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Faculty of Informatics
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Master's Thesis

An Efficient Visualization and HMI Approach to Support the Data Acquisition Process of Hand-Guided 3D Scanners

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In the name of Allah, the Most Gracious, the Most Merciful.

To my beloved Ami and Abu

Abstract

Flexible hand-guided laser scanners are widely used in industries and other fields for digitization of real world objects. This thesis proposes a visualization and HMI concept to support the data acquisition process of flexible scanners. This work propose a scanline by scanline visualization of acquired point clouds to ensure the scanned data quality during scanning process. Since, scanner is controlled by the user therefore, some parameters such as scan angle, scan speed and distance to objects plays an important role in quality of acquired data. Therefore, simultaneous monitoring of these parameters as well as scanning object surface becomes a stressful task. A new user interaction concept has been proposed which monitors and inform user about these parameters. Proposed HMI concept is based on the game visualization techniques particularly first person shooter games. This work aims to advocate the idea of using game visualization techniques in the field of scientific visualization.

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Chapter 1

Introduction

Sampling the surfaces of real world objects is a common practice in the fields of industrial measurement, scientific analysis and entertainment. Laser technology has played an important role in developing techniques for digitization of different objects. Mentioning optical 3D laser scanners as a tool for digitization of real world object is inevitable.

Optical 3D laser scanners have earned attention in process of object surface inspection, quality assurance and reverse engineering of real world objects. Increase in the use of 3D scanners have opened a new research field. Development and improvement of 3D scanning techniques as well as visualization of point clouds data has become essential for different domains of life. This part covers some application areas of 3D optical scanners and elaborate their usage.

The foremost use of optical 3D scanner devices are in industrial measurements and quality assurance. To inspect the surface quality of manufactured items they are scanned using 3D scanning devices. On the other hand resultant point clouds data are shown on the screen with indication of possible noise data and quality of the surface. Using 3D scanners for industrial measurement has a ease and time saving benefits than tactile techniques. Exact and complex measurements of different parts are needed in assembling of larger objects.

Analysing the structure and architecture of historical buildings and monuments have understand the need of 3D scanning techniques more than any other domain. Large scanners are mostly in the process of scanning huge buildings and statues, hand-guided scanners do play their part in this domain as well. Small scanners are normally used when texture of a small piece of a historical founding needs to be analyzed.

3D scanners found their usage in the entertainment industry as a technique for converting real world models into 3D models. Games and animations are always in need of using models from real life as characters in games and movies. Using scanners instead of designing a model manually has the advantage of time saving, accuracy and ease. Further it enhance the realism in the scene since a scanned model of a real world object possesses more detailed description than a designed 3D model.

Its not long since the domain of medical science has been introduced with the 3D laser scanners for measurements. Because of its ease and accuracy 3D measurement techniques are gaining more and more attention. For example, 3D laser scanners are used in dental domain to get the exact measurements for restoration. Furthermore manufacturing othosis for disable persons needs exact 3D measurements for both patient and orthosis itself. 3D scanners have produced promising results in this field in terms of accuracy.

1.1 Motivation

The subjected object under consideration may vary in size and complexity of its surface. Flexible hand-guided laser scanners are used when other types of scanners fail to fully scan the complex surface. Working of hand-guided scanner can be seen as spray painting on a surface. A laser point or line is projected on the surface from the scanner and distance is measured from another sensor device (mostly camera device). This process produces data in form of point clouds which are very dense and multiple scan passes makes it overlapping and redundant. In order to scan the surface completely, it is necessary to look for parts which were left during scanning. This process needs a preview facility during scanning process. Furthermore, simply posting data in the form of point clouds without applying necessary shading makes it impractical to visualize the surface correctly.
On the other side flexible scanners have their own limitations. Some user controlled parameters such as scanning speed, scanning angle and distance to object influences scan data quality. Monitoring these parameters is a stressful task because the user has to look at scanner, object and screen simultaneously. An intelligent user interface concept need to be introduced which should itself monitor and inform user on screen. Current scanning systems lack this functionality. In order to overcome this problem, this work specially analyse the nature of these parameters and proposes a HMI technique for real time monitoring of these parameters.

1.2 Goals

In this thesis, a special type of scanner has been considered. This device consist of an optical 3D laser scanner mounted on a measuring arm with seven joints which enables it to scan complex surfaces. The goal of this work is to analyze the scanning process and propose an optimal solution for a number of visualization problems which user faces during scanning. This section describes different goals of this work.

The main objective of this work is to propose a online visualization system for hand guided scanner. By online visualization of point clouds data means a properly shaded scanline by scanline preview functionality which leads to a hierarchy of problems. Furthermore, these scanlines are produced at about 10 Hz and real time visualization requires a number of processes to be performed as well. Following are the steps which are performed on one scanline in order to convert it into a meaningful visualization.

Normal estimation for each point is a essential step for shading. This work proposes a rapid way of estimating normals during scanning process. However, estimating normals for points includes KNN (K Nearest Neighbors) findings which is another problem. So, the second step in solving the online preview problem is to find appropriate nearest neighbors for each points. State of the art techniques deals with a whole point cloud model where this work deals with the rapidly changing and successfully increasing 3D point data. There is no accurate assumption which could be made about the further data to get help with the KNN problem.

As mentioned before, there are a number of steps which must be taken on a scanline to turn it into a meaningful visualization and processing time is the key here. Issues related to handling large amount of data are analysed and the proposed method contains multiple solutions which are be used to enhance the speed but still keep the minimum required data quality. This problem is normally referred to as data optimization in the literature, however optimization is not the focus of this work. When proposed in this text the data optimization would mainly deal with the visualization problem rather altering the original scanned data.

The second main goal of this work is to propose a user interaction concept which possess the ability to solve the problems user faces during scanning complex surfaces. This task is divided into two different parts.

In the first part some user related factors and parameters which influence the scan data quality are analysed . Since, the scanning device is human controlled it loses its accuracy due to some factors. For example the scan speed, scan angle and scan distance. However analysing these parameters are not the only part of this work. The idea is to get these parameters from the actual scanning environment to make the visualization user-adaptive. It can not be transmitted to the user until the visualization system itself does not have it. This work proposes a method to extract this information from the scanning environment and later transmit it to the visualization system so that it can be conveyed to the user interactively during the scan process

The second part of this task proposes the method to convey this information to user during scanning. The information which the user seeks by looking at scanner and the object instead of continuously looking at the object, it is made available to the user at the screen. Providing this functionality to the user would reduce the stressfulness of scanning process for sure. To accomplish this goal this thesis advocates the use of 3D games visualization techniques for information visualization. This work mainly focus on the FPS (First Person Shooter) games techniques, however uses other colour, text and shape based techniques from state of the art games as well.

1.3 Outline

This thesis in outlined in the following way.

- Second chapter aims to provide the reader the fundamental knowledge about the scanning system and later introduces the considered scanning system i.e flexible hand-guided 3D laser scanner. Further, it discusses the scanning process of an object in details, Since, This work revolves around scanning process in the whole text, therefore, a clear understanding of the steps involved is inescapable. Further, this part provides the basic knowledge about the 3D games and particularly FPS games. In the last section the idea of using 3D games techniques in information visualization is supported by giving some examples from the literature where this concept was presented before.

- State of the art techniques are discussed in the third chapter. In this part issues and problems related to the 3D scanning system research field are given as well. Further, related research work for visualization of point clouds data is discussed. Moreover some research work on nearest neighbour searching, normal estimation and point clouds shading would be analysed. Since this work proposes 3D games techniques for interaction concepts therefore state of the art techniques of the

3D games as well as till date proposed interaction concepts for 3D hand guided scanners would be presented.

- next chapter i.e. chapter four is the main core of this work. It provides all parts of the developed system in the same way as mentioned in the goals stage. The chapter four is divided into two parts. The first part discuss the proposed method for online preview functionality. The second part of the chapter four discusses the proposed HMI concept for the hand guided laser scanners.
- Chapter five contains the information about the implementation steps which were performed to analyse the results for the proposed method. The details about the developed application is presented in this chapter. Information about the used software environment and libraries are also provided in this section.
- In chapter six, proposed solution is evaluated on different data sets. Results of the proposed method is presented in the form of pictures and tables to justify the effort done on this work. Further, this chapter presents the justification of using FPS games techniques for proposed HMI technique.
- In the last chapter, an overview of the proposed solution is discussed in details with its pros and cons and some suggestions for the future work.

Chapter 2

Fundamentals

This chapter provides fundamental knowledge which is necessary for the reader to understand this work briefly. This chapter is divided into two parts. The first part shed some light on the basics of scanning systems shortly and later about the considered scanner more briefly. The second part of this chapter discusses the computer games particularly first person shooter games and later discusses the use of 3D games techniques for information visualization.

2.1 3D Laser Scanning System

This section aims to provide the reader a basic background of the 3D scanning devices. 3D scanning systems have their on set of terminologies and language which will be used in this work, therefore having a basic information about the scanning devices particularly hand-guided 3D scanners and object scanning process is inevitable. This section is divided in two parts. The first part gives an short introduction about the different kinds of 3D scanners. Further, it gives an introduction of the architecture, working and uses of 3D arm which is the main focus of this work. The second part deals with the different phases of the scanning process . By the end of this section, the reader will have brief information about the scanning process and different phases through which data travels to form a meaningful visualization. 3D Laser scanners have secured their position in various research and industrial domains. As the use and research in this domain increased, multiple kinds of scanning devices were introduced. 3D scanning devices can be categorized by their measuring principle, and using techniques. In the following section we will have a short overview of different measuring principles.

2.1.1 Measuring Principle

In this section few basic measuring principles of 3D scanning devices are described. Each and every measuring principle has its on advantages as well as limitations.

Triangulation Method

This method is based on the very basic triangulation principle. The use of triangulation principle was recorded from the 6th century when the Greek philosopher Thales used it to find the height of the pyramids [La18]. However the modern triangulation method was used by Dutch scientist Snel Willebrord who was able to find the circumference of the earth [Str70]. According to triangulation principle a triangle can be solved if two angles and the distance between them is known. Using this concept optical system can easily verify the dimension and surface properties of an object. As shown in the Figure (3.4) triangulation based optical system usually consists of two sensors which observe a common point on the object surface. Since the distance between these two sensors (base b) and angle of their focus α and β is known through calibration process, the measuring point can easily be computed using triangulation principle.

