Review Article

3D LASER SCANNERS:
HISTORY, APPLICATIONS, AND FUTURE

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ABSTRACT

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A 3D scanner is a device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance (i.e. color). The collected data can then be used to construct digital three-dimensional models.

3D laser scanning developed during the last half of the 20th century in an attempt to accurately recreate the surfaces of various objects and places. The technology is especially helpful in fields of research and design. The first 3D scanning technology was created in the 1960s. The early scanners used lights, cameras and projectors to perform this task. Due to limitations of the equipment it often took a lot of time and effort to scan objects accurately. After 1985 they were replaced with scanners that could use white light, lasers and shadowing to capture a given surface.

Many different technologies can be used to build these 3D scanning devices; each technology comes with its own limitations, advantages, and costs. Many limitations in the kind of objects that can be digitized are still present: for example, optical technologies encounter many difficulties with shiny, mirroring, or transparent objects.

There are several different kinds of 3D laser scanners, with prices ranging from the couple thousands to the hundreds of thousands.

Collected 3D data is useful for a wide variety of applications. These devices are used extensively by the entertainment industry in the production of movies and video games. Other common applications of this technology include industrial design, orthotics and prosthetics, reverse engineering and prototyping, quality control/inspection and documentation of cultural artifacts.

The 3D Laser Scanning market including hardware, software, and services is rather dynamic with major segments experiencing rapid product innovation. The market contains exceptional opportunities with rapid forecasted growth driven by both replacing older mechanical methods, and by improved workflow with lower overall project costs, which enables more projects. For the forecast period (2010 – 2015), the market is forecasted to grow with a Compound Annual Growth Rate (CAGR) of 15.4% according to a new ARC Advisory Group study.

In this review article, the important areas concerning the 3D laser scanners will be covered.

CHAPTER 1

INTRODUCTION

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INTRODUCTION

In modern engineering, the term `laser scanning' is used to described two related, but separate meanings. The first, more general, meaning is the controlled deflection of laser beams, visible or invisible (Gerald F. Marshall, 2004). Scanned laser beams are used in stereolithography machines, in rapid prototyping, in machines for material processing, in laser engraving machines, in ophtalmological laser systems for the treatment of presbyopia, in confocal microscopy, in laser printers, in laser shows, in Laser TV, and in barcode scanners.

The second, more specific, meaning is the controlled steering of laser beams followed by a distance measurement at every pointing direction. This method, often called 3D object scanning or 3D laser scanning, is used to rapidly capture shapes of objects, buildings, and landscapes.

Since the early 1980's, the analytical stereo-compiler has been the workhorse for broad-acre spatial data acquisition tasks including exploration mapping, regular mine planning and stockpile measurements (Byrne, 1997). It has also played a lesser role in subsidence monitoring, environmental lease statistics and infrastructure mapping.

Since 1994, a new airborne terrain modeling technology has been available to the surveying industry. The term "Airborne Laser Scanner" (ALS) evolved as the hardware utilized in the aircraft is a logical advancement of the Airborne Laser Profilers used primarily by the forestry industry for many years. Other titles attributed to the same piece of hardware include "LiDAR" (the term favored in the United States), and "Airborne Laser Terrain Mapper (ALTM)", the brand name used by the major hardware manufacturer in this field.

Terrestrial laser scanning has already found its place between the standard technologies for objects acquisition. The laser scanner can be described as a motorized total station, which measures automatically all the points in its horizontal and vertical field. For each measured point, its distance to the laser scanner together with the horizontal and the vertical angles are recorded. So, the space coordinates relative to the scanner position can be easily computed (Abdelhafez, 2099).

Hand-held laser scanners create a 3D image through the triangulation mechanism described above: a laser dot or line is projected onto an object from a hand-held device and a sensor (typically a charge-coupled device or position sensitive device) measures the distance to the surface.

The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the subject. These points can then be used to extrapolate the shape of the subject (a process called reconstruction). If color information is collected at each point, then the colors on the surface of the subject can also be determined.

This review article is focusing in presenting a brief look on the 3D laser scanners. In addition, it gives a general presentation about the 3D laser scanners' history, applications and expected futur.

Chapter 2 is about the fundamental of laser scanning. In this chapter, intrduction to the 3D laser scanning, history of 3D laser scanning, and 3D scanning techniques will be presented.

Chapter 3 talkes about the 3D laser scanners. In this chapter, different types of 3D laser scanners; their advantages and disadvantage will be presented.

Chapter 4 will focus on the 3D laser scanning application and the accuracy.

Chapter 5 will give an over view about the Light Detection And Ranging (LiDAR) system.

Chapter 6 will talk about the future of the 3D scanning and expected growth of the 3D scanners market.

At last, a conclusion about the subject is written to view the main elements and features of the subjects. A list of references and the related internet web sites is provided for further review at the end of this article review.

CHAPTER 2

FUNDAMENTAL OF LASER SCANNING

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FUNDAMENTAL OF LASER SCANNING

2.1 INTRODUCTION

3D scanners are very analogous to cameras. Like cameras, they have a cone-like field of view, and like cameras, they can only collect information about surfaces that are not obscured. While a camera collects color information about surfaces within its field of view, a 3D scanner collects distance information about surfaces within its field of view. The "picture" produced by a 3D scanner describes the distance to a surface at each point in the picture. This allows the three dimensional position of each point in the picture to be identified.

For most situations, a single scan will not produce a complete model of the subject. Multiple scans, even hundreds, from many different directions are usually required to obtain information about all sides of the subject. These scans have to be brought in a common reference system, a process that is usually called *alignment* or *registration*, and then merged to create a complete model. This whole process, going from the single range map to the whole model, is usually known as the 3D scanning pipeline (Fausto Bernardini, et al, 2002).

2.2 HISTORY OF 3D SCANNERS

3D laser scanning developed during the last half of the 20th century in an attempt to accurately recreate the surfaces of various objects and places. The technology is especially helpful in fields of research and design. The first 3D scanning technology was created in the 1960s. The early scanners used lights, cameras and projectors to perform this task. Due to limitations of the equipment it often took a lot of time and effort to scan objects accurately. After 1985 they were replaced with scanners that could use white light, lasers and shadowing to capture a given surface. Next is a brief history of the 3D scanning development [Site 1].

With the advent of computers, it was possible to build up a highly complex model, but the problem came with creating that model. Complex surfaces defied the tape measure as shown in figure (2.1).

Figure 2.1: Object tape measuring

So in the eighties, the toolmaking industry developed a contact probe. At least this enabled a precise model to be created, but it was so slow. The thinking was, if only someone could create a system, which captured the same amount of detail but at higher speed, it will make application more effective.

Therefore, experts started developing optical technology. Using light was much faster than a physical probe. This also allowed scanning of soft objects, which would be threatened by prodding.

At that time, three types of optical technology were available:

- **Point**, which is similar to a physical probe in that it uses a single point of reference, repeated many times. This was the slowest approach as it involved lots of physical movement by the sensor.
- **Area**, which is technically difficult. This is demonstrated by the lack of robust area systems on sale.
- **Stripe,** the third system - was soon found to be faster than point probing as it used a band of many points to pass over the object at once, which was accurate too. So it matched the twin demands for speed and precision.

Figure (2.2) shows a skitch of the three-diferent optical technolgies.

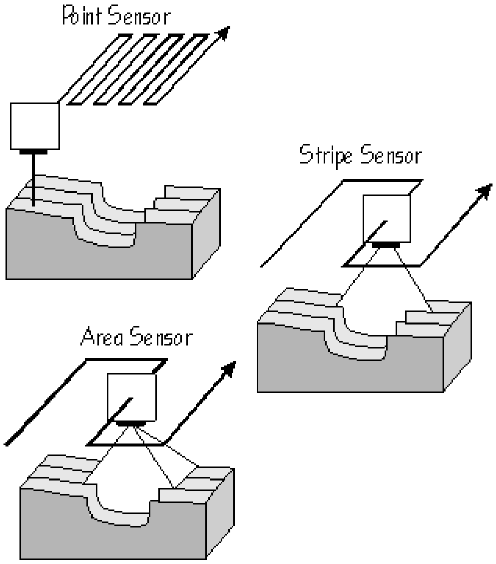


Figure 2.2: Skitch of the three diferent optical technologies

So stripe was clearly the way forwards, but it soon became apparent that the challenge was one of software. To capture an object in three dimensions, the sensor would make several scans from different positions. The challenge was to join those scans together, remove the duplicated data and sift out the surplus that inevitably gathers when you collect several million points of data at once.

One of the first applications was capturing humans for the animation industry. Cyberware Laboratories of Los Angeles developed this field in the eighties with their Head Scanner as shown in figure (2.3).

Figure 2.3: Humans head scanning

By the mid-nineties they had developed into a full body scanner as shown in figure (2.4). This is where 3D Scanners appeared.

Figure 2.4: Humans body scanning

In 1994, 3D Scanners launched REPLICA - which allowed fast, highly accurate scanning of very detailed objects. REPLICA marked serious progress in laser stripe scanning (see figure 2.5).

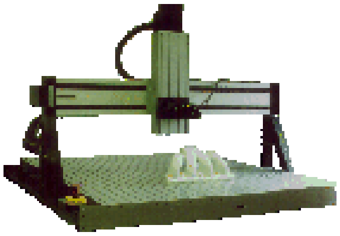


Figure 2.5: Replica 3D laser scanner

Meanwhile Cyberware were developing their own high detail scanners, some of which were able to capture object colour too, but despite this progress, true three-dimensional scanning - with these degrees of speed and accuracy - remained elusive.

One company - Digibotics - did introduce a 4-axis machine, which could provide a fully 3D model from a single scan, but this was based on laser point - not laser stripe - and was thus slow. Neither did it have the six degrees of freedom necessary to cover the entire surface of an object, neither could it digitise color surface.

While these optical scanners were expensive, Immersion and Faro Technologies introduced low-cost manually operated digitisers. These could indeed produce complete models, but they were slow, particularly when the model was detailed. Again, they could not digitise color surface (see figure 2.6).

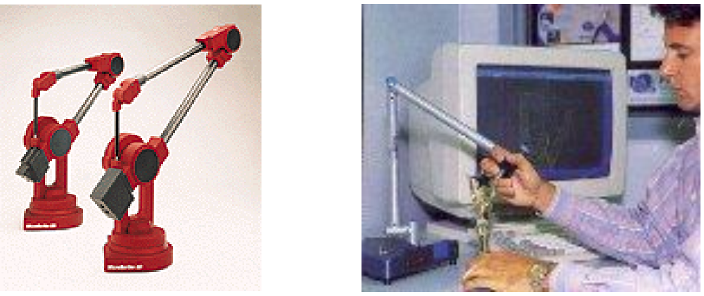


Figure 2.6: Optical scanners

By this time, 3D modellers were united in their quest for a scanner, which was:

- accurate
- fast
- truly three dimensional
- capable of capturing color surface
- and realistically priced.

In 1996, 3D Scanners took the key technologies of a manually operated arm and a stripe 3D scanner - and combined them in ModelMaker as shown in figure (2.7). This incredibly fast and flexible system is the world's first *Reality Capture System*.It produces complex models and it textures those models with color. Color 3D models can now be produced in minutes.

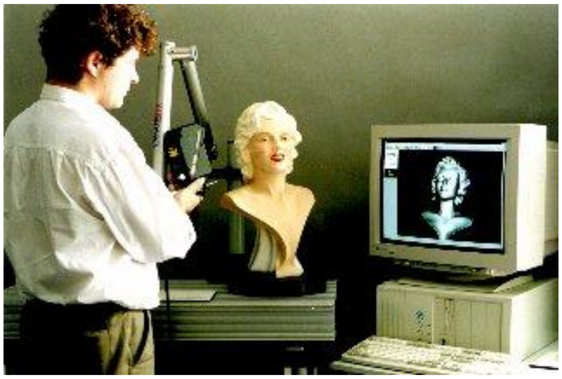


Figure 2.7: Manually operated arm and strip 3D scanner

2.3 3D LASER SCANNERS TECHNIQUES

There are varieties of technologies for digitally acquiring the shape of a 3D object. A well-established classification (Brian Curless, 2000) divides them into two types: contact and non-contact 3D scanners [Site 4]. Non-contact 3D scanners can be further divided into two main categories, active scanners, and passive scanners. There are varieties of technologies that fall under each of these categories.

2.3.1 CONTACT TECHNIQUE

3D contact scanners, generally calibrated to operate on a fixed platform, often contain a probe located at the end of an articulated mechanical arm. The arm may be robotically or manually manipulated over the part's surface. As the probe contacts the object's surface the scanner records the X,Y,Z position of the probe by taking positional measurements of the armature. The recorded positions form a point cloud, which can be used to calculate a 3D mesh. Some highly accurate 3D scanners called Coordinate Measuring Machines (CMMs) are often used by the manufacturing industry to inspect parts for early indications of assembly problems. 3D contact scanners suffer from slow scan rates and may not be ideal for delicate objects, such as precious artworks, as physical contact may damage or deform the surface [Site 36].

2.3.1.1 Traditional Coordination Measuring Machine (CMM)

Contact 3D scanners probe the subject through physical touch. A CMM (Coordinate Measuring Machine) is an example of a contact 3D scanner. A coordinate measuring machine (CMM) is a device for measuring the physical geometrical characteristics of an object. This machine may be manually controlled by an operator or it may be computer controlled. Measurements are defined by a probe attached to the third moving axis of this machine. Probes may be mechanical, optical, laser, or white light, amongst others. Figure (2.8) shows one of the CMM.

Figure 2.8: Coordinate Measuring Machine (CMM)

It is used mostly in manufacturing and can be very precise. The disadvantage of CMMs though, is that it requires contact with the object being scanned. Thus, the act of scanning the object might modify or damage it. This fact is very significant when scanning delicate or valuable objects such as historical artifacts. The other disadvantage of CMMs is that they are relatively slow compared to the other scanning methods. Physically moving the arm that the probe is mounted on can be very slow and the fastest CMMs can only operate on a few hundred hertz. In contrast, an optical system like a laser scanner can operate from 10 to 500 kHz.Other examples are the hand driven touch probes used to digitize clay models in computer animation industry.

The typical CMM is composed of three axes, an X, Y, and Z. These axes are orthogonal to each other in a typical three-dimensional coordinate system. Each axis has a scale system that indicates the location of that axis. The machine will read the input from the touch probe, as directed by the operator or programmer. The machine then uses the X,Y, Z coordinates of each of these points to determine size and position with micrometre precsion typically.

