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VOLUME COMPUTATION -
*a comparison of total station versus laser scanner
and different software*

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Abstract

The Laser scanner belongs to the new devices on the market of surveying instruments. Tests and measurements gave and still give information where a laser scanner can be used efficiently – partly better than a total station. The results of each measurement are calculated with the corresponding software of the producer or with the corresponding CAD or other surveying programs depending on the scanner. The user cannot recognize which basis is used for the computation at most of the products. A conventional surveying program is not fit for a calculation with big amounts of data, which are the result of a laser scanner measurement. Programs shut down or becomes very slow, thus a processing of the data is impossible. Consequently, the data – the number of points – have to be reduced.

These aspects results in three questions, which where investigated in this thesis:

- Laser scanner versus total station: What is more accurate and what is more efficient?
- Do different software products result in equal outcomes?
- How far can a point cloud be reduced until there are changes in the result?

To answer these questions a pile of sand (size around 400 m^3) were surveyed twice: once with a laser scanner – Leica HDS 3000 – and once with a total station – Leica TPS1200. The data of the measurement were computed with three different software products: Geo, Geograf and Cyclone. Additional to this the point cloud was reduced stepwise and in each case, the volume was calculated. Thus, the effect of the reduction could be observed.

Between the different methods, no differences result in the accuracy and - in this investigation – hardly in the time for the measurement. The results of the computations showed that there is no difference between the programs Geo and Geograf. Just the result of Cyclone diverged from the other. The point cloud can be reduced without influences on the result with the order “Unify” until a point-to-point distance of 0,30 m.

Zusammenfassung

Der Laser scanner gehört zu den neuen Geräten auf dem Markt der Vermessungsinstrumente. Tests und Beispielmessungen gaben und geben immer noch Aufschluß darüber, wo dieses Gerät effizient eingesetzt werden kann – teilweise auch besser als ein Tachymeter. Die Ergebnisse einer jeden Messung werden je nach Scanner mit der entsprechenden Software des Herstellers berechnet oder mit entsprechenden CAD oder anderen vermessungstechnischen Programmen. Bei den meisten Produkten kann man nicht erkennen auf welcher Grundlage die Software rechnet. Ein herkömmliches Vermessungsprogramm ist nicht in der Lage, die großen Mengen an Daten, die sich aus einer Laser scanner ergeben, zu verarbeiten. Die Programme stürzen ab oder werden so langsam, daß eine Bearbeitung nicht möglich ist. Also müssen die Daten – die Anzahl der Punkte – reduziert werden.

Aus diesen Punkten ergeben sich drei Fragestellungen, die vertieft in dieser Arbeit untersucht worden sind.

- Laser scanner versus Tachymeter: was ist genauer und was ist effizienter?
- Ergeben verschiedene Softwareprodukte gleiche Ergebnisse?
- Wie weit kann eine Punktwolke reduziert werden, bevor Auswirkungen auf das Ergebnis ergeben?

Um diese Fragen zu beantworten, wurde ein Sandhaufen (mit eine Größe von ca. 400 m³) in zwei unabhängigen Messungen jeweils mit einem Laser scanner - Leica HDS 3000 - und einem Tachymeter – Leica TPS1200 - vermessen. Die Messungsdaten wurden mit drei unterschiedlichen Softwareprodukten berechnet: Geo, Geograf und Cyclone. Desweiteren wurde die Punktwolke schrittweise reduziert und jeweils das Volumen berechnet. So konnten die Auswirkungen der Reduktion beobachtet werden.

Es ergaben sich keine Genauigkeitsunterschiede und – in dieser Untersuchung - kaum Zeitunterschiede zwischen den verschiedenen Methoden. Die Ergebnisse der Berechnung zeigten, daß zwischen den Programmen Geo und Geograf kein Unterschied ist. Lediglich das Ergebnis von Cyclone weicht von den anderen ab. Die Punktwolke kann auch ohne Einflüsse auf das Ergebnis mit dem Befehl „Unify“ auf einen Punkt-zu-Punkt Abstand von 0,30 m reduziert werden.

Statement

Hereby I declare that I prepared the complete present thesis stand-alone. Just the in the thesis expressly specified sources and aids were used. Literal or analogous accepted body of thoughts I marked as such.

place, date

signature

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List of abbreviations

DTM	digital terrain model
GPS	global positioning system
CAD	computer aided design
POV	point of view
FOV	field of view
TIN	triangulated irregular network
TOF	time of flight
GIS	geographical information system

1 Introduction

In this thesis, three different problems are studied:

- comparison of laser scanner and total station
- comparison of three software products (Geo, Geograf and Cyclone)
- consequence of reduction of a point cloud

In the following, the problems shall be defined particulars.

All times new technique displaces old instruments. The new ones are more comfortable, faster, more accurate and consequently economic. To decide, what is better, the new technique has to be tested and has to proof its advantages. Since laser scanners are on the market, this instrument has been tested in many fields: prior in tasks of historical documentation, as-built-documentation, etc. Until now, it is not often tested in a traditional field of surveying: volume computation. This task profits by each new step in the development of new instruments. In the past, it was not possible to survey an object without touching it. A level was used to measure cross and longitudinal sections. A total station that can measure reflectorless simplifies the whole process. Not sections are measured, but equal distributed points among the object. The way of calculation changed from a preponderant manual process to a DTM-based (digital terrain model) automatic process. The laser scanner can measure – similar to the total station – reflectorless. However, that instrument can measure a lot points more per minute. It shall be studied in this thesis if a scanner will produce more advantages and if the scanner will further simplify the task of volume computation.

Several software products for a volume computation are on the market. Each company that produces scanner designs its own software product. Additional there are conventional surveying programs and classical CAD – programs. In most programs, the user cannot see how the program works. Some manuals explain the basis on which the program computes the results. However, in most cases it is a kind of “black box”. The user imports data, pushes the correct buttons and gets a result. He has to trust on the software that it is true. In this thesis, it shall be studied if different software produces the same correct result or if there is a difference between them.

Modern hardware can save megabytes and gigabytes of data without problems. By a measurement with a laser scanner, data are produced that need this space to be saved. However, the software makes problems. Even products that are especially designed for big amounts of data – e.g. Cyclone – become slowly. Normal surveying programs shut down if the whole laser scanner data is imported. The question is if all data is needed or if the number of points can be reduced without an alteration of the result.

In this thesis, a pile of sand is measured - once with the laser scanner Leica HDS 3000 and once with the total station Leica TPS1200. The size of the pile is approximately 400 m³. The volume of the pile shall be computed exactly. The data of both measurements are worked with three programs: Geo, Geograf and Cyclone. In each software product, a DTM is created and the volume about a reference plane is computed. The results of the different methods – laser scanner and tacheometry – and the results of the different software are compared. The point cloud of the laser scanner is reduced stepwise in Cyclone. The volume is computed of each step, thus the consequence can be seen directly.

It is shown that there is no difference in the accuracy between the measurement with the laser scanner and the total station. The time for the surveying – depending on the outer conditions – and the post processing has to be the decisive factor at the choice of the method. In this investigation and in other studies, it is the same. However, if the outer conditions change and in addition, the post processing becomes more complicated, the relation will be different. The results of the volume computation – computed with Geo and Geograf – are the same. Just that of Cyclone is different. The way of calculation is the same and exact the same data are used. Thus, the basis of the creation of a DTM has to be different. The result of the reduction proves the following conclusion: the point cloud can be reduced by a determined value. However, the method of reduction and a forced border is important.

In the following, first the goals of this study – based on the literature – are shown. In chapters 3 and 4, the used software products and the used measuring instruments are described. The measurement itself is explained in chapter 5. In

the following chapter 6, the results of the measurement are pointed out. At last, in chapter 7, the result is discussed and in chapter 8, the conclusion is shown.

2 Goals of this study

2.1 ***Comparison of total station and laser scanner***

The central question before each measurement is: What is the best method to solve that problem? In this condition: What is the best method for a volume computation? There are no rules that help to make the correct decision. W. Böhler thinks that the choice of the optimal measuring method always has to occur individual and cannot be intended based on a general valid scheme of decision [Boe01]. Nevertheless, some factors can help by the consideration of the right method:

- (1) size of the task
- (2) available equipment
- (3) demanded accuracy
- (4) already existing reference nets
- (5) results of economic considerations [Mül02].

Each factor has to be considered for the decision. Without experience or other additives for some points of the list, the best method for this problem cannot be chosen.

(1) For the first point *figure 1* can be helpful. On this picture the best method depending on the size of the object and the needful accuracy are illustrated. Tacheometry and laser scanner are side by side and on a small area, they overlap. In this study, a pile of sand is measured. It has an extension of 10-10²m. According to this sketch, laser scanner is the correct method.

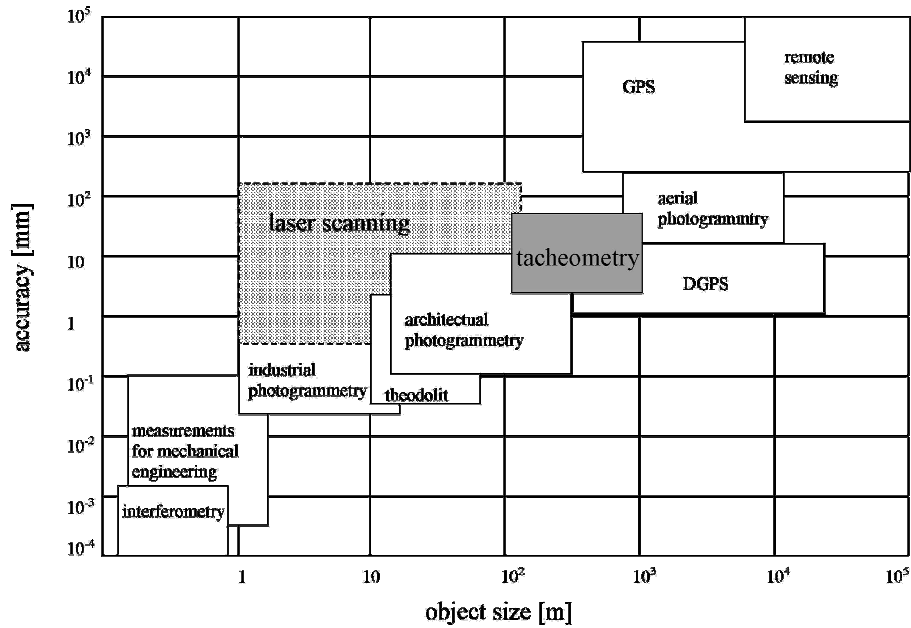


Figure 1: measuring methods depending on the size of the object [Luh00]

(2) The conclusion of the second point of the list depends on the equipment of the office. A total station is a standard instrument. It is available in all engineering offices. Laser scanners are more expensive and are bought for special tasks like historical documentation and much more besides. Today a scanner still is not used for the daily work in an engineering office. However, the possibilities of a scanner are not tested at all. There are a lot more tasks that can be done with a scanner. The scanner is termed as an additional milestone in the development of geodetic measuring instruments [Wit95]. Can that help by a volume computation? Is it worth to buy a scanner and the belonging equipment for tasks like this?

In the next table (*table 1*) some general differences between scanner and total station are shown. That is a general valid table. It applies to surveys of buildings, pipes in factories etc. Thus, the advantages and the disadvantages are balanced according to this table. Nevertheless, some of the advantages for the total station do not apply to the task of volume computation. The measurement is not reproducible and not over-determined. If the same object is measured for the second time with a total station, the result would be differed. The points are also not pre-marked lasting. Accordingly, the advantages are in favour of laser scanner.

Table 1: comparison of total station and laser scanner [Sta05]

Total station	Terrestrial Laser scanner
A few points are observed precisely	A mass of arbitrary points (regular grid ?)
Effort per point is high	Effort per point very small
Measurements are reproducible and over-determined	Measurements are not reproducible and not over determined
Points are representative	Points are non-representative
Points are pre-marked lasting	Points don't exist lasting
Choice of points during the measurement	Choice of points during post-processing
Quality =>points	Quality => geometrical elements

(3) The accuracy of the result is important to value itself. In most cases, the wished value is given and the method has to be chosen after this. The single point accuracy can be given by both methods. It is a little bit better with the total station. However, the accuracy of a single point is not interesting. The value of the complete result – the DTM – is more important. This accuracy is not just influenced by the single points but also by the density of points. The single point accuracy is lower of the scanner. However, because the density of points is higher, the accuracy of the whole model can be higher.

(4) If the measurement has to be connected to a reference net, it is easier with a total station. The scanner cannot be aimed exactly to a reference point. A second instrument has to be used to do the connection. That takes time and further equipment.

(5) Economic considerations give an overview about the necessary time for the project, costs, etc. The economical factor is mainly influenced by the time for the whole project. *F. Kern* says that the economy of time in the fieldwork is wasted by the extensive, predominantly manually accomplished, 3-dimensional interpretation [Ker03]. This is the statement respective the scanner. However, for a volume computation there is not an extensive interpretation to do. Just a DTM has to be created and the volume has to be calculated. It is an automatic process and does not need any manual work except the check of errors. Thus the waste of time by the post processing should be stopped. In this study, it is

investigated, whether the relation between fieldwork and post processing becomes better, in case an extensive interpretation has not to be done. The time per point - measured by a total station - is much longer. Therefore, if the relation between fieldwork and post processing for laser scanner becomes better, the economic factor will be in favour of the scanner.

Finally, it can be said that because of this list a decision cannot be made. Some factors argue for the laser scanner, some for the total station. The decision about the suitable measuring technique is not trivial. With laser scanner, the engineer is not offered a cure-all but an interesting especial solution [Bri02]. This study shall help to answer the question what is the best solution for a volume computation and show if it is advantageous to use a especial solution for a traditional task.

2.2 Comparison of different software

Each company that produces scanner, designs its own software. The extent of such programs is very different. Some software just can be used to scan and to process the data thus, that they can be worked with other software. Some programs offer possibilities of modelling etc. Additional to this there is a lot of conventional surveying and CAD software on the market – some with extensions for scanning data. The most products are able to create a DTM and to compute a volume. The user cannot see what is behind the buttons he has to push to start the calculation. The basis and the formulas on which the program carries out the calculation are not visible. Sometimes it also cannot be read in the manual. It is a bit of a black box, because the user does not know how the program computes exactly the result. Thus, he has to trust that the value is true. There are different methods to do a volume computation and there are no rules for the programmers how to do it. Most of the programs offer two methods: calculation that based on triangles or that based on a grid. However, different programs can use different conditions and formulas.

In this study, three software products are compared: Geo (Swedish software), Geograf (German software) and Cyclone (software by Leica, which belongs to the scanner)(see chapter 3). Each software product can compute the volume between a DTM and a reference plane or between two DTMs. The way of calculation can be chosen by the user in all programs: triangle or grid based.