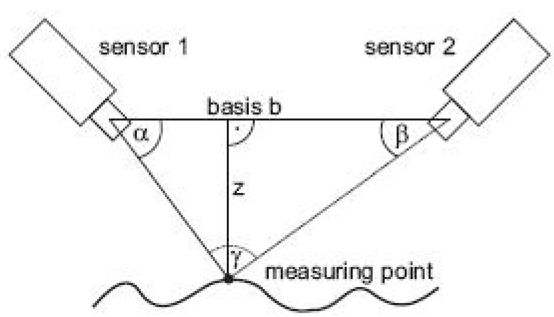


Figure 2.1: Triangulation Method [Teu07]

Light Section Method

The basic light section method works by projecting a light with a certain structure on the surface of the object. Another light sensitive sensor device is used to record the intersection points on the surface [SM71]. Capturing these points makes the surface sampling possible. There are multiple variations which differs by the light structure they use to capture surface. **Laser line projection** uses a laser beam and a camera device. It works with the fact that instead of a point, projecting a line on the surface will increase the number of points represented on the surface. The projected line deforms it's shape due the surface properties, which is recorded from the camera device and then image processing techniques the deformed line is segmented from the background information. **Fringe projection** based method uses fringe projectors which projects multiple lines on the surface. However, the process of separating line

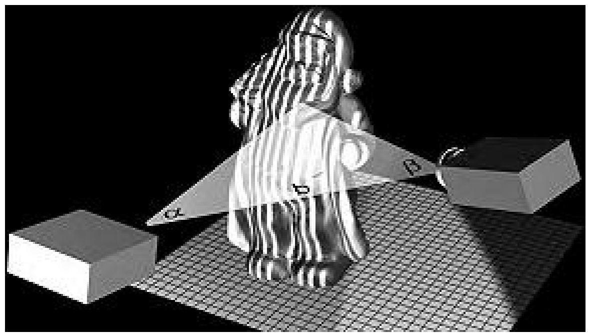


Figure 2.2: Light sectioning with fringe projection [Teu07]

segments from other lines needs a careful segmentation technique [G.M97]. These lines normally has an easy to identify structure (black and white strips see figure (2.2)). Each black white border works as a separate projection line, therefore increases the number of points sampled at one time.
Phase-shifting is a slight variation of the fringe projection method. It works by replacing black-white patterns with sinusoidal strips which are projected from a video projector. These strips are later projected with continuously changing horizontal angle. On the other hand the camera device capture images with subsequent changes in Gray values which is caused by the surface topology of the object. To analyse the deformation, the quotient of the sinusoidally and cosinusoidally shifted signals (direction of the shifting is used). Phase-shifting yields better results in terms of resolution.

Tactile Coordinate Metrology

Its been long since high-precision probes have taken place of old measuring techniques in industrial measuring technology. Probe samples single points from the surface its swapped on. However, it is a time consuming task to swap the whole surface point by point to generate surface coordinates. Therefore, probes are assisted with optical metrology. Sensors such as 3D camera/laser devices are integrated in this mechanism to increase the number of sampled points. There are multiple variations in this mechanism with respect to the mounted device on the probe and surface guidance procedure (manual, automatic).

Time of Flight Methods

Time of flight method works by throwing an signal onto the surface, and later receiving the reflected signal by an sensoring device. The time this signal takes between system-object surface-system is called time of flight. Time of flight determines the corresponding position on the surface. Variations in time of flight systems are based on the type of signal i.e ultrasonic, positron emission, infrared. These system are mostly made for digitizing large objects see figure (2.3)i. e., buildings and statues, therefore takes a significant amount of time.

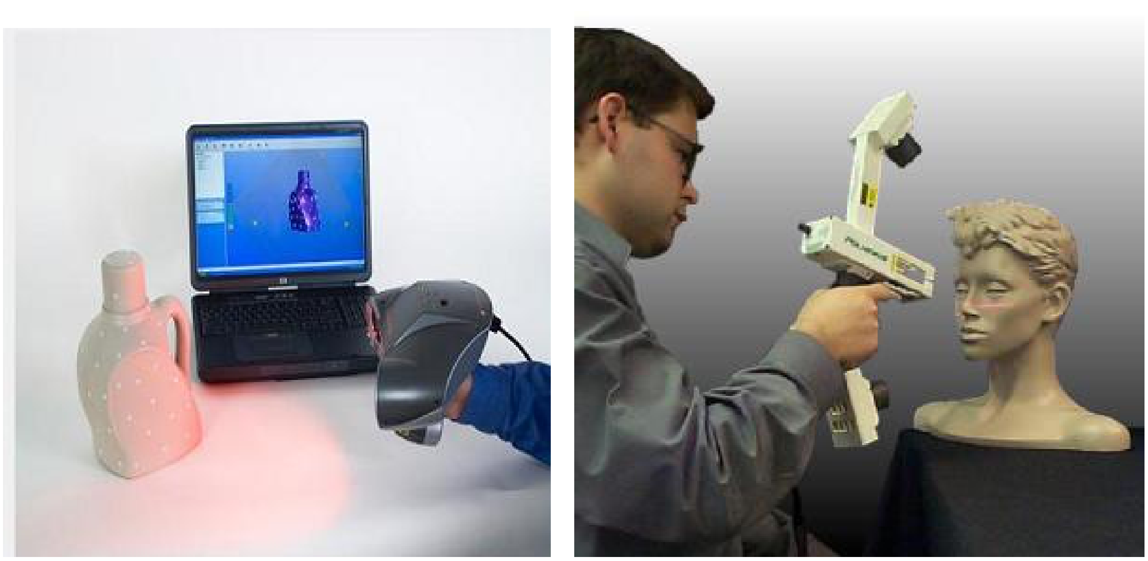
Figure 2.3: Point clouds of a building generated from a Time-of-Flight method [Gmb07]

Shape from Shading

Shading referrers to the procedure of assigning colors values to the point depending on the light positioning and surface normal at that point. Shape from shading technique works in the reverse order by determining the shape at a certain point on the surface with the help of colour values at that point. However colour values itself are not sufficient to determine the local orientation of the surface, therefore it leads to solving the problem by calculating other surface properties such as reflection, illumination and local surface. continuity [G.M97]

2.1.2 Scanning Procedure

Apart from the technical methodology of the 3D scanning systems, there are multiple kinds of scanners which are different from each other in their surface capturing method. Each and every domain has its own need of 3D scanning devices as well as their own set of target objects. Therefore 3D scanning systems are available in different architectures. Scanning devices differ in terms of their scanning process in so many ways that it is not possible to list all of them.
The foremost type of scanners are in form of box machines where objects are placed in it and sensor devices revolves around the object to capture the whole surface or vice versa. However, in case of a complex surface this kind of scanning devices fail their credibility. Domains such as industrial measurement, where small rather complex objects have to be measured, frequently adopts hand-guided scanners.
In hand guided systems sensor devices are manually guided by a human over the object surface. It gives flexibility over the kind of surface being measured since there is less chance of a part of surface to be left without scanning. However, the process is human controlled, therefore, it is prone to human as well as environmental errors. Figure (2.4) shows two kinds of flexible scanners.



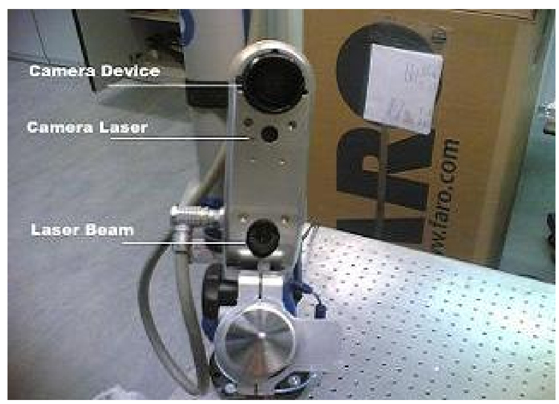
(a) ZCorp Scanner **(b)** Polhemus FastSCAN

Figure 2.4: Two Different types of Hand-Guided Scanners. Image Source :(a)Z Corporation Inc www.zcorp.com (b) http://www.polhemus.com

2.2 Employed Laser Scanner

This work mainly focus on the hand-guided laser scanning system developed by Fraunhofer Institute for Factory Operation and Automation (IFF). The considered scanner is combination of optical methodoly and tactile methods. The device consist of a scanning arm (developed by FARO technologies Inc) which is very precise (<50 m of uncertainty). To speedup the sampling process which is quite slow in case of tactile methods alone, scanning arm is mequiped with a 3D sensor device which consist of a camera and laser device. Hence introduce the optical assistance. Attached optical 3D sensor head is developed solely in Fraunhofer IFF. The sensor head consists of a camera device and laser light diode. Laser beam projects a laser line on the surface of the object which is recorded by the camera at a high speed (see figure (2.5)). The

(a) Scanning arm with sensor head



(b) Front side of scanner-head

Figure 2.5: (a) Scanning Arm with scanner head mounted (b) Scanner Head front view. Image Source :(a)Fraunhofer IFF www.iff.fraunhofer.de

contours of the laser line is segmented by the hardware based algorithms within the camera device. This makes it possible to generate contour lines with a sampling rate of 120 per second. However, this frequency can be controlled. On the other hand, only 2D data is transmitted to the attached computer in form of 2D coordinates. A scanning arm with seven axis flexibility and a sensor head mounted on it, the scanner can easily moved within a hemisphere of radius 1.20m. The table 2.1 gives a brief description of scanning device specifications.

Practically there are two laser beams integrated on the scanner head. One for projecting laser line on the surface of the object as required by the light sectioning method. A second laser beam is connected under the camera device with the same orientation which projects a second laser line on the object surface. It helps analysing the line of sight and distance of the camera device (see figure (2.5 (b))).

Property	Value
Measuring Principle	Optical Metrology & Tactile Methods
Measuring Volume	Hemisphere of radius 1.20m (Scan Arm Dependent)
Line width	80 mm
Line Depth	45 mm
Sampling Rate	60 (120) Scanlines /sec
Measuring Uncertainty	$< \pm 100\mu$m

Table 2.1: Scanner Specifications

2.3 Data Acquisition Process

The process of converting a real world object into a 3D model can be divided into a number of phases. This work only deals with the visualization of data capturing process and user machine interaction technique. However, having knowledge of all phases involved in digitization process in necessary. It will help the reader understand the problem and its proposed solution more briefly. Furthermore, the proposed solution advocate on switching place of some data processing phases, therefore, it is highly unavoidable for the reader to have fundamental knowledge about them. This section aims to provide knowledge to the reader about the sequence of steps involved in digitization of real world objects. Furthermore, types of data processing involved in each step will be explained. There may be some variation in data processing sequence of each scanner type therefore it is important to keep in mind that this part particularly deals with the considered hand-guided scanner and deployed software application.