Coordinate measuring machines include three main components [Site 2]:

- The main structure which include three axes of motion
- Probing system
- Data collection and reduction system - typically includes a machine controller, desktop computer, and application software.

They are often used for:

- Dimensional measurement
- Profile measurement
- Angularity or orientation measurement
- Depth mapping
- Digitizing or imaging
- Shaft measurement

They are offered with features like:

- Crash protection
- Offline programming
- Reverse engineering
- Shop floor suitability
- SPC software and temperature compensation.
- CAD Model import capability
- Compliance with the DMIS standard
- I++ controller compatibility

The machines are available in a wide range of sizes and designs with a variety of different probe technologies. They can be operated manually or automatically through Direct Computer Control (DCC). They are offered in various configurations such as benchtop, freestanding, handheld, and portable.

2.3.1.1.1 Specific Parts

2.3.1.1.1.1 Machine body

The first CMM was developed by the Ferranti Company of Scotland in the 1950s as the result of a direct need to measure precision components in their military products, although this machine only had 2 axes. The first 3-axis models began appearing in the 1960s (DEA of Italy) and computer control debuted in the early 1970s (Sheffield of the USA). Leitz Germany subsequently produced a fixed machine structure with moving table [Site 3].

In modern machines, the gantry type superstructure has two legs and is often called a bridge. This moves freely along the granite table with one leg (often referred to as the inside leg) following a guide rail attached to one side of the granite table. The opposite leg (often outside leg) simply rests on the granite table following the vertical surface contour. Air bearings are the chosen method for ensuring friction free travel. In these, compressed air is forced through a series of very small holes in a flat bearing surface to provide a smooth but controlled air cushion on which the CMM can move in a frictionless manner. The movement of the bridge or gantry along the granite table forms one axis of the XY plane. The bridge of the gantry contains a carriage which traverses between the inside and outside legs and forms the other X or Y horizontal axis. The third axis of movement (Z axis) is provided by the addition of a vertical quill or spindle which moves up and down through the center of the carriage. The touch probe forms the sensing device on the end of the quill. The movement of the X, Y and Z axes fully describes the measuring envelope. Optional rotary tables can be used to enhance the approachability of the measuring probe to complicated workpieces. The rotary table as a fourth drive axis does not enhance the measuring dimensions, which remain 3D, but it does provide a degree of flexibility. Some touch probes are themselves powered rotary devices with the probe tip able to swivel vertically through 90 degrees and through a full 360 degree rotation.

As well as the traditional three axis machines (as pictured above), CMMs are now also available in a variety of other forms. These include CMM arms that use angular measurements taken at the joints of the arm to calculate the position of the stylus tip. Such arm CMMs are often used where their portability is an advantage over traditional fixed bed CMMs. Because CMM arms imitate the flexibility of a human arm they are also often able to reach the insides of complex parts that could not be probed using a standard three axis machine.

2.3.1.1.1.2 Mechanical probe

In the early days of coordinate measurement mechanical probes were fitted into a special holder on the end of the quill. A very common probe was made by soldering a hard ball to the end of a shaft. This was ideal for measuring a whole range of flat, cylindrical or spherical surfaces. Other probes were ground to specific shapes, for example a quadrant, to enable measurement of special features. These probes were physically held against the workpiece with the position in space being read from a 3-Axis digital readout (DRO) or, in more advanced systems, being logged into a computer by means of a footswitch or similar device. Measurements taken by this contact method were often unreliable as machines were moved by hand and each machine operator applied different amounts of pressure on the probe or adopted differing techniques for the measurement.

A further development was the addition of motors for driving each axis. Operators no longer had to physically touch the machine but could drive each axis using a handbox with joysticks in much the same way as with modern remote controlled cars. Measurement accuracy and precision improved dramatically with the invention of the electronic touch trigger probe. The pioneer of this new probe device was David McMurtry who subsequently formed what is now Renishaw plc. Although still a contact device, the probe had a spring loaded steel ball (later ruby ball) stylus. As the probe touched the surface of the component the stylus deflected and simultaneously sent the X.Y,Z coordinate information to the computer. Measurement errors caused by individual operators became fewer and the stage was set for the introduction of CNC operations and the coming of age of CMMs.

Optical probes are lens-CCD-systems, which are moved like the mechanical ones, and are aimed at the point of interest, instead of touching the material. The captured image of the surface will be enclosed in the borders of a measuring window, until the residue is adequate to contrast between black and white zones. The dividing curve can be calculated to a point, which is the wanted measuring point in space. The horizontal information on the CCD is 2D (XY) and the vertical position is the position of the complete probing system on the stand Z-drive (or other device component). This allows entire 3D-probing.

2.3.1.1.1.3 New Probing Systems

There are newer models that have probes that drag along the surface of the part taking points at specified intervals, known as scanning probes. This method of CMM inspection is often more accurate than the conventional touch-probe method and most times faster as well.

The next generation of scanning, known as non-contact scanning includes high speed laser single point triangulation [Site 6], laser line scanning [Site 7], and white light scanning [Site 8], is advancing very quickly. This method uses either laser beams or white light that are projected against the surface of the part. Many thousands of points can then be taken and used to not only check size and position, but to create a 3D image of the part as well. This "point-cloud data" can then be transferred to CAD software to create a working 3D model of the part. These optical scanners often used on soft or delicate parts or to facilitate reverse engineering.

2.3.1.1.1.4 Micro Metrology Probes

Probing systems for microscale metrology applications are another emerging area (Hansen H.N., et al, 2006) (Weckenmann A., Peggs G., Hoffmann J., 2006). There are several commercially available coordinate measuring machines (CMM) that have a microprobe integrated into the system, several specialty systems at government laboratories, and any number of university built metrology platforms for microscale metrology. Although these machines are good and in many cases excellent metrology platforms with nanometric scales their primary limitation is a reliable, robust, capable micro/nano probe. Challenges for microscale probing technologies include the need for a high aspect ratio probe giving the ability to access deep, narrow features with low contact forces so as to not damage the surface and high precision (nanometer level). Additionally microscale probes are susceptible to environmental conditions such as humidity and surface interactions such as stiction (caused by adhesion, meniscus, and/or Van der Waals forces among others).

Technologies to achieve microscale probing include scaled down version of classical CMM probes, optical probes, and a standing wave probe (M.B. Bauza, et al, 2005) among others. However, current optical technologies cannot be scaled small enough to measure deep, narrow feature, and optical resolution is limited by the wavelength of light. X-ray imaging provides a picture of the feature but no traceable metrology information.

2.3.1.1.2 Physical Principles

Optical probes and/or laser probes can be used (if possible in combination), which change CMMs to measuring microscopes or multi sensor measuring machines. Fringe projection systems, theodolite triangulation systems or laser distant and triangulation systems are not called measuring machines, but the measuring result is the same: a space point. Laser probes are used to detect the distance between the surface and the reference point on the end of the kinematic chain (i.e.: end of the Z-drive component). This can use an interferometrical, focus variation, a light deflection or half beam shadowing principle.

2.3.1.2 Portable Coordinate Measuring Machines

Portable CMMs are different from "traditional CMMs" in that they most commonly take the form of an articulated arm. These arms have six or seven rotary axes with rotary encoders, instead of linear axes. Portable arms are lightweight (typically less than 20 pounds) and can be carried and used nearly anywhere. The inherent trade-offs of a portable CMM are manual operation (always requires a human to use it), and overall accuracy is somewhat to much less accurate than a bridge type CMM. Certain non-repetitive applications such as reverse engineering, rapid prototyping, and large-scale inspection of low-volume parts are ideally suited for portable CMMs.

2.3.1.3 Multi-Sensor Measuring Machines

Traditional CMM technology using touch probes is today often combined with other measurement technology. This includes laser, video or white light sensors to provide what is known as multi-sensor measurement [Site 9].

2.3.2 Non-Contact Technique

Non-contact 3D scanners, as the name implies, do not make physical contact with an object surface. Instead, noncontact 3D scanners rely on some active or passive techniques to scan an object. The end result is a highly accurate cloud of points that can be used for reverse engineering, virtual assembly, engineering analysis, feature and surface inspection or rapid prototyping [Site 36].

2.3.2.1 Non-Contact Active Techniques

Active scanners emit some kind of radiation or light and detect its reflection in order to probe an object or environment. Possible types of emissions used include light, ultrasound, or x-ray [Site 4].

3D Laser Scanning or 3D Laser Scanners can generally be categorized into three main categories; time of flight, phase shift, and laser triangulation. These laser scanning techniques are typically used independently but can also be used in combination to create a more versatile scanning system. There are also numerous other laser scanning technologies that are hybrids and/or combinations of other 3D scanning technologies such as accordion fringe interferometry or conoscopic holography [Site 11].

2.3.2.1.1 Time-of-flight

The time-of-flight 3D laser scanner is an active scanner that uses laser light to probe the subject. At the heart of this type of scanner is a time-of-flight laser rangefinder. The laser rangefinder finds the distance of a surface by timing the round-trip time of a pulse of light. A laser is used to emit a pulse of light and the amount of time before the reflected light is seen by a detector is timed. Since the speed of light c is known, the round-trip time determines the travel distance of the light, which is twice the distance between the scanner and the surface. If t is the round-trip time, then distance is equal to ($c.t/2$). The accuracy of a time-of-flight 3D laser scanner depends on how precisely we can measure the time (t):3.3 picoseconds (approx.) is the time taken for light to travel 1 millimeter.

The laser rangefinder only detects the distance of one point in its direction of view. Thus, the scanner scans its entire field of view one point at a time by changing the range finder's direction of view to scan different points. The view direction of the laser rangefinder can be changed either by rotating the range finder itself, or by using a system of rotating mirrors. The latter method is commonly used because mirrors are much lighter and can thus be rotated much faster and with greater accuracy. Typical time-of-flight 3D laser scanners can measure the distance of 10,000~100,000 points every second.

Time-of-flight devices are also available in a 2D configuration. This is referred to as a Time-of-flight camera.

2.3.2.1.2 Phase shift

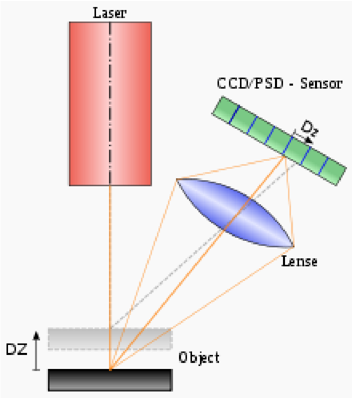
Phase shift laser scanners work by comparing the phase shift in the reflected laser light to a standard phase, which is also captured for comparison. This is similar to time of flight detection except that the phase of the reflected laser light further refines the distance detection, similar to the vernier scale on a caliper.

In the phase shift method, the phase shift between the sent and the received signal with a certain wavelength is determined. The required distance can be then computed depending on the phase shift. The maximum rang which can be measured by a certain modulation is half of the modulation wavelength. Measuring with a high frequency modulation gives precise distances but smaller range. Ambiguity regarding the measured distance can be obtained because with increasing the distance above the maximum range the phase will vary periodically (Abdelhafez, 2099). The ambiguity can easily be removed by measuring with two different modulation frequencies. Through frequency selective computation of the phase differences from both measurement channels, an unambiguous and precise range measurement can be obtained (Froehlich et al. 2000).

While the scanning speed of phase difference scanners is faster than the time of flight scanners, the point clouds resulted from scanners use the phase difference method is more noisy than those resulted from scanners use the time of flight method (Mechalke et al., 2007). The measuring range of scanners employ the time-of-flight method (200-300m) is longer than the measuring range of scanners employ phase difference method (70-80m).

2.3.2.1.3 Triangulation

The triangulation 3D laser scanners are also active scanner that use laser light to probe the environment. With respect to time-of-flight 3D laser scanner, the triangulation laser shines a laser on the subject and exploits a camera to look for the location of the laser dot. Depending on how far away the laser strikes a surface, the laser dot appears at different places in the camera's field of view. This technique is called triangulation because the laser dot, the camera and the laser emitter form a triangle (see figure 2.9). The length of one side of the triangle, the distance between the camera and the laser emitter are known. The angle of the laser emitter corner is also known. The angle of the camera corner can be determined by looking at the location of the laser dot in the camera's field of view. These three pieces of information fully determine the shape and size of the triangle and gives the location of the laser dot corner of the triangle. In most cases, a laser stripe instead of a single laser dot, is swept across the object to speed up the acquisition process. The National Research Council of Canada was among the first institutes to develop the triangulation based laser scanning technology in 1978 (Roy Mayer, 1999). Figure (2.10) shows the generation of point cloud using triangulation with a laser stripe.



Figue 2.9: Principle of a laser triangulation sensor (Two object positions are shown)

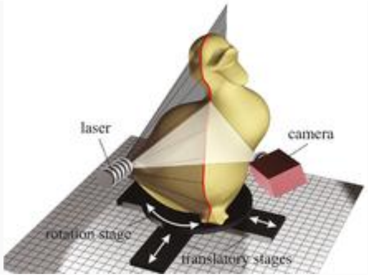


Figure 2.10: Point cloud generation using triangulation with a laser stripe

2.3.2.1.4 Strengths and Weaknesses

Time-of-flight and triangulation range finders each have strengths and weaknesses that make them suitable for different situations. The advantage of time-of-flight range finders is that they are capable of operating over very long distances, about kilometers (A. Valanis, et al, 2009). These scanners are thus suitable for scanning large structures like buildings or geographic features. The disadvantage of time-of-flight range finders is their accuracy. Due to the high speed of light, timing the round-trip time is difficult and the accuracy of the distance measurement is relatively low, about millimeters. Triangulation range finders are exactly the opposite. They have a limited range of some meters, but their accuracy is relatively high. The accuracy of triangulation range finders is about tens of micrometers (European Community's Seventh Framework Programme, 2010).

Time of flight scanners accuracy can be lost when the laser hits the edge of an object because the information that is sent back to the scanner is from two different locations for one laser pulse. The coordinate relative to the scanners position for a point that has hit the edge of an object will be calculated based on an average and therefore will put the point in the wrong place. When using a high resolution scan on an object the chances of the beam hitting an edge are increased and the resulting data will show noise just behind the edges of the object. Scanners with a smaller beam width will help to solve this problem but will be limited by range as the beam width will increase over distance. Software can also help by determining that the first object to be hit by the laser beam should cancel out the second.

