# Taming errors... pt. 2: The correspondence problem, sufficient overlap and Cloud2Cloud registration

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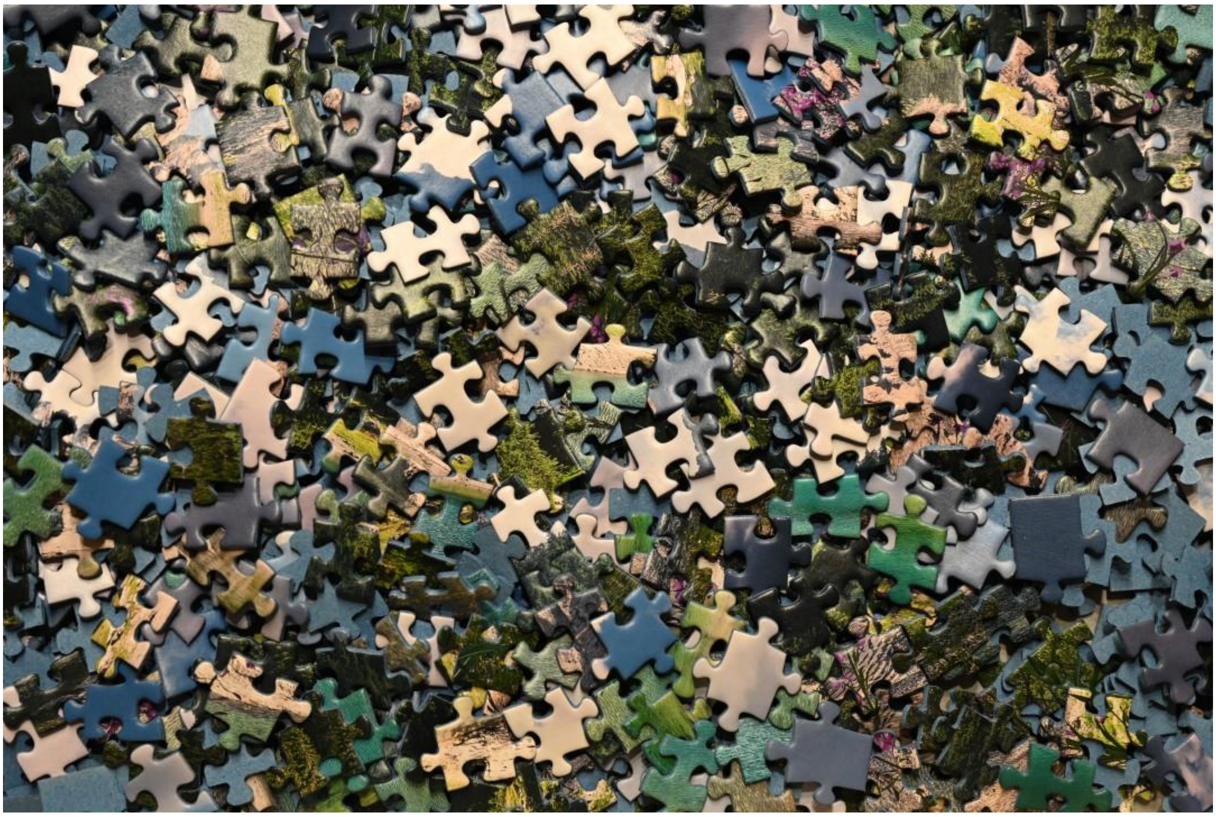



## 2. Measurement and computation of registration parameters

Several people obstinately believe in mystical creatures, a few are convinced that Elvis never died and way too many people think that registration is the simple task where laser scans are stapled together in a Frankensteinian fashion. Before the latter argument will be torn into pieces later on in this series, we have to understand a little bit more about how these algorithms and methods work. In general, scans can be referenced by using redundantly captured areas within point clouds (also referred to as (co-) registration) based on which registration parameters can be computed or by measuring their orientation and location with regard to a superior coordinate system.