2.3.1 Scanning Technique

The purpose of developing flexible hand-guided laser scanners is to overcome the short comings to machine based scanners. Objects with complex geometry are needed to be scanned very carefully so that no part of the surface should be left un-scanned. The machine based scanners lacks this functionality. This leads to the fact that the scanner should be guided on the surface of the object by human hand. The considered hand-guided scanner's working can be seen as an paint spray being moved over the object surface. However, instead of throwing paint particals on the surface of the object, the scanning system generates 3D points from the surface and transfer it to attached computer for further processing. The laser beam attached on the scanner head projects a laser line on the surface as a requirement of the light sectioning method. This laser line also tells the user about the part of the surface under the scanner focus. To determine the line of sight of the camera device, the scanner head is equipped with another laser device which projects a second laser line on the object's surface. The position of this laser line is important since it not only tells about the part of object under the camera focus, but it also clarify if the scanner is at the optimal distance from the object surface or not. The second laser is equipped in a way that both laser lines overlaps when the distance between the scanner and object surface is optimal. This distance is defined when the sensor head was designed. Having an optimal distance is important since it plays a vital role in the scan data quality. The current computer system deployed with the scanning arm does not interact with the user during this process. The only data processing performed during scanning is converting 2D coordinates form the camera device into 3D coordinates.

2.3.2 Scan Pass

There are multiple reasons which makes it impossible to scan the whole object in one pass. Object size, scanned data quality and object surface complexity are major problems which force a user to divide the scanning process into multiple parts. Once the user presses a button and start swapping the scanner over the surface of the object, the scanning system starts data transmitting procedure. Once user releases the scan button for any reason, the computer system takes its first step toward user interaction and shows whole acquired point cloud. This is in form of point clouds and gives the user an idea about the part of the object being scanned and the remaining part of the object or the holes in the scanned part. The process user performs between one pressed button is called a scan pass, and will be referred with the same name in this work.
Once the user releases the button there is multiple data processing task which are be performed here. Having a quick look at these data processing task helps in understanding this work.

Data Generation

3D optical scanners generates data in form of 3D point clouds. 3D point clouds processing is a vital field of research. A good amount of work has been done on point clouds generation and processing whereas 3D scanners are the foremost source. The points clouds are consist of 3D points with X,Y,Z coordinates and may have a structure or could be unstructured.
The considered scanner generates data at 1200 points /10ms. This results in a dense point clouds. However, with its density, resultant data possesses a very strong structure which is easily identified. Since scanning system works on light sectioning method, therefore minimum unit of points it generates at one time is in a line structure. The camera device captures Gray scale images of the projected laser line. These images contain information about the deformation of the projected line, hence the surface topology information. These images are digitized and then later contour

of the laser lines are extracted from the background information. Line width itself is not important since only the middle point of the line at the current point is used to generate 3D points. Choosing the mid point at the current location is not a trivial task. The quality of converting the 2D pixel position from the Gray image into 3D coordinate process depends upon the algorithm used for segmentation. However the considered system works on the algorithm proposed by Teutsch ([Teu07] Section 3.3.1).

Data Optimization

The data optimization refers to the increasing or decreasing number of points in the generated data. There are number of reasons why its necessary to optimize the scan data at this level. Data redundancy is a major factor which makes it important to perform optimization after each scan pass. Since, the object scanning is performed in multiple passes. Scanning the same part of the surface multiple times is a common practice. Data optimization in this regards refers to removing redundant data in form of second or later scan pass. Redundant data removal could be a trivial decision or based on important parameters such as data quality. Visualizing scan data quality is another force for driving the data optimization process. Since points clouds are generated at 1200 points per 10ms, therefore, it is hard to visualize the data quality of one scan pass. A trivial method of reducing points after every nth point is usually adopted. However, it is only performed for the visualization purpose and actual data may not be removed. A further possibility for data optimization is when new points are generated to fill the possible holes in data. However success of this process is impractical at after every scan pass therefore this process more suits at the last scan pass processing.

Error Identification and Removal

Another data processing task which can be performed after a scan pass is outlier/error identification and removal. Since, 3D scanners are deployed in different environments therefore, each domains possesses its own kinds of data errors. Identifying the structure of error adopted by each type and then identification of these structures is a important data processing task which can be performed after each scan pass. However, leaving data removal part to the user with an interaction technique is a better approach. The image captured from the camera device may contains environment errors. The most severe form of optical error is caused by the shine in the object surface. Reflected laser light from the object surface influences the amount of light on the camera lens and hence causes a blooming effect. Shadowing effect is the other extreme case of lighting effect where amount of light is reduced by the object geometry. In this case camera fails to observe the laser line and results in fragmented

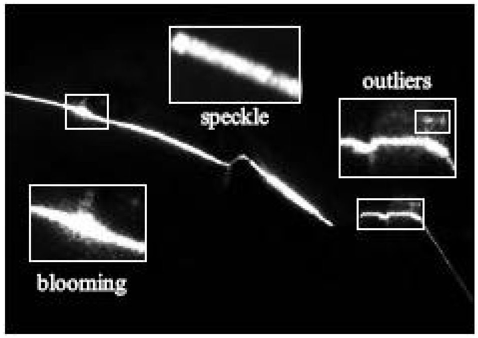


Figure 2.6: Different noise structures in captured gray-level image [Teu07]

data. To capture the gray level image from the object surface distance between the camera laser and object is an important parameter. If the laser or camera device is forced to work out of range (camera can not capture the laser line image from the distance), it causes blurring effect in the image. Figure (2.6) shows the effects of different environment error sources on camera captured image.

2.3.3 Surface Reconstruction

The last task in object digitization processes is surface reconstruction. 3D optical scanners generate data in form of 3D points. This form of data is not usable in most of the domains. Therefore surface reconstruction algorithms are adopted to convert point cloud data into more usable form of surface. There are multiple kinds of surface construction techniques, some techniques change the data format into triangles [Fab03] or spline surface and few surface generation techniques keeps the data format to points [FCOAS03]. Surface construction is an offline task and can be performed any time after the data acquisition process. Since this work focuses on the visualization and interaction concept of data acquisition procedure, therefore, details of surface reconstruction is out of scope of this work.

2.3.4 Point Clouds Structure

The data processing on point clouds with a structure is more reliable than the unstructured point clouds. A considerable work has been done to recognize structure from point clouds [Rab07]. However, 3D scanners working with laser line projection method always segments captured image in line structure, therefore, it can be assumed that the data is structured. Scan operation refers to one scan pass user performs to capture a portion of object surface. Data may contain multiple scan operations since objects can not be scanned in one scan pass. Machine based scanners contains more

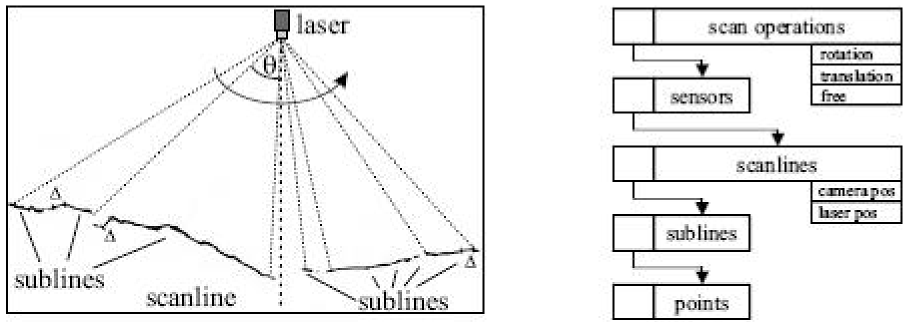


Figure 2.7: Generated point clouds structure [Teu07]

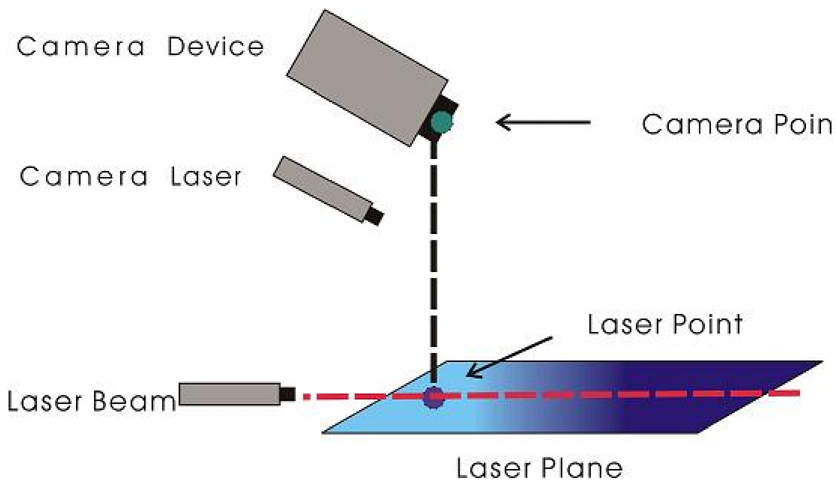


Figure 2.8: Position of the camera and the laser points in world coordinates

than one camera sensors to the whole surface, however, the considered hand-guided scanner only consists of one camera device. Therefore, the sensor information field only consist of one device. Scanline refers to the contour extracted from the one gray-level image. Since, extracted contour is not always continous, it may contain a number of sublines and will be referred with the same name in this text. Figure (2.7) shows the point clouds structure of considered 3D scanning system.
Apart from the point data, each scanline contains a camera point and the corresponding laser point. Camera point refers to the location of the camera device in the world co-ordinates. This point can be assumed as the middle of the camera lens equipped on the scanner head. The laser point does not refers to any of the equipped laser devices, rather it is the projection of the camera point on the laser plane which is near to the theoretical point. Figure (2.8) points out the laser and camera points available with each scanline. . From the above information it can be said that point clouds

data generated from the hand-guided scanner does not only contain a structure but is enriched with the device information as well. Apart from generating 3D point clouds data, Teutsch et al.[TBTM05] presented an approach to use the scanning arm with a colour capturing camera device. By applying this method the scanning arm can be used to capture photo-realistic textured 3D data. This leads to the fact that this scanning device can be used to generate ready to use 3D models as well. However the process for capturing and generating textured objects is different from the 3D point generation method.