The software designed by scanner producer is often only partially suitable and is concentrated on typical fields of tasks like creation of models of buildings, CAD-maps etc. Possibilities for irregular surfaces are partly included (creation of triangulated networks) but these are often only rough and they demand a lot of manual work in the post processing [Mar03]. However, this statement is three years old and software is updated fast. Each new version is made better and by the feedback of the user, the software is advanced.

It shall be tested if there is a difference between several software products especially between scanner software and “normal” surveying software.

2.3 *Reduction of the point cloud*

During a measurement with a laser scanner, thousands or millions points are measured and saved. These data need a lot of space on the disc. Additionally in the post processing the software gets very slow if it has to work with big amounts of data. Cyclone is designed to work with huge amounts of data, but e.g. if a mesh is created out of a big point cloud, the program takes some time to update the picture. The mesh cannot be handled in real time anymore. *M. Lindstaedt* also says that even today the capability of computer is not enough for an interactive animation of multipurpose one hundred thousand triangles [Lin05]. Thus, it is better to reduce the data at the beginning of the post processing. There are two possibilities to reduce the number of points. Models can be created – then the model replaces the point cloud - or the density of points can be reduced. The creation of models is with this method of measuring (laser scanner) only interesting with the aspect of the reduction of data and the generation of the essential information [Weh97]. For industrial surveys – pipes etc. – it is typical that geometrical shapes like cylinders or planes replace of points. Geometrical shapes can be described with less data than point clouds and essential information are easier to get. The model needed for a volume computation is the DTM. However, a DTM cannot replace the point cloud because the points are the basis of the model. In this case, a model does not reduce the data. Thus, the number of points has to be reduced. However, is this possible without a loss of the accuracy of the result? In addition, how far can the point cloud be reduced? Are there some conditions to consider? These questions shall be investigated in this study.

3 Software

3.1 Principles of volume calculation

3.1.1 General remarks

Several methods can be used to calculate a volume. Every method has its own advantages and disadvantages depending on the shape of the object. Those can be differed in two groups: linear and surface objects. Streets, railways, dams, tunnel etc are seen as linear objects. Examples for surface objects are landfills, shaft pits, dumps etc. For linear objects, the common used method is the cross-sectioning method. The volume of a surface object can be computed with the trapezoidal method (rectangular or triangular prisms), classical cross sectioning (trapezoidal, Simpson, and average formula) and improved methods (Simpson-based, cubic spline, and cubic Hermite formula)[Yan05]. The volume of a surface object can be computed by several methods of which this thesis is only dealing with the so-called trapezoidal method [Yan05]. The reason of this is that in each used program this method is utilised.

3.1.2 Trapezoidal method

Two ways are possible to calculate the volume with the trapezoidal method: rectangular or triangular prisms. The advantage of the rectangular method is the regularity of the modelling. However, extreme shapes of the terrain cannot be depicted. The triangular structure fits optimal to the terrain [Mül02]. The volume can be determined by the multiplication of the medial high with the area.

Formula for triangular prisms

$$h_{m_i} = \frac{h_{i1} + h_{i2} + h_{i3}}{3} \quad \Rightarrow \text{medial height} \quad (3.1)$$

$$V_i = F_i * h_{m_i} \quad \Rightarrow \text{volume of one prism} \quad (3.2)$$

$$V = \sum_{i=1}^n V_i = \sum_{i=1}^n F_i * h_{m_i} \quad \Rightarrow \text{volume of the whole object above a reference plane} \quad (3.3)$$

here is:

i	=	name of one triangle
n	=	number of all triangles
h_{i1}, h_{i2}, h_{i3}	=	height of each vertex of one triangle
h_{mi}	=	medial height of one triangle
V	=	volume of the object
V_i	=	volume of one triangle
F_i	=	area of one triangle

Formula for rectangular prisms

$$h_m = \frac{\sum_{i=1}^n (g_i * h_i)}{4 * n} \quad \Rightarrow \text{medial height} \quad (3.4)$$

$$V = F * (h_m - h_o) \quad \Rightarrow \text{volume of the whole area} \quad (3.5)$$

here is:

- h_m = medial height of all vertices
- g_i = number of the on the vertex adjoining rectangles
- h_i = height of the vertex
- n = number of the all rectangles
- V = volume of the whole object
- F = surface of the whole object
- h_0 = height of the horizontal reference face [Wit95]

This is the formula for an area with many rectangles. One rectangle can be calculated like the triangle (see *formula 3.2*), but then there are four heights and four divides the sum. The volume can also be determined with the product of area and the medial height. However, if there are many rectangles it is easier with this formula (formula 3.4 and 3.5).

The volume can be calculated between the object (e.g. a DTM) and a reference plane or between two objects. If the calculation is done in the second way, it is better to compute first the volume between the object and a reference plane. Then the difference of both results can be taken. If one object is not horizontal but if it is sloped, there can be errors [Wit95].

3.2 Digital terrain model (DTM)

3.2.1 General remarks

Different countries have different names for one thing: digital terrain model. There are also descriptions like digital elevation model (DEM), digital height model (DHM), digital terrain elevation model (DTEM), digital ground model (DGM), etc. All these names describe the same subject. Only the basis for the calculation is different. The first definition of the term DTM was in 1958 from Prof Miller at the Massachusetts Institute of Technology.

Definition: The digital terrain model (DTM) is simply a statistical representation of the continuous surface of the ground by a large number of selected points with known X, Y, Z coordinates in an arbitrary field [Mil58]. The aim was to describe a terrain model on a mathematical basis in this way that it could be handled and read by a computer. Today DTMs are the basis for several applications. Many data can be derived of a DTM: topographical maps; contour lines; geometrical values: direction, gradient, bend turn, area; longitudinal and lateral profile; earth mass computation; etc.

The basis data are scattered or regular points with x, y, z-coordinates and topographical information (terrain lines). They can be get by a conventional tacheometric survey or by GPS, photogrammetry, laser scanner (terrestrial or airborne) or digitising / scanning from analogous maps. Independent of the method the most important thing is the exact registration of the terrain lines (in the model: break lines). Single points have to be measured and connected to lines. Just so salient points like hollows and tops have to be measured with extra points. The more points are registered the better will be the model. However, the more points are recorded the more expensive the model will be. The skill of the terrain modelling consists in the registration of the exact shape of the terrain with a minimum of data [Mül02].

For the modelling and calculation of the DTM, there are four approaches:

1. point-based modelling
2. triangle-based modelling
3. grid-based modelling
4. a hybrid approach combining any two of the above three items

[Li04].

The most used are the grid-based and the triangle-based modelling. In most of the programs, the user can choose which one he wants to take. There are some differences in the result because of the different basis. Because the points are normally not measured in a regular grid, the heights have to be interpolated for the grid-based modelling. For that reason with this method, there is created an artificial model without direct measured points. However, if there are two horizons it is easier to make a cut and compare it or to calculate a difference model. The only thing the user can choose is the distance between the lines of the grid. The smaller the distance is, the more data have to be computed and the longer time is taken for calculation. In contrast to this, triangles are more flexible. Thus, they can better incorporate break lines etc. and the approach to the terrain is more accurate. The model is created of the original points; each point is a vertex of a triangle. If the model is created out of points, which are combined to a network with the help of triangles this is called triangulated irregular network (TIN).

There are three requirements for a TIN:

1. For a given set of data points, the resulting TIN should be unique if the same algorithm is used, although one may start from different places, for example, the geometric centre, upper-left corner, lower-left corner or other points.
2. The geometric shapes of resultant triangles are optimum, that is, each triangle is nearly equilateral, if there are no specific conditions.
3. Each triangle is formed with nearest neighbour points, that is, the sum of the three edges of the triangle is minimum [Li04].

All these requirements are fulfilled in the Delaunay-triangulation. There are different methods to create a triangulation. Each method has its own basis criterion.

- shorter diagonal: in a quadrangle these diagonal - of the two diagonals – is taken, which is shorter [Ker03].
- triangulation with minimal weight: the sum of the triangle side gets minimal; between n points there are n rectilinear connections; these are ordered of the length and all the lines which cut a shorter are eliminated (n is the number of measured points) [Mül02].
- max-min-angle criterion: triangles are created, which smallest angle is as big as possible [Ker03].

The last criterion is one of the conditions for a Delaunay-triangulation. That is also the most used triangulation. In all used software that is the basis of the creation of a DTM. That is why in the next chapter (3.2.2) it is explained what it is.

However, with all criterions something should not be forgotten: a DTM is an approach to the surface; it will never show the exact shape of the terrain. Some influences are important for the quality of the model. First the devices and the methods of surveying influences the accuracy and certainty. Things like the density of the points and the kind of the terrain are also important. At last, the method of working in post processing – e.g. grid-based or triangle-based modelling – influences the quality of the result.

3.2.2 Delaunay triangulation

A Delaunay triangulation has attributes, which are important for a DTM.

Triangles in the network are linked but not overlapping and there are no blanks between them. If a circumscribing circle is drawn around a triangle, it does not include any other points. Therefore, the triangulation is definite. Breaklines are identical with the sides of the triangles.

The principle of the Delaunay-Triangulation consists of three steps:

(1) The closest points P_j around a point P_i , so-called natural neighbours, are connected to P_i . At the middle on the lines between these neighbours and P_i the perpendicular is drawn. The perpendiculars form a closed polygon. That is named a “Thiessen”-polygon.

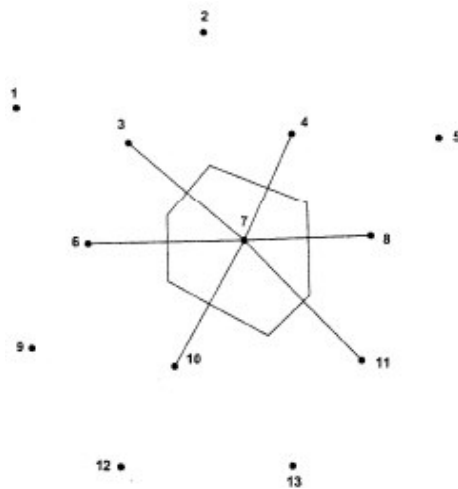


Figure 2: Thiessen-polygon [Fro00]

(2) If this “Thiessen”-polygon is constructed around all points of a point set, it is acquired “Voronoi” — diagram.

(3) The points inside of neighboured “Thiessen”-polygons are connected. The result is the Delaunay-triangulation.

[Further information Fro00]

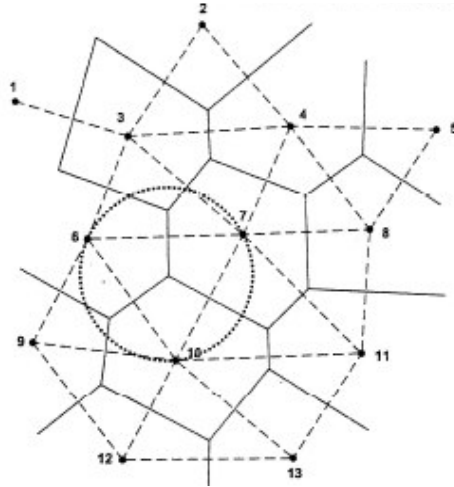


Figure 3: Voronoi-diagram, Delaunay-triangulation and the empty circle [Fro00]

3.3 Cyclone

3.3.1 General remarks

Leica Laser scanner run with a laptop and special software named Cyclone. The scanner is handled with this software during the measurement and the data are handled with it in the post processing.

In the following, the structure of the software is explained. On *Figure 4* the scheme is illustrated.

The data are organised and saved in a database. The original point clouds cannot be altered if they are once saved there. The data can be modelled or modified by using the original point cloud. Each change can be saved in a new ModelSpace. Just the alterations are saved and not the whole data. Thus, not so much dick space is necessitated.

Each database can contain several projects. A project is created for each new surveying job. They are created by the user to organise the data.

A ScanWorld is the next step in the hierarchy of folders in Cyclone and part of the project. During the measurement for each POV (point of view) a new ScanWorld is created automatically.

Definition ScanWorld: A ScanWorld is a collection of scanned point sets (scans) that are aligned with respect to a common coordinate system. If you take one or more scans without moving the position of the scanner, they can be considered part of a single ScanWorld since they are already aligned with respect to each other. ScanWorlds can contain other ScanWorlds through a registration [Lei04].

Like the database – because a ScanWorld is part of the database - the original data are read-only. Only the whole ScanWorld can be deleted.

The next step in the hierarchy is four folders, which are in each ScanWorld: ControlSpace, ModelSpace, Scans and Images. The folders Scans and Images contain the original data of the measurement – the scans the data of the points (coordinates, orientation of the scanner) and the images the pictures. The ControlSpace is created automatically when a ScanWorld is created and cannot be moved or deleted. It contains all objects that are designated as constraint objects or possible constraint objects. Those are needed for a registration. (see *chapter 3.3.2*) The objects can be reviewed, organized, or removed, but they cannot be moved or resized.

If data are modelled or modified it is done in a ModelSpace or more precise in a ModelSpace View. The second one is a subfolder of the ModelSpace. The primary ModelSpace can contain several ModelSpaces. In a ModelSpace every change is saved automatically; e.g. zoom steps, views, deleted parts of point clouds (only in this ModelSpace).

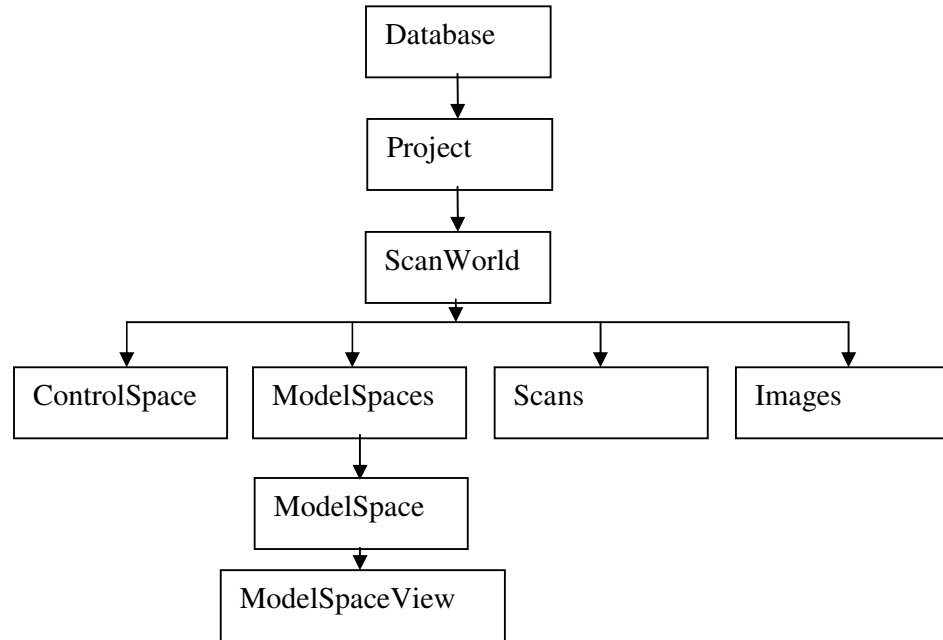


Figure 4: scheme of the structure in Cyclone

3.3.2 Registration

For each object more than one POV are necessitated. Each POV with an own ScanWorld has its own orientation, coordinate system etc. Before a complete 3D-modell of an object can be worked, each project's ScanWorld has to be integrated into a single, common coordinate system. This is done by the „registration“. After a successful registration, a new ScanWorld is produced. In a project in Cyclone, a registration object has to be created. All ScanWorlds who should be integrated in a single coordinate system are added. The ScanWorlds are transformed into the coordinate reference system of a HomeScanWorld. That is one of the original ScanWorlds or a ScanWorld with imported survey data. In the second case e.g. coordinates of a total station measurement can be imported for spheres, targets etc. If it is not set by the user, the first added ScanWorld is set as the HomeScanWorld.