At a rate of 10,000 sample points per second, low resolution scans can take less than a second, but high resolution scans, requiring millions of samples, can take minutes for some time-of-flight scanners. The problem this creates is distortion from motion. Since each point is sampled at a different time, any motion in the subject or the scanner will distort the collected data. Thus, it is usually necessary to mount both the subject and the scanner on stable platforms and minimize vibration. Using these scanners to scan objects in motion is very difficult (A. Georgopoulos, et al, 2010). Recently, there has been research on compensating for distortion from small amounts of vibration (François B., et al, 2004).

When scanning in one position for any length of time slight movement can occur in the scanner position due to changes in temperature. If the scanner is set on a tripod and there is strong sunlight on one side of the scanner then that side of the tripod will expand and slowly distort the scan data from one side to another. Some laser scanners have level compensators built into them to counteract any movement of the scanner during the scan process.

2.3.2.2 Non-Contact Active Scanners

Common active non-contact 3D scanners include laser scanners, structured optical light scanners, Modulated light scanners, Computer Tomography scanners, Magnetic resonance imaging scanners, etc. Some of these scanners will be presented in the following sub-sections.

2.3.2.2.1 Conoscopic holography (Laser)

In a Conoscopic system, a laser beam is projected onto the surface and then the immediate reflection along the same ray-path are put through a conoscopic crystal and projected onto a CCD. The result is a diffraction pattern that can be frequency analyzed to determine the distance to the measured surface. The main advantage with Conoscopic Holography is that only a single ray-path is needed for measuring, thus giving an opportunity to measure for instance the depth of a finely drilled hole.

2.3.2.2.2 Structured light

Structured-light 3D scanners project a pattern of light on the subject and look at the deformation of the pattern on the subject. The pattern may be one-dimensional or two-dimensional. An example of a one-dimensional pattern is a line. The line is projected onto the subject using either an LCD projector or a sweeping laser. A camera, offset slightly from the pattern projector, looks at the shape of the line and uses a technique similar to triangulation to calculate the distance of every point on the line. In the case of a single-line pattern, the line is swept across the field of view to gather distance information one strip at a time.

An example of a two-dimensional pattern is a grid or a line stripe pattern. A camera is used to look at the deformation of the pattern, and an algorithm is used to calculate the distance at each point in the pattern. Consider an array of parallel vertical laser stripes sweeping horizontally across a target. In the simplest case, one could analyze an image and assume that the left-to-right sequence of stripes reflects the sequence of the lasers in the array, so that the leftmost image stripe is the first laser, the next one is the second laser, and so on. In non-trivial targets having holes, occlusions, and rapid depth changes, however, this sequencing breaks down as stripes are often hidden and may even appear to change order, resulting in laser stripe ambiguity. This problem can be solved using algorithms for multistripe laser triangulation. Structured-light scanning is still a very active area of research with many research papers published each year.

The advantage of structured-light 3D scanners is speed. Instead of scanning one point at a time, structured light scanners scan multiple points or the entire field of view at once. This reduces or eliminates the problem of distortion from motion. Some existing systems are capable of scanning moving objects in real-time.

A real-time scanner using digital fringe projection and phase-shifting technique (a various structured light method) was developed, to capture, reconstruct, and render high-density details of dynamically deformable objects (such as facial expressions) at 40 frames per second (Song Z., Peisen H., 2006). Recently, another scanner is developed. Different patterns can be applied to this system. The frame rate for capturing and data processing achieves 120 frames per second. It can also scan isolated surfaces, for example two moving hands (Kai Liu, et al, 2010).

2.3.2.2.3 Modulated light

Modulated light 3D scanners shine a continually changing light at the subject. Usually the light source simply cycles its amplitude in a sinusoidal pattern. A camera detects the reflected light and the amount the pattern is shifted by determines the distance the light traveled. Modulated light also allows the scanner to ignore light from sources other than a laser, so there is no interference.

2.3.2.2.4 Volumetric Techniques

2.3.2.2.4.1 Medical

Computed tomography (CT) is a medical imaging method, which generates a three-dimensional image of the inside of an object from a large series of two-dimensional X-ray images. Similarly Magnetic resonance imaging is another medical imaging technique that provides much greater contrast between the different soft tissues of the body than computed tomography (CT) does, making it especially useful in neurological (brain), musculoskeletal, cardiovascular, and oncological (cancer) imaging. These techniques produce a discrete 3D volumetric representation that can be directly visualized, manipulated, or converted to traditional 3D surface by mean of isosurface extraction algorithms [Site 5].

2.3.2.2.4.2 Industrial

Although most common in medicine, Computed tomography, Microtomography and MRI are also used in other fields for acquiring a digital representation of an object and its interior, such as nondestructive materials testing, reverse engineering, or the study biological and paleontological specimens.

2.3.2.3 Non-Contact Passive Technique

Passive non-contact 3D technique does not radiate the subject with energy. Instead, passive 3D scanners rely on reflected ambient radiation. Most scanners of this type detect visible light because it is readily available.

2.3.2.4 Non-Contact Passive Scanners

Passive scanners do not emit any kind of radiation themselves, but instead rely on detecting reflected ambient radiation. Most scanners of this type detect visible light because it is a readily available ambient radiation. Other types of radiation, such as infrared could also be used. Passive methods can be very cheap, because in most cases they do not need particular hardware but simple digital cameras.

Common passive non-contact 3D scanners include stereoscopic video scanners, photometric scanners, Silhouette scanners and image-based modeling scanners. Examples of non-contact passive scanners will be presented in the following sub-sections.

2.3.2.4.1 Stereoscopic systems

They usually employ two video cameras, slightly apart, looking at the same scene. By analyzing the slight differences between the images seen by each camera, it is possible to determine the distance at each point in the images. This method is based on the same principles driving human stereoscopic vision.

2.3.2.4.2 Photometric systems

They usually use a single camera, but take multiple images under varying lighting conditions. These techniques attempt to invert the image formation model in order to recover the surface orientation at each pixel.

2.3.2.4.3 Silhouette techniques

They use outlines created from a sequence of photographs around a three-dimensional object against a well contrasted background. These silhouettes are extruded and intersected to form the visual hull approximation of the object. With these approaches some concavities of an object (like the interior of a bowl) cannot be detected.

2.3.2.5 User Assisted (Image-Based Modeling)

There are other methods that based on the user assisted detection and identification of some features and shapes on a set of different pictures of an object are able to build an approximation of the object itself. This kind of techniques is useful to build fast approximation of simple shaped objects like buildings. Various commercial packages are available like D-Sculptor, iModeller, Autodesk ImageModeler or PhotoModeler.

This sort of 3D scanning is based on the principles of photogrammetry. It is also somewhat similar in methodology to panoramic photography, except that the photos are taken of one object on a three-dimensional space in order to replicate it instead of taking a series of photos from one point in a three-dimensional space in order to replicate the surrounding environment.

2.4 MODEL RECONSTRUCTION

2.4.1 From Point Clouds

The point clouds produced by 3D scanners can be used directly for measurement and visualization in the architecture and construction world.

Most applications, however, use instead polygonal 3D models, NURBS (Non-Uniform Rational B-Splines) surface models, or editable feature-based CAD models (aka Solid models).

- *Polygon mesh models*: In a polygonal representation of a shape, a curved surface is modeled as many small faceted flat surfaces (think of a sphere modeled as a disco ball). Polygon models—also called Mesh models, are useful for visualization, for some CAM (i.e., machining), but are generally "heavy" (i.e., very large data sets), and are relatively uneditable in this form. Reconstruction to polygonal model involves finding and connecting adjacent points with straight lines in order to create a continuous surface. Many applications, both free and non free, are available for this purpose (e.g. MeshLab, kubit PointCloud for AutoCAD, JRC 3D Reconstructor, imagemodel, PolyWorks, Rapidform, Geomagic, Imageware, Rhino etc.).
- *Surface models*: The next level of sophistication in modeling involves using a quilt of *curved* surface patches to model our shape. These might be NURBS, T Splines or other curved representations of curved topology. Using NURBS, our sphere is a true mathematical sphere. Some applications offer patch layout by hand but the best in class offer both automated patch layout and manual layout. These patches have the advantage of being lighter and more manipulable when exported to CAD. Surface models are somewhat editable, but only in a sculptural sense of pushing and pulling to deform the surface. This representation lends itself well to modeling organic and artistic shapes. Providers of surface modelers include Rapidform, Geomagic, Rhino, Maya, T Splines etc.
- *Solid CAD models*: From an engineering/manufacturing perspective, the ultimate representation of a digitized shape is the editable, parametric CAD model. After all, CAD is the common "language" of industry to describe, edit and maintain the shape of the enterprise's assets. In CAD, our sphere is described by parametric features which are easily edited by changing a value (e.g., center point and radius).

  These CAD models describe not simply the envelope or shape of the object, but CAD models also embody the "design intent" (i.e., critical features and their relationship to other features). An example of design intent not evident in the shape alone might be a brake drum's lug bolts, which must be concentric with the hole in the center of the drum. This knowledge would drive the sequence and method of creating the CAD model; a designer with an awareness of this relationship would not design the lug bolts referenced to the outside diameter, but instead, to the center. A modeler creating a CAD model will want to include both Shape and design intent in the complete CAD model.

Vendors offer different approaches to getting to the parametric CAD model. Some export the NURBS surfaces and leave it to the CAD designer to complete the model in CAD (e.g., Geomagic, Imageware, Rhino). Others use the scan data to create an editable and verifiable feature based model that is imported into CAD with full feature tree intact, yielding a complete, native CAD model, capturing both shape and design intent (e.g. Geomagic, Rapidform). Still other CAD applications are robust enough to manipulate limited points or polygon models within the CAD environment (e.g., Catia).

2.4.2 From a Set of 2D Slices

CT, industrial CT, MRI, or Micro-CT scanners do not produce point clouds but a set of 2D slices (each termed a "tomogram") which are then 'stacked together' to produce a 3D representation. There are several ways to do this depending on the output required:

- Volume rendering: Different parts of an object usually have different threshold values or greyscale densities. From this, a 3-dimensional model can be constructed and displayed on screen. Multiple models can be constructed from various different thresholds, allowing different colors to represent each component of the object. Volume rendering is usually only used for visualisation of the scanned object.
- Image segmentation: Where different structures have similar threshold/greyscale values, it can become impossible to separate them simply by adjusting volume rendering parameters. The solution is called segmentation, a manual or automatic procedure that can remove the unwanted structures from the image. Image segmentation software usually allows export of the segmented structures in CAD or STL format for further manipulation.
- Image-based meshing: When using 3D image data for computational analysis (e.g. CFD and FEA), simply segmenting the data and meshing from CAD can become time consuming, and virtually intractable for the complex topologies typical of image data. The solution is called image-based meshing, an automated process of generating an accurate and realistic geometrical description of the scan data.

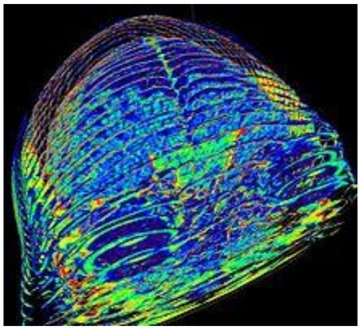


Figure 2.11: 3D reconstruction of the brain and eyeballs
from CT scanned DICOM images

In figure (2.11), areas with the density of bone or air were made transparent, and the slices stacked up in an approximate free-space alignment. The outer ring of material around the brain are the soft tissues of skin and muscle on the outside of the skull. A black box encloses the slices to provide the black background. Since these are simply 2D images stacked up, when viewed on edge the slices disappear since they have effectively zero thickness. Each DICOM scan represents about 5mm of material averaged into a thin slice

CHAPTER 3

3D LASER SCNNERS

CHAPTER 3

3D LASER SCANNERS

3.1 INTRODUCTION

There are several different kinds of 3D laser scanners, with prices ranging from the couple thousands to the hundreds of thousands. Some different kinds of 3D laser scanners will be presented in the next sections.

3.2 AIRBORNE LASER SCANNERS (ALS)

Since the early 1980's, the analytical stereocompiler has been the workhorse for broad-acre spatial data acquisition tasks including exploration mapping, regular mine planning and stockpile measurements (Byrne, 1997). It has also played a lesser role in subsidence monitoring, environmental lease statistics and infrastructure mapping.

Since 1994, a new airborne terrain modelling technology has been available to the surveying industry. The term "Airborne Laser Scanner" (ALS) evolved as the hardware utilised in the aircraft is a logical advancement of the Airborne Laser Profilers used primarily by the forestry industry for many years. Other titles attributed to the same piece of hardware include "LiDAR" (the term favoured in the United States), and "Airborne Laser Terrain Mapper (ALTM)", the brand name used by the major hardware manufacturer in this field.

Whichever term adopted, this laser technology is offering an alternative to traditional photogrammetric acquisition.

The three fundamental components of an ALS system can be summarized as follows (see figure 3.1):

1. Aircraft position is determined by kinematic dual frequency GPS, typically at 1 second epochs;
2. Aircraft orientation or attitude is continually monitored by a sensitive Inertial Reference System (IRS), typically at 50 times per second; and

3. The terrain measurement device emits a number of discrete laser beams (typically 5000 to 25000 per second), measuring the time taken for the beam to reflect from the ground back to the aircraft.

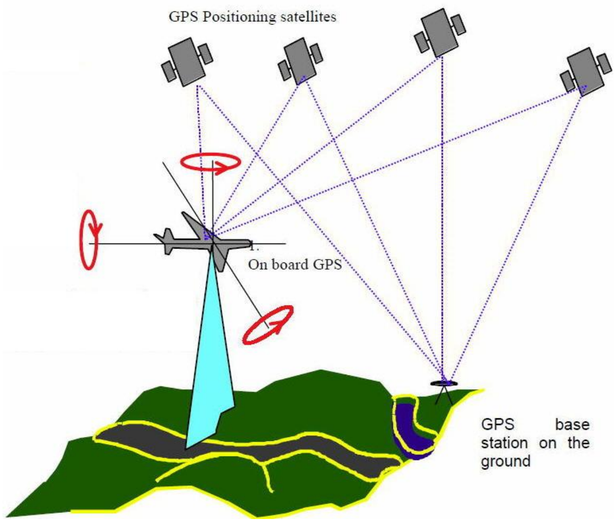


Figure 3.1: ALS system fundamental components

The laser beam is directed in a swathe across the ground by a rotating mirror. Post processing software combines the scanner's position, its attitude and the distances measured to compile a digital elevation model.