2.4 Computer Games

In this section, the reader is introduced to the 3D games and their history. Since, the HMI technique is based on the 3D games visualization techniques, therefore, information about the computer games and their history is important. 3D computer games are not a new addition in the field of computer graphics. The first video game dates back to 1947 when a Cathode Ray Tube (CRT) based game was developed [Lei08]. Gaming industry kept on evolving as the research for human machine interaction and computer graphics grew . Electronic device based games were always given the name of “Computer Game”, since computer games history is as old as the one room big computer. Computer games can be categorized into three major types according to the running platforms. **C**onsole based games are in form of hand held devices with a screen and control button equipped on it. These kinds of games give less flexibility in flavor since there are fewer options for interaction method. However their small size and portability are the main advantage on other types of games. Another variation in console based games which comes with a self computer and can be connected with a external video device such as a television. With no limitation on size and interaction concept, these types of games have more variety than the portable console games. These games led the commercial use of games in arcade business. **P**C games gave the gaming industry more boost than any other types of games. With the multiple possibilities in interactions and easy development environment, PC games earned gaming industry much respect in business sector.
Apart from the running platform computer games can be categorized by there genres and purpose. From time to time computer games changed their focus from sports based games and almost covered each and every aspect of life. Now computer games comes with almost each and every flavor which exist for movies. As the focus of the computer games diverged from sporty direction, its purpose enhanced from entertainment to education, propaganda and advertisement. Later stated set of games put a lot of effect on the society therefore they were given the name as “Serious Games” by Zyda, Michael[Zyd05].

2.4.1 First Person Shooter Games

First person shooter games date back to 1977 when this genre of computer games started with the development of “Maze War”[Mus04] (see figure (2.9)). The concept

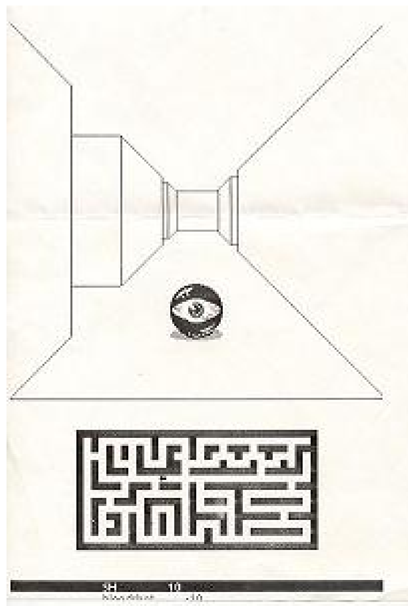


Figure 2.9: The First First Person Shooter Game [Mus04]

behind the FPS (First Person Shooter) games is to create a first person perspective viewing for the user. This creates a realism for the player since view on the screen is identical to the view of the protagonist.[1] Therefore, the viewer feels the same action which is performed by the character. Improved hardware and software based 3D graphics techniques greatly influenced the realism in FPS games. Figure (2.10) shows the difference between the quality of graphics from the first window supported Doom game in 1994 and a newer version in 2004. A significant difference between the image quality can be seen in both images. The main visualization technique behind the FPS games is to provide the necessary information without frequently changing the focus of the viewer. In real world change in the amount of information perceived by the human brain through viewing fluctuates frequently by a simple movement of head or eyes. However, on a screen this effect can not be accomplished because it would lead to a disturbance in viewing, therefore FPS games manage to restrict the movement to only major changes in view (head movement) and take the advantage of sounds effects and colours (foot steps, shadows) to transmit the missing information to the viewer.

[1]Protagonist refers to the main character in the movie.

(a) Screen Shot of Doom released in 1996

(b) Screen Shot of a newer version released in 2004

Figure 2.10: (A) Screen Shot of Doom released in 1996 (B) Screen Shot of a newer version released in 2004 Image source www.activsion.com

2.4.2 Information Visualization and Computer Games

The collaboration of information visualization and 3D games technology got focus of researcher at the start of this century[2]. In this section some scientific visualization or information visualization projects will be presented which uses 3D games visualization techniques.

Rhyne et al.[Rhy02] gave an analysis of the influence gaming industry has put on the scientific visualization techniques. According to his assumptions gaming industry had more focus of the 3D hardware and software techniques than the information visualization field. More games supported hardware and software development environment was introduced than for the scientific visualization. This fact justifies that gaming industry leads on the scientific visualization. Rhyne et al.supported his idea by giving the examples of SEE (Sensory Environments Evaluation) project run by USC Institute for Creative Technologies[3]. The Purpose of these projects is to enhance the learning capabilities of a trainee by using emotionally effected virtual environment. SEE uses games technologies to create this multi-model environment either by using a FPS based simulation or a Mixed-Reality simulations. Figure (2.11) shows a scene from the Mixed-Reality based simulation.

[2] Computer Games and Viz: If You Can't Beat Them, Join Them. The Official SIGGRAPH 2001 Computer Games and Viz

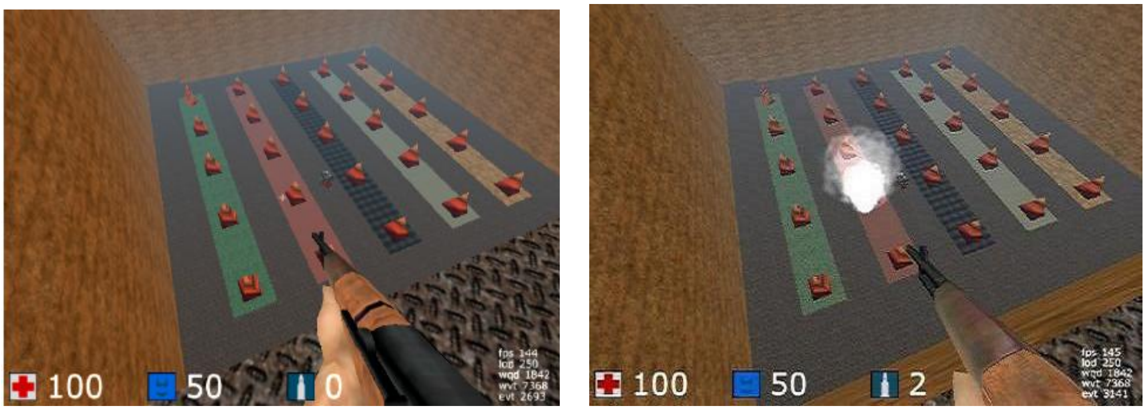
[3] University of Southern California www.usc.edu

Figure 2.11: Mixed-Reality Based Simulation [Rhy02]

K.Hussy [K.H07] from EuroPlanet [4] supported the use of 3D games technology for mission visualization. They proposed the solution for NASA/ASR spaceships for education purpose using 3D games techniques. A 3D scene was created same as a first person view of a spaceship pilot. Therefore, the user could realize how it feels like to be the part of actual environment. Same set of information was provided in 3D scene which could be expected on the real mission.

The most interesting work which designed and then implemented the 3D games techniques was given by Harrop and Armitage[HA06]. They proposed a interaction method for network monitoring and control using 3D games engines technique. There work was more interesting in the sense that the main reason for this approach was not only inventing a new interaction concept, but to add fun to the job of a network monitor. They introduced the words “shooting” and “healing” for network connection termination and re-connection. Figure (2.12) shows the screen shots of the implemented interaction concept. They used FPS view of a room to demonstrate a network. The triangular shapes in the middle of the room represents the nodes connected to this server. The change in texture, rotation and movements in the node object represents a activity performed at the current connection. The weapon in the hand of network connection gives him ability to shot (disable) a connection. Furthermore, they introduced the enemy objects in the room as foreign interference which must be eliminated as soon as possible before it effects a host.

[4] Euorpean Planatology network www.europlanet.cesr.fr



(a) View of a LAN network in form of a 3D room

(b) Network Administrator terminating a network connection

Figure 2.12: (A) A network view in form of a 3D room (B) Screen Shot of network administrator shooting a network connection Image source [HA06]

2.5 Summary

In this chapter the fundamental information about the 3D scanning systems have been presented. We discussed different types of scanning system available with respect to their scanning methodology. Further, we introduced reader about the flexible hand-guided optical 3D scanner which is main focus of this work. This part aimed to provide the user detailed information about the scanning process of a object using considered scanner. Different new terminologies were introduced which would be commonly used in this work. Second part of this chapter presents a brief introduction about the 3D games and there different types. Further, it discuss the FPS genre of 3D games. Since, this work is based on FPS interaction method therefore it was necessary to have a basic knowledge of FPS based games. In the last part, some related work was provided which have proved to use 3D games techniques for information visualization and interaction concepts. By the end of this chapter the reader should have the background knowledge of 3D scanning system, considered scanning device and 3D games and their use in information visualization.

Chapter 3

State of the Art

Research area of any domain grows as it enters various fields of life and encounters different challenges within. Digitization of real world object with 3D scanning systems has its own limitations. There are a number of problem areas which still need improvement and as the need of 3D scanning devices grows new problem are introduced to this research field. There are three main areas of the researchers dealing with digitization of real world objects.

(a) As discussed in previous chapter, there are multiple types of scanning systems which differ in their working methodology. Each type of system has its own pros and cons and not even one system can be said perfect for the challenges it faces in the working domain. A large number of research has been done to introduce new methodologies for the scanning systems as well as their generated data format. Once a system is created by adopting a new methodology or by employing in a new environment, it faces new set of problems which need to be resolved.

(b) In data processing domain research has been going on to solve the problems like, data optimization, correction, and later constructing data in the form of a surface. This field of research deals with the post-scanning problems. Data correction and optimization is performed once data has been completely acquired from the scanner. The main challenges of this area is to handle a large amount of data, finding error data and its removal and later converting it into a surface.

(c) Relatively new but an important field of research is to support the data acquisition process by introducing new data visualization techniques. Since flexible scanners has gained a good repute in this field, therefore new problems have emanated in the field of HMI (Human Machine Interaction) techniques for these flexible devices. This domain intends to increase the scan data quality by supporting data acquisition process with a interactive visualization concept. The main research area deals with problems such as, analysis of the human controlled parameters which effect scan data quality, transmission of these parameters to the system and later to the user by using an interactive visualization method. Since this area more deals with data acquisition process it would be referred as online data processing in this thesis.

This work is a contribution in the third type of research that is supporting data acquisition process. This chapter will first present issues and problems related to this work and later present state of the art techniques related to these problems.

3.1 Issues and Problems

Like every other research field, visualization of 3D data and HMI techniques for flexible laser scanners have several issues which still need to be resolved. A significant amount of research has been going on to support the data acquisition process so that quality of the acquired data could be increased by reducing the error causes. In this section some issues and problems which could be faced during creation of a good visualization and HMI techniques of flexible laser scanners will be discussed.