For the registration, constraints are established.

Definition constraints: Constraints are objects that appear in one or more ScanWorlds that represent a consistent point in space or a geometric configuration. The registration process looks at those common points or

geometric configurations (constraints) and orients the ScanWorlds to minimize the distance between common constraints [Lei04]. These objects can be targets, spheres or equivalent regions at the measuring object. To register two ScanWorlds at least three equivalent points are needed because six degrees of freedom has to be solved; three rotations and three translations. Cyclone searches automatically for constraints. Vertices are found automatically. In version 5.2 pairs of equivalent or overlapping objects without vertices have to be marked with pick points (points are marked in the pick-mode by click with the mouse pointer). However, in version 5.4 they are also found automatically. When the constraints are added, the registration is done. The registration process computes the optimal overall alignment transformations for each component ScanWorld in the registration such that the constraints are matched as closely as possible [Cyc06]. The result has to be frozen so that is cannot be changed. In the new ScanWorld, ModelSpaces can be created so that the data can be worked.

3.3.3 Reduction of the point cloud

Cyclone offers two ways to reduce a point cloud (definition point cloud: see chapter 4.1.5): the direct method with the “reduce point cloud” dialog fields and the indirect method with the “Unify” order. The methods use different ways of calculation and so they have different results.

Reduction with “Unify”

Each scan, which is done in a ScanWorld, creates an own point cloud. If there are scans with a huge number of points, several point clouds are created. In the post processing all point clouds of one ScanWorld can be unified in one point cloud. It is easier to work with one point cloud. During this procedure, it is possible to set average point spacing. The point cloud can be reduced because several point clouds have overlapping regions. In these areas, the point density is higher than it was set before the scan process. The reduction works like this: the software creates virtual 3D boxes in the background with the size (diagonal distance from left lower corner to right upper corner) of the value. Then the reduction algorithm runs over the points in each virtual 3D box and reduces the number of points inside every single box to one point. The result is a reduced point cloud with an average point spacing of the user-defined spacing.

However, the space between the points is not exactly like the value. In most cases, the space is smaller than the default value.

Reduction with “Reduce point clouds”

This order is especially made for the reduction of a point cloud. However, it can be done only with point clouds, which were not unified before. The user can set the ratio of original-to-sub sample points in vertical and horizontal direction, the number of remaining points or a percentage of the original. However, the last one is not available. In the dialog field the value of the percentage is shown when e.g. the ratio is two. However, the user cannot say 50% of the points should remain. In this procedure, every second point is just taken away if the ratio is set two. Therefore, in regions near to the scanner more points remain than in regions, which are farther from the scanner where density of points is not so high.

It can be seen that the reduction when it is done with “unify” is truer than with “reduce point clouds”. After the procedure with the first method, the point density is equal all over the object. When the calculation is done with the second method, the point density is high near and very low farther of the scanner.

3.3.4 Volume calculation

For a volume calculation in Cyclone first of all a mesh has to be created. There are three possibilities to create a mesh: basic meshing, complex meshing and TIN meshing. Just the last one contains conditions for TINs, e.g. no overlapping triangles. Therefore, it is the only choice to create the basis for a volume calculation.

Definition Mesh: A mesh is a series of triangles created using the points in a point cloud, vertices, polylines, or any combinations of the three as vertices. For each adjacent trio of points in a cloud, a triangle is created [Cyc06].

The volume can be computed as a TIN volume or as a mesh volume. The main difference is the basis for the calculation. If the calculation is done based on the TIN the calculation is done with the trapezoidal method – triangular prisms (*formula 3.1 - 3.3*). In the other case a grid is created and the volume is calculated based on rectangular prisms (*formula 3.4 and 3.5*). The user enters

the interval by which the reference plane is divided into a grid – called sampling step. The volume is computed either above or below the reference plane. The user can set the origin of the reference plane. Therefore, he can determine the height of the plane. If the TIN is used both – the volume below and above the reference plane – is calculated. The result is given as “Cut” and “Fill”.

3.4 Geo

Geo is office software for land and construction surveyors. It is produced by SBG (Svensk Byggnadsgeodesi AB) from Sweden. Software and hardware for surveying and machine control applications is designed and manufactured by SBG. Geo includes several functions: designing, setting out, surveying, drawing and reporting function. The user can choose between various modules such as road lines, tunnel, net adjustment, and – important for this thesis – terrain models and volume calculation.

In Geo, there are two possibilities to calculate a volume: model-to-model method or section method. The second method is for linear objects. In chapter 3.1.1, it is explained that for this thesis a surface was needed. So the first method will just be explained.

The start data for a volume calculation with the model-to-model method is a digital terrain model. From one or more coordinate files, a DTM is created. It consists of an irregular network of triangles like those that it is explained in chapter 3.1. The way of the calculation is explained here because it is important for the results. When the terrain model is calculated, an optimized triangle structure is created first with no regard to break lines. There is a great risk that undesired triangles are created, e.g. triangle sides crossing a ditch instead of following it. So at all intersections between triangle sides and break lines new points are introduced. The heights of these points are interpolated at the break line. Because of this, the surrounding triangle sides are connected to the break line and so the model is truer.

To make sure that the TIN is created correctly the user can set the following settings:

Max side length in outer triangles

A value can be given for a side of a triangle. If the side is longer, it is removed. However, any side of the triangle has to constitute the outer edge of the terrain model.

Check connection to own line

A triangle with any side constituting the outer edge of the terrain model and all three points on the same breakline will be removed if this box is checked.

Dividing up circle arches in segments

A DTM can only contain straight lines. The arches are split in shorter straight elements automatically. A tolerance can be given for the distance between the arch and the new straight element. The shorter the tolerance the more elements are created.

Dividing break lines in smaller parts

The user can set a maximum measure how long elements in break lines have to be. Long and narrow triangles can be avoided in this way.

The method model to model includes two possibilities of calculation: difference between two models and difference between one model and a reference height. The volume can be computed based on a grid model and based on a triangle model. The area and volume is calculated for each triangle / rectangle (formula see *chapter 3.1.2*) and the results are summed up. The result is given in “Cut” and “Fill”. A border can be set to limit the area of the calculation. For this, a coordinate file is given by the user with the coordinates of the polygon. Only the triangles inside of this polygon are calculated.

3.5 Geograf

Geograf is a software product from HHK Datentechnik GmbH from Germany. The company designs software solutions for planning, surveying, settlement and GIS (geographical information system). Geograf is a basis system with several modules and extensions. The basis system includes analysis of the measurement, construction, preparation of plans, outputs of plots, work on land register, land utilisation plan, legally binding land-use plan, street planning, mass computation and land consolidation.

In Geograf, a digital terrain model also has to be created as basis for a volume calculation. There are two possibilities to do the meshing: automatic or manual.

For both ways an outline has to be designed. That can also be done automatically or with a manual drawn polygon. The outline has to be closed and all points have to be inside, which shall be part of the mesh. If the mesh is created automatically, the edges of the mesh are only created internal in the program. Therefore, the mesh cannot be changed by the user afterwards. The edges are only designed by the coordinates of the monitor. If the mesh is created with the order “D.Linien” lines – edges - are created and can be changed afterwards. Edges can be deleted and new lines can be added manually by this method.

Before the mesh can be designed the program searches for errors. The mesh cannot be designed if the outline is not closed, if two points are close to each other, and if break lines are crossing without an intersection.

The volume computation can be done in two ways: volume between the DTM-horizon and a reference height or volume between two DTMs. The calculation is done based on triangles (see formula 3.1 – 3.3) and according to REB-VB 22.013¹. In the protocol “Cut” and “Fill” of the volume and the area of the ground and of the mesh is given.

¹ REB-VB: German standard for electrical construction settlement (Regelungen für die elektronische Bauabrechnung – Verfahrensbeschreibung 22.013)

4 Hardware

4.1 *Laser scanner*

4.1.1 Principles

The basis principle of a laser scanner is the same like the total station. Distances and angles are recorded. Then coordinates of unknown measured points can be calculated. However, a scanner is faster than a total station and automatically. This new instrument has several differences, advantages but also disadvantages.

This measurement was done with a Leica HDS 3000. In the following, the special characteristics of this scanner are shown. All specifications are from the Leica product specification [Lei06a] and can be differed from the needed scanner and this measurement. The specific values of each scanner depend on the modifications of the components and the conditions of the measurement. Based on *Böhler* and *Marbs* [Boe02] laser scanners differ in several points. Not only the accuracy is important to choose one for the best.

1. Speed

The speed is up to the method of sampling and of distance measuring [Ker03]. The methods used in HDS3000 are explained in chapter 4.1.2. HDS3000 has a maximum scan rate of 4000 points / second (instantaneous rate¹). The time of scanning depends on the scan density and the field of view (FOV). A column is measured faster than a row, so a FOV that is higher than wider is measured faster than a FOV with the same area but which is wider than higher. Time for measurement increases quadratic with increasing of the sampling [Ker03]. However, this is only the scan time. The most time during a scanning measurement is needed by transportation to and between different observation points, for setting up the scanning process, for control point measurement, etc. [Boe02].

2. Resolution and spot size

The finest possible sampling interval for two measured points is given vertical and horizontal with 1,2 mm. However, the sampling interval is not only

¹ Instantaneous rate = rate at a particular moment

decisive for the scan resolution. The local resolution is limited by the beam width. From 0-50 m the spot has a size of 4 mm FWHH (full width at the half height) / 6 mm Gaussian based. Therefore, the smallest reasonable sampling interval is here 10 mm. If the interval would be smaller, two measured points side by side would almost have the same value. This interaction can be seen at *figure 5*. At the left sketch, each point has its own value. However, the closer the points come together, the more equal becomes the value.

The number of points per row / column also defines the resolution. The maximum is 20000 points / row and 5000 points / column.

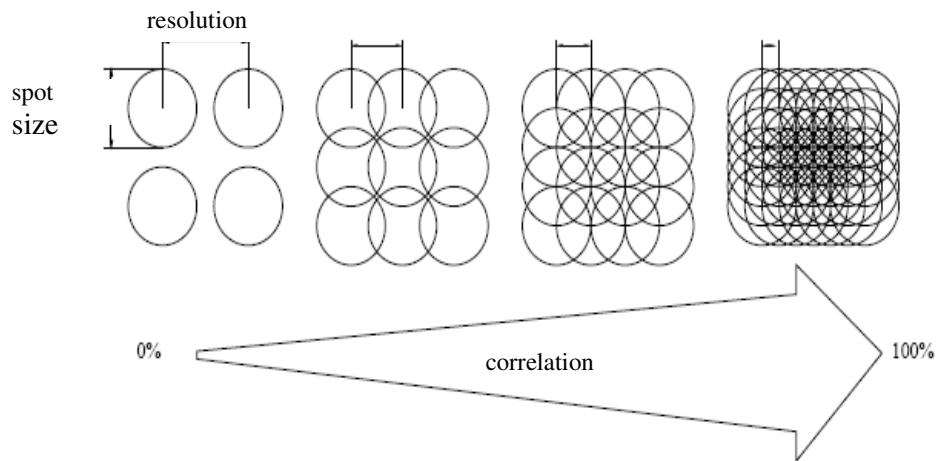


Figure 5: interaction of spot size and resolution [Ker03]

3. Range limits and influence of interfering radiation

Different effects influence the range. The most important is the albedo¹ of the material itself. The limit for the HDS3000 is given in dependence on the albedo. 300 m should be achieved if it is 90% and 134 m if it is 18%.

4. Field of view (FOV)

Scanners are differed in two classes: panorama scanner and camera scanner. The second one is not able to turn around its axes and so the FOV is in most cases 40° x 40°. The scanner was used for this measurement has a FOV of horizontal 360° x vertical 270°. The instrument has two windows, the upper and the main window. The vertical interval is limited by the bottom of the

¹ Albedo = a measure of a surface or body's reflectivity without a unit

scanner, tripod etc. because the laser beam can only be deflected until the lower edge of the main window.

On the next picture, the FOV is illustrated and a picture of the scanner is shown.



Figure 6: FOV HDS3000 [Aba06]

5. Registration devices

To combine several scans from different POVs in a common coordinate system, a registration (a kind of transformation, see chapter 3.3.2) has to be done. It can be done with equal points in different ScanWorlds. That means equal points have to be measured from different POV. Leica supplies special targets, which can be detected more or less automatically during the scan process. These targets exhibit a high reflectivity so it is easy to detect them in the scans. The intensity of the transmitted laser beam is higher than with other materials. The software contains a module, which acquires the targets with a FineScan. That means, the targets are scanned with an especial resolution of 99 columns x 99 rows (spheres) and of 38 columns x 38 rows (targets). This especial resolution assures that the targets can be acquired.

6. Imaging cameras

In some scanners, the camera is needed to give afterwards a realistic view from the object. However, in the HDS3000 it is also needed for the orientation. First, the camera in the scanner takes pictures and then the user chooses the FOV. So the scan area can be determined very exact and the scan time can be reduced. The resolution can be chosen by the user (low, medium, high). The higher

resolution entails a longer time to take the pictures. One pictures size is 24° x 24° and the image consists of 1024 x 1024 pixels at the high setting.

7. Ease of transportation

Equipment should always be light, small and insensible. However, this is not realizable with mid and long-range scanners. Therefore, the dimensions are 265 mm x 370 mm x 510 mm and the weight is 17 kg.

8. Power supply

This scanner can run with batteries. These are also part of the equipment. It shall be like this that the user can work one whole day with the power of two batteries. In the specifications, it is said that the duration is up to 6 hours per battery with room temperature. Therefore, outside – particularly if it is cold – it is less. It is a sealed lead acid battery with a weight of 12 kg. The power consumption of the scanner is less than 80 W. However, the scanner can also be connected to a normal socket.

9. Scanner software

The scanner is only usable with a laptop and the right software. Leica offers Cyclone. The latest version is Cyclone 5.5. In this measurement, Cyclone 5.2 and later 5.4 was used. In the software the setting up for the scanning process is done, the point cloud is visible and can be controlled after scanning; targets can be acquired automatically, etc.

