Hochschule Neubrandenburg
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Extraction 3D Model of the Underground Garage in Market-Center Neubrandenburg by using 3D Laser Scanning Technique

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Contents

Introduction

There is an increasing interest of the scientific community in the generation of 3D models from terrestrial laser scanner (TLS) data.

Now, Laser scanning is one of the most common techniques for acquisition of the 3D data in many departments, and not only in our range surveying. The reasons are high accuracy, resolution, precision, reproducibility, repeatability, and reliability of all types of scanner, both terrestrial and airborne laser scanners.

Indeed many other factors, such as time, cost effective, and the data volume, and the high level of details, which we can obtain by using Laser scanners, made the LS the first interest of the users.

Laser scanning systems available on the market have different specifications, and therefore each laser scanning system is applicable for a specific area of applications. Up to now, there is no all-purpose laser scanning system available. Even though, there is a wide spectrum of available laser scanning systems, terrestrial laser scanners are currently used by only few specialized engineering companies.

In this thesis I concern the terrestrial laser scanners which now have many applications in architecture, archeology, building, tunnels, transportation, surveying, and many other applications.

The use of Terrestrial Laser Scanning in the underground structures such as tunnels, and underground parking has a special importance because the use of aerial photogrammetry is not possible to generate a 3D model.

In this thesis the laser distances measuring technique both Time of Flight and Triangulation is discussed and how one can create a 3D model by using TLS.

The various TLS in the market are versatile, in order to help all the needs of users.

They can be distinguished as handheld lasers for to create a 3D image through the triangulation mechanism, scanners for wide range e.g. HDS6000, and scanners for close range are characterized by a short measuring range, but have a very high accuracy.

Therefore, their fields of application are not to be found in terrestrial surveying but in metrology. The output of laser scanning is the point cloud; it represents the coordinates of every point from the scanned surface. Before modeling we need to register the obtained point clouds from many stations in one general coordinate system. This important step is named registration.

The work is continued by generating a model, and to remove the unused points, which come from reflections or not interesting objects.

The 3D model is created by using the different available tools in the scanner software.

1. 3D Modeling

3D Modeling is the operation to represent the real world by using techniques and software, in order to obtain easy measurements and planning in the organization, in addition the cost effective, the product of 3D modeling is 3Dmodel.
3D models is the output of 3D modeling, and represent an object in the 3D space, it can be produced from the 3D measurements. By using algorithms, photographs, or scanning can be 3D model generated.
Nowadays 3D models have applications in many varieties of sciences; even the medical industry used 3D model techniques to create models of the organ. Civil engineering uses it to calculate the volumes, contour line, and also the deformation. The importance of 3D models in the architecture industry is obvious to show the front and details of buildings and landscapes. The promotion strategy uses them as designs of new devices, and structures as well as a host of other uses. And there are many other fields such as community industry, historical fields.
Using of 3D model and visualization techniques is becoming more and more popular, and it requires a large volume of data. The 3D coordinates represent the basic source of these data, and theses coordinates can be obtained from traditional methods or photographs.
It is good to attention, that complex and irregular surfaces required plenty points more than the regular surfaces to represent it exactly.

2. Methods for obtaining 3D Model

1. Remote Sensing (Photogrammetry and Lidar).
2. Topographic Maps.
3. Traditional surveying by using theodolite or total station.
4. Inertial surveys.

Here will be concerted the remote sensing and its variant.

2.1. Remote Sensing

Remote sensing is the science acquisition of information of the object or Earth's surface without actually being in intimate contact with it. This is done by using of a variety of devices for gathering information and recording reflected or emitted energy and processing, analyzing, and applying that information.

In much of remote sensing, **the process** involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. However that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors. [1]

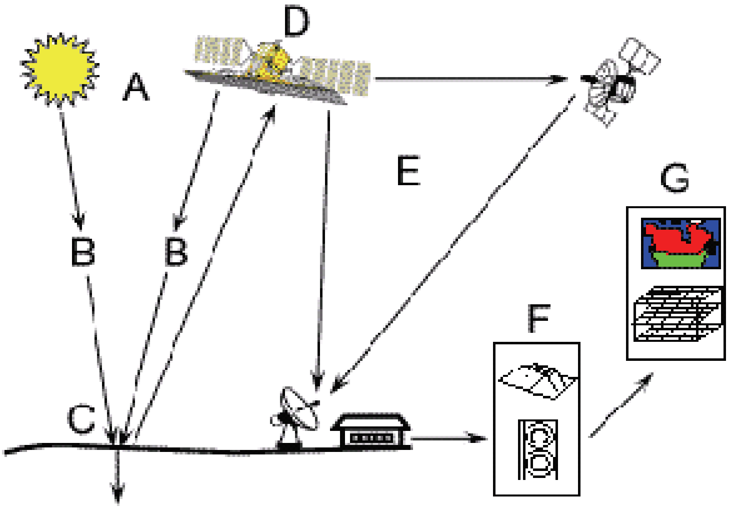


Figure 1 Remote Sensing Components and Operation

1. Energy Source or Illumination (A):

It supplies the target of interest with the electromagnetic

2. Radiation and the Atmosphere (B):

The emitted energy from energy source to the target Passes through the atmosphere and has a contact and will interact it, and this interaction takes place again, when the energy comes back from the object to the source.

3. Interaction with the Target (C):

Depending on the properties of the object, the energy interacts with it.

4. Recording of Energy by the Sensor (D):

The scattered electromagnetic energy from the object would be collected and recorded from a sensor that is sometimes may be located on the energy source, and other cases may not.

5. Transmission, Reception, and Processing (E):

After recording the energy by the sensor, it would be in an electronic form transmitted, to a processing station. The processing station will be produces into an image.

6. Interpretation and Analysis (F):

To extract the information about the object must be at first the processed image interpreted and analyzed.

7. Application (G): the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

There are two kinds of remote sensing passive and active.

Passive sensors: is the kind of remote sensing that detect the natural radiation. Reflected sunlight provides the most general resource of radiation measured by passive sensors. Examples of passive remote sensors include human ear, satellite, and radiometers.

Active sensors: these sensors have their own energy. The sensor emits radiation to scan objects and areas and then the reflected portion of the energy from the target is detected and measured by the sensor. An example of this type is RADAR, the difference time between emitted and returned signal is measured, and then used for determining the locations, and direction of an object.

The most common examples of Remote Sensing are Photogrammetry and Lidar.

2.1.1 Photogrammetry

The art of technology allows making measurements off photos. The techniques are based on the geometry of perspective scenes and on the principles of stereovision, and actually pre-date the invention of photography. [2]

The output of photogrammetry is the map, and then we can create Digital Elevation Model (DEM).

In terrestrial photogrammetry a ground camera is mounted on a tripod or hand held, it is used to record close objects less than 300 m, Cameras are used to model buildings, engineering structures, vehicles, forensic and accident scenes, film sets, etc. Other site, in **aerial photogrammetry** the camera is mounted in an aircraft and sweeps the ground along the flight path and takes overlapping photos. It is typically and quick technology to acquire wide areas.

The two main data extraction methods for analyzing these photographs:

- Quantitative: that is size, length, shape, height, area, etc.
- Qualitative: geology, vegetation, drainage, land use, etc.

The main considerations for photography are:

a. Field of View

b. Focusing

c. Exposure

a. Field of View: the camera's field of view defines how much it sees and is a function of the focal length of the lens and the size of the digital sensor. For a given lens, a larger format sensor has a larger field of view. Similarly, for a given size sensor, a shorter focal length lens has a wider field of view. The relationship between format size, lens focal length and field of view is shown below in figure (2) [3]:

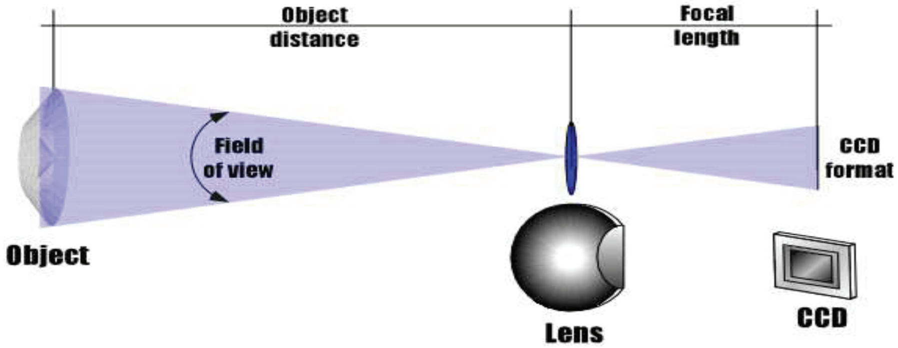


Figure 2 format size, lens focal length and field of view

b. Focusing

by moving the lens would the camera be focused, if the farther lens from the film brings closer objects into the focus. The depth of focus is not independent, it is considered as a function of the focal length of the lens, the format size, the distance between the camera and the object, the size of the object, and the f-number of the lens. [4]

c. Exposure

Exposure is the total amount of light allowed to fall on the film in the photographing. Exposure is measured in exposure value (ev), with higher values denoting more light. A faded photograph found out by a long exposure of the shot, a dark photograph found out by a short exposure.

The two primary controls of camera uses for exposure are **shutter speed** (the effective length of time the shutter is open) and **aperture** (the size of the lens hole that lets light travel through the camera). The unit of shutter speeds is seconds and fractions of a second. Apertures are measured in something called f / stops.

Generation of 3D Model from Images

Terrestrial photogrammetry analyzes digital photographs using commercially available computer software to measure objects in three-dimensional space.

The generation of 3D model from Images consists of following steps:

a. Image acquisition.

b. Determination interior and exterior orientation parameters of images.

c. 3D modeling of object and surrounding.

a. Image acquisition

For close-range photogrammetry required photographing the site using a compact hand-held digital camera with known characteristic (lens focal length, imager size and number of pixels), taking multiple, and overlapping images from different perspectives. By indicating three object points in two images of the same scene, and indicate a known dimension, other 3D points in the images can be determined and enable the production of accurate as-built measurements and 3D models.

b. Orientation

Inner Orientation

Inner orientation can be solved by determining of the three parameters Ck, x, y.

- The ***focal length Ck***: is the camera constant, it represents the distance between the projection center and the film plane.

- The location (***x, y*** on the film) of the principal point.

The principal point is defined as a point on the film plane which lies normal to the projection center.

A four parameter transformation (***offset in x, offset in y, rotation, scale***) can be too considered which is useful to transform pixel coordinates into film (camera) coordinates and back.

Exterior orientation

The exterior orientation determines the location and orientation of the camera through photographing. It consists of six parameters: projection center coordinates (X0, Y0, Z0), and the rotation angles around the 3 axis (omega, phi and kappa).

The equations of exterior orientation are written as following [5]:

$$x = -c_k \frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)}$$

$$y = -c_k \frac{a_{21}(X - X_0) + a_{22}(Y - Y_0) + a_{23}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)}$$

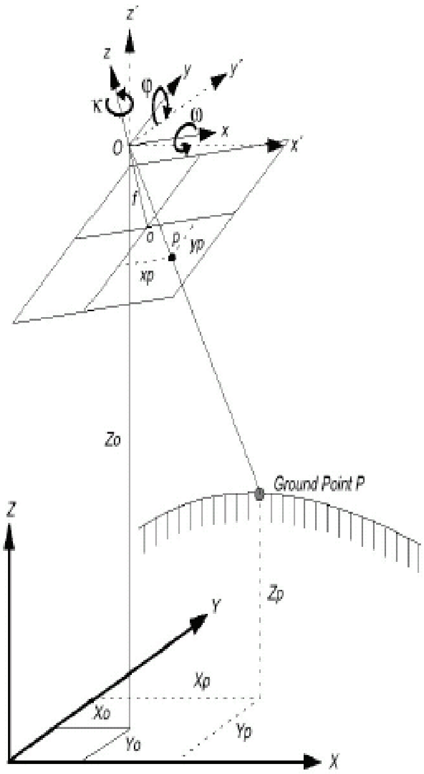


Figure 3 Exterior Orientation

Orientation of the Photo Pairs

Relative Orientation

To create 3D information from the photos, it must exist at least two photos for one object. Through photographing each of these photos has their determined locations and orientations to each other.

Means of matched tie points we can calculate the relationships of the photos themselves, and then reconstruct the 3D Object.

Absolute Orientation

In this orientation the image reference system is transformed into the real world. The relationship of this transformation is written as following [6]:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_u \\ Y_u \\ Z_u \end{pmatrix} + \mathbf{m} \cdot \mathbf{R} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

c. 3D Modeling and Analysis

after finishing the 3D virtual model from the database of photogrammetry, then the elements from that model are imported into the three-dimensional space in CAD. These components are then drawn together to create the actual 3D model is realized.

2.1.2 LIDAR

The Lidar is an acronym for (Light Detection and Ranging), Lidar is an active remote sensing system depend on the principle of laser-driven pulses of light and multispectral cameras to detect the object and then processing obtained digital information about the scene.

After processing LIDAR produces very accurate three dimensional data measurements for using them then by mapping, guidance, and navigation systems.

Lidar has multiple applications in archaeology, geography, geology, oceanography, forestry, and seismology.

It can be said in one word to describe Lidar principle; it uses the prevalent method Laser pulse to determine distance to an object or surface, and for obtaining 3D data.

3. Laser

3.1 What is exactly Laser?

Laser is the acronym laser stands for "light amplification by stimulated emission of radiation.

Laser is a sources of radiation based on atomar and quantum physical effects.