The operational parameters of laser frequency, swathe width, flying height, and aircraft velocity can be tailored to meet the optimum point density for each project. Typically, this can range from an average point spacing of 10 metres down to 1 metre or less, covering a swathe width of up to 700 metres. The scanner emits a laser of 1.04 micron wavelength which is not in the visible spectrum and is eye-safe. The scanner automatically shuts down if the system receives a return signal corresponding to a range of less than 300 metres.

At a typical operating altitude, the emitted beam is approximately 300mm in diameter at the end of the swathe. If operating over vegetation, some of the return signal is reflected from the top of the canopy, some penetrates to the canopy substrata and some penetrates to the ground. Various scanners are configured to record the distance from the first reflection it receives back ("first pulse"), from the last reflection it receives ("last pulse") or some can record multiple returns from the one emitted pulse.

An integral part of the ALS solution involves software that applies morphological filters to separate the raw ALS strikes into “ground” and “non-ground”. The software requires the operator to define the classification characteristics such as terrain angle, search distance GPS Positioning satellites GPS base station on the ground and expected deviation. It uses a recursive algorithm based on changes in slope to determine which laser strikes meet those criteria and should be called "ground” and which do not ("non-ground").

Further processing can categorise “non-ground” points into more specific datasets. These could include “pylons”, “conductors” and “vegetation” for powerline surveys; or “crowns” and “tallest trees in a cell” for forestry modelling.

Different applications of the Airborne Laser Scanners are mentioned in chapter 4.

3.3 TERRESTRIAL LASER SCANNERS (TLS)

Terrestrial Laser Scanning (TLS) uses the same principles as ALS, except that it is ground based. Locating the scanner on the ground gives some distinct advantages for capturing discrete objects from multiple angles.

These systems can measure several thousand points per second allowing data sets to be collected far in excess of that, which could be obtained by traditional surveying or photogrammetric techniques (P. Riley and P. Crowe, 2006).

TLS is most useful for capturing small (relative to those captured from an aircraft) irregular objects such as buildings, earthworks and landforms such as cliff faces which can be profiled and monitored during mining.

Terrestrial Laser Scanning is a new and efficient method for digitizing large objects and entire scenes. Since some years, several manufacturers offer different systems, which are designed and developed more or less for specific tasks (Rudolf Staiger, 2003).

Terrestrial laser scanning has already found its place between the standard technologies for objects acquisition. The laser scanner can be described as a motorized total station, which measures automatically all the points in its horizontal and vertical field. For each measured point, its distance to the laser scanner together with the horizontal and the vertical angles are recorded (Abdelhafez, 2009). So, the space coordinates relative to the scanner position can be easily computed, see figure (3.2).

This means that at one position of the laser scanner, a dense point cloud is immediately delivered. Some scanner types, like Z+F laser scanner and Leica HDS3000, can capture the entire hemisphere from one position, figure (3.2) shows the small cone under the scanner which can not be captured by a device with a 360° 310° field of view. Other scanner types, like Cyra2500, have a limited field of view (40° 60°).

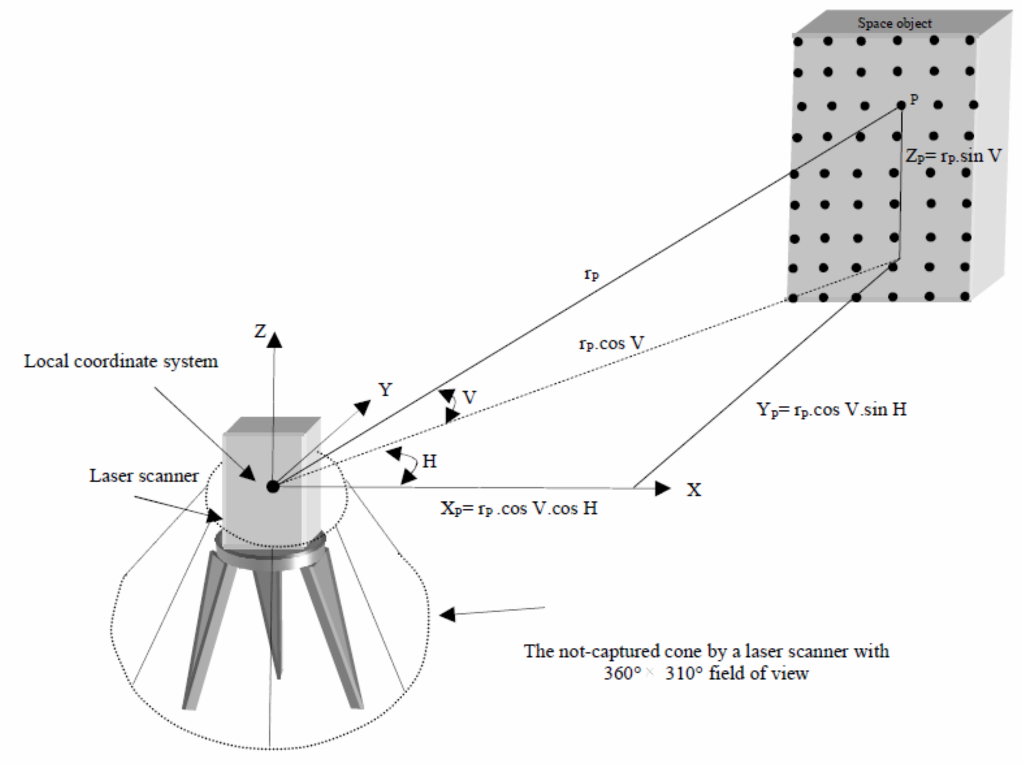


Figure 3.2: Measuring points coordinates by a laser scanner

Along with the points space coordinates, the laser scanner measures also an intensity value for each point. The intensity is defined as a measure of the electronic signal strength obtained by converting and amplifying the backscattered optical power. These measurements are commonly used to support the visual analysis of the point cloud. The intensity of the points has also a potential in more sophisticated applications such as the registration and the classification by the surface material property. An investigation of the quality of the intensity values and a possible influence on distance measurement can be reviewed in [Pfeifer et al., 2007].

3.4 HAND-HELD LASER SCANNERS

Hand-held laser scanners create a 3D image through the triangulation mechanism described in chapter 2: a laser dot or line is projected onto an object from a hand-held device and a sensor (typically a charge-coupled device or position sensitive device) measures the distance to the surface. Data is collected in relation to an internal coordinate system and therefore to collect data where the scanner is in motion the position of the scanner must be determined. The position can be determined by the scanner using reference features on the surface being scanned (typically adhesive reflective tabs) or by using an external tracking method. External tracking often takes the form of a laser tracker (to provide the sensor position) with integrated camera (to determine the orientation of the scanner) or a photogrammetric solution using 3 or more cameras providing the complete Six degrees of freedom of the scanner. Both techniques tend to use infrared Light-emitting diodes attached to the scanner which are seen by the camera(s) through filters providing resilience to ambient lighting.

Data is collected by a computer and recorded as data points within three-dimensional space, with processing this can be converted into a triangulated mesh and then a Computer-aided design (CAD) model, often as Non-uniform rational B-spline surfaces. Hand-held laser scanners can combine this data with passive, visible-light sensors—which capture surface textures and colors—to build (or "reverse engineer") a full 3D model.

3.5 ADVANTAGES AND DISADVANTAGES OF 3D LASER SCANNING

3.5.1 Advantages

3D scanners provide a fast and accurate method of digitizing real world objects. The data gathered by 3D scanners can be used for reverse engineering, part inspection, package and ergonomic design, health care, historical preservation, and rapid prototyping.

3D scanners are used to merge the arts and technology. 3D Scanners create 3D digital representations, called a polygonal mesh, of original works. 3D modeling and animation applications make it easy to make changes to the size, orientation, and shape of the polygonal mesh. The polygonal mesh can even be used for other applications such as 3D gaming, 3D special effects, 3D animation, rapid prototyping, and advanced visualization.

3D scanners are also used by designers to complement their work. The polygonal mesh derived from a 3D scanner can be used for reverse engineering, to make changes to prototypes, or even create molds and dies. Complex surface structures are easily captured as a polygonal mesh by 3D scanners. The polygonal mesh can be converted to a format native to various CAD applications. Once converted, CAD can be used to make slight adjustments to the original parts for better fitment or make even more dramatic changes such as combining a polygonal mesh with CAD objects to create personalized ergonomic parts. Simple molds can be made by subtracting the polygonal mesh from a box with a part line. The resulting CAD model can be quickly fabricated using Rapid Prototyping machines and used to pour various materials.

3D scanners have a purpose in the field of forensics. Body deformation caused by automobile accidents can be measured to determine speed at impact and help reconstruct the sequence of events leading up to the event. 3D scanners have even been used to up match up bite marks left on victims to the suspect [Site 36].

3D model scanning could benefit the design process by:

- Increase effectiveness working with complex parts and shapes.
- Help with design of products to accommodate someone else's part.
- If CAD models are outdated, a 3D scan will provide an updated version
- Replacement of missing or older parts

One of the greatest drawbacks to manual surveys is their inability to provide exhaustive survey data. For example, if an engineering firm or manufacturing company needs to identify minuscule defects in parts or objects, laser scanning can reveal the problem areas using color mapping, which shows design inaccuracies in a different color than the rest of the part or product. The defect can then be resolved by editing a solid CAD model produced from the scanning data. Another example of how laser surveying provides exhaustive data can be seen in the use of laser surveying in crime scene reconstruction to judge bullet trajectory and create crime scene animations that provide valuable information about how a crime occurred (Jimmy Drago, 2010).

Unlike manual surveying and other surveying methods, laser surveying records the physical data of an entire space, environment or object, making it impossible to accidentally omit needed data from surveys. In addition, the flawless data capture capabilities of laser surveying produces accurate results the first time around, whereas manual surveying can require numerous surveying sessions to produce worthwhile results.

If you have ever used the 2D information produced by manual surveying to make complex design decisions, then know how frustrating it can be to not have a 3D model of your subject. With laser surveying, this frustration is laid to rest. Whether the subject matter is a landscape, and interior space, a structure, a large object or a small object, laser scanning data allows you to observe your subject from multiple vantage points while using various data models.

The quick answer about the question, who can benefit from 3D scanning, is anyone in manufacturing, engineering, design, development, surveying or testing. 3D scanning technology can be applied at any point in a typical manufacturing cycle, saving time, money and material. 3D scanning results in higher quality, better fitting parts that are less costly to manufacture. The cost of a typical manufacturing design cycle is reduced by 75% by utilizing 3D scanning [Site 37]. The illustration in figure (3.3) outlines a typical manufacturing product cycle.

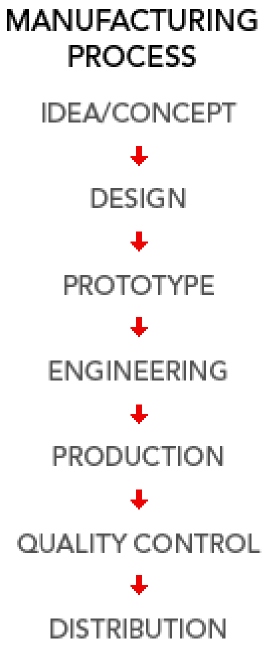


Figure 3.3: Typical manufacturing product cycle

IDEA/Concept

Use physical objects to conceptualize the idea; this is typically done by an industrial designer in clay lead design or foam lead design. 3D scanning can also be applied at the idea concept phase by digitizing objects, then using them as renderings in concept illustrations.

Design

3D scanning can be applied at the design phase by starting with a physical object and using it to design a CAD model. Oftentimes, designers need to design around or fit their design to existing objects. These mating parts can also be scanned and incorporated into the design, resulting in parts that fit better on a consistent basis. The process of using an existing manufactured part to create a CAD model is often referred to as reverse engineering or reverse modeling. By utilizing reverse engineering, new designs can incorporate and improve upon engineering optimization already inherent to the manufactured part.

Prototype

3D scanning can be applied at the prototype phase in many ways; the most common is actually to reduce the number of prototype design cycles necessary. A part designed using 3D scan data often only requires one or no prototypes since it is designed utilizing precise measurements of the physical world. 3D scanning can also be used in combination with prototyping to scale physical objects.

Engineering

By using 3D scan data, a physical object can be translated directly to the engineering phase of a project and moved on from there. 3D scan data is often used to perform CFD, CAE, FEA and other engineering analysis on objects that have been manufactured and then physically modified.

Production

3D scanning can be used to capture changes to tooling or parts that occur on the shop floor. Tooling is often "hand tuned" to achieve the final desired look and finish of a part. Using 3D scanning, hand modifications and optimizations can be transferred from tool to tool to ensure all manufactured parts match after production. 3D scanning can also be used to analyze and characterize tool wear during production, and if used correctly, to predict or eliminate tool failure. In the event of tool failure, 3D scan data can be used to recreate the optimized part.

Quality Control

3D Scanning is used to analyze the "as-built" condition of parts after they have been manufactured. Typically, non-contact technology is used to quickly inspect the overall shape and size of parts, quickly detecting issues such as part warpage or overall scale issues. Contact inspections are well suited to analyze bolt-hole locations, bores, bosses and other prismatic features. 3D scanning is used in combination with statistical analysis software to maintain and predict quality in manufacturing.

Distribution

Vision systems are commonly used in shipping and distribution centers to track and sort packages. 3D scanning is also used before and after shipping to certify product integrity during transport. 3D scanning is used in packaging as a reliable means of increasing packing density and is also used to quickly create casing and support structures.

Advantages of the 3D scanning in manufacturing:

- Quickly capture all of the physical measurements of any physical object
- Save time in design work
- Ensure parts will fit together on the first try
- Capture engineering optimizations inherent in manufactured parts
- Utilize modern manufacturing on parts that were originally manufactured before CAD
- Compare "as-designed" model to "as-built" condition of manufactured parts

3.5.2 Disadvantage

In terms of service fees, 3D laser scanning costs more than manual surveying. However, depending on the nature of the project, the cost of a manual surveying project can exceed the cost of a survey lasers project. Due to its quick, accurate data capture, laser surveying can complete a surveying project in as little as one surveying session, whereas the comparatively slow process of manual scanning can lead to significantly more billable time that negates the advantage of its slightly lower cost.

