Taming errors... pt. 1: The importance of registering terrestrial laser scans

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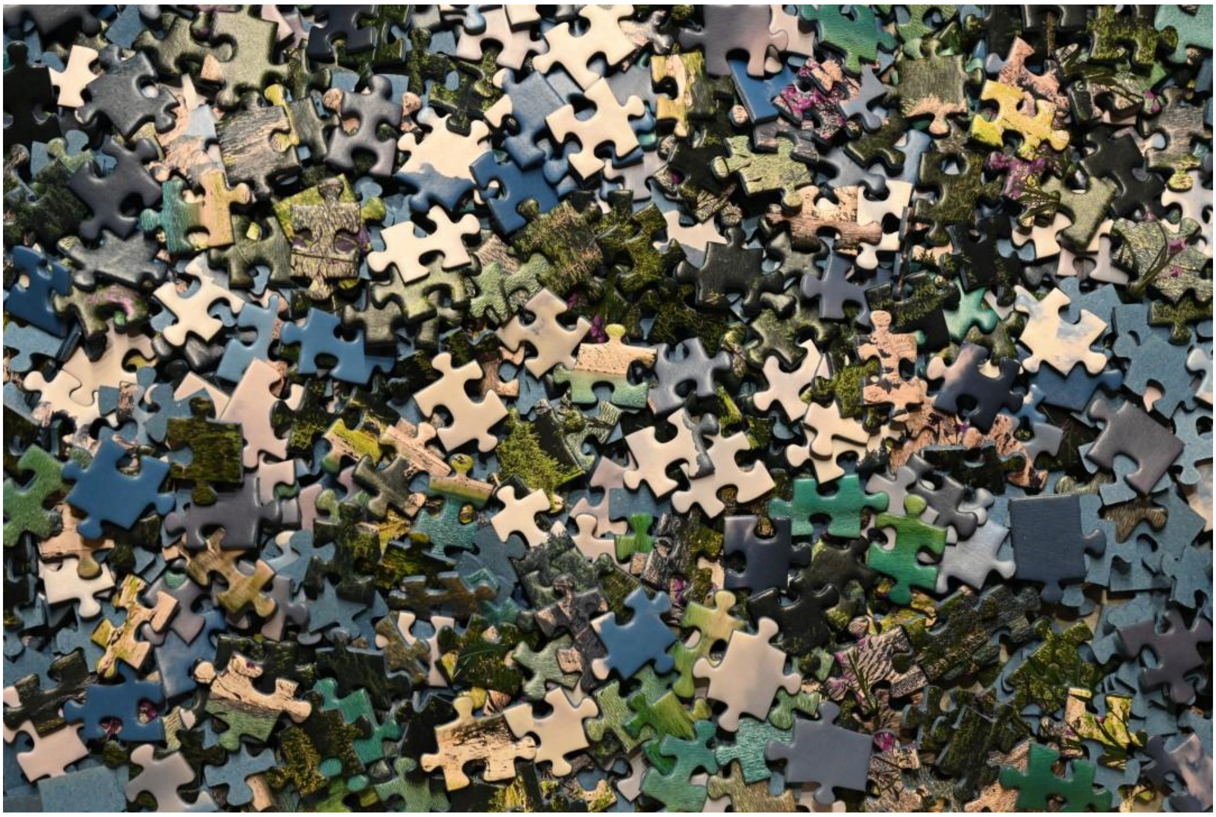

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1. Motivation

A frequently proclaimed statement about Terrestrial laser scanning is that the resulting point cloud features accuracies in the magnitude of millimetres. Interestingly this argument holds - yet only if your final product can be derived from a single laser scan where the error budget solely comprises components that are provoked by the scanner itself. In all other cases, where an object of interest must be captured from several viewpoints to receive a potentially complete documentation, the error budget increases by the influence of the so-called registration. Registration or referencing is nowadays unfortunately treated as being a triviality which do not require any Geodetic expertise or engineering skills in general even though it certainly does as you will note while reading this series. Registration is far more than just clicking a button, waiting on an unknown algorithm to finish.

1.1 What is registration?

Every scan that you capture with a terrestrial laser scanner is restricted to its current field of view. Hence, it usually requires several viewpoints to entirely capture an object of interest. Since every scan is given within the scanner's own local coordinate system so-called transformation or registration parameters need to be computed.