The fundamental processes for a laser are <u>Spontaneous, emission</u>; <u>stimulated emission</u> and <u>absorption</u>.

Light is the visible part of the electromagnetic spectrum, or accurately the Light is electromagnetic waves have radiation energy can be changed into other known types of energy.

Amplification: by amplifying made something larger, in the case of laser makes light brighter.

Stimulate: laser light is created when a pumped energy (as example, electricity) excites the atoms in the laser to emit photons. These emitted photons stimulate the creation of additional photons to generate the bright laser light**.**

Emission

In general the emission refers to the process by which the photons energy is realized by another entity. Stimulated laser emission consists of large numbers of photons that create the intense laser light.

Radiation energy moves form the source to other object, which absorbs it.

3.2 A brief History of Laser

1. 1917 Description the theory of „Stimulated Emission" by Albert Einstein.
2. 1928, Rudolph W. confirmed existence of simulated emission and negative absorption.
3. 1951, the invention of the maser by Charles Townes and Arthur Schawlow were. The term maser stands for „Microwave Amplification by Stimulated Emission of Radiation", maser was the basic of Laser.
4. 1960 Theodore Maiman invented the first Laser using a lasing medium of ruby that was stimulated using high energy flashes of intense light.

3.3 Characteristics of Lasers

Laser light is monochromatic, directional and coherent

1. **Monochromatic**: a laser light is a single wavelength. So it is almost the purest monochromatic light available.
2. **Directional**: laser light is emitted in a specific direction as a tight narrow beam.
3. **Coherent**: this characteristic of the laser light means that its wavelengths are in phase.

3.4 Different Types of Laser

The ways to define the type of laser are several.

One class of Laser based on its pumping scheme

- Optically pumped laser.
- Electrically pumped laser.

Other on the basis of the operation mode,

- Continuous Wave Lasers

- Pulsed Lasers.

Categories according to the materials used to produce laser light,

- Gas Lasers.
- Solid State Lasers.
- Semiconductor Lasers.[7]

Solid state lasers a gain medium is solid, e.g., the ruby or neodymium-YAG (yttrium aluminum garnet) lasers.

Gas lasers: they are composed of one or a mixture of gases, typical gas lasers is helium and helium-neon, HeNe, the primary output of this type is the visible red light.

Semiconductor lasers or diode lasers: are lasers with small volume and need low energy. They may be built into larger arrays, e.g., the writing source in some laser printers or compact disk players.

3.5 Components of Laser

As shown in figure 4**,** the three basic components of a laser are:

1. Gain medium a substance emits light if it is excited by energy, this substance can be (crystal, gas, semiconductor, dye, etc...).
2. Energy Pump (adds energy to the lasing material, e.g. lamp, electrical current to cause electron collisions, radiation from a laser, etc.)
3. Optical cavity are a major component of lasers, space between the laser mirrors where consisting of reflectors to act as the feedback mechanism for light amplification.

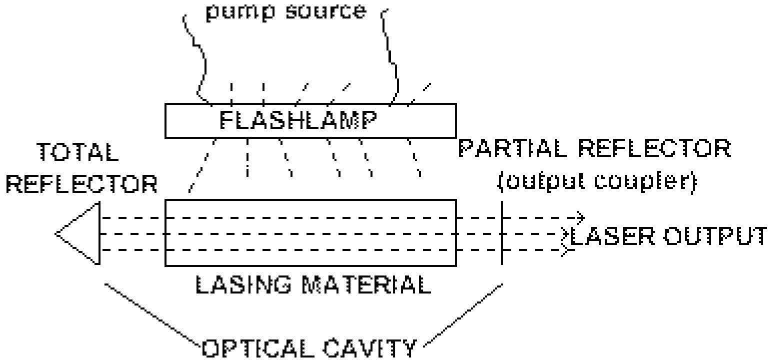


Figure 4 Laser Components [8]

3.6 How does Laser work

The steps to generate Laser are:

Pumping the material using energy either light or electricity. This pumping energy stored in the electrons of the atom, and excites them to jump to a higher orbit, creating produce a population inversion.

Another side few electrons drop back to a lower orbit and releasing a photon (quantum of light). The photons stimulate other excited electrons to transit from their orbits to lower orbits to realize more photons.

This action occurs in the optical cavity, and the photons go forth in the direction of the mirrors, till they arrive at the end of the mirror and reflect back into the gain medium, this movement forth and back creates a chain reaction, and causing the laser to "lase."

3. 7 Laser Wave Length

Table 1 illustrates various types of material currently used for lasing and the wavelengths that are emitted by that type of laser. [9]

LASER TYPE	WAVELENGTH (in nanometers)
Argon Fluoride	193
Xenon Chloride	308 and 459
Xenon Fluoride	353 and 459
Helium Cadmium	325 - 442
Copper Vapor	511 and 578
Argon	514.5 and 488 most used
Frequency doubled Nd:YAG	532
Helium Neon	543, 594, 612, and 632.8
Krypton	647.1 - 676.4 most used
Ruby	694.3
Laser Diodes	630 – 950
Ti:Sapphire	690 - 960
Nd:YAG	1064
Hydrogen Fluoride	2600 - 3000
Erbium:Glass	1540
Carbon Monoxide	5000 - 6000
Carbon Dioxide	10600

Table 1 Laser Types and wavelengths

3.8 Laser Classes

Lasers are classified according to their power to do damage. Safety thresholds for lasers laser classes are derived from the maximum permissible exposure (MPE). The classifications are as follows:

Class 1

this class safe and harmless for all conditions, thus no protection would be needed.

Class 1M

this class is safe for all conditions and do not need to use the protection equipment, users should not incorporate optic, because it can be hazard when passed through magnifying optics such as microscopes and telescopes.

Class 2

Class 2 lasers are visible and are low power lasers. This class is safe for accidental viewing for all conditions, but they are hazard for a period longer than 0.25 s.

Class 2M

these are visible lasers. There is no hazard by accidental viewing with a naked eye, but another side, must be this viewing without optical instruments.

Class 3R

this class is low risk, but potentially hazardous. They are hazard if viewed using collecting optics.

Class 3B

Radiation in this class produces a hazard to the eye and the skin if viewed directly. but viewing of the diffuse reflection is not harmful.

Class 4

Class4 represents the high Power lasers. The radiation in this class is very dangerous, a hazard is not only a result of direct or secular reflections, but also from a diffuse reflection, it can burn the skin.

3.9 Applications

The application of laser covered many ranges of our life, such as medical, military, scientific, commercial and many others.

In the medical sector, it is well known nowadays the operation of the eye, Kidney stone, and also removing the undesirable hair of the woman body.

In scientific range expands the using of laser daily, we see that in remote sensing, surveying, modeling, determination the age of the archeology and the nature of its building materials.

In addition the compact disk (CD) players use lasers, in stead of a needle, to read the stored data. In military laser is used in as target designation and ranging, and directed energy weapons.

4. Laser scanning

Laser scanning is the detection of the physical surface from more than one station using the laser. The output of scanning is a point cloud, after processing of the point cloud comes as a result the 3D model of the object.

There are different variants of Laser Scanning according to the relative position of laser scanner: Mobile laser Scanner, which is divided into kinematic laser scanning, and airborne laser scanning.

The second type is the static or fixed laser scanning. Both kinematic and fixed are terrestrial, but fixed is positioned on a defined point, and kinematic scanner is placed on mobile vehicles.

4.1 Airborne Laser scanning Technology

The airborne laser scanning system is a new technology, can be defined as an active method to detect the details of the earth surface and objects and results it in a point clouds to create a model**.**

The ALS Components

An ALS system is an integrated system; it combines the following main components, as shown in figure 5,

1. Position and orientation system (POS), global positioning system (GPS) and an inertial measurement unit (IMU).
2. Laser measurement system
3. Control and data recording unit
4. Robust Computer Support.
5. A digital camera is used sometimes.

The components of the integrated system are time synchronized; it executes the scanning of the area at a height of 500-1500 meters. The accuracy of laser canning is related of the flying altitude, that we can obtain accuracy of spatial coordinate measurements in average of 15 cm, but other hand is the maximum achievable

accuracy up to 5 cm. By using the Airborne Laser scanning technique would be able to obtain the measured distance between the aircraft and the earth's surface.
By knowing the absolute position of the mounted sensor, the z-coordinate of a point on the earth´s surface can easily be calculated from the measured distance.

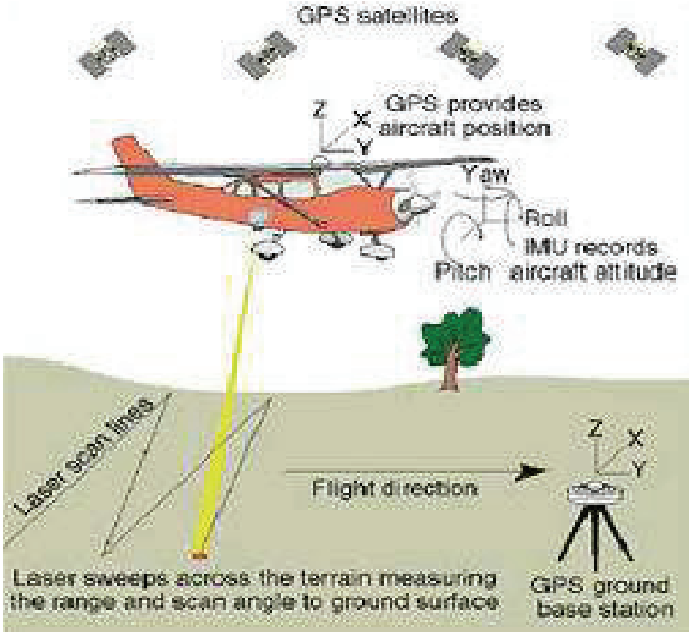


Figure 5 Components of ALS [10]

The method allows deriving high-quality DEMs with a horizontal accuracy of less than one meter and a vertical accuracy of up to 0, 15 m.
The most important application of airborne laser scanning technology is topographic surveying, especially in the difficult accessed areas such as the forested areas, other applications are, coastal and wetland monitoring, power line management, urban planning and natural hazard management.

- **Lidar sensors**

ALS systems still use almost solely the round trip time measurement principle for ranging. At the present time can be distinguished between two different types of commercial ALS sensor systems: **discrete echo and full-waveform scanners.** [11]
Discrete echo scanners based on the detection of a multiple echoes for each laser pulse in real time by means of analogue detectors, but the complete analogue echo waveform is digitized in the full-waveform ALS systems during data acquisition for subsequent off-line waveform analysis.

- **GPS** component records steady the time and the positions to the Lidar system.

- **IMU** The inertial measurement unit measures orientation of ALS in pitch, roll, and heading. The orientation values would be combined with the GPS positional information and the laser range data scan values and generated with calculation the X, Y, Z of the points collected.
- **Digital imagery/video.**

A digital camera is used in some systems to provide an image of the areas being scanned. The X, Y, Z data from the Lidar can be covered on this imagery and used in the classification process. On a few systems, a down-looking video camera may also be mounted next to the laser and used to record the area scanned by the laser sensor. Time, latitude, and longitude are usually recording as part of the video display. This information is used by the operator to view the area being collected during the flight as well as used in post processing of the Lidar data. The audio portion of the recording is used by the operator to note items or features of interest.

4.1.1 How airborne laser scanning works?

The mounted sensor in the aircraft emits fast thousand pulses from a focused infrared laser per second, these pulses hit the scanned surface and then reflect back to the sensor. The receiver in the sensor receives the reflected signal from the earth's surface, and the onboard computer can rapidly measure distances between the sensor on the aircraft and points on the earth's surface (building, tree, meadows, etc.) to collect highly accurate elevation data. The distance between the airplane and the point on the earth's surface at the moment of emission and reflectance is calculated from the time the laser pulse took to return to the plane.

After flight, software is used to merge the collected data with information on temperature and air pressure, in addition hardware characteristics and other relevant parameters, to generate 3D points and then obtain 3D model of the landscape after processing. Millions of such points are captured by ALS, providing a dense digital terrain model (DTM).

4.1.2 Comparison Airborne Laser Scanner and Photogrammetry

Table 2 presents a comparison between airborne laser scanning and the aerial photogrammetry. [12]

	Airborne Laser Scanning	**Aerial Photogrammetry**
Accuracy / precision	0.15m to 0.20m RMS	relative to photo scale, 0.08m to 20m
Resolution	typical point spacing 3m	resolution defined by project requirements
Ground support	• requires base station within 50km • ground-truth points provide survey redundancy	• ground control required • may be supplemented with Sky control
Data acquisition	can be done under cloud and at night	must be done during the day, preferably without cloud shadow
Timing	sizeable datasets available within a week or two	sizeable datasets available within a month or two
Data format / Classification	• random spot heights • semi-automatic classification	• vector line strings • manual classification
Penetration	data points measured under trees	operator interprets the ground under trees
Imagery	separate sensor required	byproduct
Cost	high startup cost	proportional to area

Table2 Features of Airborne Laser Scanning versus Aerial Photogrammetry

4.2 Kinematic laser scanning

The ranges of applied projects using kinematic laser scanning are not the same achieved by terrestrial static way.

The fixed or static terrestrial laser scanning is based on a clearly defined position and a deflection of the laser beam around the horizontal and vertical axes (2D deflection).

In mobile terrestrial laser scanning the position of scanner changes every moment during the scanning operation, the scanner acquires the environment data from a moving position.