Although laser scanners produce flawless data results that can be edited and repurposed in a variety of ways using polygon mesh models, solid surface models and solid CAD models, customers must have the right computer hardware to accommodate the significant memory requirements of the data. For technical companies such as engineering firms and manufacturing companies, this typically isn't a problem. But it can pose a problem for organizations that don't use commercial grade computer hardware, such as police departments and small design firms.

CHAPTER 4

3D LASER SCANNING APPLICATIONS

CHAPTER 4

3D LASER SCANNING APPLICATIONS

4.1 INTRODUCTION

A virtual reality application may be employed to create a three dimensional virtual space from an existing architecture. The virtual reality space may then be used in computer simulations of various desired activities. Such activities could include a workflow or manufacturing line simulation. The 3D virtual space may be used for entertainment, such as animation or a movie action scene simulation, keeping even the stunt professions safe from harm.

Transportation applications, such as a accident investigation. The scene of the accident could be 3D laser digitized, and a simulation of an actual accident event or "what if" scenarios explored.

4.2 APPLICATIONS

3D laser scanning is used in a variety of fields and academic research. It has benefited clothing and product design, the automotive industry and medical science. Laser scanning can also be used to record buildings, especially in places that people may not be able to access due to safety hazards.

3D Laser Scanning is used in numerous applications: industrial, architectural, civil surveying, urban topography, mining, reverse engineering, quality, archaeology, dentistry, and mechanical dimensional inspection are just a few of the versatile applications. 3D laser scanning technology allows for high resolution and dramatically faster 3D digitizing over other conventional metrology technologies and techniques. Some very exciting applications are animation and virtual reality applications.

In the following sub-sections, some 3D laser scanning applications will be presented.

4.2.1 Material Processing and Production

Laser scanning describes the general method to sample or scan a surface using laser technology. Several areas of application exist that mainly differ in the power of the lasers that are used, and in the results of the scanning process. Low laser power is used when the scanned surface does not have to be influenced, e.g. when it only has to be digitized. Confocal or 3D laser scanning are methods to get information about the scanned surface. Another low-power application are structured light projection systems that are used for solar cell flatness metrology enabling stress calculation with throughput in excess of 2000 wafers per hour (W. J. Walecki, et al, 2008).

For high laser power, the influence on a working piece depends on the power of the laser: medium power values are used for laser engraving, where material is partially removed by the laser. With higher powers, the material becomes fluid and laser welding can be realized, or if the power is high, enough to remove the material completely, then laser cutting can be performed.

4.2.2 Construction Industry and Civil Engineering

- Robotic Control: e.g., a laser scanner may function as the "eye" of a robot (Sören Larsson and J.A.P. Kjellander, 2006) (Matthias Dorn et al, 2003).
- As-built drawings of Bridges, Industrial Plants, and Monuments
- Documentation of historical sites
- Site modeling and lay outing
- Quality control
- Quantity Surveys
- Freeway Redesign
- Establishing a benchmark of pre-existing shape/state in order to detect structural changes resulting from exposure to extreme loadings such as earthquake, vessel/truck impact, or fire.
- Create GIS (Geographic information system) maps and Geomatics.

4.2.3 Entertainment

3D scanners are used by the entertainment industry to create digital 3D models for both movies and video games. In cases where a real-world equivalent of a model exists, it is much faster to scan the real-world object than to manually create a model using 3D modeling software. Frequently, artists sculpt physical models of what they want and scan them into digital form rather than directly creating digital models on a computer.

4.2.4 Reverse Engineering

Reverse Engineering refers to the ability to reproduce the shape of an existing object. It is based on creating a digitized version of objects or surfaces, which can later be turned into molds or dies. It is a very common procedure, which has diverse applications in various industries.

Non-contact 3D laser scanning allows even malleable objects to be scanned in a matter of minutes without compression, which could change their dimensions or damage to their surfaces. Parts and models of all sizes and shapes can be quickly and accurately captured.

3D laser scanning for reverse engineering provides excellent accuracies and helps to get products to market quicker and with less development and engineering costs.

3D Laser scanning provides the fast, accurate, and automated way to acquire 3D digital data and a CAD model of part’s geometry for reverse engineering when none is available. Also, new features and updates can be integrated into old parts once the modeling is accomplished [Site 12].

A practical mechanical and civil engineering application would be to assist in the production of "as built" data and documentation. Currently, many manufacturing or construction activities are documented after the actual assembly of a machine or civil project by a designer or engineering professional. 3D laser scanners could expedite this activity to reduce man-hours required to fully document an installation for legacy.

Laser scanning can also be a excellent method to document a rebar installation for inspection requirements [Site 13].

Following are reasons for reverse engineering a part or product [Site 14]:

1. The original manufacturer of a product no longer produces a product.
2. There is inadequate documentation of the original design.
3. The original manufacturer no longer exists, but a customer needs the product.
4. The original design documentation has been lost or never existed.

5. Some bad features of a product need to be designed out. For example, excessive wear might indicate where a product should be improved.
6. To strengthen the good features of a product based on long-term usage of the product.
7. To analyze the good and bad features of competitors' product.
8. To explore new avenues to improve product performance and features.
9. To gain competitive benchmarking methods to understand competitor's products and develop better products.
10. The original CAD model is not sufficient to support modifications or current manufacturing methods.
11. The original supplier is unable or unwilling to provide additional parts.
12. The original equipment manufacturers are either unwilling or unable to supply replacement parts, or demand inflated costs for sole-source parts.
13. To update obsolete materials or antiquated manufacturing processes with more current, less-expensive technologies.

4.2.5 Mechanical Applications

Reverse engineering of a mechanical component requires a precise digital model of the objects to be reproduced. Rather than a set of points a precise digital model can be represented by a polygon mesh, a set of flat or curved NURBS surfaces, or ideally for mechanical components, a CAD solid model. A 3D scanner can be used to digitize free-form or gradually changing shaped components as well as prismatic geometries whereas a coordinate measuring machine is usually used only to determine simple dimensions of a highly prismatic model. These data points are then processed to create a usable digital model, usually using specialized reverse engineering software.

4.2.6 Civil Applications

Civil activities could be for a roadway periodic inspection. The digitized roadway data could be contrasted to previous roadway 3D scans to predict rate of deterioration. This data could be very helpful in estimating roadway repair or replacement costing information.

When personnel accessibility and/or safety concerns prevent a standard survey, 3D laser scanning could provide an excellent alternative. 3D Laser scanning has been used to perform accurate and efficient as-built surveys and before-and after construction and leveling surveys.

4.2.7 Cultural Heritage

For most endangered heritage sites, the first tool required for preservation and restoration is a reliable, accurate site survey. Terrestrial LiDAR technologies provide 3D survey data that is more accurate and more economically produced than information from surveys using traditional techniques. 3D laser scan data can easily be converted to CAD and other imaging programs for conservation, management, and restoration works as well as virtual tourism, education, and information dissemination.

Laser scanning technologies are the latest development in survey documentation and recording. They employ laser beams that scan a subject, creating a cloud of accurately measured points in a matter of seconds. This raw set of data, known as a "point cloud," contains millions of measurements, accurate to millimeters or fractions of a millimeter, with each point precisely referenced with x, y, z coordinates relative to all other point locations. The point cloud can be viewed immediately upon scanning, providing the immediate visualization of the data as a 3D image. By mapping the points, an accurate 3D model can be created. Traditional methods such as tapes, theodolites, and more modern technology such as total stations and GPS provide relatively slow and cumbersome methods for gathering spatial data. 3D laser scanning can thus be distinguished from traditional survey by the rate at which the physical world is sampled, resulting in high definition data and, correspondingly, very large datasets.

3D laser scanning technologies can be employed to document and record a large variety and scale of objects, structures, buildings, and topographies; literally from a small exquisitely detailed sculpture to a large geo-referenced landscape. Commercially, laser scanning has been found to be very effective in the documentation of structures such as oil and chemical refineries, highways, bridges and other complex structures, producing accurate "as-built" measured drawings in very little time and with very little expense compared to traditional methods. Today, 3D scanning is growing within the Heritage field as an acceptable standard for site documentation. Immediately upon scanning, the point cloud can be used directly to visualize the subject and to accurately access measurements. In addition, the point cloud data can be processed through various software applications to create a variety of deliverables such as CAD document measured drawings, contour maps, 3D models, and animations.

There have been many research projects undertaken via the scanning of historical sites and artifacts both for documentation and analysis purposes. The following sub-sections give some examples of the application of the 3D laser scanners in the field of cultural hiritage.

4.2.7.1 Gargoyle models

The combined use of 3D scanning and 3D printing technologies allows the replication of real objects without the use of traditional plaster casting techniques, that in many cases can be too invasive for being performed on precious or delicate cultural heritage artifacts (Paolo Cignoni, Roberto Scopigno, 2008). In figure (4.1), the gargoyle model on the left was digitally acquired by using a 3D scanner and the produced 3D data was processed using MeshLab software. The obtained digital 3D model was used by a rapid prototyping machine to create a real resin replica of original object as shown on the right of figure (4.1).

Figure 4.1: An example of real object replication by
Means of 3D scanning and 3D printing

4.2.7.2 Michelangelo

1. In 1999, two different research groups started scanning Michelangelo's statues. Stanford University with a group led by Marc Levoy (Marc Levoy, et al, 2000) used a custom laser triangulation scanner built by Cyberware to scan Michelangelo's statues in Florence, notably the David, the Prigioni and the four statues in The Medici Chapel. The scans

produced a data point density of one sample per 0.25 mm, detailed enough to see Michelangelo's chisel marks. These detailed scans produced a huge amount of data (up to 32 gigabytes) and processing the data from his scans took 5 months. Approximately, in the same period a research group from IBM, led by H. Rushmeier and F. Bernardini scanned the Pietà of Florenceacquiring both geometric and color details. The digital model, result of the Stanford scanning campaign, was thoroughly used in the 2004 subsequent restoration of the statue (Roberto Scopigno, 2004). Figue (4.2) shows a photo of the Michelangelo’s David and the rendring made from the model.

Figure 4.2: On the left is a photograph of Michelangelo’s David.

On the right is a rendering made from the model.

4.2.7.3 Monticello

In 2002, David Luebke, et al. scanned Thomas Jefferson's Monticello. A commercial time of flight laser scanner, the DeltaSphere 3000 was used. The scanner data was later combined with color data from digital photographs to create the Virtual Monticello, and the Jefferson's Cabinet exhibits in the New Orleans Museum of Art in 2003. The Virtual Monticello exhibit simulated a window looking into Jefferson's Library. The exhibit consisted of a rear projection display on a wall and a pair of stereo glasses for the viewer. The glasses, combined with polarized projectors, provided a 3D effect. Position tracking hardware on the glasses allowed the display to adapt as the viewer moves around, creating the illusion that the display is actually a hole in the wall looking into Jefferson's Library. The Jefferson's Cabinet exhibit was a barrier stereogram (essentially a non-active hologram that appears different from different angles) of Jefferson's Cabinet. Figure (4.3) shows a panoramic view of laser-return intensities.

Figure 4.3: A panoramic view of laser-return intensities (roughly 19.5 million points)

4.2.7.4 Cuneiform Tablets

In 2003, Subodh Kumar, et al. undertook the 3D scanning of ancient cuneiform tablets. Again, a laser triangulation scanner was used. The tablets were scanned on a regular grid pattern at a resolution of 0.025 mm (0.00098 in). Figure (4.4) shows 3D scan of the Obverse and Right Side of a "micro-tablet" in the Johns Hopkins Archaeological Collection.

Figure 4.4: 3D Scan of the Obverse and Right Side of a
"micro-tablet" in the Johns Hopkins Archaeological Collection

4.2.7.5 Kasubi Tombs

A 2009 CyArk 3D scanning project at Uganda's historic Kasubi Tombs, a UNESCO World Heritage Site, using a Leica HDS 4500, produced detailed architectural models of Muzibu Azaala Mpanga, the main building at the complex and tomb of the Kabakas (Kings) of Uganda. A fire on March 16, 2010, burned down much of the Muzibu Azaala Mpanga structure, and reconstruction work is likely to lean heavily upon the dataset produced by the 3D scan mission (Scott Cedarleaf, 2010).

Figure 4.5 shows an atop laser scan data from a project held in early 2009 at Uganda's Kasubi Tombs, which were destroyed by fire in early 2010; the data is slated for use in the building's reconstruction

Figue 4.5: Lasers scan data of Uganda's Kasubi Tombs

4.2.7.6 Plastico di Roma Antica

In 2005, Gabriele Guidi, et al. scanned the "Plastico di Roma antica", a model of Rome created in the last century. Neither the triangulation method, nor the time of flight method satisfied the requirements of this project because the item to be scanned was both large and contained small details. They found though, that a modulated light scanner was able to provide both the ability to scan an object the size of the model and the accuracy that was needed. The modulated light scanner was supplemented by a triangulation scanner which was used to scan some parts of the model. Figure (4.6) shows preliminary models, oriented as seen from scanner diferent positions. Some of the most famous Roman monuments, such as the Colisseum and the Circus Maximus are clearly seen.