### 2.1 The correspondence problem

Engineers are usually not known to be artsy-fartsy people. However, if you have a slightly different look at terrestrial laser scanning you will note some similarities to art. Imagine you'll ask ten artists to draw a painting of the bust of Nefertiti. What you will receive are ten different artistic interpretations that all describe the very same object of interest. Imagine you'll ask ten surveyors to scan the bust of Nefertiti. Long story short: you will receive ten different geometric descriptions that all consistently describe the very same object of interest – yet they are not directly comparable.

The figure below exemplifies this effect based on three different scan lines which were taken from slightly different viewpoints. It is obvious that the points captured from different locations yield in different point samplings. Imagine you'd connect all the points from one dataset – what you will receive are three different triangulations of the scans. If you then transform these results into a common coordinate system you will get the outcome on the very right. It appears that the object has deformed while the scans were captured even though what you see is called aliasing, an effect that is hardly controllable in laser scanning.

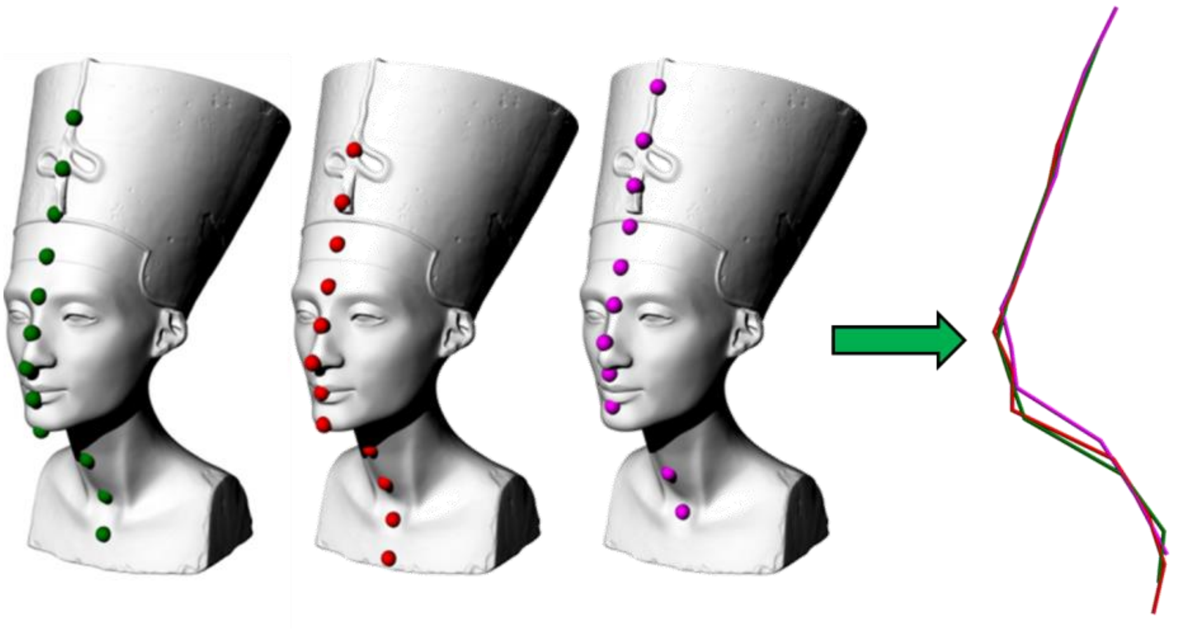

Figure 1: Genesis of pseudo-deformations due to aliasing (Wujanz 2019)

The example above has shown that aliasing is an unsolvable problem since you will never hit the exact same points with a laser scanner again (even if you scan twice from the very same viewpoint and identical settings). Hence, aliasing is rather bad news for the computation of registration parameters since we have to question the concept of point-to-point correspondences which is widespread and well-established in Geodesy. This also means that the local point resolution has an immediate impact onto the outcome. As we will see later, there are some concepts that are capable to compensate the impact of aliasing.

