plane. In case of a shifting towards the inside, a second algorithm called `findFramePoint` fixes this by searching for 3D points which lie in the opposite direction of the mirror contours geometrical mean.

7 EXPERIMENTS AND RESULTS

The mirror identification software is implemented in C/C++ based on the Open Source software *3DTK — The 3D Toolkit* (Andreas Nüchter et al., 2015). The software has been tested with a Riegl VZ-400 terrestrial laser scanner and a Zoller+Fröhlich Imager 5006 in the same environment.

For both scanners all mirrors have been identified and thus the corresponding point clouds were corrected. The only case where mirrors cannot be identified at all is if mirrors in the panoramic representation are cut off by the panorama frame. This is because in the current software version the mirror contour cannot be detected as connected in these cases. In future work we will address

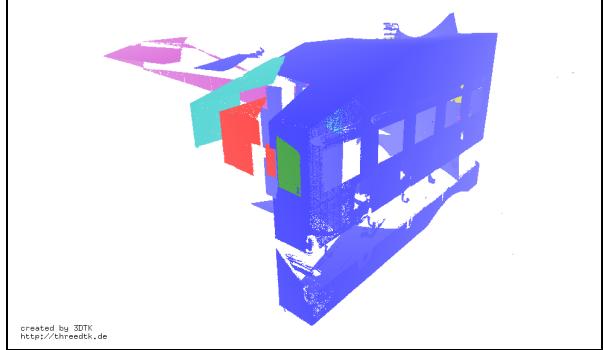
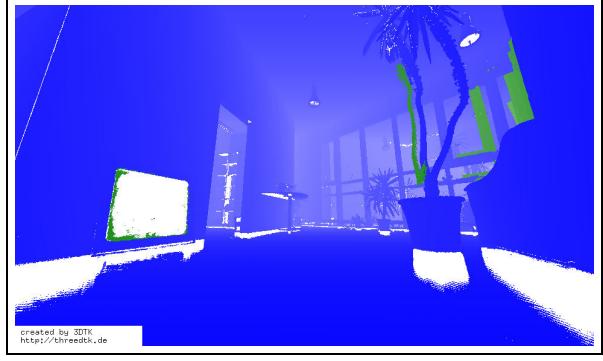


Figure 7: Screenshots of corrected point clouds in a point cloud viewer.

this issue by checking for mirrors when connecting the left and right side of the panorama image. For all tested point clouds, 3D mirror contour errors are up to 9 cm in x and y dimension and up to 3.5 cm in z dimension, which is due to the discretization induced by the (relatively low resolution of the) panorama image. There are two main effects that increase the 3D mirror contours and consequently also affect the error of the mirror plane and the corrected points. With decreasing incidence angle between laser beams and mirror plane, noise in the extracted frame increases, cf. Figure 5. If mirror plane and laser beams were parallel, the mirror would not appear at all in the point cloud.

Figure 8 shows the result of the automatic correction on data acquired with a Riegl VZ-400, a pulsed laser scanner. The top row and bottom row show that the 3D points are projected to the correct location. Figure 7 (bottom) gives a 3D view of the bottom row of Figure 8. The remaining misalignment can easily be resolved using scan matching methods, such as the ICP (iterative closest points) algorithm. The middle row of Figure 8 demonstrates, how our software can be used to look around the corner using a mirror.

All presented algorithms are also applicable to scans of a Zoller+Fröhlich Imager 5006, which measures according to the phase-shift principle. Nevertheless, there is one difference in the outcome. The corrected point clouds of the Zoller+Fröhlich Imager contain several points “flying around” which look like 3D mirror contours but shifted relative to the scanner, cf. Figure 6. Those points arise from the different principle of operation. Due to the finite spot size, if the laser beams hits the mirrors frame, the measurements are averaged between the frame point and the mirrored point. In contrast to the Riegl, this scanner is not able to distinguish several targets by Full Wave Analysis. Since those faulty points are reprojected by the correction algorithm. Figure 6 shows a 3D point cloud with corrected mirrors and erroneous contours.