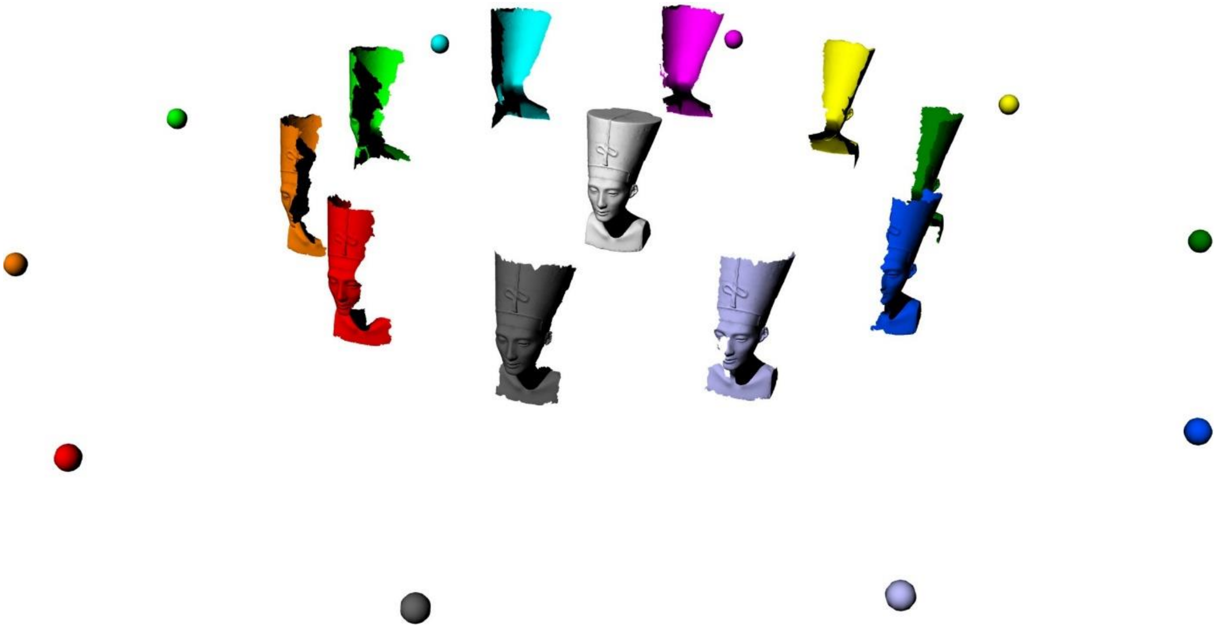

Figure 1: Object of interest (light grey), scanner's viewpoints (coloured spheres) and resulting scans (represented by coloured meshes) (Wujanz & Neitzel 2016)

Knowing registration parameters allows you to transform one point cloud into the local coordinate system of another. A 2D-example is depicted in Figure 2 in form of a puzzle. The general aim of puzzling is to assemble a connected entity that consists of individual pieces – just as in the case of terrestrial laser scanning. In order to achieve this, a single piece can be rotated around the origin of its local coordinate system as well as shifted along X and Y. These three parameters are also referred to as degrees of freedom (dof).