## 2.2 Computing registration parameters or how much overlap do I need?

It is apparent that we need overlap between point clouds in order to register them. The decisive question is: how much? Well, people have various opinions about this issue ranging from "*…at least 10%...*" to "…*enough*…". As you can see, the suggestions that I've taken from the laserscanningforum.com are rather vague. So, let's have a look at two examples where we have a lot of overlap as illustrated in the figure below. The table represents one point cloud (which is considered as the reference coordinate system) while the piece of paper represents the other.

In the first part of taming errors we've established that it usually requires three unknown rotation and three translation parameters in order to perform a 3D-registration. The scenario on the left side of the figure contains enough geometric information to solve three degrees of freedom. Yet, the piece of paper can still be shifted in two cardinal directions and rotated around the vertical axis that is parallel to the table's surface normal. The second example on the right shows a similar case yet contains more "geometric contrast" – the piece of paper was folded in a 90° angle and is now "registered" to the edge of the table. As you can see, the higher degree of geometric information allows us now to solve 5 degrees of freedom. The remaining one is the shift along the edge.

These examples showed us that we i) cannot simply quantify overlap and then assume that we will receive meaningful registration parameters and ii) that we need geometric information that is distributed in three different directions for registration. So, can we quantify "geometric contrast"? The answer is yes! You could for instance use the principle component analysis to characterise the overlapping region of two scans. BUT, registration is a challenging problem and still has heaps of potential to screw up the outcome - despite great numbers.

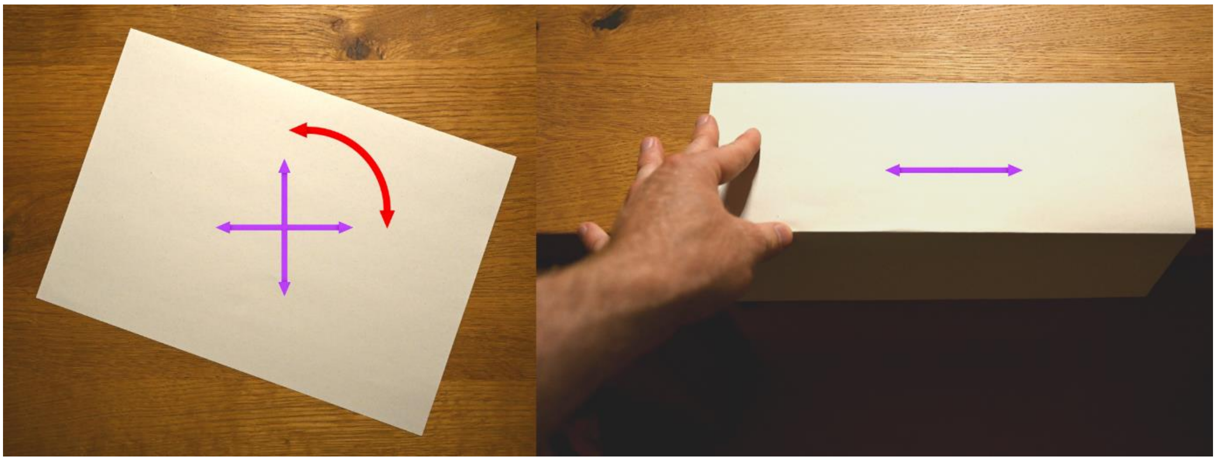

Figure 2: Overlap between two datasets that allows you to solve 3 (left) respectively 5 degrees of freedom (right)

### 2.2.1 Iterative closest point algorithm (ICP or Cloud to cloud)

The most versatile registration method is the iteratively closest point algorithm (ICP) which is also referred to as Cloud to cloud registration in practice. The input of the ICP are redundantly captured regions of two point clouds based on which registration parameters are computed. A substantial advantage of this strategy over target-based registration is the actual use of the redundant information in the overlapping regions of two or more point clouds. ICP-based algorithms rely on a sufficient pre-alignment of two datasets – otherwise they likely converge to local minima and consequently in erroneous results. The general concept of this algorithm is depicted in the figure below where the initial setup is highlighted by red boxes. Three general options can be used to satisfy the pre-alignment namely (i) manual determination of a few correspondences, (ii) measurement of the individual location and orientation of two scans by additional geodetic sensors (more about this in the next part), which today may be frequently found in up-to-date laser scanners, and (iii) use of pre-alignment algorithms.