The deflection of the mobile laser scanner differs from the fixed scanner also, that it occurs only in one deflection (vertical), and so reading the relative local scanner system, are only 2D coordinates. The absolute positions, as well as the missing third dimension for 3D coordinates, have to be acquired by additional sensors. The third dimension is generated by an automated total station, which is tracking the moving test trolley. The use of a total station also allows for the inclusion of the 3D coordinates in an absolute reference system.

The orientation of the instrument can be chosen from the users individually, according to the application.

In general the laser scanners are positioned vertically at 45° to the car direction. The benefit of such arrangement compared with a conventional orientation, appears especially with objects close to the track. The laser scanner can capture the sides of the scanned object and not just the front parallel to the track; the object edges are more clearly identifiable. This is a crucial use when carrying out object recognition.

4.2.1 Mobile Laser Scanning System Components

The components of mobile laser scanning are in general:

- Laser Scanner, providing a 2D line scan mode.
- GPS receiver and antenna which measures the position within the world geodetic systemWGS84.
- Inertial navigation system (INS), which includes Inertial Measurement Unit (IMU) for orientation measurements of the moving platform.
- Software aimed at merging the geometric profile information (laser scan data) with the position and orientation data of the scanning platform.

- Software unit to control all of these components, synchronize the time of all taken measurements.
- A fixed shock absorbing mobile platform
- Sometimes is used synchronized digital photo camera, placed on the platform.

Figure 6 Components of Kinematic Laser Scanning

4.2.2 When and why using kinematic vehicle laser scanning?

1. Fixed Laser scanning is not cost effective in surveying objects as tunnels, and roads.
2. Sampling rate and efficiency are much better by comparison with the traditional as tachymetry, or GPS.
3. By Kinematic laser scanning would be obtained a consistent point density contrary to"Stop and go" method.
4. Able to reach better accuracy and go to"closed areas" compared to airborne laser scanning.

Annotation:

Stop and Go is a laser scanning method that gathers high resolution 3D measurements together with digital images from a static mobile platform. The platform is then moved to repeat data capture at successive locations. The scan positions do not need to be accurately geo-referenced to each other since they are aligned during post-processing using software solutions. This makes Stop & Go a highly-effective method for scanning large areas quickly, but accurately. [13]

4.3 Terrestrial laser scanning

Terrestrial laser scanning is a modern technology that can be considered as an alternative traditional survey techniques, and offers the possibility to create accurate three-dimensional images of environment and existing conditions.

A laser scanner describes the scanned objects by millions of highly accurate, unique recorded points by sweeping its beam over a surrounding scene. The recorded measurements (X, Y, Z) are displayed as a "point cloud", which be processed with a providing software to generate 3D model.

The following terms are synonyms of Terrestrial laser scanning and used in the publications:

1. Terrestrial laser scanner;
2. Terrestrial 3D laser scanner;
3. Laser scanner;
4. Close-range laser scanner;
5. Ground-based laser scanner;
6. 3D scanner;
7. 3D Laser Scanner;
8. Lidar Scanner;
9. Tacheometric laser Scanner.

The standards to selecting the most appropriate laser scanner

1. Required accuracy
2. Geometry of the object
3. Range (measured distance)
4. Time available for scanning
5. Minimum point density.

4.3.1 Important terms in Laser Scanner

- **Accuracy:** the degree of agreement of a measured quantity to its true value.

- ***The modeled accuracy*** is resulting from the model created from the series of 3D points (point cloud),
- ***Baseline measurement accuracy*** estimates the quality of distance measurements extracted from a point cloud.

- **Precision** is the degree of repeatability in a measurement. This parameter is most often mixed up with accuracy in the system specifications. It can apply to:

- Raw data;
- Processed data;
- 3D model.

Kinds of precision:

- ***Single measurement precision;***
- ***Averaged measurement precision*** when we have a number of measurements and then averaged.

- **Resolution** estimates the smallest part of the surface can be recognizable.
  One should distinguish between:

- ***Range (depth) resolution*** defined as the minimum quantity differentiated by the scanner if two points are close together in range.
- ***Angular (planar) resolution*** is the minimum angular separation on a homogeneous surface at which two equal targets can be distinguished when at the same range.[13]

Scan Density is the distance between the neighboring 3D points in the data point cloud. The density of laser scanning is measured in microns. Scan data represents the surface shape of the object, which is scanned without contact laser scanner.

The typical attribute in laser scanner is that, it can capture simple and complex geometries, so it gives a more accurate detailed model of the surface than the conventional instruments and methods.

4.3.2 Geometrical Quality of Laser Scanner Measurements

The errors in Laser scanning can be classified into many groups:

1. Instrumental.
2. Object-related.
3. Environmental.
4. Methodological.

Another subdivision could be based on the observables of TLS affected by the errors, namely:

1. Range errors;
2. Angular errors, i.e. errors in both horizontal directions and vertical angles. [14]

4.3.2.1 Instrumental errors

These errors are constant and arise due the defect of the scanner design and lack of its technical specifications.

Within this classification it is distinguished also other subclasses:

Fundamental errors, these errors existing as an essential physical characteristic of laser rangefinder and beam deflection unit, i.e. these errors are due to the natural limitations of laser ranging and scanning, and it is impossible to remove or reduce by engineering efforts.

- **Errors specific to the scanner hardware**, these errors arise due essential components of laser scanner, which are the laser rangefinder, beam deflection unit, and axes errors. It is possible to remove or to reduce these errors by improving the system design, or by calibration.

Instrumental errors have both random and systematic influence on the laser scanning measurements.

- **Errors in the laser rangefinder**

We split these errors into random and systematic errors.

Random errors

These errors have many resources such as beam width uncertainly, and instrument setup errors. In the case of the time of flight scanner TOF the precision of a pulsed TOF laser rangefinder can be determined by these errors, which can be represented by the next equation

$$\sigma_r = c/2 * \sigma_t$$

Here, c is the speed of light in air and σt is the jitter of the timing moment, which is equal to

$$\sigma t = \sigma n / (dU / dt)$$

σn refers to the root-mean-square (RMS) noise amplitude at the input of the time discriminator, and ***dU / dt*** is the gradient of the timing pulse at the instant of timing.

Systematic errors

The range accuracy achieved with the laser rangefinder is limited by the following systematic errors

- **Non-linearity,** which may originate from:
  - the time measurement unit;
  - Optical system, when the receiver does not see the whole transmitter spot at each distance, which may lead to the changes in the timing pulse shape.

- ➢ **Time walk** is an error in the time discriminator, due to variations in the timing pulse amplitude and shape, which, in turn, depend on the reflectance of the surface of the target object scanned.
- ➢ **Temperature drift** in the time measurement electronics, which causes the range drift, due to:
  - o The changes in the ambient temperature (external factor);
  - o And/or the changes in the temperature inside the rangefinder after some time after switching on.
- ➢ **Scale error** a scale factor in the measured distance.

- **Errors in the beam deflection unit**

Acquisition of high-density point clouds is achieved through the combination of the laser rangefinder with the beam deflection unit, which is simply called scanner. This component introduces another source of instrumental errors. It influences the angle measurement accuracy and precision.

The limited range accuracy achieved with laser rangefinder is related to the systematic errors, which can be classified into **Non-linearity, Time walk, Temperature drift, and scale drift.**

Non-linearity originate from the time measurement unit; and optical system.

4.3.2.2. Object-related errors

This class of error is related direct to the scanned objects.

Reflectance is the ratio of laser power reflected to the incident laser power. It is the function of the following factor:

- ➢ **Material properties** of the object, such as hardness ,texture, temperature, weight, electric permittivity, magnetic permeability and conductivity;
- ➢ **Surface color** as examples a white surface will reflect lots of light and a black surface will reflect only a small amount of light. Transparent objects such as glass will only refract the light and give false three dimensional information.
- ➢ **Wavelength of the laser;**

o Incidence angle of the laser beam. The standard deviation of the measured range decreases in the increase of the incidence angle

o Surface roughness, which, in turn, depends on the wavelength and the incidence angle

- polarization;
- Temperature of the surface. When scanning a hot target, e.g. in an industrial environment, the background radiation introduced by the hot surface reduces the SNR and thus the precision of the range measurements;

4.3.3.3 Environmental errors

Environmental factors, such as ambient temperature, atmosphere, pressure, relative humidity, illumination, Vibration etc., are important in TLS and contribute to the measurement error, introducing variability difficult to control. Below, the influence of these factors on TLS measurements is discussed.

4.3.3.3 Methodological errors

The error sources as the density of laser spots and range to the object.

4.4 Applications of Laser Scanner

Historical Modeling: 3D laser scanning represents now a new technology to create robust data to model the historical sites and documenting the archeological memorial.

Forensic:

In cases of murder scene, an auto accident, a collapsed building, and dilapidated stairway has the laser scanning a typical application.

Laser scanning has the ability to model and analyse forensic information from real scenes. The 3D data is exported to software for visual examining scenes to determine causes and sequence of events.

With laser scanning, everything in range is quickly captured in 3D as well as distant structures which can play a significant part in the total interpretation.

As example, using 3D digital image of 3D scanner helps to provide information, such as measuring the vehicle that lead to know the impact speed, and the deformation of the vehicle.

Civil engineering

Laser scanners are providing information about the spatial data and also other information of the subject such as true color which giving the impression of sense of the project in 3-D, returned laser intensity which is the amount of light captured by the instrument, helping to depict the scene, and project management data including location, date and time information, weather conditions, and scanner position.

Applications in the Construction Industry

3D models, that created by laser scanner, support the design process and provide complete and accurate dimensional measurements. Theses data are used to model interior and exteriors of existing buildings, and though 3D models saved the required time in planning.

Structural deformation monitoring

Huge information provided by laser scanning, and can be utilized to find the construction deformation. With comparison between laser scanning and other ways such as GPS to obtain deformation quantities, we find that GPS offer deformation information only for chosen limited points, whereas a scanner measures the deformation surface.

The performance to extract deformation motion by laser scanner operates on the model of the surface, and then compared with distinct date.

Planning, Logistics, and Management

The 3D laser scanner point cloud provides accurate information about the location and levels of the scanned objects. In addition the scanned data are tied to real world coordinates which permits it to be used for GIS or spatial statistical analysis, the point cloud can be viewed in contours and digital elevation model, which permits the viewer see the site in a context that is more closely allied to reality.

5. Laser Scanner Classification

It is difficult to do a classification of laser scanning system, but we can classify into two main classes, conatct3D scanners, and non/contact active scanners, and within these two classes there are many other subclasses.

5.1 Contact 3D Scanners

These scanners must locate very close to objects, so they are called coordinate Measuring Machines (CMMs). The CMMs have to touch the object being scanned. The advantage of this type is highly precise in their images, other hand has a limitation that not all objects can in contact with the scanner. It is difficult to scan liquids or glass objects.

5.2 Non-contact active

Active scanners use a laser beam to detect the object or environment and come back.

This type of scanners can be also divided in sub-categories: the first according to the field of view, the second according to the principle of the distance measurement system,

5.2.1 Classification according to the field of view

Camera Scanner: examples for this type are CYRA 2500 and ILRIS 3D.

Typical chrematistic of this type that it scans a limited field of view circa 40x40°. Hence, it is not suitable for using for a long range distance measurement, but it is useful for capturing the barcode images, which are then processed by complex techniques.

Panorama Scanner:

Examples for this type are Imager 5003 (ZOLLER & FRÖHLICH).

The FOV of panorama scanner is limited by the base of the instrument, and it is designed for indoor scanning. Hybrid Scanner: often the Horizontal Movement, e.g. to 60°. GS 200 ENSI) and LMS Z 360 (RIEGL) represent this group.

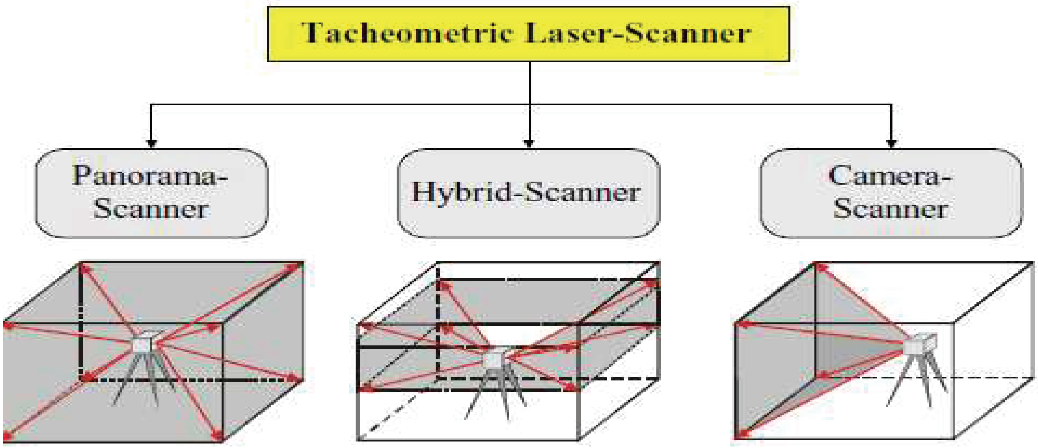


Figure 7 types laser scanner according FOV. [15]

5.2.2 The scanners distance measurement principle:

- **Triangulation**: This system based on the famous method in surveying Triangulation, two sensors are used which simultaneously record the reflected laser pulse, and then it will be possible to calculate the distance to the object.
- **Time of Flight**: in this technique the scanner emits laser pulses and then measured the time of flight, from which the distance to the object can be determined.

- **Phase Comparison**: The scanner sends a known frequency and phase of beam of light, and then by the comparison between the emitted phases of the light and returned phase the distance to surface can be measured.