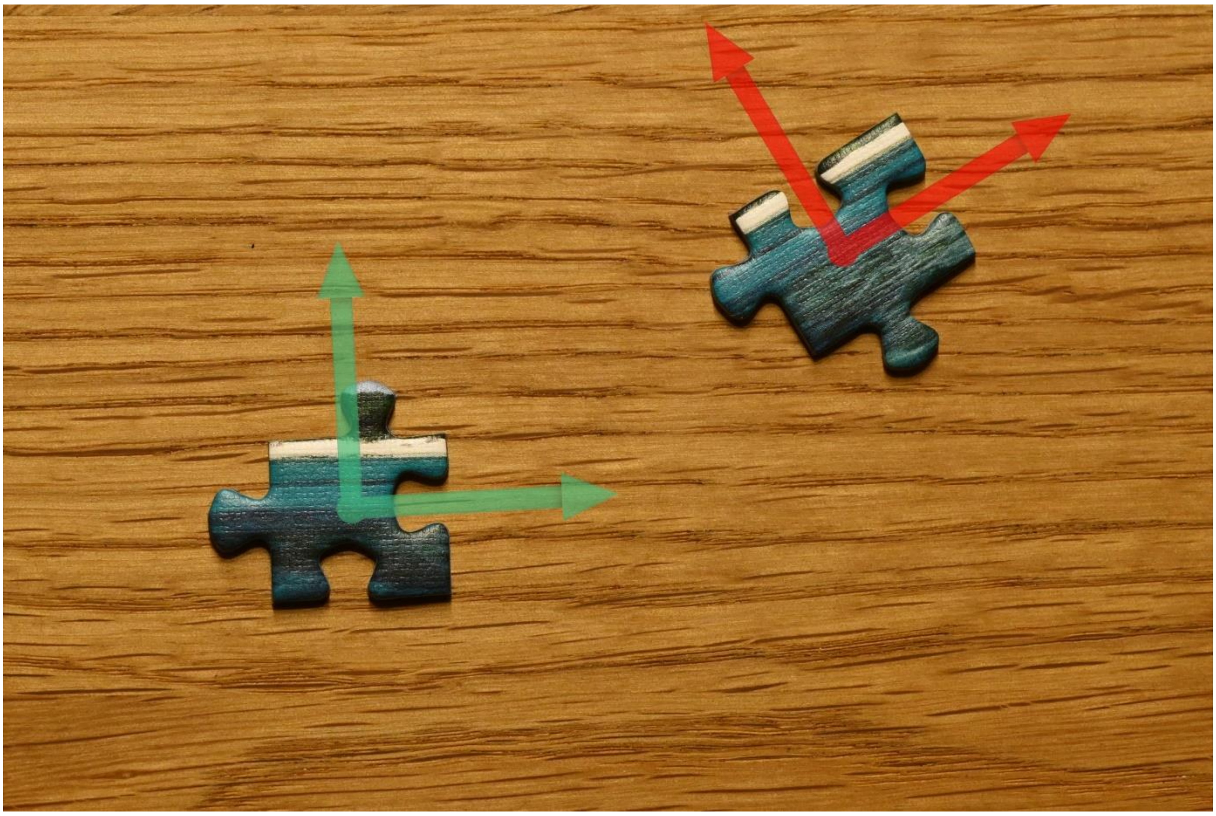

Figure 2: Local coordinate systems of two pieces of a puzzle

In the case of 3D-laser scans six degrees of freedom need to be solved since shift and rotation can be applied to the three cardinal axes X, Y and Z. The equation below shows how the registration between scan *A* and scan *B* is computed. Based on the registration parameters that include **t**, which denotes the relative shift between the two coordinate systems, as well as **R,** which represents the corresponding rotation, the coordinates of scan *B* are registered into the coordinate system of *A*.

$$\begin{bmatrix} x_A \\ y_A \\ z_A \end{bmatrix} = \mathbf{t} + \mathbf{R} \cdot \begin{bmatrix} x_B \\ y_B \\ z_B \end{bmatrix}.$$

Note that there are many ways to compute or measure registration parameters as we will see later in this series, yet it is apparent that the accuracy of registration has an immediate impact onto the outcome. It may not sound like much, but the problem space becomes much larger and accordingly more complex for 6-dof-problems in comparison to 3-dof ones as exemplified earlier by the puzzle. Consequently, users of **ANY** registration software must hence cope with false registrations which are inevitable. We will discuss this issue from an economic perspective in section 1.3 as well as in detail in the context of quality assurance.

1.2 Well, it’s not just the sensor – the issue of error propagation

One thing that sensors and human beings have in common is that whatever you do, you always do it slightly wrong. In the context of sensors this imperfection is referred to as noise respectively precision, uncertainty or accuracy even though these terms mean slightly different things. Although it is definitely important to know how accurate the applied sensor is, it is always vital to know the entirety of factors that influence the outcome and, most importantly, how to quantify and “tame” them. Let’s have a look at a simple example.

Imagine a client asks you to determine the distance between Berlin and Moscow with an accuracy better than 2 millimetres. To cut down costs you’re deploying a tape measure provided by a Swedish furniture store. Since the length of the tape measure is just 1 metre, you must determine the distance in small steps. This is achieved by repeatedly measuring a single metre and placing the tape measure to the virtual end of the previous length.