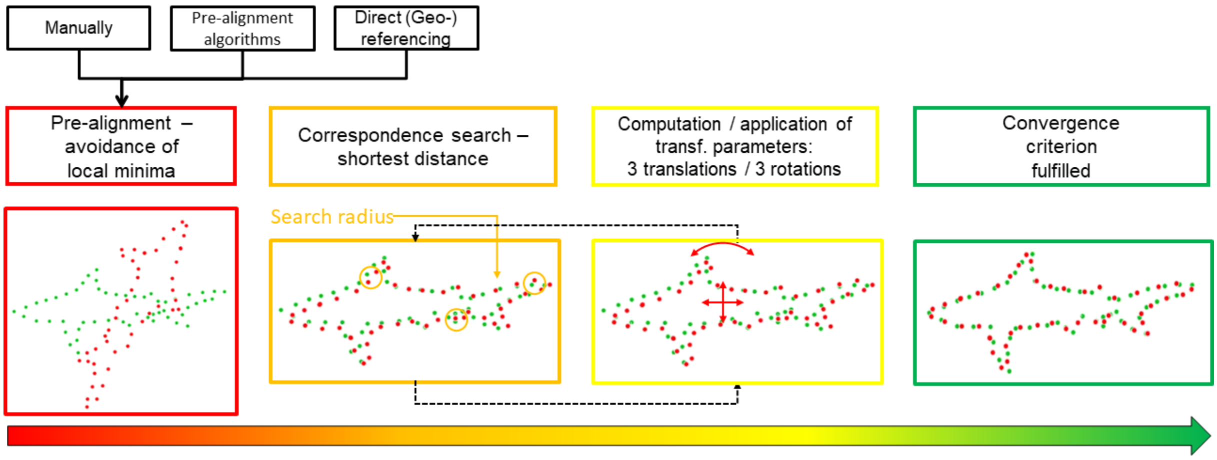


Figure 3: Workflow of the ICP-algorithm

The next step, as emphasised by orange boxes, is the correspondence search. Depending on the implementation correspondences are either determined by the shortest distances between one point to another (Besl & McKay 1992) or from a point to a plane (Chen & Medioni 1992). Based on this information registration parameters are computed and applied to one of the datasets as highlighted by the yellow boxes. The black dotted arrows between the orange and yellow boxes indicate that these steps are iteratively repeated until a convergence criterion is fulfilled, and the final solution has been found. A consequence of the iteration is that different correspondences are established during the course of the algorithm.

Let's have a closer look at the correspondence problem on example of point to point correspondences (Besl & McKay 1992). The figure below illustrates a single point from one point cloud, highlighted in red, and three points from another point cloud that are tinted in green. Point to point correspondences are established based on the closest distance between a point from scan A and a point from scan B as highlighted by the yellow sphere in the centre of the figure. Assuming that the right part of the figure shows a single point correspondence based on the final alignment of a cloud to cloud registration, the yellow line represents the final misclosure. Imagine you'd be using an error-free scanner: the differences in point sampling would still be causing notable residuals even if a perfectly planar surface was captured. Hence, it is obvious that the local point sampling has an immediate influence on the error metric.