3.1.1 Visualization of Acquired Data

As discussed in the previous chapter, 3D scanners generates data in the form of dense point clouds. This data does not create an informative view when presented in raw format. To analyze the quality of data an informative view must be provided. Therefore, this data must be properly shaded or reconstructed in form of a close surface. To perform the shading of a given point, direction of the point must be calculated to determine the light intensity which will effect the considered point. Since, a single point does not have any direction information in three dimensions, therefore local neighborhood of the point must be calculated to determine the local orientation. This problem leads to the nearest neighbors calculation. As stated before, a moderate size of point cloud is normally consists of millions of points, So, finding a intelligent data structure to store these points in order to calculate k number of nearest neighbors or all points with a given radius r is the next big hurdle in shading process. Next step in this process is to find the orientation of the given set of points to evaluate the local orientation of the surface.

3.1.2 HMI Technique

Flexible 3D scanners assist users with their flexibility to easily scan objects with complex surface. However, this flexibility comes with a cost of instability in the generated data. Since handling of the observing sensors are now controlled by human hands, therefore, the amount of parameters which effect scan data quality slightly increase. Finding these parameters is not the only responsibility of a HMI technique, more challenging task is to inform the user about these parameters at the run-time. Determining the appropriate visualization technique for each parameter is the driving force for this research domain. By appropriate visualization technique means that selected visualization format should not only correctly convey the information but rather should be less disturbing for the scanning procedure itself. An ideal HMI technique would be considered when it reduces the causes of error at the scan time and reduce the work load of data processing phase. However, it should be made clear that not all of the error causes can be determined at the run time by the system itself particularly those which are caused by the environment (vibration, dust) and surface properties(shine or complexity in surface).

This thesis deals with both visualization of acquired data as well as HMI concept for the data acquisition process. In the next part, related work for visualization and HMI concept problems is presented.

3.2 Nearest Neighbour Calculation

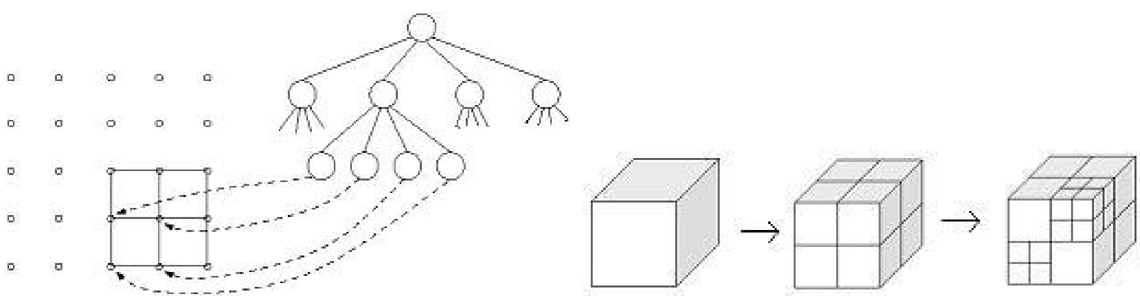
the points cloud data are normally very dense therefore, efficient storage technique and rapid accessibility of the random points needs a good data structure. Further, the point clouds data processing starts with the finding of nearest neighbours of all points. A considerable work has been done to find a quick method for nearest neighbours calculation[SSV07]. To solve the nearest neighbour problem tree based data structures are implemented which facilitate the nearest neighbour search for a given point.In this section we will present three main tree data structures for KNN finding in point clouds data . In the end, an analysis of the three data structures will be discussed.

3.2.1 Octree

Octree is a 3D formation for the generalized rooted Quad tree. Raphael Finkel and J.L. Bentley [RF74] defined working of QuadTree which divide their each child into four quads, Octree forms one higher dimension and hence divide its nodes upto eight children. Each divided cell is called an octant. Octree recursively divides the space by giving each internal node eight further cells (see figure (3.2.1)). Each node contains information about the

- Dimension [xmin,xmax], [ymin,ymax], [zmin,zmax]
- Pointer to the eight children
- NULL for a leaf node
- A unique label

The depth of the Octree is defined by a user controlled parameter. Figure (3.1) shows the subdivision of an isosurface using Octree. In nearest neighbor finding application for point set data, Octree suffers from the same limitation as its parent (quadtree) which is limitation to the given depth. Vaidya et al. [M.89] removed the depth defining limitation by implementing a box based data structure for quad trees. However, Octree still faces problems in finding$k$ nearest neighbours in a point set data. Since Octree only has certain amount of possibilities to traverse in a node, therefore, they suffer from computational time in scanned point clouds where nearest neighbours have to be found within a given radius. However, Octrees are still useful for the other problems in computer graphics where a space has to be divided to form a hierarchy. Figure (3.1(a)) shows storage technique of Octree for Isosurfaces.

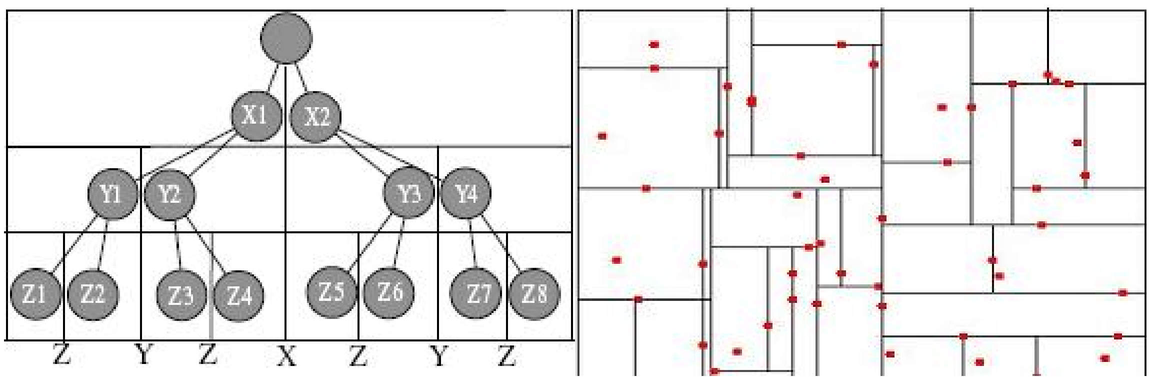


(a) Octree for Isosurfaces **(b)** Subdivision of a Octree Node

Figure 3.1: Octree Subdivision

3.2.2 KdTree

The KdTree is a binary space partitioning tree. A KdTree can be defined as the generalized form for 1D binary search tree. However they can support upto k dimensions. They work on the subdivision mechanism adopted by the 1 dimensional range search trees which split a set of points in roughly equal numbers where left side contains points with less value than the mid. On the right side points have values more than the mid value. KdTree's working can be seen as the binary partitioning according to the mid (median) of the ith dimension where i is one of the coordinate axis and recursively changes after each iteration. These splitting planes are called hyperplanes. At each iteration data is sorted to find the exact median value on which the data



(a) **(b)**

Figure 3.2: KdTree for 2D points [HMHB06a]

will be split, However, Teutsch [Teu07] proposed the method to find median of the considered dimension in which data will be divided into two partitions. A mid value is chosen which forces all the small elements to the left and greater elements to the right. The method used is called "selection" which does not perform a complete sorting. Only one pass would be enough to divide it into two pieces. At the hyperplane that is the internal node only this median value is stored, the data points are stored at the leaf nodes. There is another variation in KdTree which stores 3D point itself in the leaf node it is called KdTrie however it has Octree storage requirement. A KdTree can answer the following queries,

- Input: a set of points X in k dimension.
- Search: a range R parallel to axis (a window or box[1]).
- Output: All Points such that p ∈ X and p ∈ R.

A KdTree takes O(n) storage for n set of points and O(n log n) time for construction. KdTree has important uses in point clouds because of their efficient nearest neighbour finding as well as offer for less storage than the Octree. They are almost always balanced since the data is divided at the median value. For a search query, algorithm recursively search only those area which intersect with the range R. In case of 3D data,

[1]Different terminologies given to this range or input for queries for further reading [dBCvKO02]

instead of a window or box, a cube shape represents the range. However, KdTree can search for nearest neighbours within a radius in which case the range R would be a radius of a sphere. Once a leaf node or the 3D point in case of point clouds data is reached, a proper distance is calculated. If the distance falls in the range, it is selected as the nearest neighbour or discarded otherwise. Teutsch [Teu07] has analyzed the KdTree construction and KNN search for scanned point clouds. In fact in his work the working of Kdtree was observed on both flexible 3D scanner and scanning machine data[2]. The observed practical performance was based on three different spherical radius ranges of 0.1 mm ,0.2 mm and 0.3 mm. For results and further reading see [Teu07] page number 87 Table 6.1. Apart from KNN finding KdTree has its use in other fields of computer graphics such as ray tracing [HMHB06b] and other space partitioning techniques. A large amount of research work is done to improve the Kdtree performance and construction. Kun Zhou et al. [ZHWG08] proposed the real time Kdtree construction algorithm for GPUs[3]. They used the BFS (breadth-first search) order to construct the nodes within the Kdtree.

3.2.3 Range Tree

Range tree overcomes the query search problem of KdTree. KdTree has the drawback that once the number of reported points are small in numbers its search time increases. This draw back is reduced by range tree since it gives search queries a relatively low time. However this efficiency comes with the cost of storage. Range tree has O(n log n) storage. The reason for increase in the storage is that Range tree stores interval tree for each further dimension. Each inner node contains the higher value for its left subtree, however the point data is stored in leaf nodes. As shown in figure (3.3) range trees make an extra tree for each dimension. Since it is a generalized tree and can be made for up to a variable number of dimensions, therefore, for each new dimension it would cost an extra storage.

All three tree based structures have their pros and cons in terms of accuracy, speed and storage. They have their own uses in computer graphics field. However, if judged critically, Kdtree has an edge over others in point set data. The reason for their success is the optimal amount of storage and KNN finding speed. Octree suffers from both storage and speed problems and on the other hand range trees give an excellent KNN query result but significantly increase the storage requirements. In the analysis of speed and storage Kdtree has optimal results for both.