Measurement System	Rang [m]	Range accuracy [mm]	Manufacturers
Time of flight	~ 1000	>10	Mensi,Riegel, Cyra
Phase measurement	< 100	< 10	Zoller+ Froehlich
Optical triangulation, Laser radar	< 10	< 1	Minolta, Leica

Table3 scanners distance measurement principle and their ranges. [16]

5.2.2.1 Triangulating 3D Laser Scanners

This type is named triangulation 3D laser scanners because it is based on the principle triangulation.

A thin stripe of laser light is emitted onto the surface of an object and is viewed by a digital camera. Both positions of the laser emitter and the digital camera and are fixed and known, and this permits to simple calculation of the position of points along the laser band in 3-dimensions.

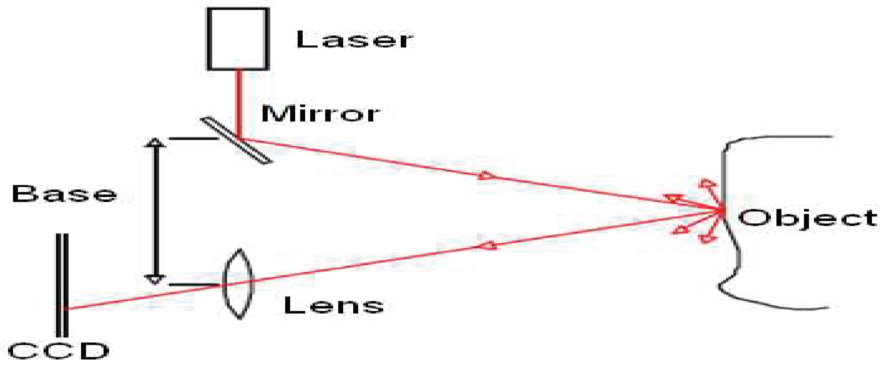


Figure 8 Principle of triangulation laser scanner

Because of the high accuracy and resolution of triangulation laser scanner, they are ideal for scanning and recording the small features such as archeological columns and other fine details.

Other site the high accuracy have a special importance for the users, who study and determine the changes of the stones caused by the variable weather factors (temperatures, wind, humidity … etc.).

5.2.2.2 Time of Flight 3D Laser Scanners

A time of flight scanner shoots a laser pulse travels to the object and measures the time taken for the pulse to return to the scanner. The speed of light is known and constant, and then the distance from the scanner station and the scanned surface can be easily calculated.

The laser scanners move backwards and forwards and shoot the laser pulses across the object at regular time intervals. The 3D series of point are calculated from the horizontal, vertical angles plus the measured distance.

One essential difference between time of flight scanners and triangulation scanners is the low accuracy of TOf; therefore they are suitable for scanning the large structures not for fine detailed features. Whereas the order of accuracy of TOF is on the order of millimeters, the accuracy of triangulation scanners are on the order of micrometers.

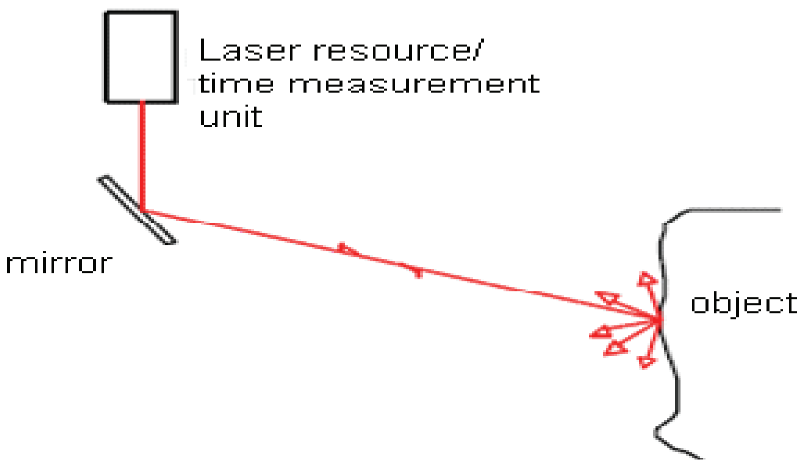


Figure 9 Time-of-Flight Laser Scanning

Time of flight scanner can be divided into two categories: Direct time of flight and indirect time of flight.

- **Direct Time-of-Flight**

The direct time of flight method determines the travel time (Δt) of an impulse to a surface and back by

$$S = c * (t_e - t_r) /2 = c * \Delta t / 2$$

S: the distance between instrument and target.

Δt: the difference in time.

t_e : time of departure of pulse

t_r : time of arrival of pulse

c: the speed of light.

The accuracy of time of flight depends on how precisely we can measure the time. One of the most important characteristics of time of flight terrestrial laser scanner is its ability to be used to cover long ranges up to several hundreds reaches even to one kilometer.

The emitted laser may have high energy for traveling a long distance because the energy of the received signal for measuring the travel time has to be sufficiently high. Since the emitted pulses cannot be generated in a short time, the minimum time interval between two laser pulses for determining distances is limited. Thus, the frequency of measuring distances is defined and characterizes the sampling frequency of a laser scanner. Typical sampling frequencies for laser scanners are between 1 kHz and 30 kHz.

The range resolution is limited according to the time resolution.

- **Indirect Time-of-flight**

Indirect time of flight has also subdivisions: Phase difference method FMCW (beat frequency), AMCW (phase difference), and polarization modulation.

- **Continuous Wave**

Lasers can generate pulsed or continuous beams; their power takes average values between microwatts to over a million watts.

A laser is called continuous-wave if its output (beam of coherent light) is constant generated over an interval of seconds or longer.

Continuous-wave operation means the continuous laser generation and also the continuous laser emission, either on a single resonating chamber mode or on several modes.

- **Amplitude Modulated Continuous Wave (AMCW)**

In AMCW lasers the emitted light is modulated with a sine wave of a distinct frequency. The reflected wave comes back by time difference Δt and seems proportionately phase-shifted with comparison to the emitted energy. The distance is proportional to the phase, up to an ambiguity at a 2π phase difference:

$$z = \phi * \Delta r / 2\pi$$

The range **Z** is proportional to the phase difference ϕ and the ambiguity interval,

ΔR.

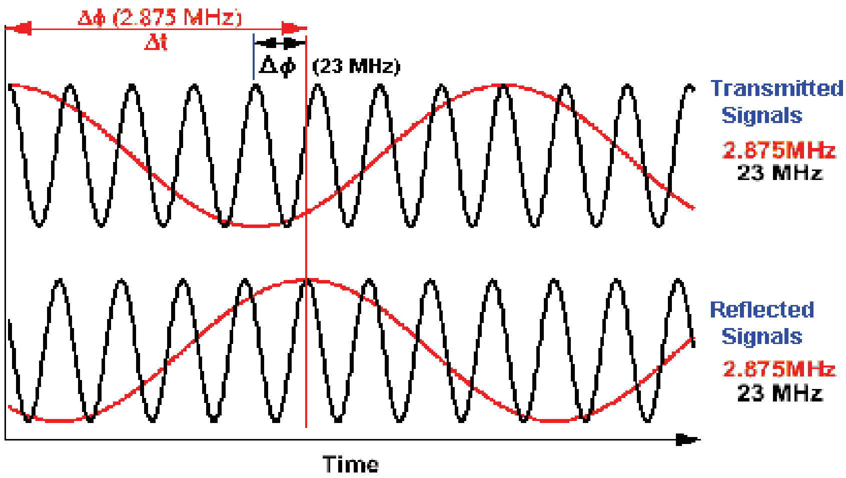


Figure 10 (AMCW)

Z+F laser scanner is an example of (AMCW). It utilizes a dual-frequency amplitude-modulated signal. Z+F laser scanner operates on the principle that the phase difference between the emitted and returned laser signal are measured by the receiver at both modulation frequencies.

So the factors that affecting accuracy of the phase difference ranging method could be concluded as Follows:

1. Frequency of the tone or modulation.
2. Accuracy of the phase-measurement loop depends on signal strength, noise, and so on.
3. Stability of the modulation oscillator.
4. Number of cycles (or measurements) that can be averaged together for a range measurement.
5. Turbulence in the air during scanning process.
6. Variations in the index of refraction of the air.

Frequency Modulated Continuous Wave (FMCW)

AMCW lasers operate by modulating the emitted light with a sine wave of a varying frequency, and mixing it with the returned energy. The measured beat frequency can estimate the range. Although it is possible to scheme other frequency modulations, the frequency "chirp" generally follows a periodic triangular waveform.

With triangular frequency modulating, the distance to the object is proportional to the pulse frequency. Figure (11) illustrates this method.

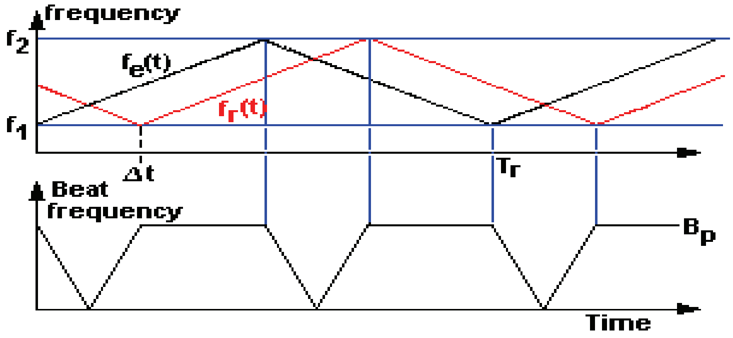


Figure 11 (FMCW) [17]

5.3 Comparison between total station and laser scanner

The comparison between the chrematistics of laser scanner and total station is illustrated in the following table:

	3D laser scanner	Total station
Volume of data	huge	small
output	point cloud	points
Range	hundreds meter	up to more than kilometer
Positioning	same	same
Program	special program	All CAD programs
Level of Details of observed body	very high	not always valid
Effort	simple	simple
Time	1000s points per second	no less than some minutes for one point
Cost effective	TLS is better than total station	
Points selection	the whole points of a scanned surface	chosen points

Table 4 Comparison between total station and laser scanner

5.4 Coordinates reference system

As previously mentioned the point cloud is acquired by laser scanner as vertical and horizontal angles and a distance for each point that is in the 3D polar coordinate system. These acquired data is transformed into Cartesian coordinate system and this transformation creates a 3D point cloud.

The reference of this system is internal for the instrument. Its origin {0; 0; 0} lies in the TSL geometric rotation centre**.**

X= r cosφ cosα, Y= r cosφ sinα, Z= r sinφ.

Where; r: the distance between the laser source and the target.

φ and α the orientation angles of laser points.

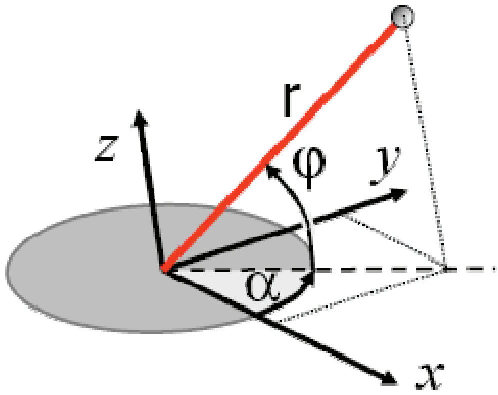


Figure 12 Coordinate System of Point Cloud

For a "panoramic" scanner, this coordinate system can be described, for example, as follows:

1. origin – in the scanner electro-optical centre;
2. z-axis – along the instrument vertical (rotation) axis;
3. y-axis – along the instrument optical axis with an arbitrary horizontal angle, e.g. the first horizontal angle or the approximate north on a built-in magnetic compass, if any x-axis orthogonal to the two previous axes, so that the right-hand system is formed.

Other coordinate systems of TLS:

The default setting of the coordinate axes during scanning with the Cyrax 2500 is with the origin of the coordinate axis at a point within the scanner. The orientation of the axes is dependent upon the position of the scanner.

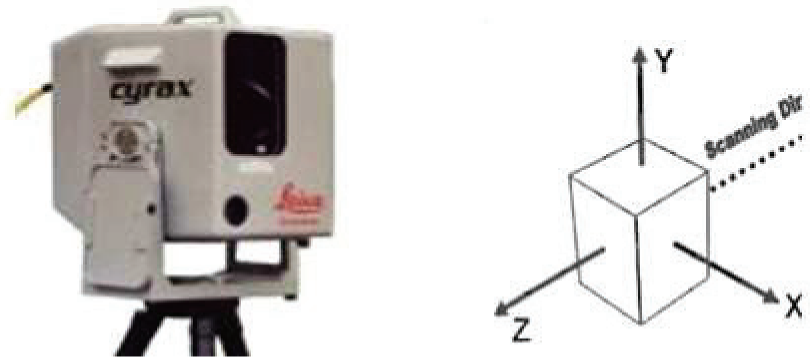


Figure 13 Cyrax 2500 and its default coordinate system

The default position of a Cyrax scan cloud is with the Y coordinate up, the Z axis in the opposite direction of the scan, and the X axis pointing to the right of the scanner. In figure 14, we see another coordinate system that belongs default to HDS 3000.

Figure 14 HDS 3000 and its default coordinate system [18]

5.5 Scanning Benefits

The benefits of using Laser scanning are numerous and proven.

1. Accurate data acquisition
2. Creation of accurate 3D models
3. Allow a large area covering and obtain huge amount of data may be obtained.
4. Rapid data capture which helps to reduce the time of measuring and as a consequence the number of workers and the costs.
5. The remote data acquisition with laser scanner allows to avoid the risks which may take place in some constructions, such as high-voltage transmission lines In addition it has a great benefit to observe and model the unreachable areas.

