Taming errors... pt. 3: On artificial targets for scan registration

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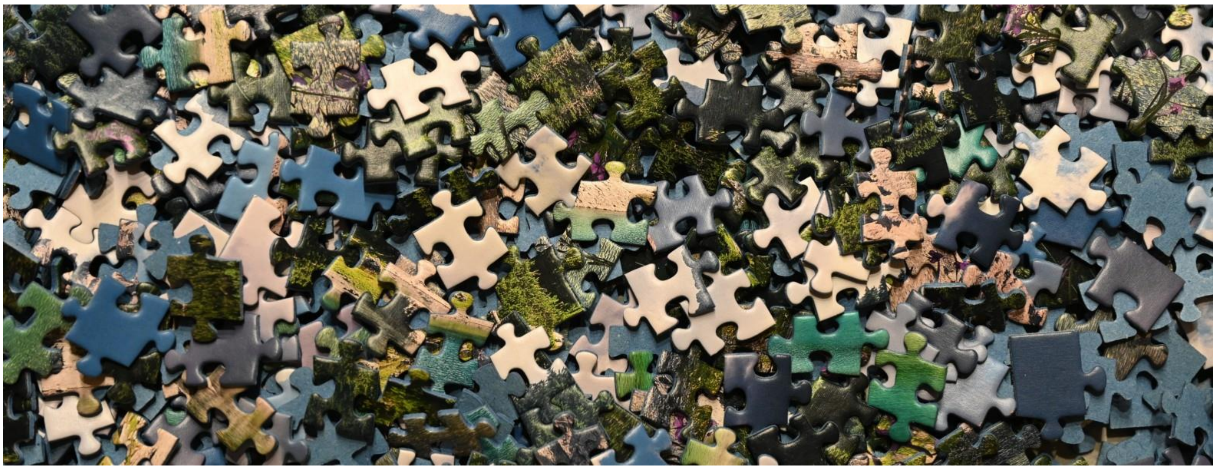
12th September 2019



2.2.2 Artificial targets

A quite common way of transforming several scans into an equal coordinate system or reference frame is by using artificial targets. Therefore, spherical or planar checkerboard targets are used, which must be placed within the scene. The locations of at least three targets per viewpoint must be chosen in a way that they do not lie on a straight line but span a potentially large area. If the task is to transform an already registered block into a reference frame by means of control points, then again at least three targets are necessary per scan block.

After data acquisition, the target centres need to be determined either by computing the centre point of the sphere through adjustment calculation or by using appropriate algorithms (Abmayr et al. 2008, Janßen et al. 2019). After extracting the target centres, point to point correspondences are established. Based on this information registration parameters among the viewpoints and between a scan block and a reference frame can be computed and finally applied to the corresponding point clouds. The figure below shows a selection of different checkerboard targets.

Figure 1: A fine selection of checkerboard targets
(image courtesy of Jannik Janßen, University of Bonn, Germany)

The reason why artificial targets are still very popular is three-fold; in contrast to the ICP it does not require pre-alignment for registration, the problem of aliasing (see part 2) is compensated to a satisfactory degree which allows to compute reproducible points and consequently to establish point-to-point correspondences – just as in tacheometry. Long story short: people can continue to work as usual – even if it does not make sense.

Why so pessimistic? Well, several disadvantages can be associated with this strategy such as the tremendous effort of distributing the targets in the area of interest which slows down the process of data acquisition and consequently making no sense from an economic point of view. A general assumption of this approach is that the majority of targets remain geometrically stable throughout the survey campaign. However, this might not be the case, especially in public spaces - since artificial targets have numerous natural enemies such as:

- Construction workers, janitors, pupils, teenagers, kids and old folks (cleaning up this mess)
- moisture in the context of paper targets
- reflection in the context of laminated paper targets
- pets
- wind and heaps more.