[2]Scanning machine device is constructed by Fraunhofer Institute for Factory Operation and Automation [Teu07]

[3]Graphics Processing Unit

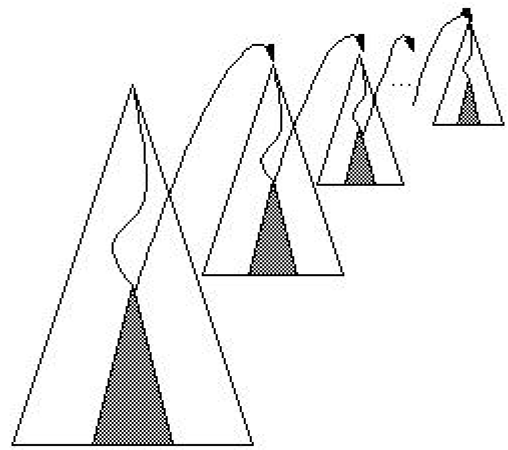


Figure 3.3: A d dimensional Range tree [dBCvKO02]

3.3 Normal Estimation

After finding the nearest neighbours for the point clouds data, next data processing is to find the local orientation of the surface. The normal estimation is necessary step for calculating local orientation, which is important for the shading process. A 3D point itself does not have any orientation, therefore local orientation of the surface is estimated for this purpose. On a triangular surface this can be computed without any significant effort. However in case of 3D point clouds this information is not presented in any form in the given data.

To find the orientation of a given point a 3D plane is fitted on the neighborhood of the given point. Normal vector calculated from this fitted plane is used as the direction of this given point [Hop95]. With this method tangent plane P with a unit vector $\vec{n}$ for a given point x in the **R**3 dataset S requires calculation of a set of k nearest neighbors points X such that X $\in$ S. At start it is assumed that k is user defined. The tangent plane P is defined such that it is a least square best fitting plane for the points X. The center of the plane o is taken to be the centroid of points X. The next part that is to find the normal vector $\vec{n}$ of the plane P is estimated by forming co-variance matrix[4] CV which is a symmetric 3 x 3 positive semidefinite matrix:

[4]Statics and probability theory describes covariance matrix as a matrix of covariances between elements of a vector [vK81]

$$CV = \sum_{y \in X} (y - o) \otimes (y - o) \tag{3.1}$$

In equation 3.1, $\otimes$ refers to the tensor or outer product of these vectors. The determination of normal vector $\vec{n}$ is based on the eigen values denoting CV. The resultant vector may have the opposite direction which should be corrected using the values from the nearby planes. HOPPE described the effect of k (number of neighbors) in

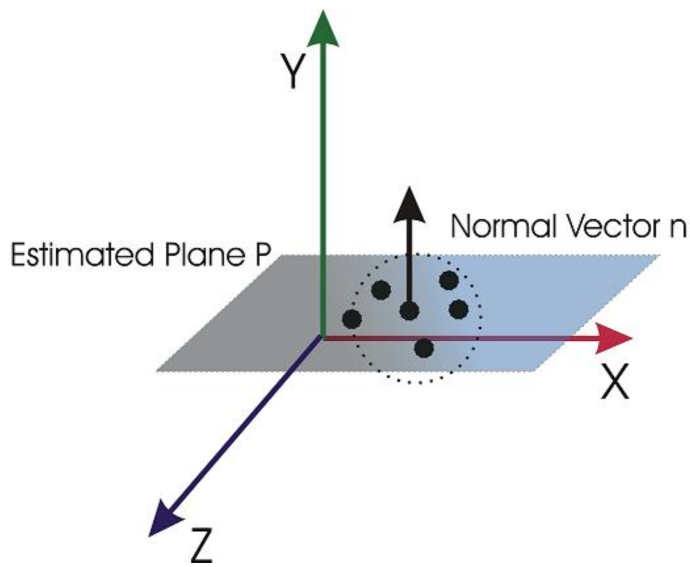


Figure 3.4: Plane P fitted on a set of points X with normal vector $\vec{n}$

the way that less number of k would result in domination of error on the surface orientation. On the other hand, an increase in the number of k would effect the normal vector locality and will provide orientation of more broader surface. To overcome this problem HOPPE proposes an adopted or automatic calculation of value of k such that k should remain optimal with respect to the local surface properties. For a adopted k , the algorithm should incrementally find points, on the other hand calculate the changing eigenvalues of the covariance matrix (For further reading see [Hop95] Section 3.2).

A slight variation in the HOPPE algorithm was adopted by Niloy J. Mitra [MN03] for noisy point set data. They proposed normal estimation algorithm for both **R**2 curve based and **R**3 point clouds data. Our interest in [MN03] is because they overcome the fixed k problem. They proposed to use adoptively computed a maximum radius r which should be used to search for nearest neighbors for each point. Since their equation to calculate r depends upon the value of k , therefore they iteratively calculated k for given r and vice versa to approximate the optimal number of nearest neighbors. They observed that after three recursive iteration to calculate r for given k and k for given r it returns the optimal value for both r and k (further reading [MN03] section 4.2).

In their work for shape modeling on the point set geometry Pauly et al.[PKKG03] demonstrated the relation between distance to the neighborhood. They proposed to assign weights to the found neighbors according to their distance to the considered point. Their idea behind weighted neighbourhood is based on the assumption that closest neighbours should have more effect on the local orientation than of those which are farther from the considered point.

Teutsch [Teu07] analysed the use of plane fitting method for points clouds generated from 3D laser scanners. He found the geometric plane fitting method to be more stable than the algebraic fit. Plane fitting method is based on least square orthogonal distance fitting [Ahn04]. Equation for a plane can be represented as

$$(X - X_o)^T n = 0 \text{ with } \|n\| = 1 \tag{3.2}$$

Where X_o is the point in plane and n is the direction vector for it. A plane is geometric fit if sum of squares of the distances to the given point is minimal. The sum of the orthogonal distances from each measured point X_i to this plane is computed by

$$\sigma_0^2 \equiv \sum_{i=1}^{m} \left[(X_i - X_o)^T n \right]^2 = n^T \left[\sum_{i=1}^{m} (X_i - X_o)(X_i - X_o)^T \right] n = n^T M n \tag{3.3}$$

Central moment tensor is given by a 3 X 3 symmetric square matrix M such that :

$$M \equiv \begin{bmatrix} M_{xx} & M_{xy} & M_{zx} \\ M_{xy} & M_{yy} & M_{yz} \\ M_{zx} & M_{yz} & M_{zz} \end{bmatrix} \tag{3.4}$$

Elements of the M are given by the relation to the mean values (X_o , Y_o , Z_o)

$$\begin{array}{lll} x_i = X_i - X_o, & y_i = Y_i - Y_o, & z_i = Z_i - Z_o, \\ M_{xx} = \sum_{i=1}^{m} x_i^2, & M_{yy} = \sum_{i=1}^{m} y_i^2, & M_{zz} = \sum_{i=1}^{m} z_i^2, \\ M_{xy} = \sum_{i=1}^{m} x_i y_i, & M_{yz} = \sum_{i=1}^{m} y_i z_i, & M_{zx} = \sum_{i=1}^{m} z_i x_i, \end{array} \tag{3.5}$$

Further, M is decomposed using the singular value decomposition [PTVF02] which converts M into the following equation

$$M = V_M W_M V_M^T \tag{3.6}$$

Where W_M contains a diagonal matrix containing principal central moments, V_M contains the principle axes of central moments. The fitting plane is then computed by the mass center $\bar{X}$ and the principle axis v_{MJ} with its smallest moment w$\bar{X}$.

$$\left(X - \bar{X}\right)^T v_{MJ} = 0 \tag{3.7}$$

He observed that the above presented method is more reliable by using (SVD) to solve the problem.
Normal plane fitting methods have an edge on the other techniques because of their consistency in the error data. In normal vector calculation, plane fitting methods have proven to be more reliable for scanner data processing.

For the noise free point set data amanta et al.has proposed [AB98] Voronoi based [5] method in his work for reconstruct polygonal meshes . Amenta et al.Voronoi based algorithm state that for a point P in the **R**3 point set S, normal can be estimated by calculating the Voronoi diagram VP and dual Delaunay triangulation TP. According to their method if CP is the Voronoi cell for point p , then with the farthest point x which is called the Pole of the p , normal for p can be estimated. Amenta and Ben has proved their theorem theoretically however this method is not efficient in case of a noisy data which is highly expected in scanned point sets.
To overcome the limitations of Voronoi based method, Dey and Goswami presented Big Delaunay Ball based algorithm [DG04]. A ball would be called Delaunay if its

[5] Denote the Euclidean distance between two points p and q by dist(p,q). In the plane we have dist(p,q) :=$\sqrt{(px - qx)2 + (py - qy)2}$. Let P := $\{p1, p2, ..., pn\}$ be a set of n distinct points in the plane, these points are the sites. Voronoi diagram of P is defined as the subdivision of the plane into n cells, one for each site in P, with the property that a point q lies in the cell corresponding to a site pi if and only if dist(q, pi) <dist(q, pj) for each pj . P with j $\neq$ i. [MdBO]

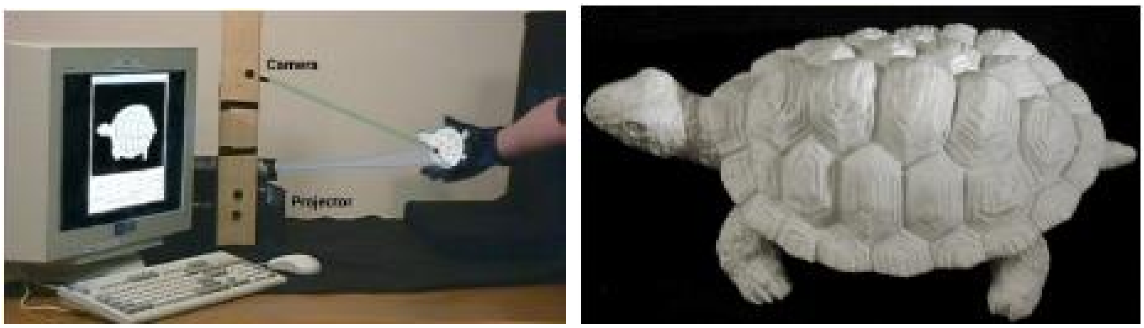
center is at a Voronoi vertex v and has a radius $\|v - p\|$ where v belongs to the Voronoi cell of point P. They introduced the term polar balls such that if it contains a pole in the center. In the view of above defined polar balls and Delaunay balls the algorithm of Amenta et al.algorithm can be described as, If a point p is on the boundary of a polar ball, the segment joining p and the center of the polar ball can estimate the normal. Their algorithm's credibility is based on the observation that certain Delaunay balls remains large and can play the role of polar balls. So, they defined the pole for a point p to be the farthest vertex in its Voronoi cell with a large Delaunay ball according to the radius of the nearest neighbor's comparison with a given threshold.
Tamal K. Dey [J05] compared Voronoi based techniques and proposed that the Big Delaunay Ball based algorithm is robust of all, However it comes with the cost of speed since it is based on Delaunay triangulation of the whole point clouds rather local computation.