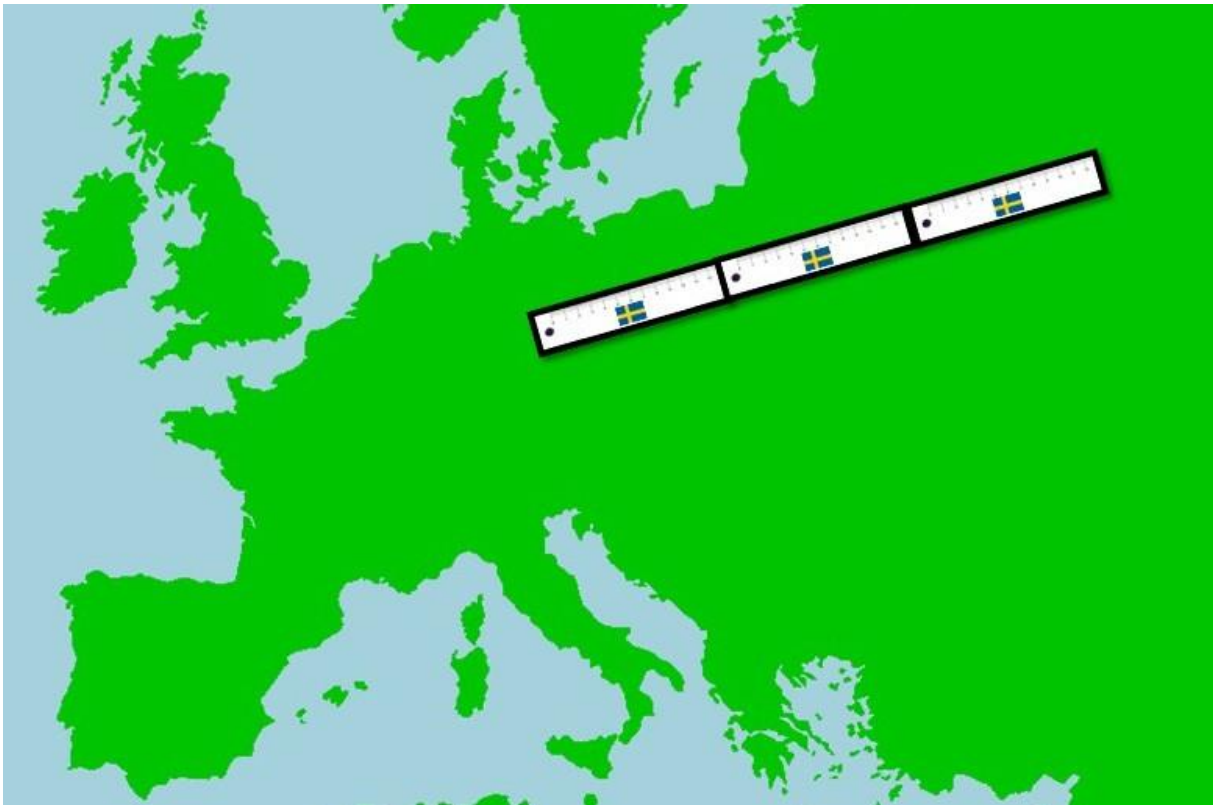

Figure 3: Measuring the distance between Berlin and Moscow with a tape measure

When the client requests a proof, that you have satisfied the desired accuracy you simply refer to a resolution and accuracy of 1 mm – which is the one of your “measurement device”. What you’ve neglected is, among other influencing factors, the error of placing the tape measure repeatedly.

In terrestrial laser scanning a similar simplification is frequently used to persuade potential clients – the influence of registration is simply left out of the equation yielding in unrealistic and hence meaningless results. This is rather astonishing since a tool called error propagation to gather and quantify all influencing factors is widely known in Surveying and Geodesy for quite a while (Helmert 1872).

For this reason, geodesists and surveyors always look at the problem from two perspectives: a functional and a stochastic one. The statement "The distance is 137 m..." is for them only a part of the truth. The statement only becomes complete when one adds "... and has an accuracy of 3 mm". The accuracy of a value depends on two factors: the accuracy of the sensor and the error propagation during the calculation of the value.

Let’s go back to the example of the puzzle and imagine that every piece represents a laser scan. The figure below illustrates the result from a functional perspective, which is the puzzle in the centre, as well as the stochastic one highlighted by translucent puzzles. It is obvious that adjacent pieces nicely fit together so we could say that the relative quality measures between two scans must yield in small numbers. What these numbers do not tell is how the error accumulates, the more pieces are added to the puzzle.