From the perception of geometrical quality, the omitted use of the inherent redundancy within the overlapping region has to be seen quite critical. In other words, the overlap between two scans may contain several million points – but only a handful of points are used in the end to establish the transformation parameters. That brings us right to the subject of target configuration and quality assurance. Targets should be located in a way that they are i) well distributed so that they span a potentially large area within the overlapping region and ii) most importantly are therefore not collinear. Otherwise numerically instable results arise while the quality measures, usually described by residuals between targets, indicate a satisfactory result.

In order to demonstrate the impact of target configuration let us perform a little experiment. What you need are two beer coasters, slices of a wine cork, a pen and three thumbtacks. Each coaster represents a single scan, the crosses highlight the locations from where the data was captured, and the boundary of the overlapping region is signified by a line. At first, “drill” holes close to each other in the centre of the two coasters by using the pen. Then put the tacks in the holes and stick them into a cork slice that is located on the other side of the coaster. Fix the first coaster with one hand, wiggle on the second one and watch the movement of the cross on the second coaster. Repeat the experiment but this time place the holes close to the boundary of the overlapping region. Note that this concept is similar to the Gruber region (Gruber 1924) in classical photogrammetry. What you will notice is that the coasters will be less stable in the first experiment compared to the second one. That’s not really surprising but what is astonishing is that the “residuals” in both experiments are numerically more or less the same. The residuals in our case are described by space around the tack which has the diameter of the pen’s tip. In summary, we can conclude that residuals are easy to interpret BUT do not always tell the whole story (just as in the case of the ICP; see part 2). We will have a look at alternative quality measures in the next section.

Optional: If you’re keen to simulate Cloud to cloud registration with this simple experiment, then add about 20 holes to the overlapping area. In order to replicate the lower degree of precision for every single correspondence wiggle the pen around so that each hole increases its diameter.

Figure 2: Two scans with a poor distribution of artificial targets (left), covering the Gruber region (centre) and finally “registered” by thumbtacks (right)

As mentioned earlier there are two strategies to determine the centres of artificial targets. The first one using spherical targets is solely based on geometric information. Therefore, points, which were captured on the surface of spherical targets, are processed within a least squares adjustment to estimate its unknown parameters. A sphere can be parameterised by its centre point as well as its radius. Apart from just estimating (yes, this is the proper term for adjusting parameters) the unknown parameters, every adjustment also analyses how well these parameters have been determined and are hence vital for quality assurance. And that brings us straight to the pros and cons of this strategy. Spheres have a miraculous characteristic which is very helpful for registration: they are invariant against a chosen perspective - they look the same from everywhere. In addition, the aforementioned quality measures are geometrically interpretable. However, these targets are costly and bulky so that hence a scan operator typically has only a handful of targets. This means, that these targets are usually used to register pairs of scans which excludes the option of adding redundant connections for the sake of control.

The second strategy is based on checkerboard targets which uses a mixture of geometric and radiometric (intensity values) information as input. At first, a plane is adjusted through the points captured on the target while intensity values are used to determine a vector to the centre of the target (note that there are many ways to achieve this). This vector is finally intersected with the plane yielding in a single point. The vast majority of algorithms in commercial implementations used to determine the target centres are based on image correlation. This approach is well-known and arguably applicable in practice yet their quality measures, the correlation coefficient, cannot be interpreted in a geometrical way which is important in weighting individual target centres. An undesirable effect arises if paper targets are placed on curved surfaces such as pipes or are scanned from very slant angles of incidence. The consequence is that the detected target centres are likely to be biased, as depicted in Figure 3, yielding in increased residuals between different scans. An advantage of this approach is that these targets can be simply printed on paper and are hence quite cost-effective.