4.1.2 **Distance measurement**

Laser scanner can be divided in three groups when they are differed in the method of distance measurement: time-of-flight (TOF), triangulation and phase-shift measurement. The triangulation method is used for short distances (<0,2 – 10m), the phase-shift measurement for short-mid ranges (<100m) and the time-of-flight principle for mid-long ranges (2 – 2000m).

In HDS 3000 it is used the pulsed TOF method. This method is explained in several literatures [Ker03; Ama01], so it shall be given only a short review of the principles of TOF.

The time is measured that the laser needs to cover the distance from the scanner to the object and back. Thus, with the knowledge the velocity of the laser pulse and the physical formula

$$s' = c * \Delta t \quad (4.1)$$

s' = double distance between scanner and object

c = velocity of the laser pulse

Δt = measured “flying” time of the laser pulse

the distance can be calculated. However, it has to be reduced by the half, because the time is measured about one round (the way to the object and back).

$$s = \frac{c * \Delta t}{2} \quad (4.2)$$

s = distance between scanner and object

To obtain 1mm accuracy, the accuracy of the time interval measurement should be 6,7 ps [Ama01]. Therefore, the determination of the time is the most important thing at this method. To realize the speed of the measurement each distance is measured just one time.

4.1.3 Angle measurement

The HDS3000 is a panorama scanner. It means that the FOV is only limited by the tripod, the bottom of the scanner etc. Therefore, the laser pulse has to compass each point in the area around. Therefore, he has to be deflected in two directions. The first angle is realized by a very fast rotating mirror. This mirror deflects the laser pulse in vertical direction. To deflect the laser pulse in the horizontal way the laser scanner is turned around his vertical axis by a servomotor. Therefore, for each point two angles are measured: a vertical and a horizontal angle. This measuring method is known as the tacheometric measuring principle.

4.1.4 Accuracy

Different accuracies are important for a laser scanner measurement. In the product specifications the single point accuracy (distance and position) is given. In most cases, only the modelled surface of the object is wanted for the result. Therefore, the accuracy of these is important just as the result of the targets, which are needed for the registration.

Two statements prove this:

For the user the accuracy of one 3D-point is the basis information to evaluate the accuracy of these dimensions which are needed for each problem and

which can be won of modelling of a major number of points in the point cloud [Boe04]. The decisive dimension in the examination of the accuracy is the 3D-precision of a single measurement (angle and distance measurement)[Sch02]. That means the accuracy of the whole measurement depends on the accuracy of each measured point. In the following table (*table 2*) the accuracies of a single point measurement are shown.

Table 2: Accuracy of a single measurement HDS3000 [Lei06a]

Position	6 mm
Distance	4 mm
Angle (horizontal / vertical)	60 micro radians / 60 micro radians, one sigma
Modelled surface precision	2 mm, one sigma
Target acquisition	2 mm standard deviation

These values are determined by Leica and are not checked by the author.

Especially the value of the distance can be put into question.

Further influences are termed in chapter 4.3.2

4.1.5 Point cloud

The output of a measurement is a point cloud.

Definition: A point cloud W is a set of three-dimensional Cartesian coordinates (x_i, y_i, z_i) respective of the laser scanner coordinate system from one scan, which was produced by polar distance measuring from one pole (x_p, y_p, z_p)

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} \in W$$

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = D_i \begin{bmatrix} \sin Hz_i \sin V_i \\ \cos Hz_i \sin V_i \\ \cos V_i \end{bmatrix} + \begin{bmatrix} x_p \\ y_p \\ z_p \end{bmatrix} \quad [\text{Ker03a}]$$

$$Hz_i \in [0, 2\pi]$$

$$V_i \in [0, \pi]$$

Based on that definition it can be seen how the coordinates of the measured points are calculated. The point cloud has several properties, for example the point cloud discretises the surface of the object, guess of an empty space (between laser scanner and measured point), et al. [Ker03].

4.2 Total station

4.2.1 General remarks

Today a total station is a usual measurement instrument in the surveying fields. Because of that it shall only be highlighted the technical data that are important to show the differences between a laser scanner and a total station. More about the principles of total station can be read in [Deu02].

In this measurement, a Leica TPS1200 was used. This total station utilizes for the distance measurement the phase-shift method. For the angle measurement, a coded glass circle is read by a linear CCD array. By the help of a compensator, it is ensured that the vertical axis has no tilt. If the axis is not correct, all angle measurements are immediately corrected. A correction is calculated and added to all angles. The measurement is done several times for one point. Therefore, the final value is the average of all measured values. It is used a coaxial, visible red laser in the reflectorless mode. So the orientation can be controlled by the red laser point on the object, if this is done only rough by the collimator.

4.2.2 Phase-shift measurement

The laser pulse is made up of two parts: the carrier wave with a constant frequency and one on that modulated sinusoidal signal. Subject to the length of the distance, the signal experiences a phase shift. This is the difference between the phasing of the emitted and the received signal. Because of this phase shift and the whole wavelength, the distance can be calculated. To solve the ambiguity several single measurements with different wavelength are used.

4.2.3 Accuracy

The next table shows the accuracy of the total station TPS1200, Type 1203.

That instrument is used in this investigation.

Table 3: accuracy of the total station [Lei06b]

Angles (Type 1203)			
Hz; V	3'' (1 mgon)		
Display least count	0,1'' (0,5 mgon)		
Distance measurement			
with prism (standard mode)	2 mm + 2 ppm	measure time:	typ. 1,5 sec
without prism (0-500 m)	3 mm + 2 ppm	measure time:	typ. 3-6 sec, max. 12 s
	(atmospheric conditions: object in shade, sky overcast)		
	(day of the measurement: sunny, 20°C, some wind)		
Laser dot size	at 20 m:	7 mm x 14 mm	
	(longer distances (20 m) were not used in this measurement)		

Hz: horizontal angle; V: vertical angle; standard mode: two modes available for the distance measurement => fast and standard mode (first mode is faster, but not so accurate)

4.3 Comparison of laser scanner and total station

4.3.1 General remarks

The principles of a laser scanner and a total station are the same: both can measure 3D-coordinates with reflectorless methods. There are so many common points, that *L. Bornaz* says, a terrestrial laser scanner can be considered as highly automatic motorised total stations [Bor04]. One difference between both methods is the time per point; another factor is the accuracy. *W. Böhler* expresses to the last argument, laser scanner use simpler algorithms for range computation that may lead to poorer accuracy values [Boe02]. Another

big difference is the choice of measured points. Therefore, it is said, that unlike total stations, where the operator directly chooses the points to be surveyed, laser scanners randomly acquire a dense set of points [Bor04]. In the following table (*table 4*) a general comparison between laser scanner and total station is done. There it can be seen that both - laser scanner and total station - have its advantages and its disadvantages. It depends on the special task which method is the best.

Table 4: comparison of total station and laser scanner [Sche04]

	Object of comparison	Laser scanner	Intelligent total station / robot-total station
general	rate of measuring	High	low
	importance of points	low, point cloud, random distribution	high, single points, aware classification
survey	choice of points	a posteriori, single points not measurable	a priori, only single points
	connection of POV	Laborious	easy
	extra net	in general	not applicable
	hidden points	not measurable	half automated with an extrapolation bar
	manual measurement	not includable	often avoidable, direct includable
	remote	partly (?)	+
	work mode	full automated	manual / half automated
handling	post processing	laborious in the extraction of edges and corners, easy with	not applicable with easy shapes
	meshing	Automatically	recording of complex structures is possible
Visualisation	visualisation	by complex structures a lot of manual work	parametric, differential equalisation, automatic rendering is
	rendering	differential equalisation almost automatically with 3D-grid, manual intervention, rendering automatically	device control by image, possible online
costs	acquisition	100%	10-20%
	universal usability	special instrument	universal surveying instrument
	handling of the instrument	comparatively laborious	easy
	field work / post processing	1 / 10	1 / 1

4.3.2 Distance measurement

It was shown that the laser scanner uses the time-of-flight, the total station the phase-shift principle to measure the distance. Higher accuracies can be achieved with the phase-shift method but the disadvantage is the ambiguity [Ker03] that has to be solved. In addition the energy content of a separate pulse can be increased at the TOF-method, thus the range is grown. In instruments that use the phase-shift principle, the measurement has to be done several times to solve the ambiguity. The time per point is longer than for the TOF-principle. Thus, for long distances and fast measurements the TOF-method has more advantages. For short distances, the phase-shift-principle is better, but not so fast.

Both principles are electro-optical methods. Except for the positioning with the total station, both measurements were done reflectorless. Several problems can appear with reflectorless range finder, for example obstacles that reflect the laser; fog, dust, etc that absorb the laser or if the object is too far away [Ker03]. Nevertheless, most of them can be avoided when the measurement is done manually and not e.g. by a laptop with a program without taking care for the measurement. The measurement with the laser scanner was done with a laptop but it was controlled and it was always observed. So the only influences remained in this measurement were temperature, atmospheric pressure, ambient light, the angle of incidence and the material of the object and the structure of the surface – rough, sleek, etc. These are systematic influences. That means they are in each measurement and cannot be avoided. The typical methods of correction and reduction eliminate the first three points. The influences of the last points are unknown [Ker03]. However, in both methods these influences are the same.

4.3.3 Accuracy

The used systems measure distance and angles in different ways. Therefore, there are different accuracies for the single point measurement. With the total station, the single point accuracy is higher. Nevertheless, because of the bigger beam width the resolution is not so high as by the laser scanner. That was not important for the total station measurement in this case because the distance

between two neighbour points was big enough that correlation was not available between points.

5 Methods of measuring

5.1 General remarks

How big had the pile to be? That was a general question before starting measuring. The measurement should be transferable to bigger piles such of coal or sand. To realize that condition it had to be the same qualifications for the pile to measure.

The accuracy of volume determination depends on the ratio between the surface area S and the volume V (S/V) [Ker02]. It means, the smaller the ratio the better the accuracy of volume determination. With small volumes, changes in the determination of the surface have a strong influence in the accuracy of the volume determination. That are volumes up to 20 m^3 [Ker03a]. So a pile should be measured which was bigger than 20 m^3 to make sure that the results can be transferred to bigger piles.

Another condition should be that the pile is not accessible. Therefore, the concept of the measurement had to consider also that point.

Finally, a place for the measurement was found on a building lot. It was three piles next to each other consisting of sand, stones and earth. At one side was a slope up to the street with grass and weed. The other sides were more or less plain and out of earth, sand and stone. Near to one pile lay a bucket. In parts, the building lot was used as a parking range. Therefore, at one side the cars drove up and down. On the picture, the piles can be seen; in the front, the street with the slope is shown.



Figure 7: picture of the piles

Every POV needs time and produces more data. *M. Alba* says this that trying to capture some more data as possible and than to use only those are really needed is in general false [Alb05]. Therefore, it was an intention to need as less POV as possible. The POV had to be out of traffic and on a hard ground. Finally, it could make with six POV. One POV was placed in the middle of the piles and five around of them. For the total station measurement, the same number and places were used. The conditions were different. Each point had to be seen from the point before. The points were pre-marked with nails.

The measurements with scanner total station were done independent from each other. To combine both measurements six targets were put on the pile. That was necessary because the scanner was not set up exact above the nails to save the time. Every target should be seen from two POV. It were used three half spheres, large size, diameter 6", and three planar targets, 3"x3" square targets. The half spheres were used because they could be better detected in the point cloud and they could not fly away. The number of these targets was under so the planar targets also had to be used. The first one was only put in the sand. The planar targets were fixed with adhesive tape. One target flow away during the measurement and could not be put back on the same place. So it could not be used for the measurement.



Figure 8: on the left: planar target; on the right: half sphere (each on the pile)

5.2 Total station

5.2.1 General remarks

At a total station measurement, the measured points are chosen before the measurement. It is important to choose the right amount of points. Insufficient points produce a low accuracy. Too many points are inefficient because of the work of the survey, the amount of data, longer handling time etc. The correct survey is important for the quality of the DTM. *G. Müller* says the art of the terrain modelling comprises of the survey of the exact shape of the terrain with a minimum data [Mül02].

5.2.2 Set up and targeting

The positioning was done like a ring polygon in a local coordinate system. From three points, the point in the middle was measurable. The total station and the prisms were set up with tripods about the nails. Because of having under tripods, the first POV and the first back point had to be set up again. Not all tripods could be force-centred.

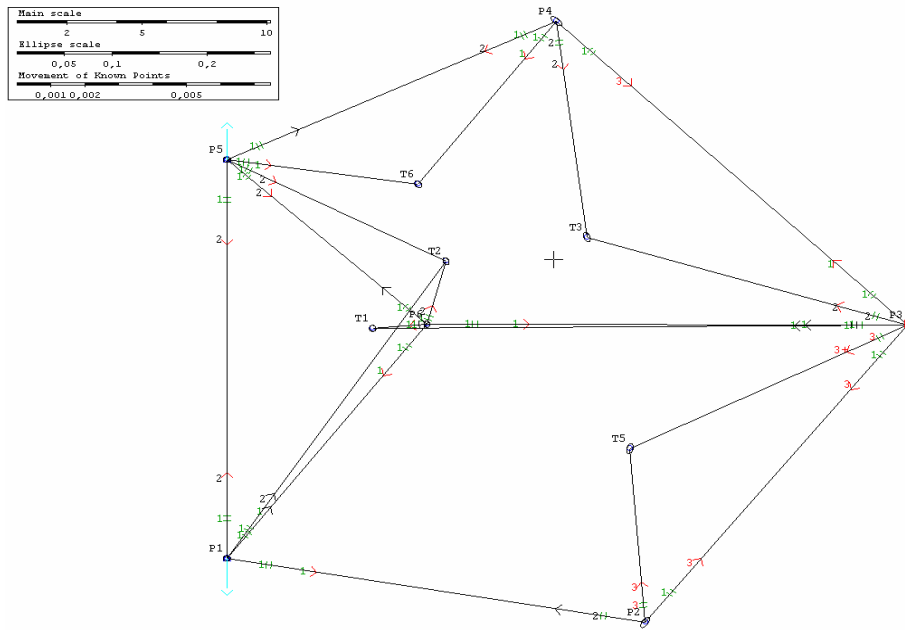


Figure 9: sketch of the total station measurement

5.2.3 Data collection

From each POV the back and the next positioning point was measured one time in one round. The targets and the points on the pile were measured once in the reflectorless mode. One target could be measured only from one POV. Points for break lines were measured, points on the pile and some on the ground. The aiming of most of the points was done only by the collimator. Because of the colour and the structure of the piles, it made no difference if the point was aimed exactly by the cross hairs or only by the collimator. Only points on the border were aimed exactly because there the contrast was big enough. The points got a code to differ them. The group of points for each break line was written down manually.

5.3 Laser scanner

5.3.1 General remarks

There are several ways do combine ScanWorlds of different POV: targets, spheres and equivalent planes. The advantages and disadvantages can be seen in the following table.