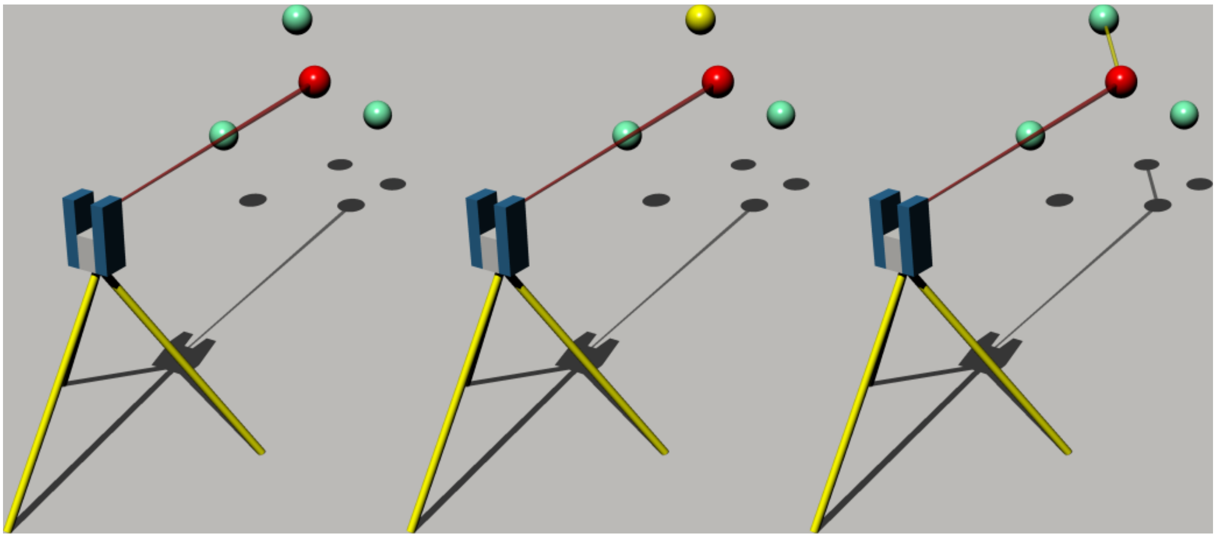

Figure 4: The concept of point to point correspondences (Wujanz 2019)

In order to at least compensate the aforementioned effect Chen & Medioni (1992) suggested to establish point to plane correspondences. Figure 5 uses the very same geometric example as in Figure 4 but now we triangulate the points of the reference dataset. Then, the face normal of the triangle is computed and the red point from the second dataset is projected onto the triangle yielding in the yellow error vector as depicted in the centre of the figure. This course of action is the equivalent to a linear interpolation and thus compensates differences in local point sampling (BUT only if there no notable aliasing effects). Consequently, the error vectors are usually smaller compared to the metrics of point to point correspondences. An unpleasant scenario is shown on the right of the figure where an additional point was added to the scene which leads to another triangle. The red point can now be projected on two triangles leading to an ambiguity.