6. Laser Scanner Components

6.1 Components of Laser Scanner

A terrestrial laser scanning system (TLS) consists of the following components

1. Scanning unit (scanner).

2. Control unit. 3. Power source. 4. Tripod and mount, 5. Power cable and Ethernet cable.

Figure 15 the components of TLS

6.1.1 Scanning Unit

The scanner head is the main component of laser scanner instrument.

The scanner head comprises two modules first (initial) and second (auxiliary) module. The first module can rotate, and supported in a first direction, so that it can deflect the laser light from the first direction to the second direction, perpendicular to the first direction. The second module is a turning module, which is fixed to the first module and supported in the second direction. In addition the second module has a scanner mirror able to incline about the first axis.

A disadvantage of the scanner head is that the direction of incidence of the focused laser beam is oriented substantially perpendicular to the working field of the scanner. The scanner is thereby primarily suited to plane processing which means that for three dimensional processing additional axial movements of the workpiece are generally necessary. [18]

The core components of a scanning head are:

1. Laser rangefinder;

2. Laser beam deflection unit (opto-mechanical scanner);

6.1.1.1 Laser rangefinder

A TOF laser range comprises the following components:

1. Laser source (transmitter),
2. Receiver section of the returned signal,
3. Timing discriminators,
4. And a unit for measuring the time.

The main sections of the transmitter are:

a) The laser

b) The power supply.

c) The driver and repetition rate regulator.

d) The laser cooling system. [19]

In order to improve the precision of single-shot, it is needed to increase the rotating-rate of the measurement pulse, so the beat of the laser transmitter should be reduced (having narrower width) and more powerful and the bandwidth of the receiver should be higher.

The time difference between the emitted laser pulse and the back signal is measured with TDC (time-to-digital converter), by counting the number of clock pulses of a high frequency oscillator (clock), by means of a digital counting method together with an analog interpolation method .

The range from the scanner to the object surface is calculated as follows

$$R = c^* t/2$$

Where R is the computed range, and c is the speed of light.

The resolution of the range is dependent on- and proportional to the resolution of the time difference measurement Δt,

$$\Delta R = c^* \Delta t/2$$

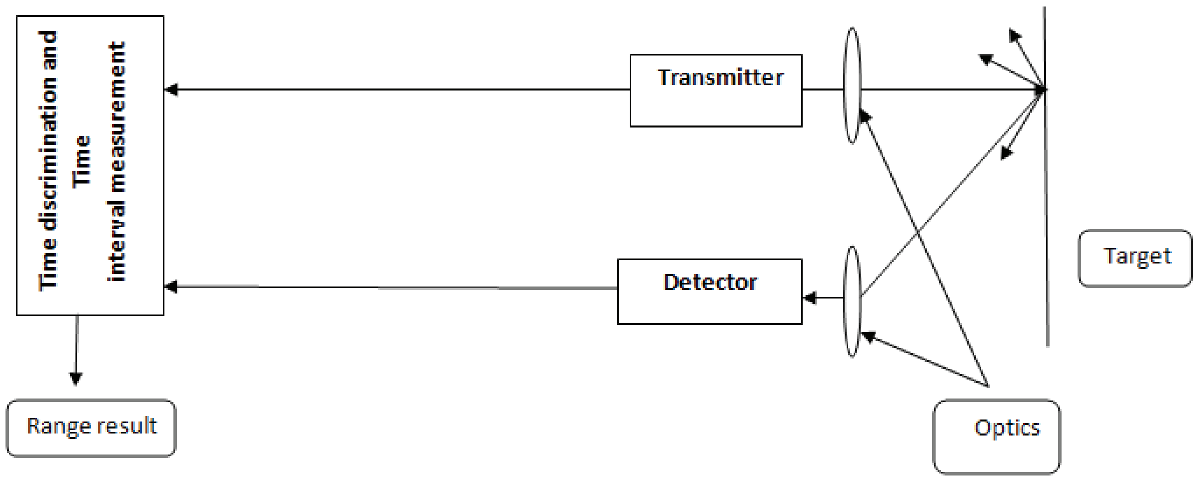


Figure 16 a pulsed laser rangefinder

6.1.1.2 Laser beam deflection unit

- **Properties of Laser Beams**

Monochromaticity

Laser light is emitted over a very narrow range of wavelength

$$d = n*\lambda/2$$

d is the cavity length, n is an integer, and λ is the wavelength.

Coherence:

Laser light is usually spatially coherent, which means that the light either is emitted in a narrow, low-divergence beam, or can be converted into one with the help of optical components such as lenses.

Directionality

A laser beam is highly collimated and has a very low angular divergence.

Divergence

Beam divergence angle of beam spread measured in (milli) radians can be approximated for small angles by the ratio of the beam diameter to the distance from the laser aperture.

Brightness:

The brightness of a light source is defined as the power emitted per unit surface area per unit solid angle.

- **The mechanism of laser beam deflection unit**

The scanner detects only the points in its direction of view; thereby it can scan only one point at a time. Thus a rotating system will be needed, in order the scanner to rotate and scan the whole surface; therefore the beam deflection unit is essential used in the scanner.

By using the laser beam deflection unit, the 3D measurement of an object can be gained.

The major element in the beam deflection unit is the oscillating mirror, which deflects the laser beam in the vertical direction, and occasionally in the horizontal direction.

There are three types of this mirror:

- Rotating flat mirrors;
- Rotating polygonal mirrors;
- Oscillating (galvanometric) mirrors. [13]

Oscillating (galvanometric) mirrors

Oscillating mirrors shown in Figure (17) are oscillating flat mirrors, oscillating at a constant frequency, between maximum and minimum angles, driven by a galvanometric motor controlled by a sine-wave generator. The instant angle of scanning can be determined as following:

$\theta(t) = \theta_{max}/2 * \sin(\omega t)$

$\theta(t)$ instantaneous scan angle

θ_{max} : the maximum scan angle of the oscillating mirror

ω: is the oscillating frequency of the mirror , t: the time.

A polygonal mirror integrated with the motor and the bearing system is called a polygonal scanner.

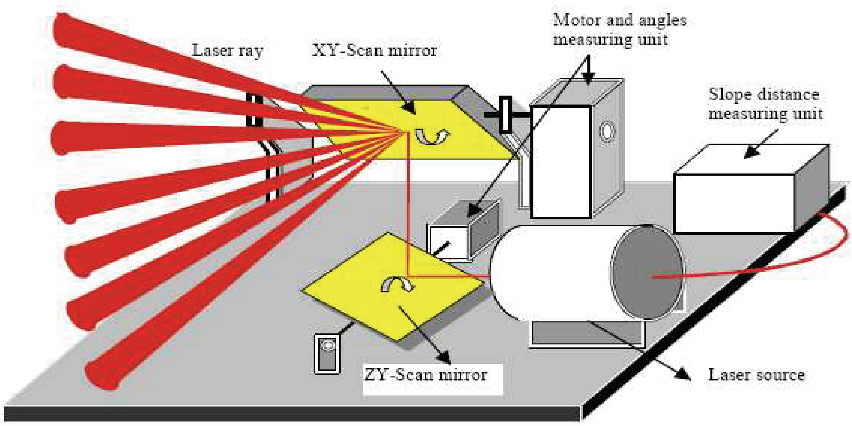


Figure 17 Oscillating mirror [20]

Rotating polygonal mirrors

These are rotating optical elements with three or more reflective facets.

This type of polygonal mirrors is the most cost-effective to manufacture. They may be made of aluminum, plastic, glass or beryllium. Thin optical coatings may be pasted onto the facets surfaces in order to improve their reflectance and/or to improve the durability. The advantages of such mirrors are high speed, the availability of wide scan angles, and velocity integrated with the motor and the bearing system is called a polygonal scanner.

7. Practical use

An automatic approach will be presented here to create building (the entrance of the underground parking) models from terrestrial laser points which are acquired with HDS6000. Our method starts by extracting important building features (wall, ceiling, door, edges, beams, and columns) from a segmented terrestrial point cloud. Then visible building geometries are recovered by direct fitting polygons to extracted feature segments. For the inexact observed building parts, geometric assumptions are made from visible parts and knowledge about buildings. Finally solid building models can be obtained by combining directly fitted polygons and assumptions for occluded parts. This approach achieves high automation, level of detail, and accuracy.

7.1 Recommendations from Leica

The successful execution of the project requires a good understanding of the project's aims and the conditions of the working field.
Many considerations must be taken when planning of the project to achieve and obtain the desired results.
Cyrax introduces some outlines for the user to help him in planning:

1. Define the purpose and objectives,
2. Define the scope of the work,
3. Define deliverables,
4. Gather site documentation,
5. Define field conditions.

In our project the above suggestions are followed step by step, therefore satisfied results are obtained.

7.1.1 Definition of the purpose and objectives:

After a discussion with Professor Heger at Hochschule Neubrandenburg "University of applied sciences", it is decided to create a model of the entrance of the underground parking in the market-square center in Neubrandenburg City using laser scanning technology, as an application of this technology in the field of civil engineering.
The work and scanning started after getting the approval from "**Neubrandenburg City Hall**".
The model is accepted to be utilized from the experts in "**Neubrandenburg City Hall**" as a document for getting measurements.

The heights and the 2D plans are not required in our project.

7.1.2 Definition of the results:

The clear understanding of the goals of the project and in which ranges would be used gives us a clear definition of the final deliverables needs to be established up at the beginning of the job. In general the output of the job may deliver in one or numerous formats:

1. Full 3D model in Cyclone
2. AutoCAD (2D or 3D)
3. Microstation (2D or 3D)
4. PACE
5. PDMS.

My project has produced a 3D model in Cyclone because Cyclone is easier to manipulate than other programs, offers a good precision and accuracy for the clients, on the other side its output can be exported into other formats to create 2D or 3D model using other programs.

7.1.3 Defininition of the Scope

The determination of the scope must be determined in all projects once the clear understanding of the results has been achieved.

The scope has 4 attributes: level of completeness, level of detail, level of accuracy, and extent of the work. [18]

1. **Level of completeness**: in general completeness defines the size of the equipment in the structure and its components will be scanned/modeled in addition the surrounding area if they are required to be included.
   In this definition only elements of the entrance of the underground parking are scanned and modeled with a high accuracy.
2. **Level of Detail**: The scanning of the parking provides enough information for the required modeled elements and their sizes.
3. **Level of accuracy:** this level defines the acceptable tolerance between the actual dimension/location and the scanned/modeled dimension and the influences the execution of the field work.[18]
4. **Extent of the work**: before scanning, there was a good imagination of the parking and of what has to be modeled.

The above mentioned attributes impact the effort and reduce the cost of the project.

7.1.4 Gather Site documentation:

The essential documentations of the work were gathered for a better planning of the project and to get better results at the end.

These documents are:

1. Photographs are taken during a visit in the underground parking.
2. Site plans are obtained from “Firma Lessner”, which designed the underground parking.
3. Appropriate drawings are done to illustrate some details in the construction.

An actual walk through the underground garage is the best recommendation to prepare the bid.

Figure 18 The Entrance of the underground parking

7.1.5 Define Field Conditions

In this point some problems were faced during the work in the field because of the vehicle motion**.** Cones are used to alert the drivers to our work.

Leica Geosystem advices the users of HDS 6000 that its battery provides eight hours of scanning time. Users must take care that also the battery of the laptop has enough power in order to continue the scanning without requiring AC local power.

7.2 Methodology of Works in the field

The methodology of the research involved with the tasks below:

1. Ground control survey
2. Targets survey
3. Scanning
4. Data processing

7.2.1 Ground control survey

A traverse of multiple points must be established around the building if the object's façades would be scanned; on the other hand in the cases of highways, tunnels, or such as in an underground garage an open traverse is established along the construction.

Therefore an open traverse was established combining a baseline measurement using GPS. The remaining stations where measured with a total station.

•The control survey aims to provide precise control stations for scanning task, and to prevent the unnecessary survey.

•The control survey was carried out by means of total station.

•The control stations were setup along the entrance of the parking using temporary control markers.

•The output of the control survey is the 3D coordinate of the control stations.

•The coordinates were then used to calculate the 3D coordinates of the targets.

Targets survey

Black-White-Targets attached to the walls are used as landmarks. Their 3-D coordinates are measured with a total station in a world wide system before the scanning process.

In general, the laser scanning utilizes targets in order to obtain better accuracy by modeling. These targets are used in registration.

One can distinguish two types of the targets: artificial and natural.

Artificial targets

The artificial targets are more useful than natural targets because they can be easily recognized by scanning, can also well modeled in the point cloud with a the high quality of determination their positions with the surveying techniques.

The size and the shape of the chosen artificial targets used in the project are dependent on the figure and color of the scanned object, and the measurement range. For example, sphere targets are used for scanning a memorial, to get better accuracy, but using black/white targets in this case is in vain.

Artificial Targets from Leica Geosystem HDS

Leica Geosystems HDS uses several artificial targets (Figure 19).

Planar (Figure 19, left) and printable (center) targets provide known differences in reflectivity which allow the automatic identification and extraction by Cyclone software. Sphere targets (right) use the adjustment theory to obtain the centre of the target.