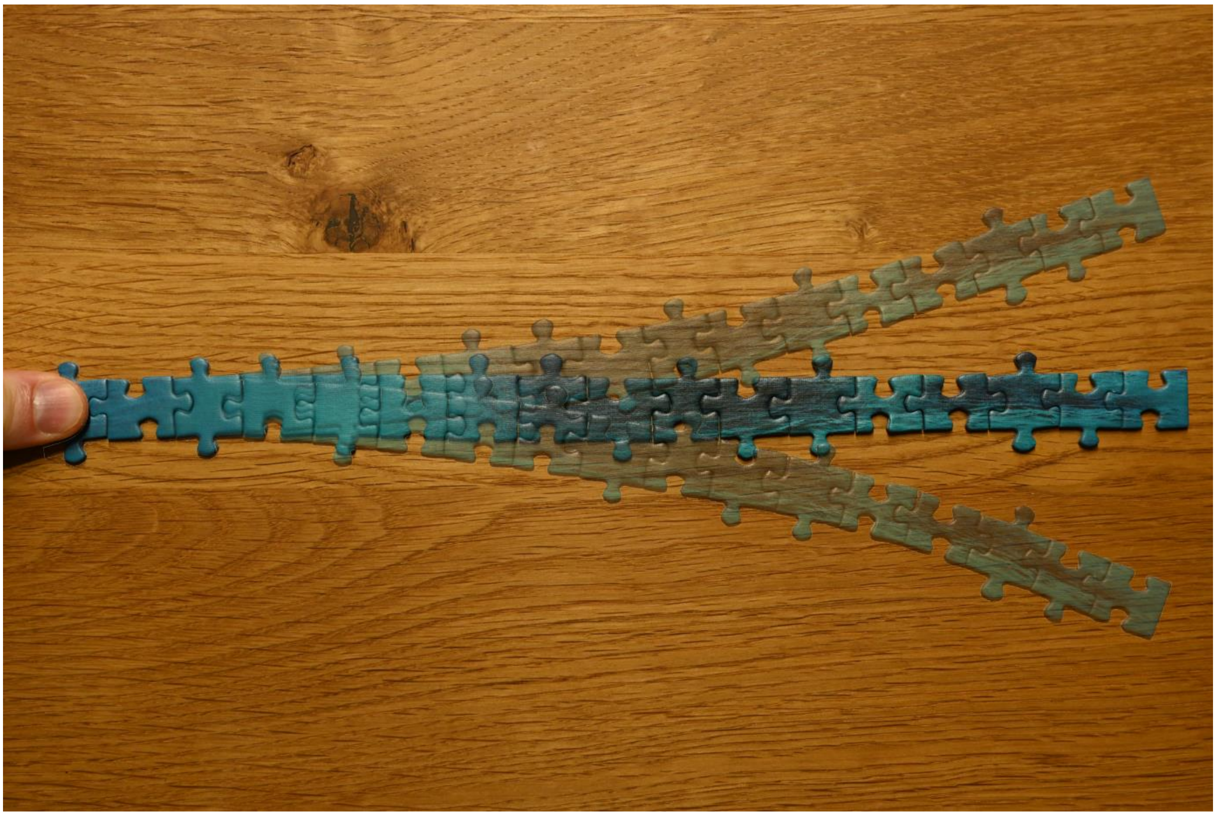

Figure 4: The effect of error propagation exemplified on a puzzle

The task of error propagation in the context of laser scan registration is to predict the resulting error that is provoked by the network configuration considering various error sources. In essence, these quality measures indicate the geometric stability of your network which is needed, e.g. to prove that your registered scans are accurate enough to verify a scanned structure in the light of a specific building tolerance or the specified accuracy of a client. Hence, the task of the engineer who performs registration is to design a network in a way that it fulfils given requirements.

1.3 The economic impact of registration

Let's have a look at the economic influence of registration at project scale which is depicted in Figure 5. It shows four different typical stages of scanning projects starting from thorough planning and data acquisition. Once the data is captured the primary data processing stage begins for instance by converting file formats, filtering and of course registration. In the second step, the actual deliverables are produced e.g. by digitising objects in the point cloud or performing deformation measurement between two different epochs. The vertical axis illustrates the chance of influencing the outcome as well as the corresponding cost of change.