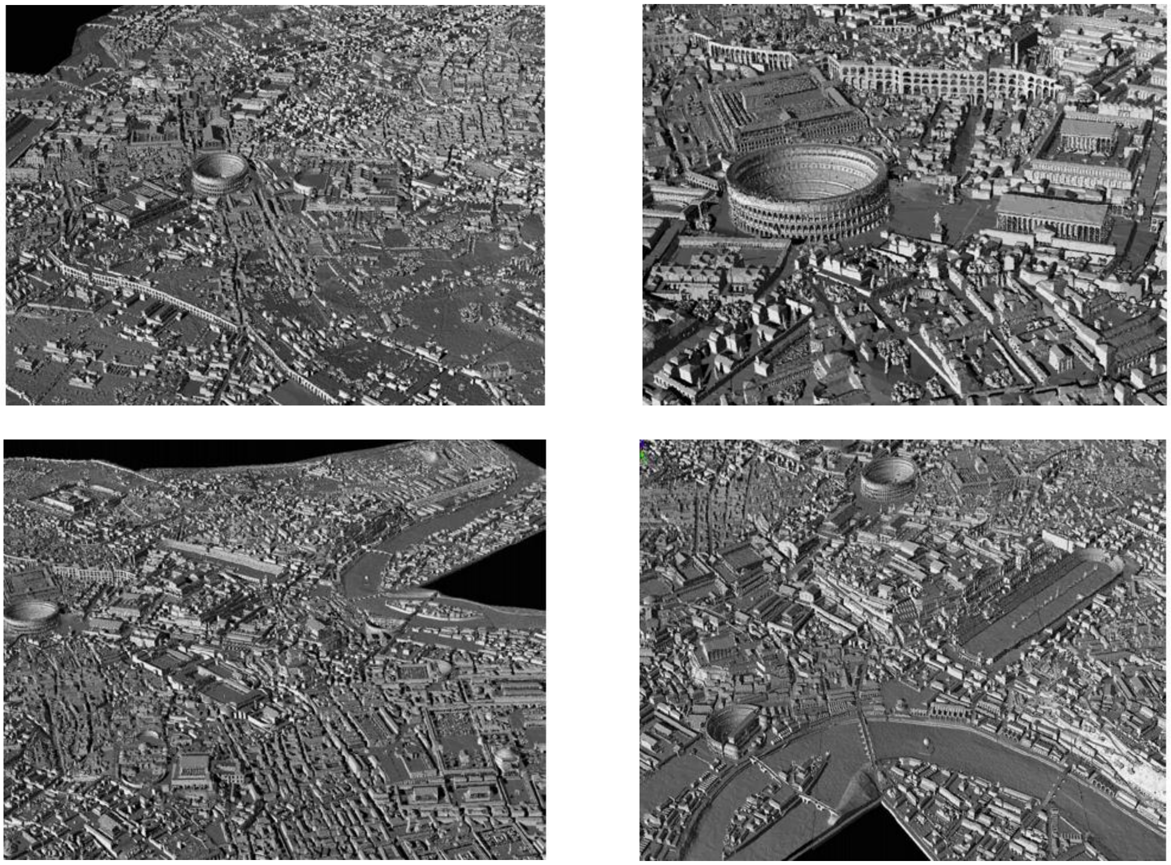


Figure 4.6 Preliminary models, oriented as seen by different scanner position

4.2.8 Medical CAD/CAM

3D scanners are used in order to capture the 3D shape of a patient in orthotics and dentistry [Site 10]. It gradually supplants tedious plaster cast. CAD/CAM (**C**omputer-**A**ided **D**esign/ **C**omputer-**A**ided **M**anufacturing) software are then used to design and manufacture the orthosis, prosthesis or dental implants.

Many Chairside dental CAD/CAM systems and Dental Laboratory CAD/CAM systems use 3D Scanner technologies to capture the 3D surface of a dental preparation (either *in vivo* or *in vitro*), in order to produce a restoration digitally using CAD software, and ultimately produce the final restoration using a CAM technology (such as a CNC milling machine, or 3D printer). The chairside systems are designed to facilitate the 3D scanning of a preparation *in vivo* and produce the restoration (such as a Crown, Onlay, Inlay or Veneer) [Site 4].

4.2.9 Quality Assurance and Industrial Metrology

The digitalization of real-world objects is of vital importance in various application domains. This method is especially applied in industrial quality assurance to measure the geometric dimension accuracy. Industrial processes such as assembly are complex, highly automated, and typically based on CAD data. The problem is that the same degree of automation is also required for quality assurance. For example, it is a very complex task to assemble a modern car since it consists of many parts that must fit together at the very end of the production line. The optimal performance of this process is guaranteed by quality assurance systems. Especially the geometry of the metal parts must be checked in order to assure that they have the correct dimensions, fit together, and finally work reliably.

Within highly automated processes, the resulting geometric measures are transferred to machines that manufacture the desired objects. Due to mechanical uncertainties and abrasions, the result may differ from its digital nominal. In order to automatically capture and evaluate these deviations, the manufactured part must be digitized as well. For this purpose, 3D scanners are applied to generate point samples from the object's surface, which are finally compared against the nominal data (Christian Teutsch, 2007).

The process of comparing 3D data against a CAD model is referred to as CAD-Compare, and can be a useful technique for applications such as determining wear patterns on molds and tooling, determining accuracy of final build, analyzing gap and flush, or analyzing highly complex sculpted surfaces. At present, laser triangulation scanners, structured light, and contact scanning are the predominant technologies employed for industrial purposes, with contact scanning remaining the slowest, but overall most accurate option.

4.3 3D LASER SCANNING ACCURACY

4.3.1 INTRODUCTION

Surveying results must meet certain specifications in order to provide the necessary accuracy standards for a certain application. On the other hand, if instruments and methods are used which yield accuracy far above the needed standard, this will result in unnecessary cost and expenditure. Therefore, any geometric surveying task comprises not only the derivation of the relative positions of points and objects but also an estimation of the accuracy of the results. Least squares adjustment based on over determination usually yields a reliable information concerning the accuracy of the results as well as the accuracy of the observations. If the number of observations is not sufficient for an adjustment, one may estimate the accuracy of the results by propagating the errors of the observation instruments to the results. In this case, the accuracy of the measurement device has to be known.

In the case of laser scanners, a large number of 3D coordinates on an object’s surfaces measured in a very short time. Important object features, such as corner points or edges, are not directly recorded; instead, they have to be modeled from the point clouds in a separate process. While it is possible to record the same object several times from different observation points, it is impossible to record the very same points in these repeated surveys. Therefore, deviations can only be noticed after objects have been extracted from the point clouds and modeled. If the geometric properties of the object are known, however, the deviation of single points from the object’s surface may be an indication for the accuracy. Using a plane surface would be the simplest case, but cylinders or spheres can also be considered.

4.3.2 General Remarks

The accuracy specifications given by laser scanner producers in their publications and pamphlets are not comparable. Experience shows that sometimes these should not be trusted and that the accuracy of these instruments, which are built in small series, varies from instrument to instrument and depends on the individual calibration and the care that has been taken in handling the instrument since every point cloud produced by a laser scanner contains a considerable number of points that show gross errors. If the point cloud is delivered as a result of surveying, a quality guarantee, as possible for other surveying instruments, methods, and results, cannot be given. Many institutions have already published methods and results concerning accuracy tests with laser scanners (e.g. Balzani et. al. 2001, Johansson 2002, Kern 2003, Lichti et. al. 2000, 2002).

4.3.3 Angular Accuracy

The laser pulse is deflected by a small rotating device (mirror, prism) and sent from there to the object. The second angle, perpendicular to the first, may be changed using a mechanical axis or another rotating optical device. The readings for these angles are used for the computation of the 3D point coordinates. Any deviations will result in errors perpendicular to the propagation path. Since the positions of single points are hard to be verified, few investigations of this problem are known. Errors can be detected by measuring short horizontal and vertical distances between objects (e.g. spheres) which are located at the same distance from the scanner and comparing those to measurements derived from more accurate surveying methods (Boehler W., et al., 2003).

4.3.4 Range Accuracy

In the case of ranging scanners, range is computed using the time of flight or a phase comparison between the outgoing and the returning signal. Ranging scanners for distances up to 100 m show about the same range accuracy for any range. Triangulation scanners solve the range determination in a triangle formed by the instrument's laser signal deflector, the reflection point on the object's surface and the projection center of a camera, mounted at a certain distance from the deflector. The camera is used to determine the direction of the returning signal. In contrast to the ranging scanners, the accuracy of ranges acquired with triangulation scanners diminishes with the square of the distance between scanner and object (Boehler, Marbs, 2002). Ranging errors can be observed when known distances in range direction are measured with the scanner. If scanners are not equipped with a defined reference point (such as forced centering), it is only possible to measure range *differences* between targets. Plane, cylindrical or spherical targets may be used if their precise positions are surveyed with instruments and methods more accurate than the laser scanner. Whereas a systematic scale error will be present in any spatial distance measured, a systematic constant (zero) error will be eliminated when distance differences in range direction are determined. The constant error will influence distances between two points which are located in different directions as seen from the scanner, however. If both points are located in the same distance from the scanner, the deviation of their distance will amount to the zero error when the direction difference is 60°; it will amount to twice the zero error when the direction difference is 180° (e.g. when scanning all walls with a panoramic scanner from one single observation point in the center of a room). A very fast and easy check for the noise (accidental error) of range measurements can be achieved when a plane target perpendicular to the observation direction is scanned and the standard deviation of the range differences of the points from an intermediate plane through the point cloud is computed. As an additional result, this test also detects if range is internally only provided with a certain resolution (e.g. 1 cm) which is the case for some instruments (Kern, 2003).

4.3.5 Resolution

The term “resolution” is used in different context when the performance of laser scanners is discussed. From a user’s point of view, resolution describes the ability to detect small objects or object parts in the point cloud. Technically, two different laser scanner specifications contribute to this ability, the smallest possible increment of the angle between two successive points and the size of the laser spot itself on the object. Most scanners allow manual settings of the increment by the user. Since the combined effects of increments and spot size determine object resolution, a test object comprising small elements or small slots in front of a plane can serve to determine application related resolution information.

4.3.6 Edge Effects

Even when well focused, the laser spot on the object will have a certain size. When the spot hits an object edge, only a part of it will be reflected there. The rest may be reflected from the adjacent surface, a different surface behind the edge, or not at all (when no further object is present within the possible range of the scanner). Both, ranging scanners and triangulation scanners produce a variety of wrong points in the vicinity of edges. The wrong points are usually to be found on the ray from the laser deflection point to the edge point, behind the edges (when looking from the scanner). The range error may vary from just a millimeter to values of several decimeters. Obviously, wrong points are inevitable since the laser “spot” cannot be focused to point size. It can be assumed that well focused lasers will show better results. When using a standard target with different types of edges, the performance of different types of scanners can be compared. A systematic effect can be observed when cylindrical and spherical targets are observed from a close distance (Lichti et. al. 2002). In this case, at the peripheral parts of the object, the center of the reflecting surface area is not identical with the center of the transmitted spot.

4.3.7 Influence of Surface Reflectivity

Laser scanners have to rely on a signal reflected back from the object surface to the receiving unit in case of ranging scanners and to the camera in case of triangulation scanners. In either case, the strength of the returning signal is influenced (among other facts such as distance, atmospheric conditions, incidence angle) by the reflective abilities of the surface (albedo). White surfaces will yield strong reflections whereas reflection is weak from black surfaces. The effects of colored surfaces depend on the spectral characteristics of the laser (green, red, near infrared). Shiny surfaces usually are not easy to record. It has been observed that surfaces of different reflectivity result in systematic errors in range. For some materials these errors may reach amounts several times larger than the standard deviation of a single range measurement. Some scanners which provide some type of aperture adjustment show errors in the first points after the laser spot has reached an area of a reflectivity differing considerably from the previous area, and it can be observed that the correct range is achieved only after a few points have been measured. For objects consisting of different materials or differently painted or coated surfaces, one has always to expect serious errors. These can only be avoided if the object is temporarily coated with a unique material which, of course, is not applicable in most cases. If the effect has to be examined and evaluated, one may use plane white targets and apply the material in question to the center part of the target. When the intermediate planes are computed for the coated center part only and then for the rest of the (white) target without using the center part, the difference between those planes will give an indication of this effect.

4.3.8 Environmental Conditions

4.3.8.1 Temperature

Any scanner will only function properly when used in a certain temperature range. Even within this range, deviations may be observed, however, especially in the distance measurement. It should be noted that the temperature inside the scanner may be far above the temperature of the surrounding atmosphere due to internal heating or heating resulting from external radiation (sun).

4.3.8.2 Atmosphere

Since short distances only are measured, the change of the propagation speed of light due to temperature and pressure variations will not seriously affect the results. Many users report however that measurements in surroundings where dust or steam is present lead to effects similar to the edge effects described above.

4.3.8.3 Interfering radiation

Lasers operate in a very limited frequency band. Therefore filters can be applied in the receiving unit allowing only this frequency to reach the receiver resp. the camera. If the radiation of the illumination source (sunlight, lamps) is strong as compared to the signal, enough of this ambient radiation will pass the filter and influence the accuracy or prevent any measurements at all.

4.3.9 Specifications and Considerations besides Accuracy

This article concentrates on accuracy considerations. Of course, other scanner specifications influence their applicability as well (Boehler, Marbs, 2002). Among these are measuring speed, range limits, field of view, laser class, registration devices for the combination of several scans and the transformation to a control network, the availability of imaging cameras which can work in combination with the scanner, weight and ease of transportation, power supply (battery operation), ruggedness when operated in bad weather or hostile environments, availability and quality of software. Besides, the quality of the user support and the guarantee conditions are not the same for all producers. These should be checked carefully in addition to the technical specifications before a decision is made to favor one product or another.

CHAPTER 5

LIGH DETECTION AND RANGING (LiDAR)

CHAPTER 5

LIGHT DETECTION AND RANGING SYSTEM (LiDAR)

5.1 INTRODUCTION

Light Detection And Ranging (LiDAR) is an optical remote sensing technology that can measure the distance to, or other properties of a target by illuminating the target with light, often using pulses from a laser.

LiDAR technology has application in geomatics, archaeology, geography, geomorphology, seismology, forestry, remote sensing and tmospheric physics (Cracknell, et al, 2007), as well as in airborne laser swath mapping (ALSM), laser altimetry and LiDAR Contour Mapping.

LiDAR uses the same principle as RADAR. Just transmiting a beam of light to a target (the ground) and measuring the time it takes for the beam to echo back and calculating Range from the result. LiDAR differs from RADAR mainly in its ability to resolve very small targets and penetrate vegetation.

The acronym LADAR (Laser Detection And Ranging) is often used in military contexts. The term "laser radar" is sometimes used even though LiDAR does not employ microwaves or radio waves and is not therefore radar even though both systems employ electromagnetic radiation.