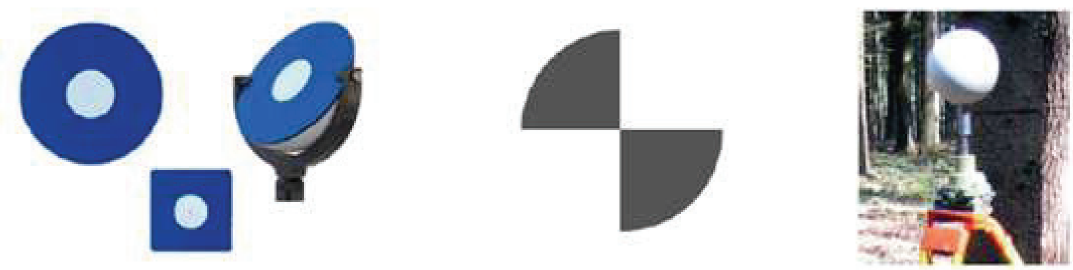


Figure 19 Targets from Leica

The most appropriate object for laser scanning in terms of deriving coordinates of a discrete point is a sphere.

They have many advantages

1- The sphere is defined in 3D by the center coordinates and its radius.

2- Sphere has a homogenous surface and is invariant reading the view angle

But sphere targets have one **disadvantage** that the angle of incidence worsens with increasing distance from the center and vice versa. [19]

The following table shows the difference between actual and detected displacement of the targets. Each series stays within a maximum difference of 0.6 mm. The errors lie within -0.34 to 0.28 mm on average with standard deviations of about 0.13 mm.

Target	µ [mm]	σ [mm]
Sphere Target (Leica)	0.28	0.15
Sphere Target (TUM)	-0.34	0.10
Planar Target	-0.22	0.12
Printable Target	0.15	0.14

Table 5 Mean error and standard deviation

7.2.3 Scanning and Targets acquisition

It was necessary to use an industrial tripod for setting up the scanner head in the underground parking in order to avoid the slipping of the legs on the slope ground. Some recommendations are advised for this step:

1. Extending the legs to a suitable height to allow a comfortable working.
2. To get sufficient and precise scanning the bubble must be checked.

Target Acquisition

Preview scanning of the whole range is done before starting the target acquisition. The importance of target acquisition comes from the importance of the registration which represented the main step in modeling.

The targets are attached in the range of laser scanning on the walls and columns to be easily acquired. Before scanning some conditions are taken into account:

1- The type of the targets is chosen black-white, because it is more necessary in our field work,

2- The number of the targets,

3-Targets must cover the whole volume of the underground parking,

During the scanning process a few different types of mistakes were made that created additional work in the office. One example is the failure to scan the correct targets such as in the case of target 114, it was inserted as target 115. This is typically detected during the acquisition process and requires the operator to reacquire the correct target.

Scanning

Some problems and difficulties are faced during the scanning,

1. Because the low height of the ceiling in some parts, it was not possible to establish the TLS, and the height and the position of the scanner had to be changed.
2. There was a difficulty during the scanning, because of the motion of the cars and wagons inside the underground parking, which resulted in more noise points as well as its influence on the working to take care.
3. Because of the narrow width of the edges at both sides in parts of the entrance of the underground parking additional danger for the persons it was also not possible to set up the scanner anywhere.
4. It is avoided to mount the laser scanner in the slop entrance of the underground parking.

The laser scanner must be mounted on a stationary, nonvibrating surface. Vibrations or scanner movement during the scanning operation will cause failures and require re-scanning the area.

From the above mentioned items it can be said that working in the underground structures there are always some more efforts to choose the scanning stations and targets acquisition.

Time Requirements

This point had to be discussed to find out the benefit of using the laser scanning system in this project.

The total work required time for ca.9 hours in the field work, four hours are spent at the first day, and five hours at the second day, considering that it was not possible to work in the afternoon, because the increasing motion of the vehicles in the underground parking during this period.

About 200 hours were spent to generate the model; many factors made the analysis a complicated process:

1. Trying to model some portions in more than one method (e.g. patch and mesh) then comparing them to obtain the better views and results,

2. Some parts of the construction were not sufficient scanned, that all made the modeling step more complex and depending on the knowledge of the object form from the photos.

3. The slow execution of the commands in Cyclone, because the huge data while merging the ModelSpaces together.

7.3 Used instrument in Scanning

Figure 20 shows a HDS6000 used in my project.

HDS Laser scanner offers us a huge amount of data of the object surface in the form of a series of 3D point measurements using a laptop computer, laser scanner, and tripod.

Figure 20 HDS6000

What is High Definition Surveying?

In general, High Definition Surveying, or HDS, is a multipurpose terrestrial based laser scanning, which combines high accuracy and efficiency over long ranges. It is integrated computer technology and often high precision network control. Instead of surveying one point at a time on a singe line, it can collect thousands of points per second with a very high degree of accuracy.

Leica has developed the following HDS scanner

Leica HDS2500 is also named Cyrax 2500

Leica Scanstation

Leica Scan Station2

Leica HDS3000

Leica HDS4500

Leica HDS6000

Leica HDS6000

The Leica HDS6000 is a phase-based portable laser scanner, with a weight of 14 kg. The HDS6000 has a maximum 360° x 310° field-of-view and extended range can translate directly into fewer instrument setups, and scan targets that need to be placed, scanned, and surveyed. Its Position accuracy of 1m to 25 m range; 10 mm to 50 m range, angular accuracies (horizontal/vertical) 125 μrad/125 μrad, and a beam spot size of only 8mm at 25m and 14mm at 50m range, the scanning rate is 500.000 points per second. Leica HDS6000 has a max range of the scanner is 80m, its accuracy can achieve 6 mm and it also has an increasing scan density at which smaller objects and targets can be modeled more accurate. At the same time it has less noise and that allows more objects to be modeled more accurate to meet a project's precision requirements. The color of the point cloud indicates the strength of the signal return from the target.

Why the HDS 6000 is chosen?

1. The entrance of the underground parking has some complex geometry in some parts, therefore the using of the traditional methods such as total station will not aid our aims,
2. It is needed to create a model of the whole space of the entrance, not only for some parts,
3. The manufacturer of HDS 6000 provided the scanner with programs for both scanning and modeling, therefore is no need to use or buy an other program.

7.4 Office Compilation

7.4.1 The point cloud

The point cloud is the basic output for object scanning. It represents the visible scanning surface using a list of XYZ coordinates in a common coordinate system. In addition to the XYZ coordinates the point cloud includes information about the intensity and the RGB (red, green, blue) values, which are considered as the fourth dimension.

The coordinate system gives the viewer an understanding of the spatial distribution of a subject or site.

The RGB values of the returned and recorded laser pulse provide information about the reflection characteristics of the surface.

The file format of the point cloud is mostly ASCII format; therefore it can be read by all pre-processing software.

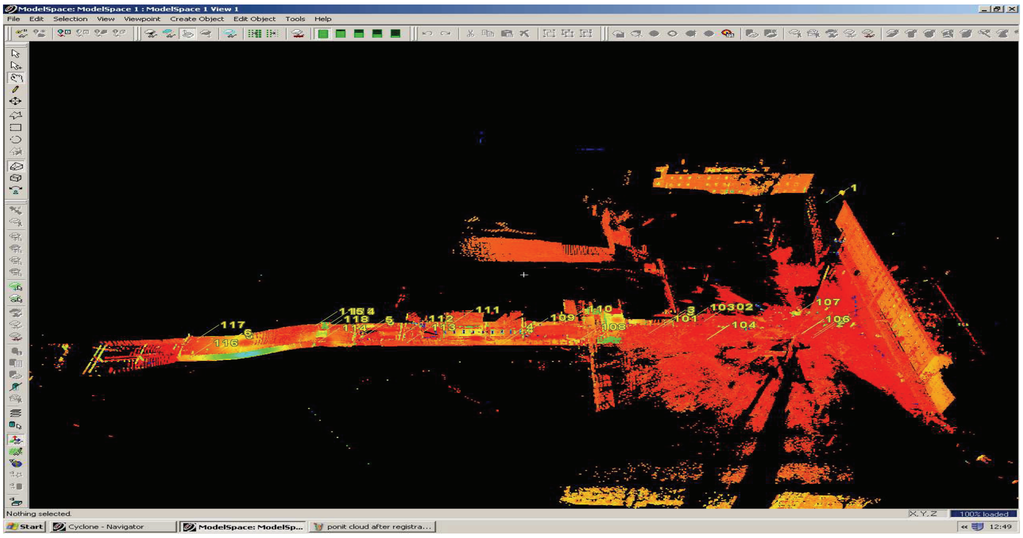


Figure 21 the point cloud of the entrance underground parking

Each row in the file comprises the data of one laser point, and it has the following form:

x1, y1, z1, intensity1

x2, y2, z2, intensity2

x3, y3, z3, intensity3

….

Before registration, the values x, y and z describe the position of the laser point referred to the default coordinate system of the scanner.

After registration all points are related to one coordinate system its axes **East**, **West,** and **Up** represent the x, y and z directions respectively.

The intensity of each point has a value that range from 0 (black) to 255 (white).

Thus the row of laser point is then:

Color point cloud:

x1, y1, z1, r1, g1, b1

x2, y2, z2, r2, g2, b2

x3, y3, z3, r3, g3, b3

…..

It must be referred here that each scanner manufacturer develops its own point cloud processing software.

7.4.2 Point Cloud Processing Software

Most manufacturers have developed their own laser scanners and also their associated point cloud processing programs.

Each processing program has many versions, in order to offer simple and quick using and learning for the users.

After scanning, the point cloud is exported in an X, Y, Z file, and can be processed and analysed with any software package. Many software packages exist for this purpose:

- Cyclone and Cyclone Cloudworx (Leica, www.leica-geosystems.com)
- Polyworks (Innovmetric, www.innovmetric.com)
- Riscan Pro (Riegl, www.riegl.com)
- Isite Studio (Isite, www.isite3d.com)
- LFM Software (Zoller+Fröhlich, www.zofre.de)
- Split FX (Split Engineering, www.spliteng.com)
- RealWorks Survey (Trimble, www.trimble.com)

7.4.3 Data Registration Concepts

After scanning, each scan station represents a scan world in the software. These scanworlds can not create a 3D model, because each of them has its own local coordinates.

In order to be able to integrate the TLS data into other geospatial data, one has to transform the "registered" point cloud of the whole object into a chosen external, geodetic, coordinate system (object space), either local or national. This procedure is called georeferencing.

3D Laser scanning system can generate millions of 3D points within a short time when scanning an object. On the scanning object surface, the high density points would form a "point cloud".

After registration the point cloud can be digitally measured and sliced. It can be used for distance measurement, volume calculations, solid modeling, etc. [23]

Data registration is considered an important step to get the whole 3D model in one scan world coordinate system for the scanned object while one scan is not enough to describe an object geometrically. Each scan world has its local coordinate system.

7.4.4 Data Registration ways:

Data Registration Using Targets

Data registration using targets is the most common way for data registration.

It is based on the principle of distributed targets which are scanned during the scanning process. When the scanning is finished, two possible ways may be followed to register the final 3D model. Two ways are classed to achieve the registration, first if registration targets are available, second if the targets are not available. [20]

1. **Targets are available**

For registration to a predefined coordinate system:

In this case, the coordinates of the registration targets should be also available from another measuring tool such as a total station (the targets are called ground control points). Fix the coordinates from the total station coordinate system and transform the local coordinates of each scan world into it. The disadvantage of this method is using an extra instrument (total station) which will raise the cost of the projects.

For registration to a local coordinate system:

• Fixing the coordinate system of the targets in the first scanworld (home scan) then transform all the neighboring scan worlds (floating scans) into the first one.

The advantage of the targets based on the registration method is their increasing accuracy of the final 3D Model for the scanned object. [20]

2. **Targets are not available or difficult to be achieved,**

There is another way to achieve the registration. This way is based on the point clouds. Then the targets do not have any importance here.

During the scanning step, all the adjacent scans must be overlapped; this overlapping helps the users during the registration.

This way is achieved using Cyclone as following:

1. Examination of the images of the scanworlds in order to see the relationship between them.
2. Then creation of registration objects.
3. After opening the registration object and adding the scanworlds, the two added scanworlds can be shown in two bottom viewers.
4. Three identical points from each viewer must be chosen and at the end the registration must be achieved.

The advantage of this way is no need to artificial or natural targets, but on the other side it is difficult to be used for the objects, which have fine details such as archeological columns.

Many techniques could be used to calculate transformation parameters between adjacent scans based on the point cloud itself. The iterative closest point (ICP) method is one of the most popular methods for this purpose.

The iterative closest point (ICP)

ICP is an algorithm employed for matching two point clouds. This matching is used to reconstruct 3D surfaces from different scans.

Principle of the Iterative closest point algorithm

1. The problem Align (registration) two point clouds
2. The input raw data of scanning
3. The output is refined transformation
4. To solve the problem iterate two steps repeatedly: find the best correspondence between the two point sets based on spatial distance, and update the transformation based on the found correspondence.

Removing "Noise":

The wealth information provided from laser scanner allows millions of points to be recorded in a short time which are often complex and do not aid to get the wanted aim of scanning. The output of the scanning is not ideal, it contains other points, which are not interesting for the user, but they are sometimes named as noise points.

These noise points have many reasons:

1. Points caused by very bright object
2. Laser passes through the transparent objects such as glass or plastic, hence scanning objects are not interesting for us.
3. Reflected laser beam from the objects between scanner and the scanned object such as (trees, cars, and other natural or artificial barrier that can not be avoided).
4. Reflections caused from the errors resulted from the scanner itself.