Table 5: different methods of combination [Ker03]

Advantages	Method with		
	Targets	Spheres	References of the object room e.g. planes
<i>Can be combined with tachymeter</i>	Yes	Yes	No
<i>Automatically extraction</i>	Yes	Yes	No
<i>Can be individualised</i>	No	Yes	No
Disadvantages			
<i>Dependence on direction of aim</i>	Yes	No	Yes
<i>Work of installation</i>	Low	Low	None
<i>Measurement of intensity necessary</i>	Yes	No	No
Characteristic			
<i>Handling</i>	Well	Satisfying	Adequate
<i>Accuracy</i>	Very well	Very well	Satisfying
<i>Reliability</i>	Very well	Well	Satisfying

For this measurement, spheres were used. The targets that were used for the combination of the total station and the laser scanner measurement could also be used. However, to keep the conditions mentioned above (*chapter 5.1*) the laser scanner measurement had to be independent and the pile should be not accessible. The using of targets also was bad for this measurement because they were not measurable from each POV. Thus, the targets were not used. Therefore, the spheres seemed to be the best solution. The method of equivalent planes was the worst solution. The area of overlapping had to be 20% that would forced more POV.

5.3.2 Set up and targeting

The scanner was set up at the same places as the total station. However, the instrument was not centred over the nails and not set up horizontal. That was done to save the time. The spheres should be positioned so that they were as near as possible on the pile. Otherwise, each sphere had to be scanned in an extra scan. It was tried to use less tripods as possible to reduce the equipment and the work of installation. Five spheres were set up. Two spheres were put on lamps with magnetic mounts and three spheres were put on tripods. So four spheres were placed around the piles and one sphere was placed in the middle. The sphere in the middle had to be put away for the last POV that was at the same place. The others were not moved during the measurement. Therefore,

three spheres could be seen at least from any POV. To solve a free positioning as it was done here it needs three connecting points because the scanner was not set up horizontal. So for each POV the three translations and the three rotations could be calculated. (see also chapter 3.3.2)

5.3.3 Data collection

First images were taken to see the orientation of the scanner. The FOV was determined by a rectangular fence, which was drawn manually. With the probe button, the distance to the object was measured. The distance was measured in the direction of the targeting cross hairs. Therefore, the maximal distance for scanning could set up. The main scans were scanned with a sampling interval of 0,01m x 0,01m. The spheres, which would not been part of the main scan, were scanned and then acquired with fine scans. The sampling interval was 99 x 99 (rows x column). After the scan of the pile, the remaining spheres and the target on the pile were acquired with fine scans. The sampling interval for the targets was 38 x 38. All fine scans had to be controlled. It was not sure that the scanner chose the right area for the fine scan and acquired really the sphere. Especially the spheres, which were put on the lamps, were difficult. The lamppost was also round, thus the software could not distinguish the sphere of the lamppost. The targets and the spheres were labelled during the acquisition. The next picture shows the POV with its FOV. The green lines demonstrate these. The numbers "S1-S4" mark place of the spheres.

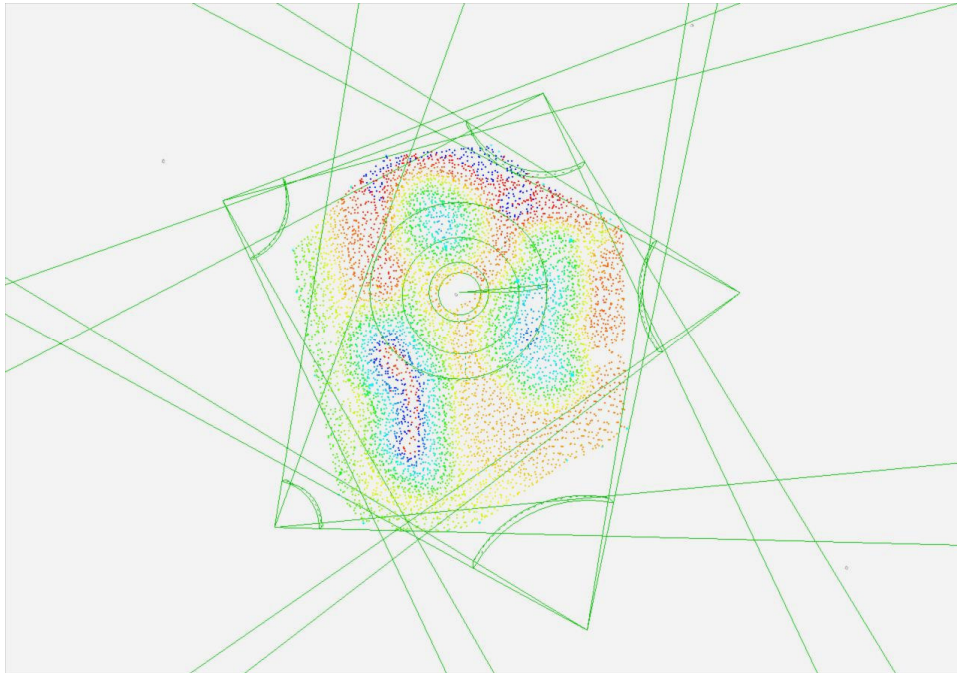


Figure 10: Sketch of the FOV

5.4 Data processing / volume determination

5.4.1 Geo

The data processing of the total station data is done complete in Geo. Because of the arrangement of the POVs – the ring polygon - an adjustment with POVs and targets was done. First, a free adjustment was calculated to find errors and then – based on this result – an elastic adjustment was done to compute the final coordinates. Heights were computed separate of position coordinates. Local coordinates were introduced for the first POV ($x = 1000,000$; $y = 1000,000$; $z = 100,00$) and all calculations was based on this local coordinate system.

The break lines were drawn based on the field script. The point numbers can be shown next to the points so that it was no problem to connect the right points. On the next pictures, the difference between the point cloud with and without break lines can be seen.

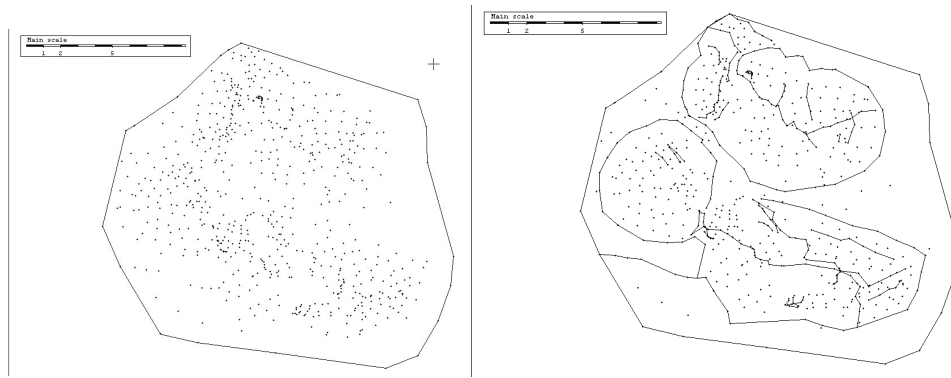


Figure 11: on the left: point cloud; on the right: point cloud with break lines (both in Geo)

It is possible to show the point cloud in a 3D-view. That is good for a check for “runaways”. Because of the rough aiming just with the collimator, it could happen that a point was not measured at the pile but at the area behind or at an obstacle.

Points like this could be seen at the 3D-View. There they could be deleted easily. In this measurement, two points were measured at the bucket and they had to be deleted. It was clear that they did not lie on the pile.

To make sure that in all three programs the same ground area for the calculation was used a line was drawn around the piles. The edges of this polygon were part of the measured point set of the total station data. The same polygon was used in Geograf and Cyclone. All points (scanner data and total station data) outside of this polygon were deleted manually. Because of the different extension of the point cloud of total station data and laser scanner data the polygon had to be smaller than the extension of the point sets was.

For the volume determination, the DTM had to be created. The following picture shows the DTM for the total station data. The red lines describe the break lines. In the outer area at the ground, there are less points and the triangles are bigger. At the piles, there are more points and so there are more and smaller triangles.

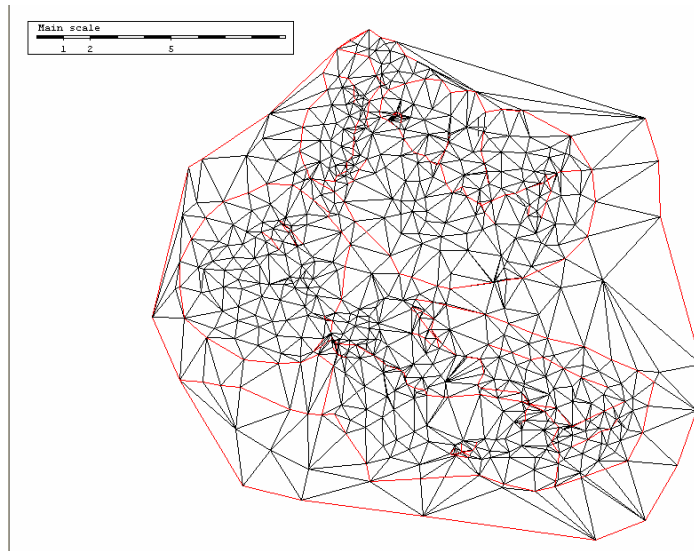


Figure 12: DTM out of total station data with break lines

The volume was computed between the respective DTM and a reference plane at the height of 98,50 m. The area was restricted to the inside of the polygon. The choice of the height of the reference plane is in such a way that all points are situated above the plane. For the calculation of the difference models instead of the reference plane a second DTM (based on different data) was utilized.

Not the original laser scanner data was used but the reduced point cloud with a point-to-point distance of 0,50 m. The data set of the original point cloud was too big and the program shut down. However the next picture shows that the reduced point cloud with about 6000 points is still enough for a heavy DTM. The space in the middle shows the area around the last POV. This area also could not be measured from any other POV. Therefore, there are just a few big triangles.

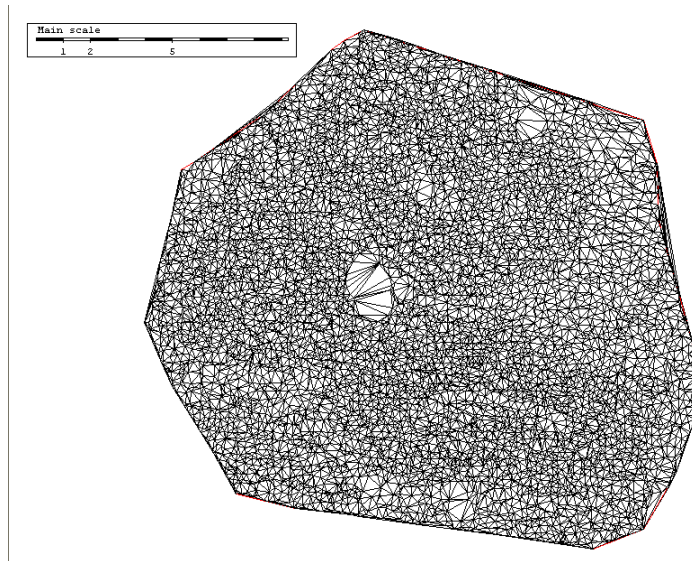


Figure 13: TIN of the reduced laser scanner data

The respective data were exported out of Geo to Cyclone and Geograf. That needed some tricks because of the special characteristics of the programs. The export to Geograf is explained in *chapter 5.4.3*.

For the export to Cyclone the coordinates were saved in a .pxy-format. Normally the project in Geo is saved in the .geo-format. The difference is the kind of division: once the decimal place of the coordinates is differed with a point and once with a comma. That is important for Cyclone, because it is an american program. If the coordinates are imported with commas the values will be rounded off. American programs just know a point as a sign for a division. Then the data had to be opened with the program "Notepad" or a similar one and saved as .txt-format so that it could be read by Cyclone. But just the total station data without break lines could be imported. With the help of "CloudWorks", an extension of AutoCad, the data can be read direct as .dxf-format. The data can be processed like in Cyclone.

5.4.2 Cyclone

In Cyclone, the laser scanner data were processed. The total station data just was imported and the volume was calculated.

Before the volume of the scanner data could be computed, the point cloud had to be processed like the total station data in Geo. The targets were acquired automatically during the measurement. In the post processing, it had to be

checked if the vertices were placed in the middle of the target and if they were labelled in the right way. It was shown that the labelling was partly faulty and the targets were not acquired in the centre. This had to be corrected manually. It was tried to do the acquisition automatically but the program always placed the vertex next to the centre of the targets and not exact in the middle. One target had to be deleted because the FineScan was placed next to the real target. The right centre could not be discerned. The target that flow away also had to be deleted.

The correct labelling and the correct acquisition is the basis for a good registration. This was done first without the coordinates of the total station measurement and consequently without a HomeScanWorld. Thus, the laser scanner measurement could be checked without influences and conditions of coordinates. In a second registration, the coordinates for the targets were imported in a ScanWorld and this was set as HomeScanWorld (see *chapter 3.3.2*). The result of this registration was the basis for the further work. The result was opened and saved in a new ModelSpace. Each new step – change of the data - was saved in a new ModelSpace to save the step done before. In the first ModelSpace, the points of the polygon out of Geo were imported. In Cyclone a fence can be drawn. This can be a rectangle or a polygon. The last one was drawn from point to point of the polygon out of Geo. All points outside of this fence were deleted. Thus, the same ground area should be used like in Geo. However, the edges had to be put manually on the polygon points. The program did not offer an automatic catch mode. The accuracy of this method depended on the user. The bucket, a stave and grass and weed had to be deleted manually with the help of fences.

The point cloud had to be reduced in two ways: with the order “unify” and with the order “reduction of the point cloud”. Because it is not possible to reduce a point cloud in the second way if the point cloud is unified first this method had to be used. The point cloud was reduced stepwise by 25%. At the last step, the number of points was just 428. Each step was saved in a new ModelSpace thus the reduction “Unify” could be started at the step with the deleted obstacles. For this method, point-to-point distances had to be set. The reduction was done for 0,01 m; 0,02 m; 0,05 m and 0,10 m. Then the distance should become bigger by 0,10 m per step. However, the number of points was the same in the

bounds of 0,30 m - 0,40 m; 0,50 m – 0,80 m and 0,90 m – 1,70 m. 1,80 m was the last possible distance. So at last, there were nine steps of reduction. In each ModelSpace, a mesh was created and the origin height of the reference plane was set up to 98,50 m. The volume could be calculated between the reference plane and the mesh. Once the calculation was done by “TIN volume” – based on the formula 3.1-3.3 – and once it was done by “Mesh volume” – based on formula 3.4-3.5. Thus, the difference between both methods could be seen.

For the comparison of the software, the total station data was imported in a new ScanWorld in Cyclone. Each point had to be picked individually to create a mesh. It was not possible to choose all points by one pick, as it is possible with a point cloud. At last, the volume was computed just as the laser scanner data.

5.4.3 Geograf

In Geograf, the data out of Geo were used. The .dxf – file was the only possible exchange-format, which is known by both programs. Nevertheless, it could not be directly imported. The data had to be opened and saved again in AutoCAD, just to get the right structure.