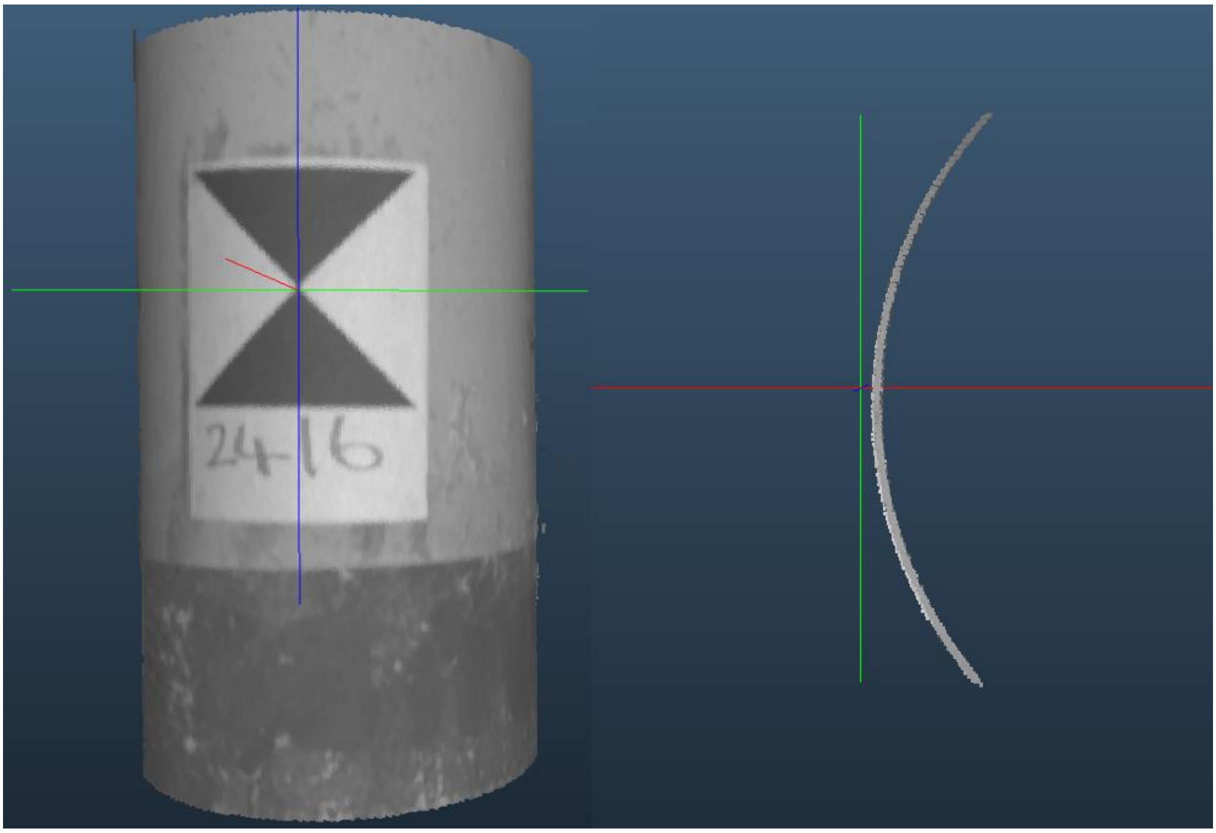


Figure 3: Erroneous target centre detection (image courtesy of Christoph Held, Zoller + Fröhlich, Germany)

The thoughts and arguments mentioned above draw a dark (but realistic) image of targets for registration. Yet, there is hope since these little helpers are quite handy when transforming individual or already registered scans into a superior coordinate system. Unfortunately, people overestimate or are simply unaware of the error budget that is involved when connecting scans to a coordinate system other than the ones of a terrestrial laser scanner. First of all, every sensor (and registration algorithm) is subject to error propagation. Thus, it is foolish to assume that all points are equally accurate - or even worse – error free! If your aim is to insert e.g. tacheometric control points, then perform a block adjustment (there will be more about this subject at a later stage) and introduce the individual accuracy of every single point. Otherwise, the inner geometry between scans can be severely distorted. The other important source of uncertainty in the error budget of artificial targets is the digitisation error that determines how well a centre was detected – which is also an individual measure that people rarely consider.

References

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