The hideous effect of registration is that it can a) create errors easily exceeding the error of the scanner itself and b) that registration causes systematic errors that affect all other connected scans. Hence, it is desirable to identify false registrations or tensions in your network rather sooner than later in order to avoid costly revisions. It is always unpleasant if e.g. a member of your CAD-department, or even worse, your client points out existing issues. Interestingly the economic loss may hit you on two levels namely the time to fix false registrations and all related deliverables and of course the loss of reputation since customer tend to talk to each other.

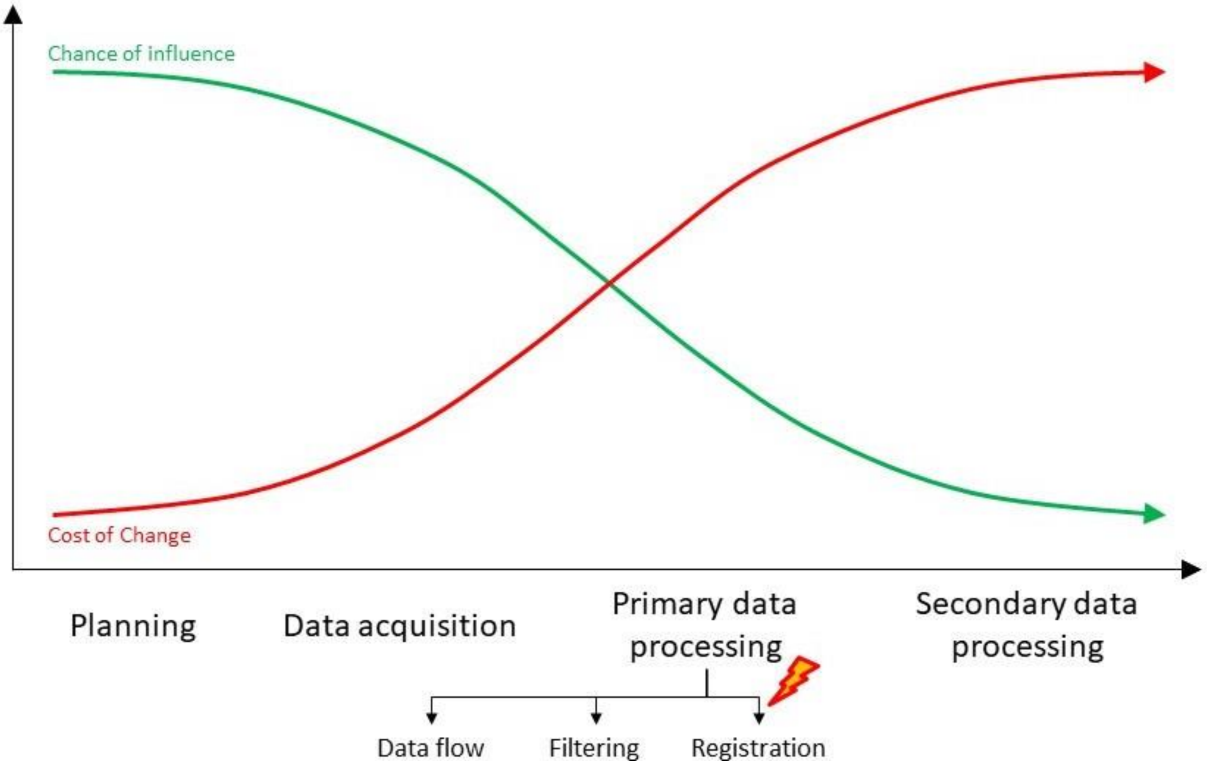

Figure 5: Influence of registration in the p

rocess chain of a laser scanning project

Now, let's look at economic risks at market scale. For more than a decade, marketing strategists of some laser scanner manufacturers did a great job in telling you that everyone can collect and process scans in order to create a bigger market. Well, in theory I could perform brain surgery equipped with a carpet knife, an electric saw, a needle and some string. However, it requires more than just a few tools to carry out complex tasks - it also requires expertise. The inherent economic danger in simplifying problems beyond recognition is that poorly trained users pass on erroneous deliverables to their customers which consequently endanger the entire laser scanning industry.

References

Helmert, F. R. (1872). Die Ausgleichungsrechnung nach der Methode der kleinsten Quadrate: mit Anwendungen auf die Geodäsie, die Physik und die Theorie der Messinstrumente (Vol. 1). Teubner Publishing.

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