The calculation could not be done directly because the program shows some errors, although the data were used in Geo without problems. Crossing break lines had to be split in separate lines. Because of that, points were added by cutting lines. In Geo, break lines intersected only in the ground view and not in the 3D view. There they had not to be split. If points were nearby, one of them had to be deleted because they were seen as identical points. For the volume computation, two DTMs were created: a horizontal DTM as reference plane and a DTM out of the total station / scanner data. The volume was calculated between both horizons.

For the comparison of the different methods, a grid was created. Because the equal coordinate systems the points of the grid have identical coordinates for both methods (total station data and scanner data). The heights were automatically interpolated. The heights of the total station data were subtracted of heights of the scanner data. This calculation was done in Excel. So both DTMs can be compared.

6 Results of the total station and scanner data

6.1 Adjustment

Each single observation differs from the true value. More observations than necessary are done, so that each value is over-determined. By calculations, the most probably value is computed. This method is called adjustment. First, a free adjustment was done to find big errors in the measuring elements. At a free adjustment no constraints are used - just the over-determined observations. One point gets a local coordinate and the direction to another point is set, so that the system has an orientation. There it could be seen that three directions were erroneous. These observations were not considered in the adjustment. The final coordinates were calculated in an elastic adjustment with movable positioning points. At this method, all points – also the positioning points – are movable and get corrections, not just the one-time observed points at the object. It is truer than a constrained adjustment the second possibility after a free adjustment. That is used if the measurement is connected to a global reference net so that accuracy of the positioning points is higher than the measured points.

For the horizontal adjustment the results are shown as the

$$\text{Helmertscher point error } s = \sqrt{s_x^2 + s_y^2} \quad (6.1)$$

Here is

s = medial point error

s_x and s_y standard errors as X and Y coordinates

It shows the standard deviation of a point and shows a dimension of the dispersion of the average.

elastic horizontal adjustment

Table 6: result of the horizontal adjustment

	<i>Arithmetic average</i> <i>[m]</i>	<i>Best error</i> <i>[m]</i>	<i>Worst error</i> <i>[m]</i>
All new points	0,007	0,006	0,009
Positioning points	0,007	0,005	0,009
Targets	0,006	0,004	0,007

First for the height adjustment, it was also done a free adjustment but all observations could be used. Thus, the final heights were calculated in an elastic adjustment with movable positioning points.

elastic height adjustment

Table 7: result of the height adjustment

	<i>Arithmetic average of height error [m]</i>
All new points	0,004
Positioning points	0,001
targets	0,002

6.2 **Registration**

The values in *table 8* show the error of each constraint after the local and the global registration. In general, this is the distance between two constraint objects after the optimal registration has been computed for their ScanWorlds. If the RMS (root-mean-square) error value is in the 1 cm range for HDS¹ data, the alignment is likely to be good. HDS3000 data has an RMS of 6mm in general [Cyc06].

Table 8: result of the registration

	Global registration: result with targets + coordinates	Local registration: results only with spheres
average [m]	0,002	0,002
Max error [m]	0,005	0,003
Min error [m]	0,000	0,000

¹ HDS = high density scanner, name of the group of all scanner from Leica

The registration was done twice. The first time just the spheres were used as constraints. So the laser scanner measurement could be controlled without the influences of the coordinates of the adjustment. When the measurement would be done without a comparison with a total station, the targets would not be used. The connection to an official reference net also would be done in another way. Therefore, that is the result you would have with a laser scanner measurement. Nevertheless, for the comparison it was necessary to have both measurements in the same coordinate system. The second registration was done with the targets and their coordinates of the adjustment. The ScanWorld with the imported data was set as HomeScanWorld. A lot more constraints were established in this registration.

6.3 **Reduction of the point cloud**

The results of the reduction are shown in the table in the addendum (A1). The computed volume is tabulated dependent on the number of points and the method of calculation: TIN-volume (triangular prisms) and mesh-volume (rectangular prisms).

The following table shows the results of the data when the point cloud was reduced with the order „reducing point cloud“.

Table 9: results of the reduced point cloud with the order "reducing point cloud"

Red.step	percent of reducing (from the step before)	no of points	no of vertices	no of faces	Volume [m3]
calculation without a constant border					
0	Original	462869	402563	805069	393,561
1	25%	111848	109672	219296	393,105
2	25%	25693	25661	51284	391,298
3	25%	6494	6493	12959	387,781
4	25%	1654	1654	3287	375,523
5	25%	428	428	837	330,728
calculation with the ring polygon as a constant border					
0	Original	462869	402563	805069	395,594
1	25%	111848	109574	219124	395,839
2	25%	25693	25679	51337	396,128
3	25%	6494	6510	13002	396,951
4	25%	1654	1673	3329	397,955
5	25%	428	447	877	405,178

Here is:

Red.step = number of the step of reduction

When the point cloud was reduced, the ground area became smaller with every step. This had a big influence on the volume determination. Therefore, the lower table shows the results with a constant border. In this case, the mesh was created of the points of the ring polygon and the point cloud.

6.4 Comparison of needed time

This comparison of time is valid especially for this measurement.

Table 10: comparison of needed time

		Total station	Laser scanner	both
field work		specifications in [min]		
	searching POV, placing of targets, pre-marking			30
	placing of spheres		15	
	time / POV	different	30	
	time on all POV	180	180	
post processing				
	adjustment	30		
	registration		15	
	drawing break	30		
	sorting out of Unify		15	
	calculation of volume	2	5	
	total time	272	265	

For the total station measurement, the time / POV could not be said in general. Not for each POV all tripods had to be set up new. So here, it was only given the time for the whole measurement.

6.5 Comparison of different ways of measuring and software

In all tables is:

- BL = break lines
- Cy = Cyclone
- Points = number of points
- TINs = number of TINs

In the first table, the results are shown of the volume determination with the different programs. These volumes were calculated above a reference plane of 98,5 m. The number of points and the number of created faces are shown. The surrounding area is rather flat, because of that a plane of a constant height (98,5m) can be use as a reference plane. It is deeper that the deepest point of the measurement.

Table 11: results of different programs

program	total station						laser scanner		
	With BL			without BL			without BL		
	volume [m ³]	points	TINs	volume [m ³]	points	TINs	volume [m ³]	points	TINs
Cyclone	-	-	-	400,581	658	1299	396,096	7168	14312
Geo	395,931	750	1477	397,453	658	1294	392,925	7267	14484
Geograf	396,694	671	1297	398,139	658	1297	393,449	7145	14221

In the program Geo 99 points were added by break lines and 339 duplicate points were skipped automatically for the calculation of the total station data with break lines. For the laser scanner data, 99 points also were added by break lines automatically. The reason is explained in chapter 3.4. In Geograf crossing break lines had to have a point of intersection, so new points were introduced in this program (see 3.5).

The differences between the results of the different programs are shown in the second table.

Table 12: differences between different programs

Difference between	data			percent by the particular smaller volume		
	total station		laser scanner			
	with BL	without BL	without BL			
Cy – Geo [m ³]	-	3,128	3,171	-	0,79%	0,81%
Cy – Geograf [m ³]	-	2,442	2,647	-	0,61%	0,67%
Geo – Geograf [m ³]	-0,763	-0,686	-0,524	0,19%	0,17%	0,13%

In the final table, a comparison of the different basis data and so of the different methods with all programs is shown.

Table 13: comparison of different basis data

Program	Difference between the basis data			percent by the particular smaller volume		
	total station with BL - total station without BL	total station with BL - Scanner	total station without BL - scanner			
Cyclone [m ³]	-	-	4,486	-	-	1,13%
Geo [m ³]	-1,522	3,006	4,528	0,38%	0,76%	1,15%
Geograf [m ³]	-1,445	3,245	4,690	0,36%	0,82%	1,19%

In *figure 14*, the difference model between scanner data and total station data with break lines is shown. The model is well-balanced green. That shows that the difference between the methods is spread equally over the whole area. There is no position with an error or wrong points. The distance is between circa -0,16 m and +0,11 m. The exact values are shown in *figure 15*.

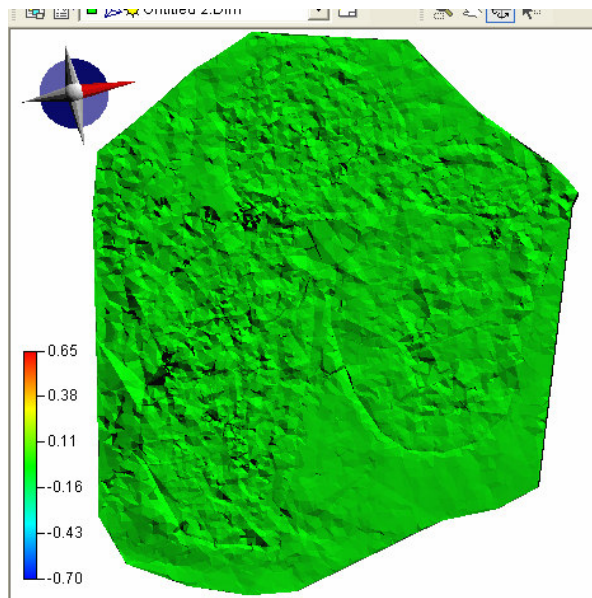


Figure 14: difference model between scanner data and total station data with break lines

In Geograf, grids were created about the DTM for scanner and for total station data (explained in *chapter 5.4.3*). The heights of the equal points were subtracted. The next table shows the result of this comparison.

Table 14: results of the comparison scanner / total station

class of difference	numbers of difference	percent of the whole set
+0,35 to +0,25	1	0,09%
+0,25 to +0,15	7	0,60%
+0,15 to +0,05	110	9,55%
+0,05 to -0,05	828	71,88%
-0,05 to -0,15	179	15,54%
-0,15 to -0,25	22	1,91%
-0,25 to -0,35	3	0,26%
-0,35 to -0,45	1	0,09%
-0,45 to 0,55	1	0,09%

Difference statistics from the comparison:

Maximum	= 0,345 m
Minimum	= -0,532 m
Average	= -0,01 m
Standard deviation	= 0,06 m

In the graphic (*figure 15*) the values of *table 14* are charted.

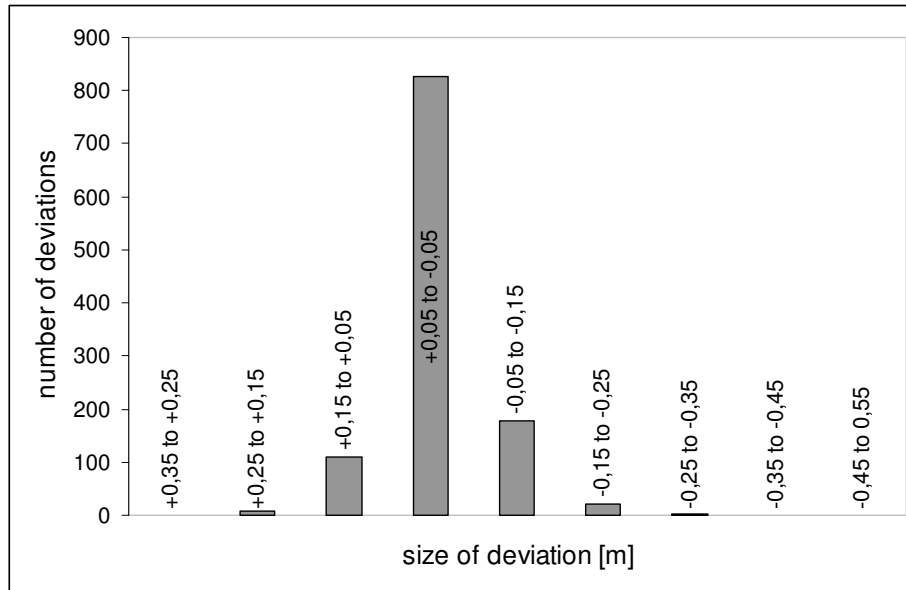


Figure 15: deviations between the DTMs of scanner and total station data

In that table and the graphic the result of the difference model in Geo (*figure 14*) is represented in statistical values and of a different program. The result is the same in Geograf. Most of the points are in the area +0,05 m to -0,05 m. That is 72% of all points of the grid. In the model just the values with bigger deviations cannot be seen, the area is stable green. In the graphic, the column also cannot be seen because the scale and the value are too small. These are just a few runaways. The standard deviation is 0,06 m. That is good for a comparison between two different DTMs. On *figure 15* it can be seen that it is a normal distributed sample. The confidence coefficient of a normal distribution – or Gaussian distribution – can be tested by a z-score test:

$$z = (x - \mu) / \sigma \quad (6.2)$$

Here is

- $x =$ the tested value, it should be believed, that there is no difference between the difference models, so it is 0
- $\mu =$ average, here -0,01m
- $\sigma =$ standard deviation, here 0,06m
- $z =$ the absolute value, here 0,17

The result z is far smaller than 2,57 (statistical value) and proofs that the tested value (0) is with the probability of 99% true. So it can be said, that there is no difference between the difference model of the scanner and the tachymeter.

7 Discussion

7.1 *Reduced point cloud*

The reduction was done in two ways: once with the order “reducing point cloud” and once with the order “unify”. For both methods the mesh was created once only with the point cloud and once with the point cloud and the points of the ring polygon. Therefore, in the first case, the ground area decreased and in the second case, it was kept constant. If the ground area is kept constant, the result only shows the changes because of the decrease of the points and the getting worse approximation of the mesh to the real surface. When the ground area also decreases, the volume is calculated on a different basis with every step. That covers the effect of the getting worse approximation. Therefore, if the point cloud shall be reduced a constant border has to be kept. In the other case, the result would show a wrong conclusion.

Reducing point cloud

The results for this method differ up to -63 m^3 with the decreasing ground area and $+12 \text{ m}^3$ with the constant ground area. In percent of the result from the original data it is $-15,94\%$ for the first way and $+0,38\%$ for the second way. The margin is so big because the ground area decreases very fast. The first result is not acceptable. The result differs too much from the original result away. The result with the constant polygon is better but still too big.

The following picture shows the mesh created of the stepwise-reduced point cloud. The green line is a sign of the ring polygon. It is the last step (reducing step no 5) of reduction and the number of points is 428. The picture shows how much the area gets smaller because of the reduction of the point cloud.