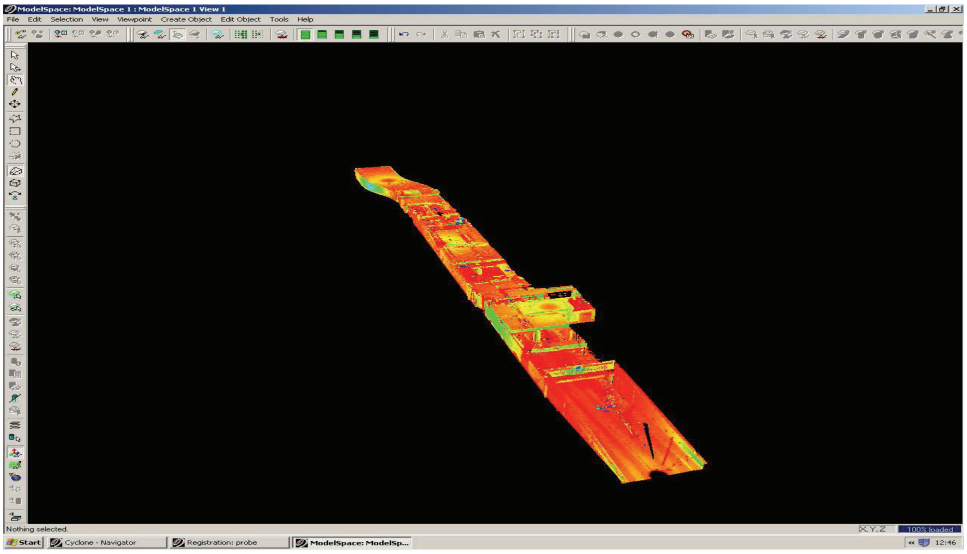


Figure 22 Point Cloud after Registration

Therefore, after the registration is fully completed, the first step of the data processing is to remove the redundant data that represented the noise points resulted because of one or more of the reasons mentioned above.

The traditional surveys do not include these noise points. Therefore it is not needed tools to remove noise in their related programs but with using the scanning to create a model, the manufactures have developed suitable tools in order to do it.

One of the often used and easy ways to remove the noise points is to draw a fence composed of cut lines, and then remove the interior or exterior noise. Fortunately, due to recent major advances in point cloud processing software powerful tools have emerged to allow the surveyor to quickly and easily eliminate noise. Another way to eliminate the noise is an automated process called "**region grow**" which utilizes algorithms that "crawl" across contiguous surfaces to parse out the noise from the surface. In this experiment for example, trees, grass, houses, telegraph pole on a slope may be removed to leave a clear slope for generating DTM later. [24]

The users try to divide the point clouds into subclasses to ease data processing; this operation is called segmentation.

Segmentation is based on the idea to separate the point cloud into groups depending on their types as a first step, and at a second step extract the geometric information from the data set by modeling it separately. At last merging all separated entities into one model to obtain the final form.

The scanned object which has simple geometrical features (for example, a bas-relief or a uniform façade without balconies or high parts protruding), can be easily modeled, but it can be complex if it was as example a historical building with columns, eaves, statues and niches on the façade, etc..

The Applied segmentation in the underground parking is simplified according many considerations, which are determined from Vosselman, G. [25]

These constraints to recognize the features are

Size constraint, Position constraint, Direction constraint, Topology constraint.

1. **Size constraints**: walls, ceiling, ground can be easily distinguished from other features.
2. **Position constraint**: many components of the construction are located always in a certain position, such as the roof, the ground, and the columns.
3. **Direction constraint**: such as walls, which are always vertical, but the roof not.
4. **Topology constraint**: describes the relation between the features to each other. For example, the ground intersects always with walls and the walls have intersection with the roof.

Segmentation techniques

Manual segmentation

This way is easy; it is dependent on segmenting of the object into simple segments. Then by means of the tools of the modeling software this operation can be carried out. The modeling can be created either by meshing, boxes, or patch. There are also some shapes which can be modeled directly such as the steel shapes or pipes.

This type of segmentation will be easy if it is used for simple objects without composed or complex geometry but it would be even more difficult in the case of complex objects. Then it requires a remarkable effort by the operator to identify the parts in the point clouds. Therefore, the experts make more and more efforts to simplify the implementation of the segmentation by developing automatic segmentation ways.

On other occasions, it is possible to segment manually the objects using graphic management software such as AutoCAD. Therefore, the objects are segmented, and some portions of the object are placed on different layers.

This way is followed in our project. The entrance is segmented into six categories, and extracted the model for each one alone.

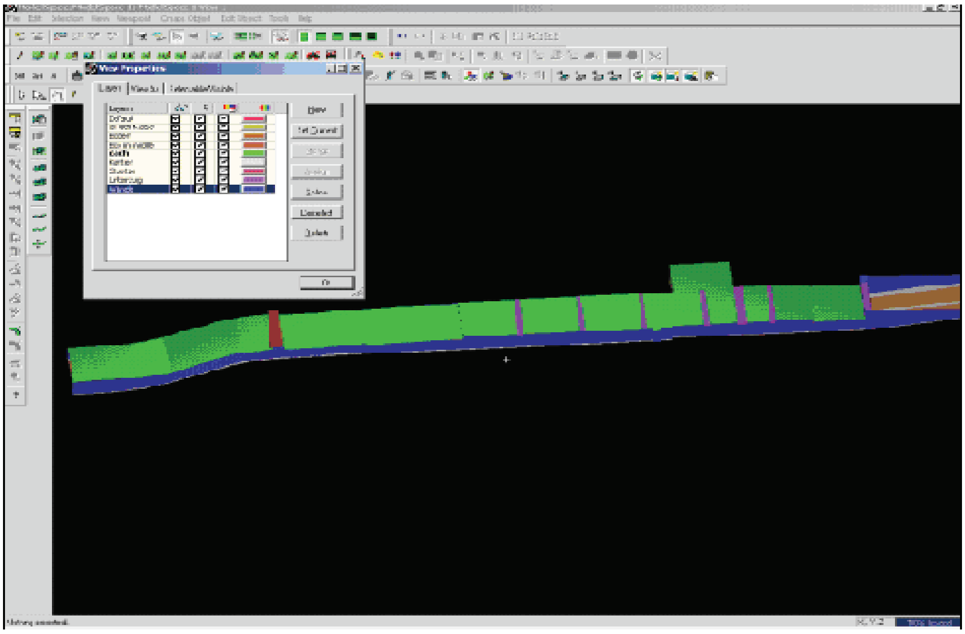


Figure 23 the model in Layers

Automatic Segmentation

At first the automatic segmentation is developed to be used in the domain of aerial laser scanning but some of the segmentation algorithms and techniques can also be applied in terrestrial laser scanning.

Segmentation through the identification of the main planes of the object

In order to be able to model the point clouds acquired with ground type laser scanners it is first of all necessary to divide the 3D model into its main planes. In the case of a building, the main planes can be represented by the individual façades or, as it is the case for more complex buildings, by portions of these façades.

Methods using the 3D Hough-transform

Use it for detecting the roof planes; Hofmann introduces it for the analysis of tin structure parameter spaces, und it includes transformations from one space into a parameter space.

Methods using the RANdom SAmpling Consensus algorithm (RANSAC):

The RANSAC (Random Sample Consensus) Algorithm

The basic summery of the Algorithm

1. Selecting randomly a minimum subset of the input data. Call this **N**, and the whole dataset **M**.

2. Computing the parameters of the model **X** so that they fit the sample.

An example can illustrate the first two steps: to find a plane in the dataset, three points from the dataset can be selected for determining the plane parameters.

3. Finding how many points of **M** fit our determined model with parameter **N** within a predefined tolerance **ε**. Call this **K**.
4. If the **K** is big enough the search will stop and exit.
5. Otherwise, repeat steps 1 through 4 (maximum of **L** times).
6. The process terminates when the likelihood of finding a better model becomes low.[26]
7. The minimum number (m) of trials needed to reach a probability (p) to find at least one good set of observations -assuming a certain percentage (w) of observations to be erroneous - is given by relation

$$L = \log(1\text{-}p)/\log(1\text{-}(1\text{-}w)^{S})$$

Where (S) is the minimum number of points necessary to calculate the parameters of the model (in the case of a planar model, S=3).

Fitting and Editing

The hierarchy of database in cyclone

In the Cyclone navigator and after adding a new database to the server, the user faces the following hierarchy of the object.

A scan world represents several scanned point sets, the data associated with the scan world can only be read and not moved or modified but can not be deleted. [18]

The control Space which is created automatically when the scan world is created has the same properties as the scan world.

ModelSpace folder contains various ModelSpaces.

ModelSpace View is the object that can be worked on.

Geometry modeling

After segmenting the point cloud into different groups, the work is going straightforward to modeling of the point cloud.

When the segmentation is finished, the work is gone straightforward in the labor using Cyclone in modeling and classifying each groups in a layer with a different color to be easily recognized.

The idea of modeling was simple; the selected part of point cloud is surrounded with an arbitrary or rectangular fence. It is opened in a new ModelSpace, and then fitted with a suitable method which is available in Cyclone.

In Cyclone Navigator the work started from the registered unified ModelSpace View. In this part, the used ways for modeling the entrance of the underground parking are presented and illustrated.

Patch

In Cyclone, a patch is a planar object [18]. It is used to model the walls, ceiling, ground, and edges.

Using patch in modeling has many benefits for our project because of its simple and easy manipulation. Some of its main properties are listed:

1. Patch can fit the cloud surface,
2. Patch can be resized, copied, moved, and extended,
3. Patch can be inserted with given dimensions (length and width) as well as a given orientation,
4. In some cases holes can be opened within the patch if it is required.
5. Patch can be extruded by given a thickness, thus a 3D model is obtained.
6. Patch can be colored to give better visual view for the user.

The following figure shows the modeling of walls using patch.

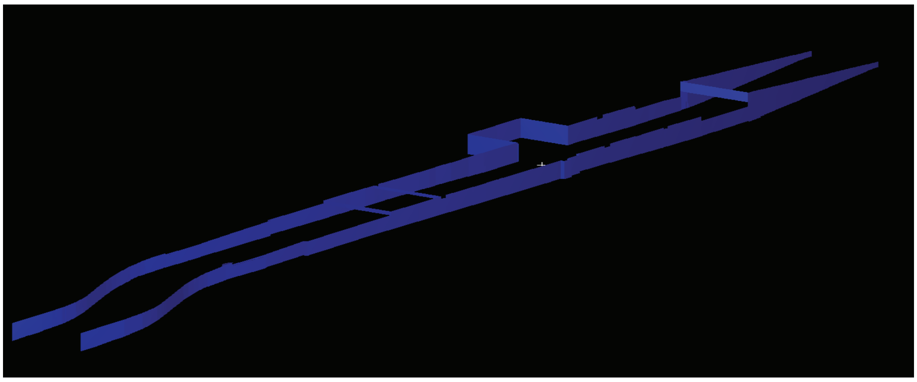


Figure 24 Wall model

Figure 25 shows the modeling of edges and ground using patch with consideration that the edges are modeled with extruded patch.

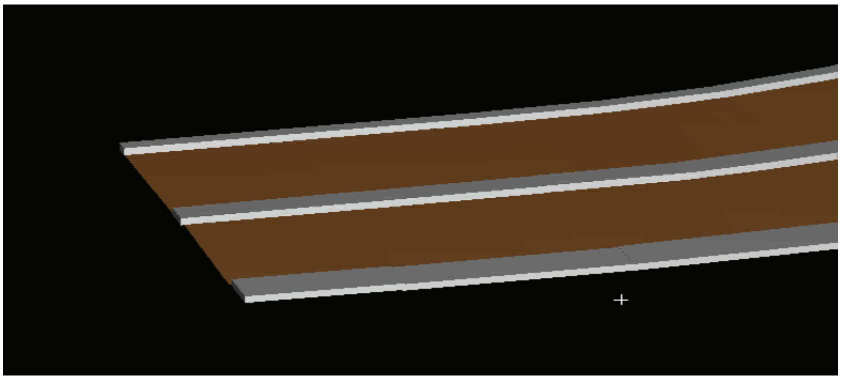


Figure 25 edges modeling with patch

Box

Boxes are useful to model rigid rectangular/ squared objects such as the columns and beams. Boxes share patches in some properties. They can also be moved, copied, resized.

Figure (26) shows the columns and beams using boxes.