5.2 LiDAR HISTORY

LiDAR acronym first appeared in 1953, long before the invention of lasers. The first LiDAR was used as light sources, conventional or pulsed lamps with high-speed shutter, formed short pulse. In 1963, the United States have begun field tests of portable laser rangefinder XM-23 with a radiated power of 2.5 W and a range of measurable distances 200-9995 m. XM-23 was originally unclassified sample and became the basic instrument for civilian investigators 1960. Civilian use of laser range finders has been restricted to the high cost of integrated circuits at the time. Then, in the first half of 1960, began experiments on the use of LiDAR with a laser emitter for atmospheric studies. In 1969, a laser rangefinder and a target mounted on the Apollo-11, the space craft, used to measure the distance from Earth to the Moon. During the 1970's, on the one hand, debug technology of laser range finders and compact semiconductor lasers, on the other - began investigating the scattering of the laser beam in the atmosphere. By early 1980, these studies have become so well known in academic circles that the acronym LiDAR has become a household name - LiDAR, which recorded the Webster Dictionary, 1985. In those same years, laser range finders have reached the stage of mature technologies (at least in military applications) and have been separated from LiDAR technology industry [Site 33].

5.3 GENERAL DESCRIPTION

LiDAR uses ultraviolet, visible, or near infrared light to image objects and can be used with a wide range of targets, including non-metallic objects, rocks, rain, chemical ompounds, aerosols, clouds, and even single molecules (Cracknell, et al, 2007). A narrow laser beam can be used to map physical features with very high resolution.

LiDAR has been used extensively for atmospheric research and meteorology. Downward-looking LiDAR instruments fitted to aircraft and satellites are used for surveying and mapping – a recent example being the NASA Experimental Advanced Research LiDAR [Site 15].In addition LiDAR has been identified by NASA as a key technology for enabling autonomous precision safe landing of future robotic and crewed lunar landing vehicles (Amzajerdian, et al, 2011).

Wavelengths in a range from about 10 micrometers to the UV (ca. 250 nm) are used to suit the target. Typically, light is reflected via backscattering. Based on different kinds of backscattering, the LiDAR can be accordingly called Rayleigh LiDAR, Mie LiDAR, Raman LiDAR and Na/Fe/K Fluorescence LiDAR and so on (Cracknell, et al, 2007). Suitable combinations of wavelengths can allow for remote mapping of atmospheric contents by looking for wavelength dependent changes in the intensity of the returned signal.

5.4 DESIGN

A basic LiDAR system involves a laser range finder reflected by a rotating mirror (top) (see figure 4.1). The laser is scanned around the scene being digitised, in one or two dimensions (middle), gathering distance measurements at specified angle intervals (bottom).

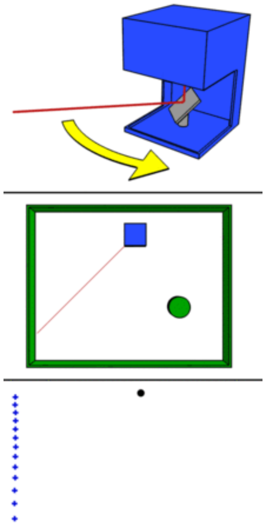


Figure 4.1 Basic LiDAR design concept components

In general, there are two kinds of LiDAR detection schema: "incoherent" or direct energy detection (which is principally an amplitude measurement) and Coherent detection (which is best for Doppler, or phase sensitive measurements). Coherent systems generally use Optical heterodyne detection which being more sensitive than direct detection allows them to operate a much lower power but at the expense of more complex transceiver requirements [Site 16].

In both coherent and incoherent LiDAR, there are two types of pulse models: *micropulse LiDAR* systems and *high-energy* systems. Micropulse systems have developed as a result of the ever increasing amount of computer power available combined with advances in laser technology. They use considerably less energy in the laser, typically about one microjoule, and are often "eye-safe," meaning they can be used without safety precautions. High-power systems are common in atmospheric research, where they are widely used for measuring many atmospheric parameters: the height, layering and densities of clouds, cloud particle properties (extinction coefficient, backscatter coefficient, depolarization), temperature, pressure, wind, humidity, trace gas concentration (ozone, methane, nitrous oxide, etc.) (Cracknell, et al, 2007).

There are several major components to a LiDAR system:

1. **Laser** — 600–1000 nm lasers are most common for non-scientific applications. They are inexpensive, but since they can be focused and easily absorbed by the eye, the maximum power is limited by the need to make them eye-safe. Eye-safety is often a requirement for most applications. A common alternative, 1550 nm lasers, are eye-safe at much higher power levels since this wavelength is not focused by the eye, but the detector technology is less advanced and so these wavelengths are generally used at longer ranges and lower accuracies. They are also used for military applications, as 1550 nm is not visible in night vision goggles, unlike the shorter 1000 nm infrared laser. Airborne topographic mapping LiDARs generally use 1064 nm diode pumped YAG lasers, while bathymetric systems generally use 532 nm frequency doubled diode pumped YAG lasers because 532 nm penetrates water with much less attenuation than does 1064 nm. Laser settings include the laser repetition rate (which controls the data collection speed). Pulse length is generally an attribute of the laser cavity length, the number of passes required through the gain material (YAG, YLF, etc.), and Q-switch speed. Better target resolution is achieved with shorter pulses, provided the LiDAR receiver detectors and electronics have sufficient bandwidth (Cracknell, et al, 2007).
2. **Scanner and optics** — How fast images can be developed is also affected by the speed at which they are scanned. There are several options to scan the azimuth and elevation, including dual oscillating plane mirrors, a combination with a polygon mirror, a dual axis scanner. Optic choices affect the angular resolution and range that can be detected. A hole mirror or a beam splitter are options to collect a return signal.
3. **Photodetector and receiver electronics** — Two main photodetector technologies are used in LiDARs: solid state photodetectors, such as silicon avalanche photodiodes, or photomultipliers. The sensitivity of the receiver is another parameter that has to be balanced in a LiDAR design.
4. **Position and navigation systems** — LiDAR sensors that are mounted on mobile platforms such as airplanes or satellites require instrumentation to determine the absolute

position and orientation of the sensor. Such devices generally include a Global Positioning System (GPS) receiver and an Inertial Measurement Unit (IMU).

3D imaging can be achieved using both scanning and non-scanning systems. "3D gated viewing laser radar" is a non-scanning laser ranging system that applies a pulsed laser and a fast gated camera.

Imaging LiDAR can also be performed using arrays of high speed detectors and modulation sensitive detectors arrays typically built on single chips using CMOS and hybrid CMOS/CCD fabrication techniques. In these devices, each pixel performs some local processing such as demodulation or gating at high speed down converting the signals to video rate so that the array may be read like a camera. Using this technique many thousands of pixels / channels may be acquired simultaneously. In practical systems the limitation is light budget rather than parallel acquisition [Site 17]. High resolution 3D LiDAR cameras use homodyne detection with an electronic CCD or CMOS shutter (Medina A, Gayá F, and Pozo F, 2006).

A coherent Imaging LIDAR uses Synthetic array heterodyne detection to enables a staring single element receiver to act as though it were an imaging array (Strauss C. E. M., 1994) avoiding the need for a gated camera and all ranges from all pixels are simultaneously available in the image [Site 18].

There are ongoing military research programmes in Sweden, Denmark, the USA and the UK with 3D gated viewing imaging at several kilometers range with a range resolution and accuracy better than ten centimeters [Site 19].

5.5 APPLICATION

Other than those applications listed above, there are a wide variety of applications of LiDAR, as often mentioned in National LiDAR Dataset programs.

5.5.1 Agriculture

LiDAR also can be used to help farmers determine which areas of their fields to apply costly fertilizer. LiDAR can create a topological map of the fields and reveals the slopes and sun exposure of the farmland. Researchers at the Agricultural Research Service (ARS) blended this topological information with the farmland's yield results from previous years. From this information, researchers categorized the farmland into high-, medium-, or low-yield zones (Don Comis, 2010). This technology is valuable to farmers because it indicates which areas to apply the expensive fertilizers to achieve the highest crop yield (see figure 4.2).

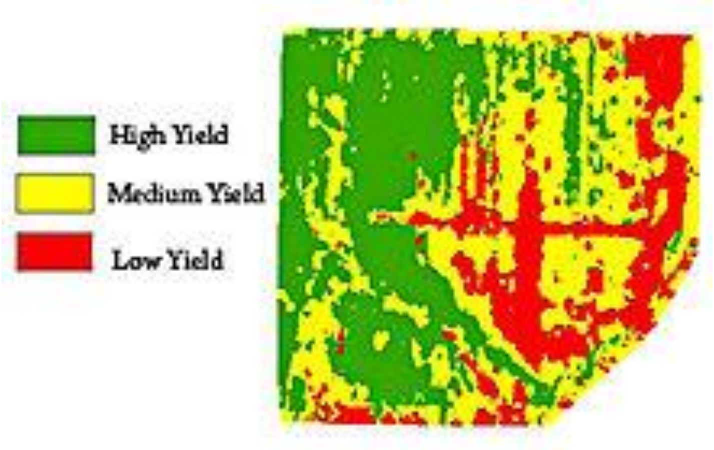


Figure 4.2: Agricultural Research Service scientists' farmland category

5.5.2 Archaeology

LiDAR has many applications in the field of archaeology including aiding in the planning of field campaigns, mapping features beneath forest canopy [Site 20], and providing an overview of broad, continuous features that may be indistinguishable on the ground. LiDAR can also provide archaeologists with the ability to create high-resolution digital elevation models (DEMs) of archaeological sites that can reveal micro-topography that are otherwise hidden by vegetation. LiDAR-derived products can be easily integrated into a Geographic Information System (GIS) for analysis and interpretation. For example at Fort Beausejour - Fort Cumberland National Historic Site, Canada, previously undiscovered archaeological features have been mapped that are related to the siege of the Fort in 1755. Features that could not be distinguished on the ground or through aerial photography were identified by overlaying hillshades of the DEM created with artificial illumination from various angles. With LiDAR the ability to produce high-resolution datasets quickly and relatively cheaply can be an advantage. Beyond efficiency, its ability to penetrate forest canopy has led to the discovery of features that were not distinguishable through traditional geo-spatial methods and are difficult to reach through field surveys (John Nobel Wilford, 2010). Figure (4.3) shows an example of forst canopy on an archaeolgical site.

Figure 4.3:"CITY LIVING" a plaza in Caracol, a Maya city in Belize. Jungles surrounding it were penetrated using a new method, lidar.

5.5.3 Biology and Conservation

LiDAR has also found many applications in forestry. Canopy heights, biomass measurements, and leaf area can all be studied using airborne LiDAR systems. Similarly, LiDAR is also used by many industries, including Energy and Railroad, and the Department of Transportation as a faster way of surveying. Topographic maps can also be generated readily from LiDAR, including for recreational use such as in the production of orienteering maps [Site 21].

In addition, the Save-the-Redwoods League is undertaking a project to map the tall redwoods on California's northern coast. LiDAR allows research scientists to not only measure the height of previously unmapped trees, but also to determine the biodiversity of the redwood forest.

5.5.4 Geology and Soil Science

High-resolution digital elevation maps generated by airborne and stationary LiDAR have led to significant advances in geomorphology, the branch of geoscience concerned with the origin and evolution of Earth's surface topography. LiDAR's abilities to detect subtle topographic features such as river terraces and river channel banks, measure the land surface elevation beneath the vegetation canopy, better resolve spatial derivatives of elevation, and detect elevation changes between repeat surveys have enabled many novel studies of the physical and chemical processes that shape landscapes. In addition to LiDAR data collected by private companies, academic consortia have been created to support the collection, processing and archiving of research-grade, publicly available LiDAR datasets. The National Center for Airborne Laser Mapping (NCALM), supported by the National Science Foundation, collects and distributes LiDAR data in support of scientific research and education in a variety of fields, particularly geoscience and ecology [Site 22].

In geophysics and tectonics, a combination of aircraft-based LiDAR and GPS has evolved into an important tool for detecting faults and measuring uplift. The output of the two technologies can produce extremely accurate elevation models for terrain that can even measure ground elevation through trees. This combination was used most famously to find the location of the Seattle Fault in Washington, USA (Tom Paulson, 2001). This combination is also being used to measure uplift at Mt. St. Helens by using data from before and after the 2004 uplift [Site 23].

Airborne LiDAR systems monitor glaciers and have the ability to detect subtle amounts of growth or decline. A satellite-based system is NASA's ICESat , which includes a LiDAR system for this purpose. NASA's Airborne Topographic Mapper is also used extensively to monitor glaciers and perform coastal change analysis [Site 24] . The combination is also used by soil scientists while creating a soil survey. The detailed terrain modeling allows soil scientists to see slope changes and landform breaks, which indicate patterns in soil spatial relationships.

5.5.5 Meteorology and Atmospheric Environment

The first LiDAR systems were used for studies of atmospheric composition, structure, clouds, and aerosols. Initially based on ruby lasers, LiDAR for meteorological applications was constructed shortly after the invention of the laser and represent one of the first applications of laser technology.

- **Elastic backscatter LiDAR** is the simplest type of LiDAR and is typically used for studies of aerosols and clouds. The backscattered wavelength is identical to the transmitted wavelength, and the magnitude of the received signal at a given range depends on the backscatter coefficient of scatterers at that range and the extinction coefficients of the scatterers along the path to that range. The extinction coefficient is typically the quantity of interest [Site 25].

- **Differential Absorption LiDAR (DiAL)** is used for range-resolved measurements of a particular gas in the atmosphere, such as ozone, carbon dioxide, or water vapor. The LiDAR transmits two wavelengths: an "on-line" wavelength that is absorbed by the gas of interest and an off-line wavelength that is not absorbed. The differential absorption between the two wavelengths is a measure of the concentration of the gas as a function of range. DiAL LiDARs are essentially dual-wavelength backscatter LiDARs.

- **Raman LiDAR** is also used for measuring the concentration of atmospheric gases, but can also be used to retrieve aerosol parameters as well. Raman LiDAR exploits inelastic scattering to single out the gas of interest from all other atmospheric constituents. A small portion of the energy of the transmitted light is deposited in the gas during the scattering process, which shifts the scattered light to a longer wavelength by an amount that is unique to the species of interest. The higher the concentration of the gas, the stronger the magnitude of the backscattered signal (IVATF, 2011).
- **Doppler LiDAR and Rayleigh Doppler LiDAR** are used to measure temperature and/or wind speed along the beam by measuring the frequency of the backscattered light. The Doppler broadening of gases in motion allows the determination of properties via the resulting frequency shift (Xinzhao Chu, 2011) (Li, T. et al., 2011). Scanning LiDARs, such as NASA's HARLIE LiDAR, have been used to measure atmospheric wind velocity in a large three-dimensional cone (Thomas D. Wilkerson, 2002). ESA's wind mission ADM-Aeolus will be equipped with a Doppler LiDAR system in order to provide global measurements of vertical wind profiles [Site 26]. A Doppler LiDAR system was used in the 2008 Summer Olympics to measure wind fields during the yacht competition (Jacqueline Hewett, 2008). Doppler LiDAR systems are also now beginning to be successfully applied in the renewable energy sector to acquire wind speed, turbulence, wind veer, and wind shear data. Both pulsed and continuous wave systems are being used. Pulsed systems using signal timing to obtain vertical distance resolution, whereas continuous wave systems rely on detector focusing.