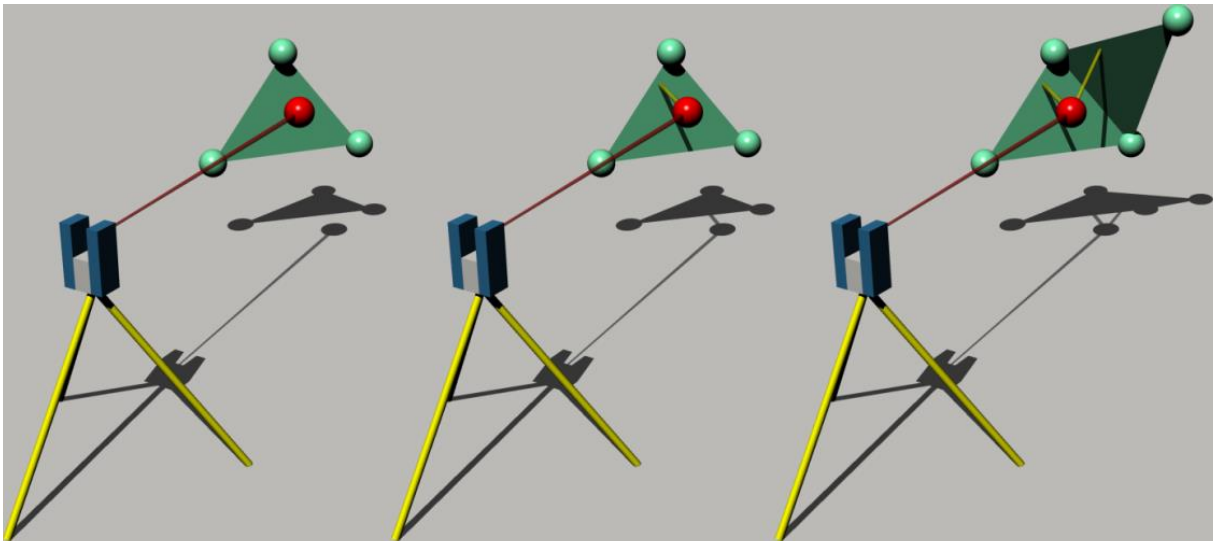

Figure 5: The concept of point to triangle correspondences (Wujanz 2019)

A common problem in ICP-based algorithms is quality assurance which is demonstrated in the following. Two entirely different datasets, see Figure 6, serve as input that were registered with a commercial solution. The settings of the algorithm can be found on the bottom left of the figure. The sample size indicates for how many points the ICP should try to find correspondences. Leaving this value unrestricted would be very computationally demanding. The second value determines the largest distance between two points from two datasets that can form a correspondence. It is obvious that the resulting quality measures of the ICP are always smaller than this value. The right-hand side shows the generated result which is obviously non-sense even though the numerical quality measure, which is the mean residual of the corresponding points, indicate a very accurate result. This example illustrates one characteristic of the ICP: it always finds a solution – yet not necessarily the right one. Hence, visual inspection is always recommended when using this algorithm. However, simply looking at data is quite subjective. Hence, a more sophisticated solution for sound quality assurance will be discussed later on. In addition, ICP-based approaches are very delicate against changes that occured in a scene in between scans (Wujanz et al. 2016)

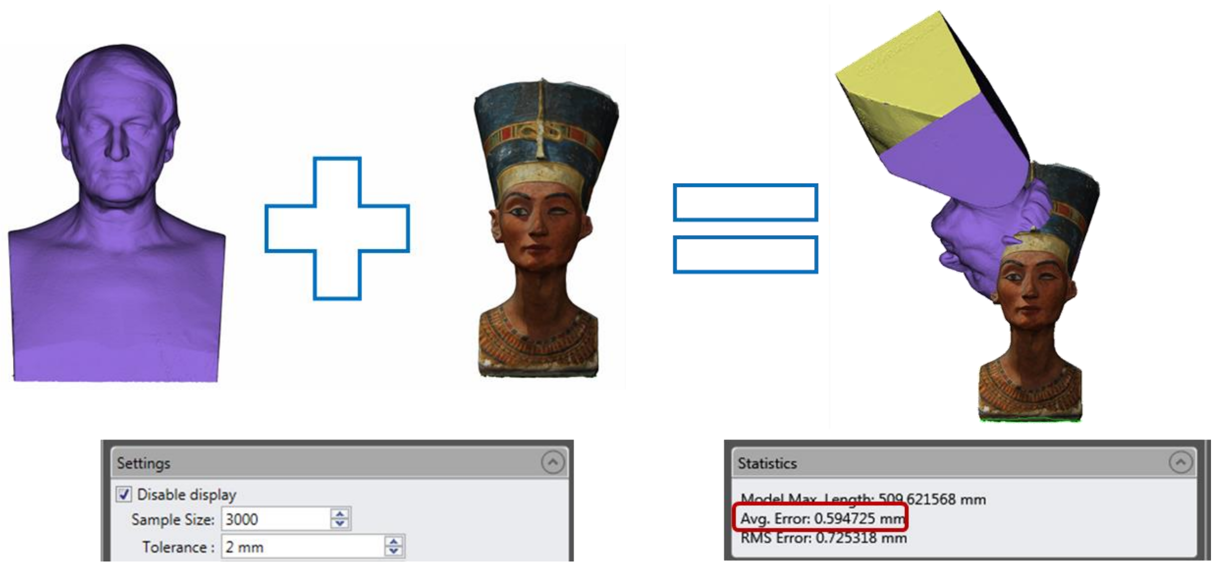


Figure 6: The issue of numerical quality assurance with the ICP

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