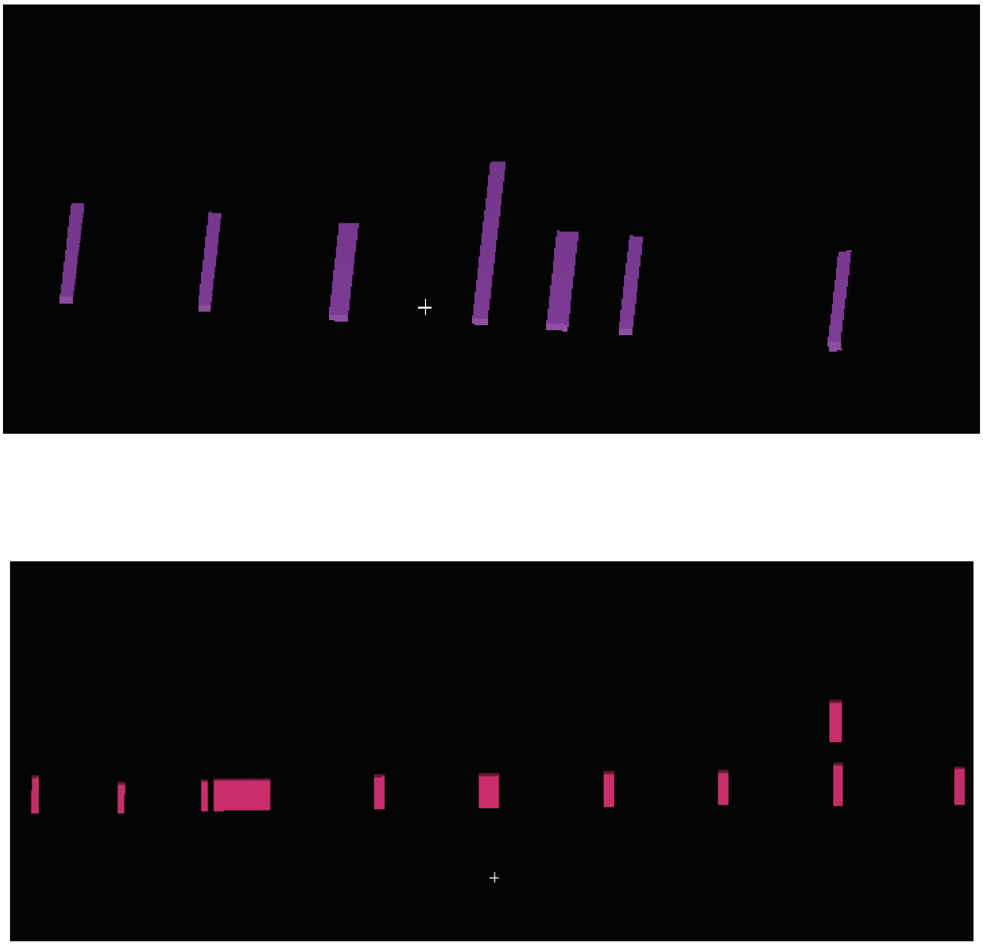


Figure 26 Model of beams –top- and columns –bottom-

Mesh

Mesh is a series of connected triangles, created through the combination of any three points in the point cloud.

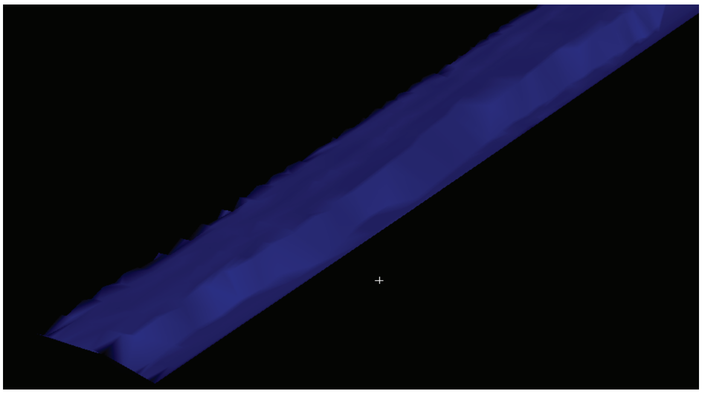
Cyclone offers the user three kinds of meshes to create visual results.

1. Basic mesh: to create a basic mesh consisting of triangles drawn by using trios of adjacent points as triangle vertices.
2. Complex mesh: to create mesh consisting of triangles drawn by using trios of adjacent points that they are likely to lie in the same plane.
3. Tin mesh: (**T**riangulated **I**rregular **N**etwork of lines) to create a mesh wherein no two vertices share the same horizontal coordinates; the current coordinate system determines the “up” direction for a tin mesh.[18].

Using the tin mesh to model the ground did not give the desired visual result especially to create the model of the middle edges which has a very poor density in the plane (XZ) of the point cloud. The proof of this result can be found out from the definition of the mesh which is generated from the combination of any three points in the scanning cloud.

Notice: Cyclone enables filling and manipulating the holes within the mesh if they are in the same plane. That is not possible if the hole expands between two perpendicular planes.

Figure (27) shows this case:



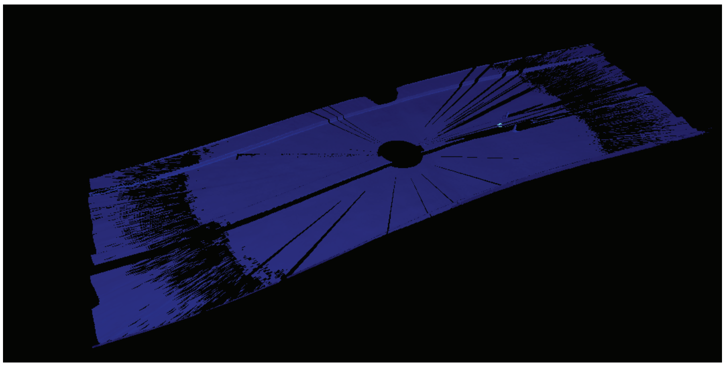


Figure 27 modeling with mesh

A second problem is, if two sub-point clouds are modeled with Mesh they can not be identified, and they seem as two separated meshes as shown in Figure (28).

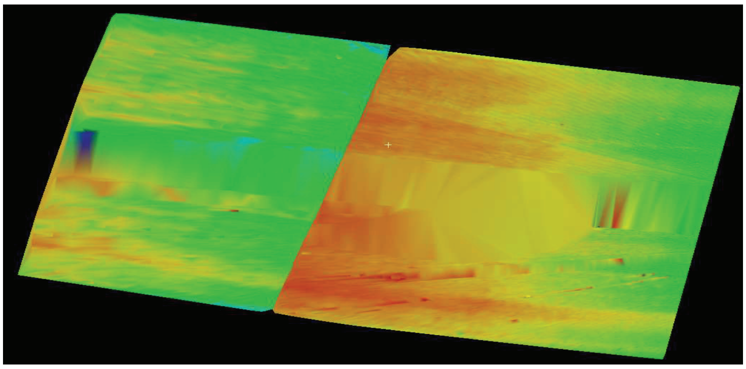


Figure 28 modeling the ground with mesh

But the Modeling Step was not simple, because:

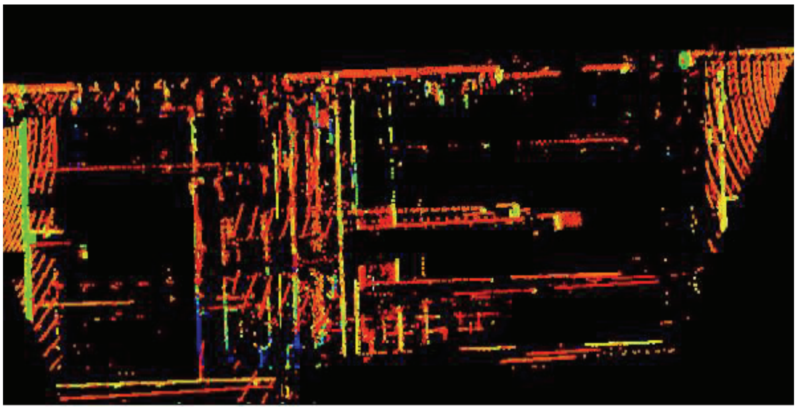


Figure 29 uncompleted ceiling scanning

1. The segment of the ceiling, which is shown in the figure (29), is not an exactly observed and composed of low density of points, therefore it had to depend on the general imagination of the geometrical shape.

2. Some objects have some complex shapes, which are not supported to model with Cyclone Software, such as the curved walls in our case, to model these parts; they were divided into small segments.

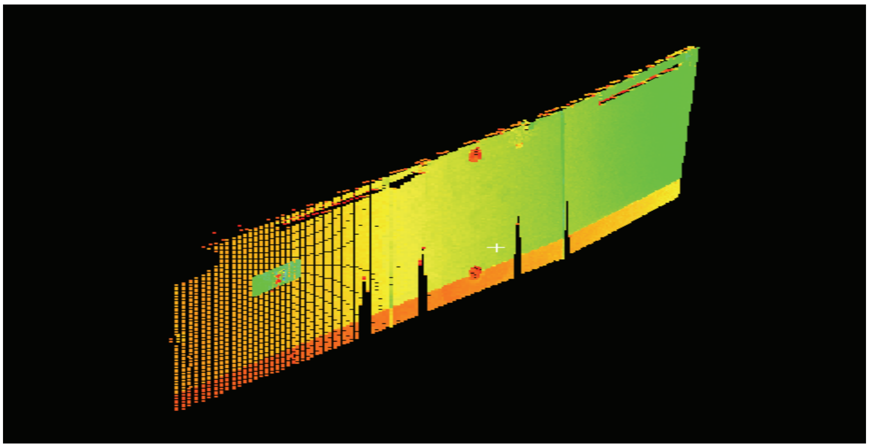


Figure 30 curved Segment

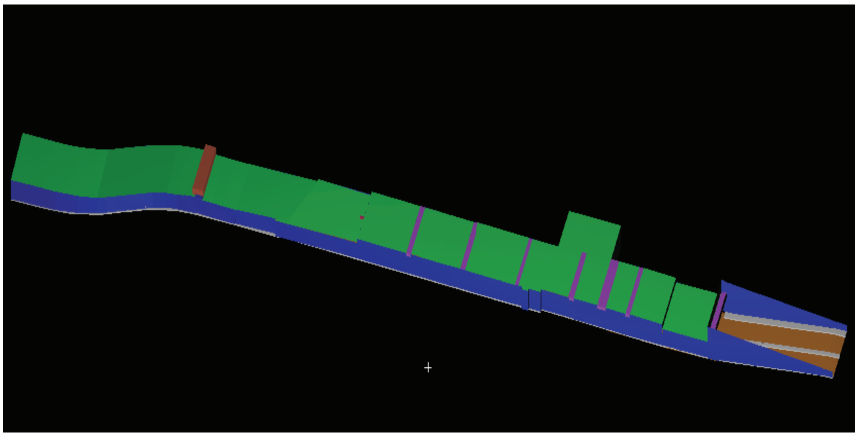


Figure 31 the model of whole construction

8. Conclusion

Laser scanning becomes nowadays one of the most important technologies for the researchers and experts to develop their abilities to offer the users satisfying results associated with easy usage and cost effective.

It was obvious during the scanning that the accuracy of the scanner is related to the range, positioning and, with attention that the influence of the weather factors is not considered.

This high accuracy (9 mm) resulted from the precise observation and coordinate determination of the targets and stations as well as the overlapping of the point cloud obtained from each station. These good results of the observations led us to achieve the registration with a maximum failure not more than 3mm.With attention that a single point cloud is not possible to generate a model.

The removing of noise points was carried out only for the external noise points around the entrance of the underground parking because of the difficulty removing the internal noise points immediately after registration. Therefore this step was carried out while each portion is segmented to model it.

The density of the point cloud varied between its parts according to the distance from the scanner. Therefore it was easier to model the close objects, which have high density than the far objects with low density.

The available tools in Cyclone software helped to generate the whole model without holes. Some difficulties were faced in the very low density parts as shown in figure (29) using the patch tool, which depends on the "region growing" principle allowed us to obtain the desired model of such these cases.

The total time required to generate the model was nine hours scanning in the field and ca. 200 hours in the office, this means that one hour in the field required about twenty two hours in the labor.

Of course this is not a rule in all projects, because it is dependent on many factors such as the nature and the conditions of each project, the geometry of the scanned and modeled object, the required level of details, the experience of the users, and the ways followed in modeling.

One point I want to refer, that is the slowness of Cyclone to execute the commands, especially while merging the modeled objects together after modeling. This stage then

took a long time. Sometimes more than two hours are spent! But I can not ensure; whether this is a shortcoming of Cyclone and is considered as a weakness of the package, because I did not find any notice of it in other researches.
Another shortcoming is noticed during the office data processing, that Cyclone does not support the modeling of curved geometries. Some difficulties were faced to identify the modeled objects and parts.
The idea to segment the point cloud before modeling offers us the easy effort in modeling and objects manipulation, and no problem is faced during the above advised steps of segmentation from Vosselman, G. (Referred in Chapter 7.4.4).
Due to various available Cyclone tools Cyclone can be considered easy software to learn and to use. An example can be referred from our project is that problems arising from mesh triangulation of the holes. Holes in tow planes (XY and XZ) make it necessary to search another tool to solve this problem, therefore the extruded patch was chosen in this case. This all led us to find out and to say that HDS is unique in its approach and in its capabilities and has set new standards in the still young history of laser scanning.
It is obvious in my project that terrestrial laser scanning offers an alternative to traditional survey techniques. The high speed data capture of the entrance of the underground parking took ca. nine hours but if it is compared with the speed of other instruments and their level of details laser scanner will certainly be the first choice for the users in the future, especially in complex and large structures.
The output of this project represented the basic of other users to utilize it in their projects, or to model the structures with other software according to their requirements.
One suggestion for future project based on the data of our project may be the combination of this database with GIS application in civil engineering.

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Attachments:

Coordiantes of the targets and positioning stations.

The Model of the underground parking.

Symbols

AC Alternating current

ALS Airborne Laser Scanner

AMCW Amplitude Modulated Continuous Wave

APD avalanche photo diode

CAD Computer Aided Design

CMM Coordinate-measuring machine

Cw Continuous-wave

DEM Digital Elevation Model

FMCW Frequency-Modulated Continuous Wave

FOV field-of-view

GCP Geodetic Control Point

GPS Global Positioning System

HDS High Definition Surveying

ICP Iterative Closest Point

IMU Inertial Measurement Unit

INS inertial navigation system

LIDAR Light Detection and Ranging

POS Position and orientation system

RANSAC RANdom SAmpling Consensus algorithm

SNR signal-to-noise Ratio

TDC Time-to-digital converter

TLS Terrestrial Laser scanner

TOF Time of Flight

3D three Dimensions

List of Figures

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Bilal Sayed Youseif

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.

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Place, date signature