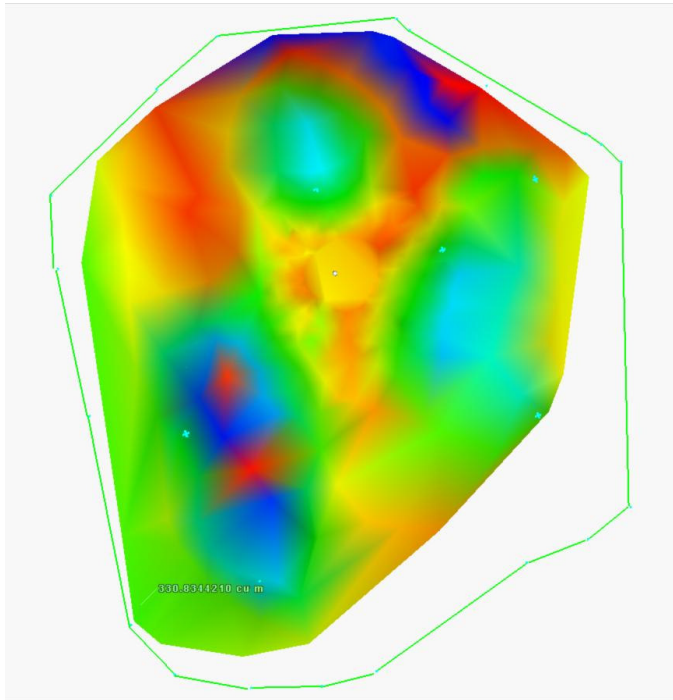


Figure 16: mesh of reducing step no 5

Unify

At the beginning, the volume shows a difference of two cubic meters between the methods with and without ring polygon. The original point cloud without a reduction was the basis for both calculations. When the volume was calculated without the ring polygon as a border, the ground area was defined by a fence. All points outside of the fence were deleted. The difference shows the inaccuracy of this method. However, the tendency of the result is the same like the method of the order “reducing point cloud”: the volume decreases with the decreasing ground area and it increases with the constant ground area. The margin is smaller by the order “unify”. The results differ up to $-1,481 \text{ m}^3$ with the decreasing ground area and $+3,004 \text{ m}^3$ with the constant ground area. The ground area does not decrease so fast like with the first method. The graphic (see *Figure 15*) shows that the changes appear at the same step of reduction. There is no difference in the result of the original point cloud and of the reducing step no 5 (25620 points). The first change can be seen at step no 6 (7149 points). Relating to the volume of the original point cloud the difference of the last reducing step is only 0,75%.

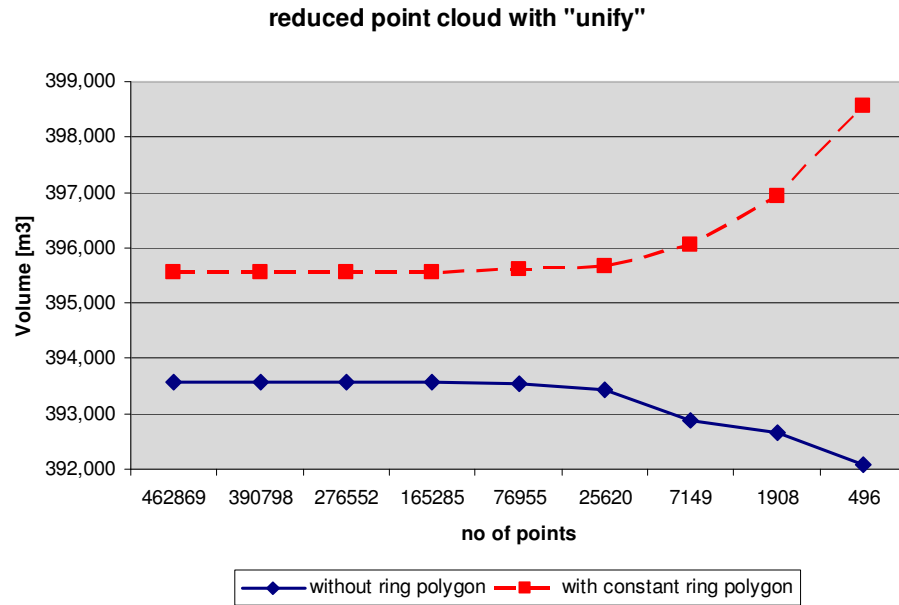


Figure 17: diagram of reduced point cloud

The result of the calculation with the order “unify” and with the constant border can be seen as the right result. The order “Unify” is more certain than the order “reducing point cloud”. The best argument for this is the dimension of the changes of the area. The ground area decrease faster with the order “reducing point cloud”, the points are not deleted evenly. The big changes can be seen in *figure 16*. By contrast in the next picture (*figure 18*) it can be seen the changes with the order “Unify”. The green line is a sign for the ring polygon. There are no big changes. At some points, the area gets smaller and the green line can be seen but at some points, the area gets bigger, too. If the pile is bigger, the curve at the graph is expected to run the same way. Until step 7 no alterations are expected. The difference will alter percentage to the growth of the object. Finally, it can be said that each point cloud can be reduced by the order “unify” until a point-to-point distance up to 0,3m and without changes in the result.

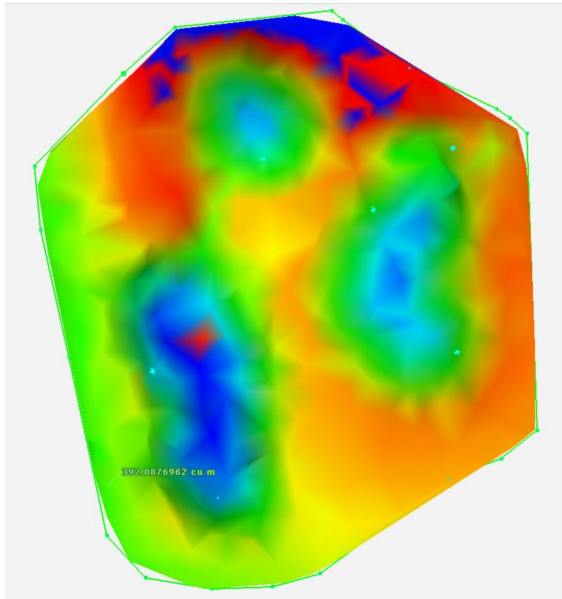


Figure 18: reduced mesh with polygon line; reducing step no 8

7.2 Comparison of applied software

The calculation was done three times with three programs independent of each other. In each program, exact the same basis data has been used. In Cyclone, the calculation was done twice: once triangle-based and once grid-based. However, a difference can just be seen in the second or even third decimal place. Thus in the comparison the values of the “TIN –volume” (triangle-based) are used. Accordingly, in all three programs the results of the triangle-based method are utilized. Nevertheless, the conditions to create a DTM are different.

The calculation is done with different numbers of points for the total station data with break lines and for the scanner data. Therefore, a different number of TINs is used. If two points are at close quarters in Geo and in Geograf, one is deleted. These programs are not designed to compute such large amounts of data like scanner data. Thus points, which are nearby, are seen as identical points. In Geograf, break lines have to have an intersection point. Because of this, points were added by cutting lines. This is not done automatically; each point has to be created manual. When the calculation was done with the total station data without break lines, the number of points was exact the same in all three programs. Nevertheless, the number of TINs was different. So the

programs cannot use exact the same way of creating a DTM. Because of the different conditions for the creation and accordingly different DTMs there are different volumes. However, there is no relationship between the number of TINs and the size of the volume. It is not true that more TINs in the calculation mean a smaller volume and a higher quality.

The following graphic (*Figure 19*) shows the size of the differences for the several methods. The exact values are tabulated in *table 11*. It can be seen that the difference between Geo and Geograf is very small and the difference of these both and to Cyclone is bigger.

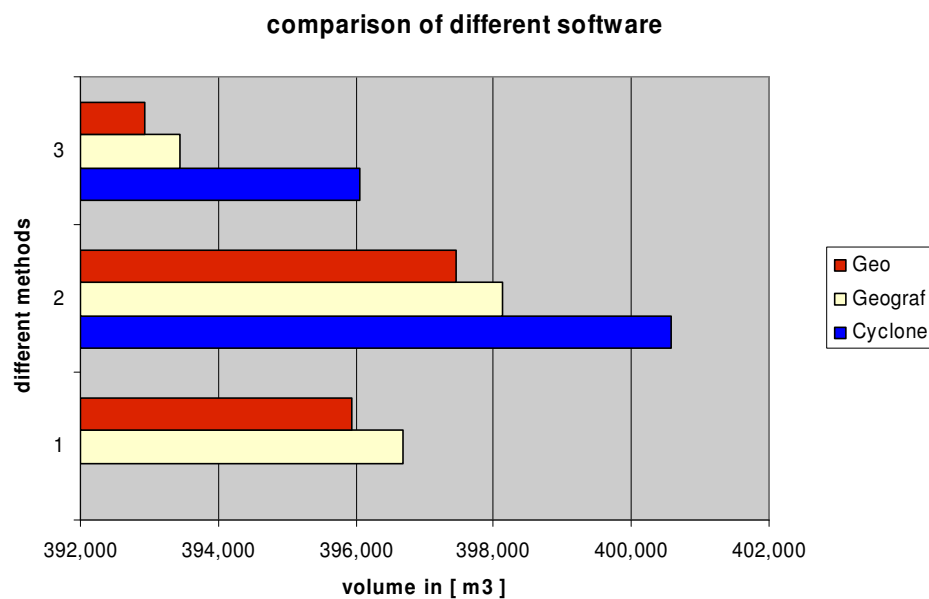


Figure 19: comparison of different programs

The different methods are:

1 => total station data with break lines

2 => total station data without break lines

3 => laser scanner data

In Geo and Geograf, difference models of the different methods were computed. In *table 15*, the results of the difference models and the differences between two programs are shown. This was done to test the statement that there is a difference between computations from a reference plane to a DTM and between two DTMs. (*chapter 3.1.2*) The result of these calculations is better than the others. The difference is smaller than by the comparison of the

volumes above the reference plane. The difference between both programs is also smaller.

Table 15: differences between two DTMs

difference model	Geo	Geograf	difference
scanner – total station with BL [m²]	11,892	11,944	-0,052
scanner – total station without BL [m²]	13,066	13,089	-0,023
total station with BL – total station without BL [m²]	2,667	2,983	-0,316

Comparisons of different software products were done seldom until now. M. Lindstaedt tests three different software products for scanning data. She says that the result of the 3D- triangulation depends highly on the software. Unfortunately, the applied algorithms are not known [Lin05]. Thus, the exact reason for different results can just be assumed.

7.3 Comparison of time

The comparison of time, which was done in chapter 6.4, applies only for this special measurement. Each new object and each new task will have new conditions and factors. Therefore, the time will also change every time depending on size and shape of the measuring object and the expenditure of the connection to a reference net the relation between laser scanner and total station also can change.

Laser scanner

Different conditions need different solution. Some things are especially for this measurement, which are not on each place where a pile is to measure. A few points are named here as examples. There were lampposts around where the spheres could put on. Grass and weed were at the ground, which had to be deleted. Targets on the pile had to be measured for the combination with the total station measurement. Additional a reference net was not necessary. All these points influences the time for the measurement.

Here the grass and weed was deleted by hand. When there is a lot of grass, it would be done with special software, which can do the deletion faster and more accurate. The measurement was done at a quite place. Therefore, no human

beings, cars or vehicles of the building lot disrupted the laser. Things like this also have to be deleted.

The lampposts around the lot replaced tripods. Two spheres could be put on lampposts with magnetic mounts. If all spheres had to be put on tripods, it would take more equipment and longer time to set up the spheres. It depends on the shape of the pile / measurement object how many spheres have to be used. The more spheres the more time is taken. At a bigger pile, where it is not possible to look over it, a lot more spheres or other targets have to be used. At lampposts, spheres can also be set up higher than by a tripod.

Each measurement should be connected to a reference net. In most cases, it is mandatory. Nevertheless, it is also easier to repeat the measurement or to compare it with succeeding jobs. It was not done in this task. If a laser scanner measurement is connected to a reference net, a total station or GPS is also used and an adjustment or transformation has to be done. All these things take extra time. With the HDS3000, it is not possible to combine the measurement direct with a reference net. The new laser scanner ScanStation from Leica has compensators, the accuracy of the angle measurement is higher and it is possible to do a back sight. Reference points can be measured directly and the internal system can be orientated like a total station with a free stationing. Therefore, a total station or GPS is not necessary at that system. The connection to a reference net will be easier.

The longest time is taken by acquisition of the spheres and targets and the changes between the POV. The targets were only used to combine the total station with the laser scanner measurement. Much more targets would be used, if they should also be used for a registration. Because of the shape of the pile, it was not possible to do the registration just with targets. Without the targets, the time for the acquisition would be shorter. The more irregular an object is, the more POV have to be needed. In this investigation, many POV were used in relation to the area. That was necessary because of the shape of the object (three piles). And each POV more takes time.

It is said that the relation between fieldwork and post processing is between 1 / 5 and 1 / 10 with a laser scanner. Nevertheless, the tenfold expense is often not enough [Mar03]. In this measurement, the relation is 5,5 / 1. If buildings are measured and the aim is a 3D-Model, it is a lot of work to create an exact

model, to design planes and edges. Here nothing has to be done but the registration, cleaning of the data, Unifying of the point clouds and creating of a mesh. Therefore, the relation is contrary.

The time for the measurement depends on many aspects. Each point influences the time in different ways.

Total station

The time for the total station measurement is mostly influenced by the time to set up tripods with prisms and turning around of the prisms for the positioning.

The pure time for measuring of the points was only 5-10minutes per POV. If the pile and so the distances between the POV would become bigger, the time for the measurement would rise. However, not because of the rising number of points, but because the ways to turn prisms etc. it takes longer. The number of points does not make a big difference. Hundred points more would mean five minutes longer if aiming and measuring would take three seconds per point.

In the post processing, the drawing of the break lines can be made easier / substituted with a total station, which allows to measure lines. Then a script is also not necessary. By codes, the points are assigned to lines during the measurement and can be imported in the program. Therefore, the break lines have not to be drawn in the post processing. However, for short lines – only two or three points - it is not very well, because it takes time to choose the right settings. Some total stations also offer a program that scans planes like a scanner. It is just much slower than a scanner. That might be helpful for objects with huge irregular planes. In the total station software, just a rectangular square can be given for a framework. Therefore, if the outer shape is irregular the covering is bad. That means, in some regions no points are measured, and at some places, the total station cannot measure anything because the grid is bigger than the object. If the total station cannot measure the point at the first time, it tries thrice and then it tries the next point. That takes time and power.

Comparison

In this measurement, the laser scanner is a little bit more effective than the total station. However, it is just 7 minutes. That is almost equal. The time for the fieldwork is for both measurements the same, but the post processing is done few minutes faster for the laser scanner. Other studies investigate equal or similar problems. In his studies *I. Kruse* found out, that the total station

measurement takes 80% of the time for the fieldwork with the laser scanner [Kru05]. The goal of the measurement was the creation of a 3D-model of a golf course. The shape of the area was more flat and bigger. That is an advantage for the total station. Not so many points are necessary to describe the shape of the ground. *F. Schneider* compared in his thesis a laser scanner measurement with GPS. The time for the fieldwork is not directly comparable to this study, GPS does not need a positioning or visible reference points. GPS took only a third of the time of the laser scanner. Nevertheless, the time for post processing is comparable: for laser scanning it took 60% more of the time of GPS to get a result [Schn04]. *F. Schneider* determined the volume of a gravel pit. He has also to draw break lines at the GPS data. *V. Dittscheidt* and *C. Engels* came to the result that for small regions there is no difference between laser scanner and tacheometry. They surveyed a dump for a volume computation partly with a total station and the whole dump with the scanner. The fieldwork took more time with the total station but the post processing was faster. Therefore, in the end it was the same [Dit05]. In contrast to this, *G. Antova* said that both pre- and post-blast measurements, as well as stockpile volumes, can be collected much more effectively using laser scanning technology. She tested the use of laser scanner for open mine mapping and thinks a total station as labour intensive, costly and hazardous [Ant06]. *C. Hönninger* and *T. Kersten* compared direct a measurement by a total station with a laser scanner. They found out that laser scanner is just with an automatically analysis of the point cloud just as efficient as a tacheometric survey [Hön05]. They measured an area with many trees, weed etc. that had to be deleted. By a comparison just of the fieldwork, laser scanner takes 80% of the time of the total station measurement.