Both plane fitting methods and Voronoi based methods work well for the point clouds data. However, for particularly scanned point clouds which possess significant error data, plane fitting methods have shown accurate results.

3.4 State of the HMI Concepts

In this section, the state of the art HMI techniques being used with flexible hand-guided scanners are provided. We will discuss their approaches for visualization of the acquired data. We will only present those scanners which have human interaction during the object scanning. The amount of work in literature for hand guided scanners are very rare due to some reasons. The foremost reason is that flexible scanners vary in sizes, methodology and scanning procedure in so many ways that one generalized techniques can not be adopted for each scanner. Second main hurdle is their use as commercial products, therefore, their working is not publicly published or introduced.

Szymon Rusinkiewicz et al.presented a portable scanner with structured light range scanning [RHHL02]. Instead of projecting a point or line on the surface of the object they have used fully structured triangulation patterns. The camera device takes a picture every 0.6 second. However, instead of moving the scanner over the object to generate data, their camera and laser device remains on one position and object is slowly moved in their line of sight to capture the whole surface. To ensure that user has completely scanned the whole surface the user is presented with the preview of scanned data in real time. Due to the large amount of data acquired it is presented in raw format. The preview does not give any information about the

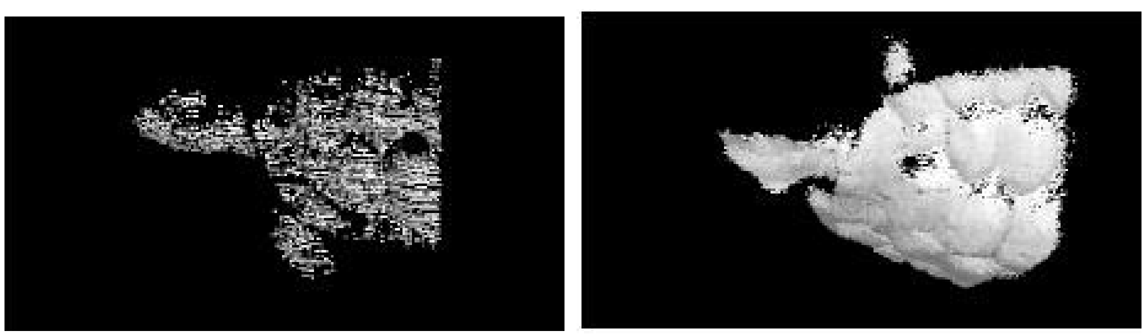


(a) Portable scanner device connected to the computer while fixed on the table

(b) Close view of the object being scanned with portable scanner

Figure 3.5: (A) Portable scanner device connected to the computer while fixed on the table (B) Close view of the object being scanned with portable scanner [RHHL02]

quality of data since it is not properly shaded, however it does demonstrate the holes in the surface. To provide the preview functionality they triangulate each raw image taken from the camera. Further they calculate the normal vector for each vertex in the data. First they aligned all the images and then merged by quantization of all the points into a 3D grid in a way that all those points which lie on the same position are combined [RB92]. For rendering they used splatting which is

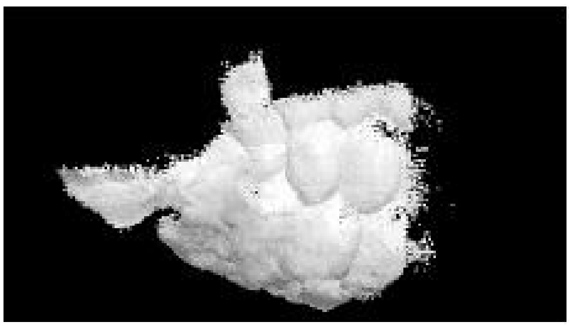


(a) Preview of object being scanned in early stage

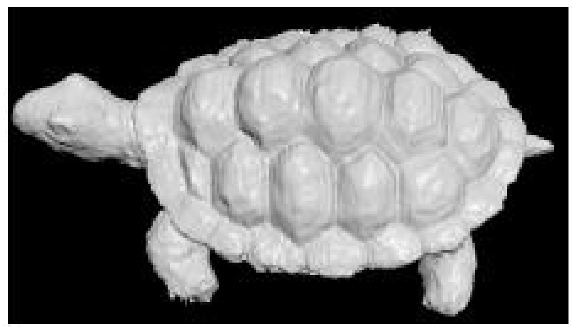
(b) Preview of object being scanned in early stage

Figure 3.6: Preview of surface scanning using portable scanner [RHHL02]

quite common practice in 3D surface rendering. Their chossen splatting because it helps in removing the holes in the data. They combined splats from the neighboring points if they overlap the point with a certain ratio. Figures (3.6) and (3.7) shows the different steps of surface sampling and their respective live preview. For offline surface reconstruction they performed some simple post processing steps. Since post processing is performed when the user has stopped the scanning process therefore the grid data structure is discarded due to flexibility in processing time. After that all processing is performed on real range images. They merged range images using high quality VRIP [CL96] algorithm. For surface reconstruction they used classical marching cubes algorithm [MIN99]. Their work has shown good results since shaded models are capable of providing information about the scan data quality and holes in the surface, however, they did not informed about any other post processing such as decimation, smoothing, or filling of inaccessible holes performed on the data.



(a) Preview of object being scanned in final stage



(b) Preview of surface scanning after complete scan and surface reconstruction

Figure 3.7: Preview of surface scanning during scan and after off-line surface reconstruction [RHHL02]

Another flexible 3D scanner with human interaction exist in literature with the name AutoScan. It was proposed by N.A Borghese et al. [BFB$^+$98]. Autoscan is based on Elite tool [BRFP91] which is used in medical motion analysis. In Elite physical patches called markers are attached to the considered body/object. Data returned from the markers are used to analyze the motion of this object. However in AutoScan, no physical markers are used. Elite implemented for AutoScan is provided with the virtual markers. These markers are laser shapes projected on the object surface using a laser pen device by the user. Position of markers on the object surface are computed as the mean position for its constituent pixel. This position is observed by the camera device attached with the computer system. Camera device remains still during the scanning process. AutoScan has same advantages and limitations which a flexible scanning device has. Since it has a human handled device that is laser pen which drops markers on the object's surface. Thats why they presented a live preview functionality. They did not perform any shading or surface reconstruction algorithm for live preview. Scanned data is pasted as it is on the attached computer screen in form of raw point clouds. Once all the surface is completely sampled,

Figure 3.8: Scanning a woman's face using AutoScan [BFB+98]

(a) Live Preview of AutoScan scanning process

(b) Live preview of AutoScan scanning process

Figure 3.9: Preview of surface scanning during scan and after Delaunay Triangulation [BFB+98]

Delaunay triangulation is performed to reconstruct the surface. Fig 3.9 (a) shows the live preview of a women's face being scanned. Figure (3.9(b)) shows a reconstructed surface using Delaunay triangulation.

3.5 Summary

In this chapter we have presented state of the solutions to the problems in the field of 3D scanning. We presented the reader with state of the art techniques for KNN finding in 3D point set data. Not all of them were relevant to the problem or to the proposed solution, however having a brief knowledge about the advantages and disadvantages of basic tree based structures was necessary to acknowledge the proposed system. Further we discussed the techniques for normal estimation for 3D point clouds data. We discussed two basic techniques such as plane fitting method and Voronoi based method. We discussed the pros and cons for these techniques. We also presented different techniques in literature which are based on these two techniques and analyzed their efficiency in different problem domains. In the last part we discussed some projects relevant which include human interaction for 3D scanning and possess live preview functionality as a ingredient for scanning system.

Chapter 4

Proposed Approach

In this chapter, the proposed solution for the given problem is presented. However, before explaining the proposed visualization and HMI techniques, it is necessary to have a look at the given problem. After explaining the problem statement, proposed technique is explained in a short paragraph without going into the inside technical details. To increase the readability of this chapter, it will be divided into two main parts. First part will deal with the visualization of the acquired data and second part will briefly describe the proposed HMI techniques.

4.1 Problem Statement

This work deals with the flexible laser scanner's data acquisition process. There are three main objectives of this work.

(a) Online preview functionality for the scanned data during data acquisition process. The online preview refers to a shaded scanline by scanline preview which should be presented during the data acquisition process. Since the data is dense and contains significant amount of error, therefore, presenting raw data does not serve the purpose. Online preview must be properly shaded to give a brief information about scan data quality.

(b) Second main objective is the analysis of the human hand controlled parameters which effect scan data quality. Flexibility of the considered device enables the user to easily scan objects with complex surface, however, this flexibility comes with the cost of uncertainty in the data quality. Since, it is a human controlled device, there are multiple parameters which are effected during scanning process because of human control. These parameters must be monitored by the user to ensure the scan data quality.

(c) Third main objective is to propose an excellent visualization and HMI technique which should convey the above said parameters to the user at run time. Further, the visualization technique should avoid the need of simultaneous monitoring of screen and object which is the main cause of having a hectic scanning technique .

4.2 Proposed Solution

As a solution to the above mentioned problems, this thesis presents a visualization system for flexible 3D scanners. An online shaded preview technique is proposed for the scanned data. Proposed system provides feedback during scanning procedure on the screen in the form of shaded point clouds, which gives an informative view about the scan data quality. Further, the human controlled parameters are analysed and proposed an HMI approach which assists the user during scanning process for monitoring these parameters to reduce the suspected errors. Since, scanning and monitoring these parameters is a hectic task and needs frequent changing of the focus from the screen to the object, therefore using 3D games techniques particularly, FPS games techniques to provide all the information on the screen is proposed.
For further discussion, this work is divided in two main parts. The part one will deal with the visualization technique for scan data quality i. e., online preview of the scan data. In this part, the proposed algorithm is discussed. In the second part, first, the human controlled parameters as well as their suspected effect on the scan data quality is briefly discussed. Later,the FPS technique based solution to convey these parameters to the user without frequently changing the focus from screen to the object and scanner is presented. The proposed solution aims to provide the same amount of information on the screen which the user seeks by looking at the object, hence reduces the flickers in focus.