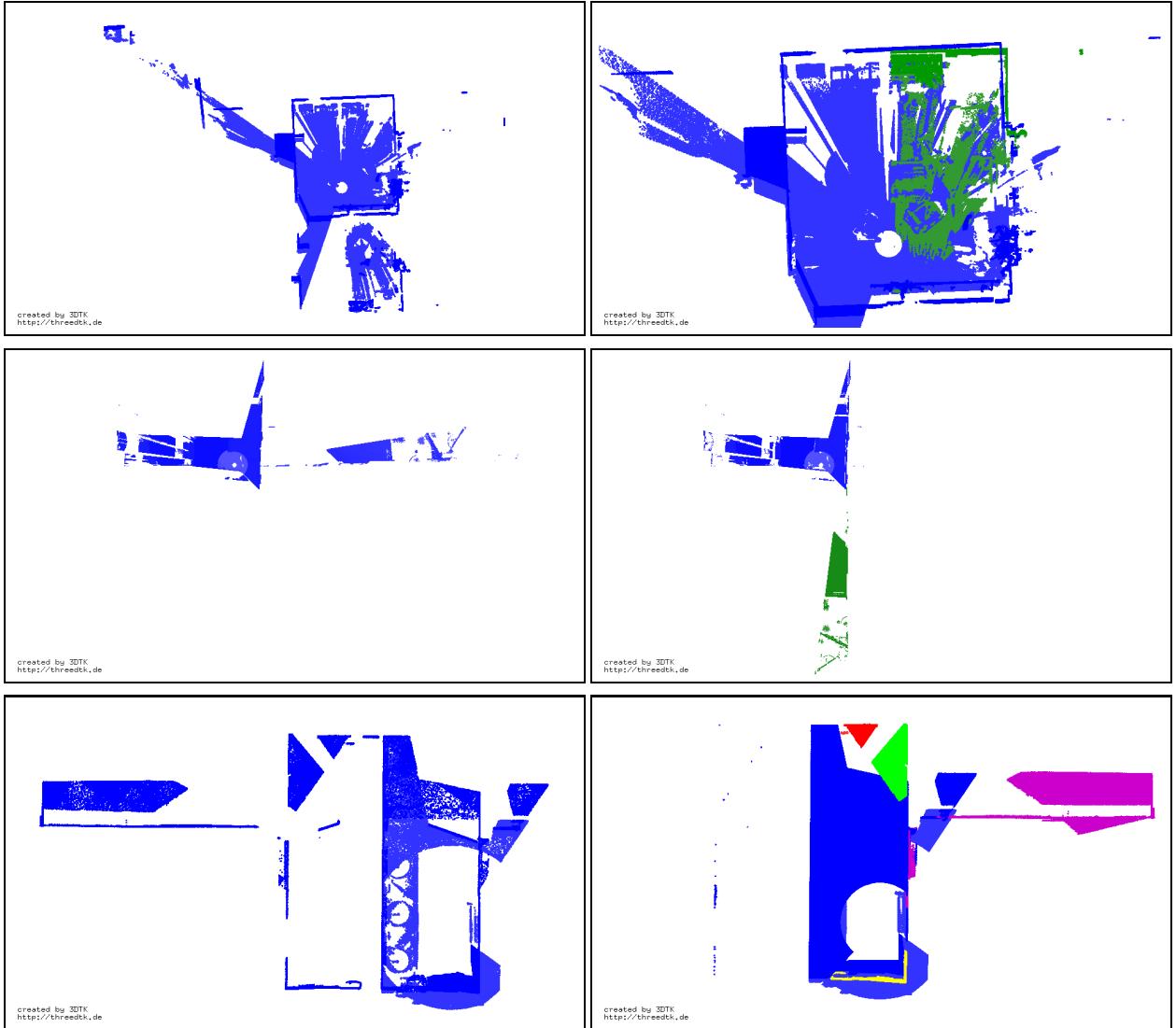


Figure 8: Screenshots of 3D point clouds in bird eye view. Left: Uncorrected point clouds. Right: Corrected point clouds. Top: Office environment. (Note that right picture is zoomed) Middle: Office corridor. Bottom: Bathroom with 5 mirrors.

8 CONCLUSIONS AND OUTLOOK

This paper describes a complete solution to correct point clouds that contain a mirror of known size. It has been demonstrated to work well in various environments and with pulsed and phase-shift scanners.

Needless to say, a lot of work remains to be done. In future work, we will concentrate on arbitrary mirrors, i.e., without knowing the mirror size in advance. Furthermore, we will integrate this technology into our registration and mapping methods and aim to develop a method to distinguish mirrors from windows. Overall, we aim at reducing the time needed for manually correcting and post-processing 3D point clouds.

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