Finally, it can be said that a general conclusion cannot be fixed. Several persons compared a scanner with a total station. After the results of this investigation and compared to the results of others it cannot be said that a laser scanner altogether takes less time for a project. For the fieldwork, a scanner takes less time in most cases than a total station, but in the post processing, the total station data can be worked faster. It depends on the object and on the area around how much time it takes for measuring and for the post processing: size of the object, obstacles in the data etc. The more structure an object has the

more the use of a laser scanner is worth it. Thus for each task and each object the decision has to be made again.

For this study, a specific case – size and shape of the object - was investigated. What would happen when the pile is bigger? The time for fieldwork would arise for both methods, ca. a half hour per POV. For the laser scanner time for post processing would not arise a lot. The steps, which have to be done in the post processing, are the same for small and for big piles. It would just be more work to control the registration. For the total station, it would arise when the break lines are drawn manually. The relation between fieldwork and post processing would change for both methods.

7.4 Comparison of the accuracy

The different methods of measuring can be compared after expense (time for field work, post processing, equipment etc.) and after accuracy (difference between the results). The first point is discussed in *chapter 7.3*. The second point is discussed in this chapter.

To compare different methods several ways are possible. In this study with the program Geo, difference models of the different methods are created and the volume between two DTMs is calculated. In Geograf, an identical grid is created and the heights of equal points are compared.

In the next pictures, the DTMs of the respective data are shown. On the first picture (*figure 20*) it can be seen that the scanner data is very fine and the triangles are small because of the big amount of points. Just in the middle of the piles are bigger triangles because there the density of points is very small. This region was the place of the last POV and the ground could not be seen from another POV.

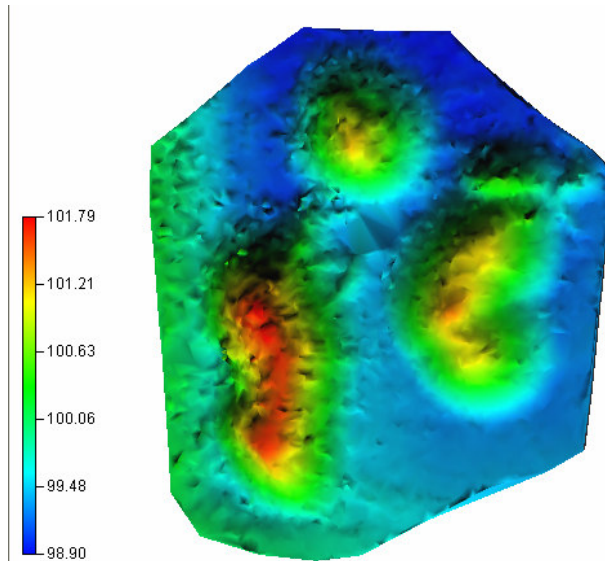


Figure 20: DTM of the reduced scanner data in Geo

The next picture shows the DTM out of total station data with break lines. It looks blurred. The transition from pile to the ground cannot be discerned clearly, although a break line marks the border. The scale starts at the lowest point and ends with the highest point. The difference between scanner data and total station data is at the lowest point just one centimetre and at the highest point eight centimetres. It is wondrous, that the highest point at the total station data is higher than the equivalent point of the laser scanner data. However, perhaps the highest point is deleted of the scanner, because just the average persists.

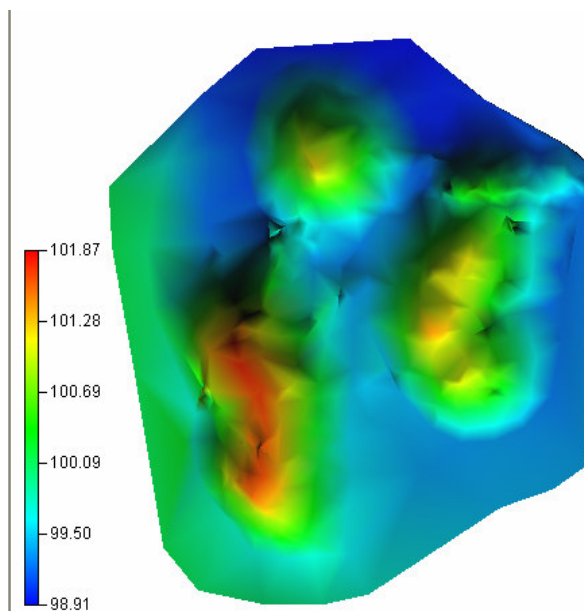


Figure 21: DTM of total station data with break lines in Geo

In the last picture, the total station data without break lines are shown. The picture is more blurred than the picture before. The highest and the lowest point is the same, because the same points were used. There is not a big difference between the two pictures of total station data. The break lines just make the picture a little bit more clearly.

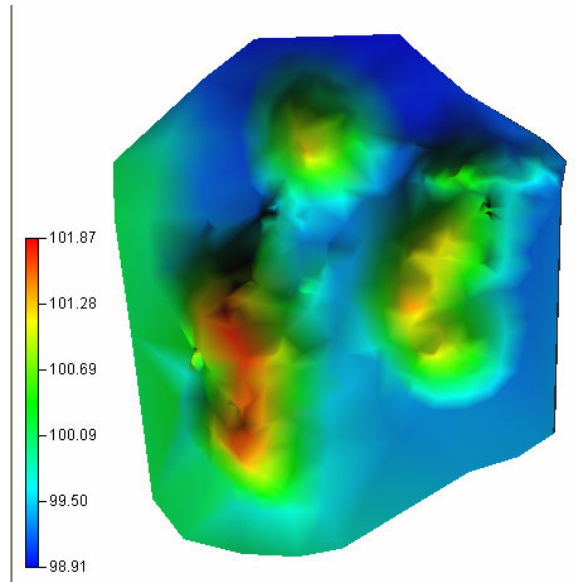


Figure 22: DTM of total station data without break lines in Geo

At *table 15*, the size of the volume of the difference models between the several methods is shown. The difference between the total station data with and without break lines is the smallest. It is just 0,7% of the whole volume out of total station data with break lines. For this small area, 658 points were measured. That is a lot in terms of an area like the one, which was used. The most triangles automatically were created correct without the compulsion of break lines. This demonstrates that the number of points can be reduced if break lines are used. If too many points are measured, it makes no sense to create break lines because the result is the same. Because of that small difference, following only the scanner data and the total station data with break lines are compared. That difference volume is 3% of the whole volume.

In other studies, the same result was found out. *G. Antova* found out that for laser scanner volume accuracies are well within allowable error budget, equal or surpassing that of the survey and dispatch figures [Ant06]. *V. Dittscheidt* and *C. Engels* had also the same result for a laser scanner and a total station. They used the scanning program for the total station. Just in areas with much

weed, trees and bushes, the total station had disadvantages and erroneous points. The density of the grid was too small to find wrong points, which did not belong to the ground [Dit05]. *C. Hönninger* and *T. Kersten* came to the result of the average of 0,2 m. That shows the difference of control points in an area that was measured once with a total station and once with a laser scanner [Hön05].

Comparable to the results of the others the result of this study shows the same direction. There is not a big difference between the data got by a laser scanner or a total station. The choice of the method has to be decided by other factors than the accuracy.

7.5 Comparison of the methods

In *chapter 7.3* and *7.4*, the different methods are compared per time for measuring and per accuracy of the result. Nevertheless, there are more factors, which are to consider.

H. Stanek had to measure projects with piles of rubble, coal etc or dumps for volume computations. For projects like this, he can use many specific advantages for terrestrial laser scanner. The large range with eligible resolution allows the temporal and economical optimizing of the measuring program as well as the avoiding of endangering respectively there is an avoiding of break of operating because of the reflectorless measurement [Stan05]. These are some advantages of the laser scanner. Nevertheless, most of them also apply to a total station. The large range is the same and some total stations can measure reflectorless, too. Just the resolution is worse respectively it takes a lot more time to get the same resolution with a total station. However, the results in *chapter 7.4* shows that in the calculated result there is no difference between total station data with few points and laser scanner data with many points.

Another argument fits for tacheometry. *G. Müller* says the tacheometric survey distinguishes by low expense of appliances, easy verifying and reconstructing of the data and, if necessary, short-term analysis of the measuring on the spot [Mül02]. If an adjustment is not to do, the data can be got relative fast at the fieldwork. It is more complicated to get directly the result out of scanner data. The registration takes some time. It will be easier with the new Leica ScanStation. With the known backsight / azimuth, a POV can be combined

directly to other POV like a total station and then the registration is easier to do. In this case, the result also can get fast with the laser scanner at the fieldwork.

The costs are a further aspect of the new technology laser scanner compared to tacheometry. *G. Antova* says, depending on the special features, the nominal cost of laser scanner is six to eight times more expensive compared to an ordinary total station and digital camera [Ant06]. In addition to the high equipment there have to be trainings for personal that should work with the new technique. A total station is a standard instrument and every engineer can work with this. Therefore, the laser scanner has to be so much more efficient than the total station that the higher costs are justified.

In the literature, authors are different opinions what the better method – laser scanner or tacheometry - is or if one method is better than the other is in general. Some publishers think that laser scanner will replace the “old” instruments, some that the scanner will complete the list. *R. Staiger* means terrestrial laser scanner is doubtless a method that the possibilities of the surveyor expand. That means that not just one method is replaced by another but solutions can be offered which have not been possible until now [Sta05]. Volume computation is a traditional, classic task for surveyors. The used “old” methods are well proofed and known. It is hard to make a change to a more effective method.

For volume computations, there is no difference in the result between laser scanner and tacheometry. The time can be different depending on the structure of the object and the conditions around the object. Both can be done with one person. Nevertheless, the costs for the equipment are different. Each measuring object has to be checked for advantages / disadvantages of the scanner:

- structure and size of the object
- time for post processing because of registration and interferences during the measurement
- costs of equipment (equipment available or has to be bought)

8 Conclusion

In this thesis, three problems were investigated:

1. How much can a point cloud be reduced without alterations in the result?
2. Different software – different results?
3. Which method is better for a volume computation: laser scanner or tacheometry?

The result of each question can be considered on its own. Thus, each question has its own conclusion.

During a measurement with a laser scanner, many data is saved. The calculations with “small” programs like Geo and Geograf show that it is impossible for such programs to compute huge amounts of data. Moreover, even Cyclone, a program that is designed for big amounts of data, shows problems. The mesh out of the original point cloud cannot be moved. It takes a lot of time until the changed view is shown. This proves that it is necessary to reduce the data before the calculation starts. The results of the different computations show that it is very important to use a constant border for the calculated area. If the point cloud is reduced, the points in the outer areas are also deleted. Thus, the ground area gets smaller and this effect covers the desirable result. The reduction of the point cloud with two different processes shows that the order “reducing of a point cloud“ is not suitable as method. The points are deleted too irregular. The more the point cloud is reduced the worse the area is design by the DTM. The result of the order “Unify” demonstrate that the point cloud can be reduced to a point-to-point distance of 0,3 m. It is expected that, if the measuring object becomes bigger, the result – the difference to the original point cloud - will change percentage to the growth of the object. A further conclusion is that the number of measured points immediately at the measurement can be maintained low. The density does not have to be so high. The lower the density the lower is the time for measuring. The second problem is the comparison of the software. The results of the programs Geo and Geograf are very similar. It shall be like that. The user has to trust on the result that the program gives out. Just Cyclone shows a bigger difference. The reason is that the programs have different conditions for the

creation of DTMs – respectively TINs. This program is not designed for tasks like volume computations. Perhaps if the scanner is used more often for topographic surveys the software will become better in this field.

The main and last problem is the comparison of laser scanner and tacheometry. The investigation is done into accuracy and time. The factor of expenses is just considered theoretically. Especially respective the size of the object there is no difference between the results of laser scanner and tacheometry – not in this investigation and not in that of other persons, too. Contrasting to this the results of this and other studies are scattered in the comparison of the time. In most cases, the laser scanner is faster in the fieldwork but slower in post processing than the total station. In the sum, the time is the same. The bigger the object is and the more structure the shape has the more advantages has the laser scanner. In this case, many break lines would have been to measure with the total station. Thus, the fieldwork and post processing will become longer. An object of the size and structure like the one it is used in this study is in the border zone of the choice of the method. It is not worth to buy a laser scanner just for the task of volume computations. Nevertheless, if a scanner is available and the time for the measurement has to be short it is advantageous to use one. The future will bring new methods, easier and faster. Then a new investigation has to be done, with new arguments and new results.

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¹ DVW = deutscher Verein für Vermessungswesen; german organization of surveying

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Addendum

A1

Red.step	point-to-point distance [m]	mesh without ring polygon				mesh with constant ring polygon						
		no of points	no of vertices	no of faces	Volume [m3]	TIN [m³]	difference	no of vertices	no of faces	Volume [m3]	TIN [m³]	difference
0	original	462869	402563	805069	393,569	393,561	0,000	402103	804176	395,556	395,594	0,000
1	0,02	390798	379438	758819	393,570	393,561	0,000	379177	758324	395,555	395,594	0,000
2	0,05	276552	273182	546307	393,562	393,554	-0,007	273143	546256	395,553	395,587	-0,007
3	0,1	165285	164694	329333	393,562	393,556	-0,005	164712	329394	395,553	395,591	-0,003
4	0,2	76955	76863	153670	393,537	393,517	-0,044	76882	153734	395,597	395,604	0,010
5	0,3	25620	25611	51167	393,437	393,435	-0,126	25629	51235	395,654	395,681	0,087
6	0,5	7149	7149	14253	392,872	392,905	-0,656	7168	14312	396,064	396,096	0,502
7	0,9	1908	1908	3778	392,671	392,654	-0,907	1926	3828	396,921	396,903	1,309
8	1,8	496	496	963	392,088	392,047	-1,514	515	1009	398,559	398,548	2,954

Red.step.

⇒ number of reducing step

Point-to-point-distance

⇒ distance between two points, value given by the user to set the size of reducing (see also chapter 3.3.3)

Volume

⇒ volume calculated based on a grid

TIN

⇒ volume calculated based on a TIN

difference

⇒ difference between the volume (TIN based) of the original point cloud and the volume of the particular step of reducing