- **Synthetic Array LiDAR** allows imaging LiDAR without the need for an array detector. It can be used for imaging Doppler velocimetry, ultra-fast frame rate (MHz) imaging, as well as for speckle reduction in coherent LiDAR (Strauss C. E. M, 1994). An extensive LiDAR bibliography for atmospheric and hydrospheric applications is given by Grant, 1995.

5.5.6 Law Enforcement

LiDAR speed guns are used by the police to measure the speed of vehicles for speed limit enforcement purposes and offer a number of advantages over radar speed guns (Craig Peterson, 2007) .

5.5.7 Military

Few military applications are known to be in place and are classified, but a considerable amount of research is underway in their use for imaging. Higher resolution systems collect enough detail to identify targets, such as tanks. Here the name LADAR is more common. Examples of military applications of LiDAR include the Airborne Laser Mine Detection System (ALMDS) for ounter-mine warfare by Arete Associates [Site 27].

By utilizing LiDAR and THz interferometry wide area Raman spectroscopy, it is possible to detect chemical, nuclear, or biological threats at a great distance. Further investigations regarding long distance and wide area spectroscopy are being conducted by Sandia National Laboratories [Site 28].

A NATO report (RTO-TR-SET-098) evaluated the potential technologies to do standoff detection for the discrimination of biological warfare agents. The potential technologies evaluated were Long-Wave Infrared (LWIR), Differential Scatterring (DISC), and Ultraviolet Laser Induced Fluorescence (UV-LIF). The report concluded that: *Based upon the results of the LiDAR systems tested and discussed above, the Task Group recommends that the best option for the near-term (2008–2010) application of standoff detection systems is UV LIF* [Site 29].

The Long-Range Biological Standoff Detection System (LR-BSDS) was developed for the US Army to provide the earliest possible standoff warning of a biological attack. It is an airborne system carried by a helicopter to detect fabricated aerosol clouds containing biological and chemical agents at long range. The LR-BSDS, with a detection range of 30 km or more, was fielded in June 1997 [Site 30].

Five LiDAR units produced by the German company Sick AG were used for short-range detection on Stanley, the autonomous car that won the 2005 DARPA Grand Challenge.

A robotic Boeing AH-6 performed a fully autonomous flight in June 2010, including avoiding obstacles using LiDAR (Spice, Byron, 2010) (Koski, Olivia, 2010).

5.5.8 Physics and Astronomy

A worldwide network of observatories uses LiDARs to measure the distance to reflectors placed on the moon, allowing the moon's position to be measured with mm precision and tests of general relativity to be done. MOLA, the Mars Orbiting Laser Altimeter, used a LiDAR instrument in a Mars-orbiting satellite (the NASA Mars Global Surveyor) to produce a spectacularly precise global topographic survey of the red planet.

In September 2008, NASA's Phoenix Lander used LiDAR to detect snow in the atmosphere of Mars [Site 31].

In atmospheric physics, LiDAR is used as a remote detection instrument to measure densities of certain constituents of the middle and upper atmosphere, such as potassium, sodium, or molecular nitrogen and oxygen. These measurements can be used to calculate temperatures. LiDAR can also be used to measure wind speed and to provide information about vertical distribution of the aerosol particles.

At the JET nuclear fusion research facility, in the UK near Abingdon, Oxfordshire, LiDAR Thomson Scattering is used to determine Electron Density and Temperature profiles of the plasma (Steve Cowley, 2010).

5.5.9 Robotics

LiDAR technology is being used in Robotics for the perception of the environment as well as object classification [Site 32]. The ability of LiDAR technology to provide three-dimensional elevation maps of the terrain, high precision distance to the ground, and approach velocity can enable safe landing of robotic and manned vehicles with a high degree of precision (Amzajerdian, et al.2011). Figure (4.3) shows a LiDAR-equipped mobile uses its LiDAR to construct a map and avoid obstacles.

Figure 4.3: LiDAR-equipped mobile uses its LiDAR

to construct a map and avoid obstacles

5.5.10 Surveying

Airborne LiDAR sensors are used by companies in the remote sensing field to create point clouds of the earth ground for further processing (e.g. used in forestry) [Site 33].

Figure 4.4: Aerial LiDAR surveying from a paraplane

Operated by Scandiavian Laser Surveying

5.5.11 Transportation

LiDAR has been used in Adaptive Cruise Control (ACC) systems for automobiles. Systems such as those by Siemens and Hella use a LiDAR device mounted on the front of the vehicle, such as the bumper, to monitor the distance between the vehicle and any vehicle in front of it [Site 18]. In the event the vehicle in front slows down or is too close, the ACC applies the brakes to slow the vehicle. When the road ahead is clear, the ACC allows the vehicle to accelerate to a speed preset by the driver.

5.5.12 Wind Farm Optimization

LiDAR can be used to increase the energy output from wind farms by accurately measuring wind speeds and wind turbulence.(Mikkelsen, et al., 2007), and an experimental LiDAR [Site 34] is mounted on a wind turbine rotor to measure oncoming horizontal winds, and proactively adjust blades to protect components and increase power (Mikkelsen, et al., 2010).

5.5.13 Other Uses

The video for the song "House of Cards" by Radiohead was believed to be the first use of real-time 3D laser scanning to record a music video. The range data in the video is not completely from a LiDAR, as structured light scanning is also used (Nick Parish, 2008).

CHAPTER 6

3D SCANNERS' FUTURE

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3D SCANNERS' FUTURE

6.1 INTRODUCTION

Business3D laser scanning equipment senses the shape of an object and collects data for the location of the outer surface. This distinct technology has found applications in many industries including discrete and process manufacturing, utilities, construction, archaeology, law enforcement, government, and entertainment.

The 3D Laser Scanning market including hardware, software, and services is rather dynamic with major segments experiencing rapid product innovation. The market contains exceptional opportunities with rapid forecasted growth driven by both replacing older mechanical methods, and by improved workflow with lower overall project costs, which enables more projects. For the forecast period, the market is forecasted to grow with a compound annual growth rate (CAGR) of 15.4% according to a new ARC Advisory Group study [Site 35].

According to Research Director Ralph Rio, the principal author of ARC's (3D Laser Scanning Worldwide Outlook), "*3D laser scanning is an exceptionally dynamic market". Technology advances in the areas of workflow, software, and ease-of-use are rapidly expanding the applications for it*". Ralph continued, "*One example is the increase in computational horsepower and memory size with 64-bit computing which supports using a massive point cloud rather than smaller segments. This is just one of many areas providing a huge improvement in productivity and lower overall project cost.*"

6.2 HIGHER PRODUCTIVITY DRIVES MARKET GROWTH

A 3D laser-scanning project involves several areas of cost, which correspond to the phases of a surveying or metrology project. The costs include the scanning equipment, labor to execute the scan, and post processing. Improvements in software and workflow processing have significantly reduced the labor costs, particularly for post processing. As the total project cost decline, more projects move above the line for justification and execution. Just like economics 101 — as costs decline, volume increases. The increased volume drives the purchase of additional scanning hardware and software, which contributes, to a growing market.

6.3 SHORTER RANGE MARKET SEGMENT IS STRONGEST

The 3D laser scanning market has sub-segments that coalesce around technical capability, corresponding applications, and distinct suppliers. There are three market sub-segments based on range (distance) for the laser scan. They are:

- Short Range: usually under a meter
- Medium Range: typical application of under 50 meters
- Long Range: typically up to two kilometers

The segment for short-range equipment and software is experiencing both rapid technological innovation and revenue growth. In the medium range sub-segment, the hardware is more stable with software providing increasing value-added business benefits. The long-range sub-segment has some very interesting application areas, but has relatively expensive equipment.

6.4 SOFTWARE INNOVATION IS ACCELERATING

The software applications available for converting the point cloud dots into more useable information within a design authoring software program have high value to the end user. They provide the link between the laser-scanning instrument and usable information. This area of software is rapidly evolving with improved functionality and, in a way, intelligence.

6.5 3D LASER SCANNERS FUTURE MARKET ANALYSIS

ARC Advisory Group has carried out a 3D scanning system five Year Market Analysis and Technology Forecast through 2015, which can be summarize as follows:

6.5.1 3D Laser Scanning Market Contains Exceptional Growth Opportunities

Technology advances in the areas of data quality, software processing, and ease-of-use are rapidly expanding the applications for 3D laser scanning. The more effective product offerings are improving the business benefits of 3D laser scanning while achieving correspondingly greater revenue.

6.5.2 Strategic Issues

The study provides an assessment of market growth that begins in 2010 with some remaining impact from the current economic conditions. The assessment continues through 2015.

- How can suppliers increase their value proposition?
- Which industries and applications offer the greatest opportunity?
- Will new distribution channels be required?
- How will differentiation be achieved in the future?
- What strategies are needed for today's global market?

Figure (6.1) shows the results of the 3D scanner market forecasting from 2010 up to 2015.

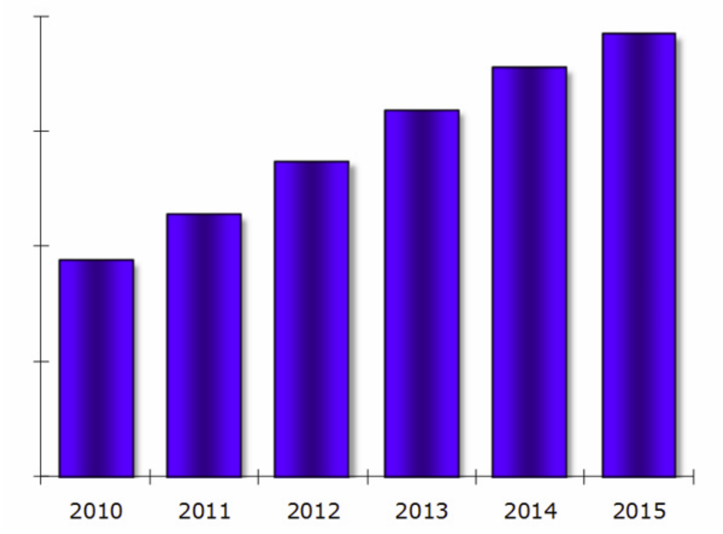

Figure 6.1: The Worldwide 3D Laser Scanning Market

6.5.3 Worldwide Study Table of Contents

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6.5.3.2 Scope

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    - $250 Million to $1 Billion
    - < $250 Million

6.5.3.4 Market Forecast List of Figures

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    - Long
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    - Process Manufacturing
    - Government
    - Utilities
    - EPCs

- Shipments by Application Type
    - Facility Design and Build
    - Asset Management
    - Reverse Engineering
    - Dimensional Inspection
    - Crime Scene Investigation & Forensics
    - Agriculture
    - Civil Engineering
    - Heritage and Archaeology
    - Entertainment
- Shipments by Distribution Channel
- Shipments by Customer Size

6.5.4 Supplier Profiles

Profiles for the major suppliers servicing this market are included. Each profile reviews the company’s business, products, and services as it applies to this market segment. Suppliers profiled include 3D Digital, BuildIT, ClearEdge3D, Creaform, Delcam, FARO, Geomagic, Hexagon, InnovMetric, INOVx, INUS Technology, kubit USA, Laser Design, Maptek, Measurement Devices, MEL, NextEngine, Nicon Metrology, Optech, Perceptron, Pointools, Quantapoint, RIEGL, Roper Industries, ShapeGrabber, Topcon Positioning Systems, Trimble Navigation, Zoller+Fröhlich.

6.5.5 Regional Study Table of Contents

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CONCLUSION

CONCLUSION

3D laser scanning equipment senses the shape of an object and collects data that defines the location of the object’s outer surface. This distinct technology has found applications in many industries including discrete and process manufacturing, utilities, construction, archaeology, law enforcement, government, and entertainment.

Laser scanning technology has matured and developed in the past two decades to become a leading surveying technology for the acquisition of spatial information. Wide varieties of instruments with various capabilities are now commercially available. The high-quality data produced by laser scanners are now used in many of surveying’s specialty fields, including topographic, environmental, and industrial. These data include raw, processed, and edited dense point clouds; digital terrain and surface models; 3D city models; railroad and power line models; and 3D documentation of cultural and historical landmarks.

3D laser scanners are working with three main types of techniques, which are:

- Time-of-Flight,
- Phase Shifting, and
- Trianglation

3D scanners are manily divided into three types, which are:

- Airborne scanners
- Teristerial scanners
- Hand-held scanners

3D laser scanners have a wide rang of applications which applicable to very small object to a wide range areas.

Light Detection And Ranging (LiDAR) is an optical remote sensing technology that can measure the distance to, or other properties of a target by illuminating the target with light, often using pulses from a laser.

LiDAR technology has application in geomatics, archaeology, geography, geomorphology, seismology, forestry, remote sensing and tmospheric physics, as well as in airborne laser swath mapping (ALSM), laser altimetry and LiDAR Contour Mapping.

LiDAR uses the same principle as RADAR. Just transmiting a beam of light to a target (the ground) and measuring the time it takes for the beam to echo back and calculating Range from the result. LiDAR differs from RADAR mainly in its ability to resolve very small targets and penetrate vegetation.

The 3D laser scanning market, including hardware, software, and services, is rather dynamic with major segments experiencing rapid product innovation. This market contains exceptional opportunities with rapid growth driven by both replacing older mechanical methods, and by improved workflow with lower overall project costs, which enables more projects.

Technology advances in the areas of data quality, software processing, and ease-of-use are rapidly expanding the applications for 3D laser scanning. The more effective product offerings are improving the business benefits of 3D laser scanning while achieving correspondingly greater revenue.

The market for 3D laser scanning instruments is likely to grow at 15.4 per cent compound annual growth rate (CAGR) in the next year, according to statistics from a leading business information company, which make the 3D laser scanners’ market to be doubled by 2015.

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