4.3 Online Preview Functionality

In this section, proposed solution for online preview functionality will be presented. As discussed before, scanned point clouds have a dense structure and can not be presented without properly shaded or reconstructed in surface. The optimal solution for the online preview functionality would be in the form of an online surface reconstruction algorithm, however, there are number of reasons why online surface reconstruction algorithm can not be adopted. Firstly, the state of the art techniques for surface reconstruction have yielded good repute in terms of quality, however, these techniques consume a significant amount of time which is not available in the current scenario. Secondly, the amount of suspected error in the scanned data does not allow

adoption of an online surface reconstruction algorithm as an optimal solution because scan passes may or may not be made part of the final data, therefore, it is possible that a scan pass which was reconstructed could be discarded by the user, hence will result in unfruitful effort. Furthermore, the amount of information necessary for a user during the scanning process to ensure the scan data quality is minimal in contrast to the computation effort necessary for the online reconstruction phase. Therefore, following a route which leads to an online reconstruction algorithm would not be an ideal choice.
The proposed solution for online preview is to shade the point clouds after finding the nearest neighbours for each point and present data on the screen with minimal delay. To discuss the proposed solution, first a generic algorithm which was adopted as the main idea for the given problem will be presented. Later,the further steps which were taken to maintain the ratio between the speed and the quality of the proposed algorithm are presented.

4.3.1 Nearest Neighbour Calculation

To calculate the normal vector for each point finding the nearest neighbours is the first step. For a point clouds data finding the nearest neighbours for whole point set is not a big deal and literature provides a lot of algorithms for nearest neighbour calculation in point set data as discussed in section (3.2). However, the important point that should be made clear is that nearest neighbours are calculated from the surroundings of a given point which is not completely available in the given problem. For a given scanline, previous nearest neighbours can be calculated easily because the previous scanline would have been already stored. However, no assumption can be made for the forthcoming data. Therefore, the algorithm relies on the previous data only. For nearest neighbour query KdTree is adopted . KdTree has shown good results for the point set data acquired from the 3D scanners (see section 3.2.2). The generic algorithm for normal calculation can be seen in procedure (NormalCalculation()).
The proposed method creates KdTree for each newly generated scanline. Further, for each point in the current scanline, nearest neighbours are searched in both the current KdTree and the previous KdTree. As a test case, fixed radius KdTree query is used. This simple algorithm was tested on the different datasets with radius 1 and yielded good results in terms of quality. In the basic algorithm there is no check for number of nearest neighbours found in one tree. However, if the number of nearest neighbours are significantly smaller than the other points, that point is discarded and coloured white to represent an error. Furthermore, any scanline with less than three points is considered as an error and discarded before any computation. However, number of error scanlines are considerably low and seldom found in data.

Procedure `NormalCalculation`

```
Input : Points Clouds Data PC
foreach ScanLine S in PC do
    Tree = MakeTree(S)
    foreach Point P Where P ∈ S do
        KNN=FindNearestNeighbors (PrevTree)
        KNN=FindNearestNeighbors (Tree)
        Normal=EstimateNormal (KNN)
        Normal=CorrectNormal (Normal)
    PrevTree=Tree
```

4.3.2 Normal Estimation

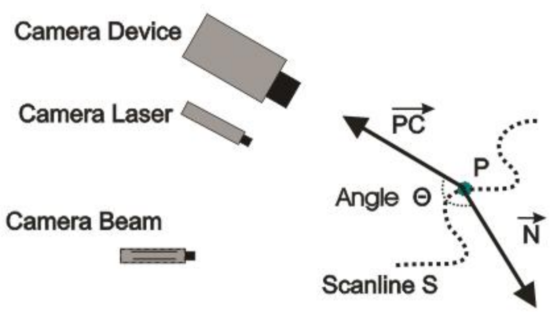
For normal estimation normal plane fitting method is adopted. In fact, the method proposed by Teutsch [Teu07] which was described in section (3.3) is used. However, there is a small glitch in this method in terms of normal vector direction. The estimated normal vector direction could be pointing in the opposite direction, since the estimated normal depends upon the coordinate system. The figure(4.1b) shows a normal vector pointing in the wrong direction. However, flipping the normal to the correct direction is not a big problem. The angle between the two vectors i. e., from the point to camera point and calculated normal vectors are compared. If the angle between these two vectors is greater than 90 degrees than the given vector is flipped to the opposite direction. In mathematical terms it can be written as,

$$\vec{n} = -\vec{n} \quad if \quad \arccos\left(DotProduct\left(\vec{PC}, \vec{n}\right)\right) \quad > \quad 90 \tag{4.1}$$

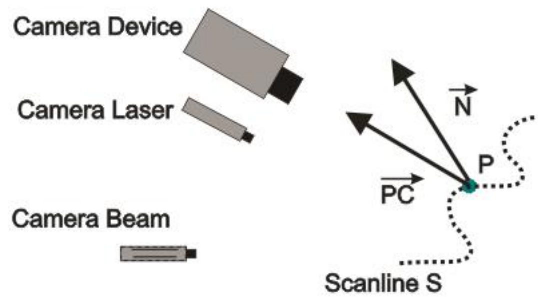
Assuming that $\vec{PC}$ is unit vector from point P to camera point of the given scanline, and $\vec{n}$ is the estimated unit vector of the point P . Figure (4.1) explains the procedure in detail.

Normal Refinement

The plane fitting method relies upon the quality of the nearest neighbours provided for the plane fitting. Therefore, it is expected from the point set data that the nearest neighbours would be provided from the surroundings of the given scanline rather



(a) Wrong normal vector with angle greater than 90



(b) Flipped normal after correction

Figure 4.1: (a) Wrong normal vector with angle greater than 90 (b) Flipped normal after correction

from one direction i. e., previous data. However, in the given scenario points from the previous scanline are searched for nearest neighbours. This fact can not be neglected that normal direction of a point changes as its surrounding changes. Therefore, the normal which was estimated with only previous data would not be accurate. The results showed that non-refined normals still fulfils the purpose for scan data quality assurance. However, for a simple solution, the normal updation method proposed by T. Bodenmueller et al. [BH04] can be adopted. They explained this method such that, normals for all the searched nearest neighbours of a given point must be estimated since the new point has changed the neighbourhood. However, in the given scenario the simple solution would be to only change those neighbourhood point which were found from the previous scanline. However, this solution should only be adopted in the case when the computation time is not a problem which is not the case with present scenario. The optimal solution would be, to keep the current normals and if found necessary, normals should be again estimated once the complete scanpass has been done. One KdTree can be used to store the whole point clouds once again and then same KNN and normal estimation procedure can be adopted for whole point clouds of one scanpass.

4.3.3 Shading

For shading of points clouds, no extra efforts are done. The basic Gourad [Gou71] shading model which is less computationally less expensive than the Phong Shading.is adopted. Once all the KNN and normal estimation has been explained the shading

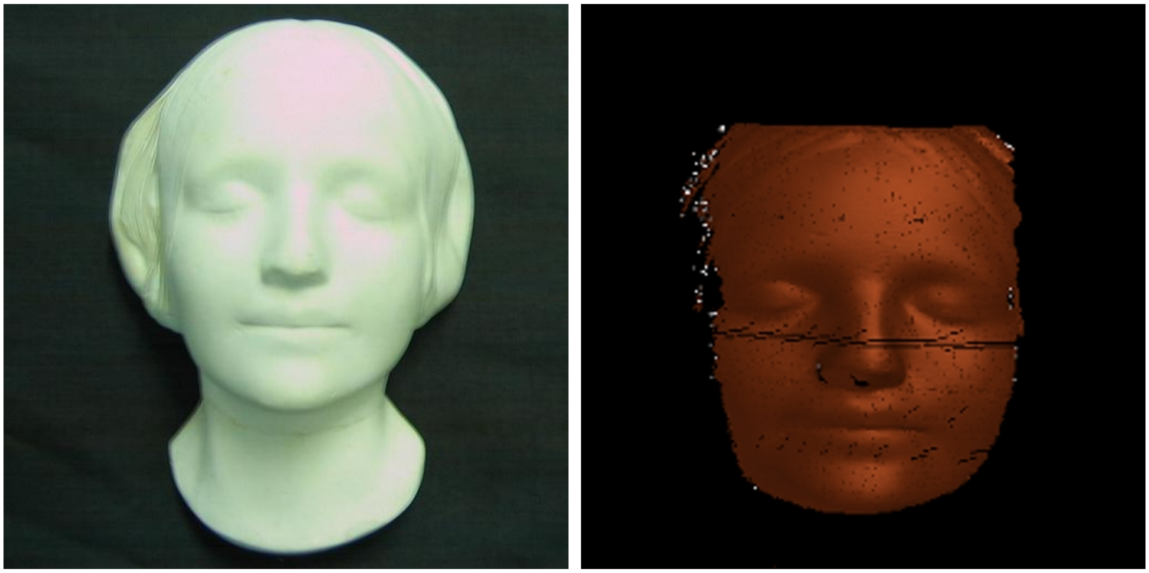
Procedure `OnlinePreview`

```
Input : Points Clouds Data PC
foreach ScanLine S in PC do
    Tree = MakeTree(S)
    foreach Point P Where P ∈ S do
        KNN=FindNearestNeighbors (PrevTree)
        KNN=FindNearestNeighbors (Tree)
        Normal=EstimateNormal (KNN)
        Normal=CorrectNormal (Normal)
        AssignNormal (Normal,P)
        DisplayPoint (P)
    PrevTree=Tree
```

of the point clouds during scanning process can be seen as in procedure (OnlinePreview()). Figure (4.2) picture shows a shaded point clouds of a woman's face using the above algorithm. The presented model has 389756 points, the amount of time taken to scan this data is approximately 6 Seconds. On the other hand the time taken by the basic algorithm to shade this model is significantly high about 11 seconds. The quality of shading can be seen as in a acceptable range since the gaps and holes in the data can be easily seen. The gaps between the scanlines are visible which shows data density with the given speed.
At the quality level, the algorithm serves the purpose. The time consumed to shade the model is unacceptable. To overcome the time issues, two solutions are proposed which will be presented in the forth coming section. The two proposed methods can be categorized as spool based approach and implementation based approach.

4.3.4 Spool Based Method

There were two main parts in the basic online preview section which cause the computation time to increase than the required time. The first time consuming portion is to make the separate KdTree for each scanline. On the other hand, the range given to the KdTree is 1. For the dense point clouds, using 1 mm radius return average thirty nearest neighbours which are more than enough for accurate normal estimation. However, searching these points needs a lot of time. To overcome these two problems, Spool based method is proposed. The KdTree used to this approach has adopted

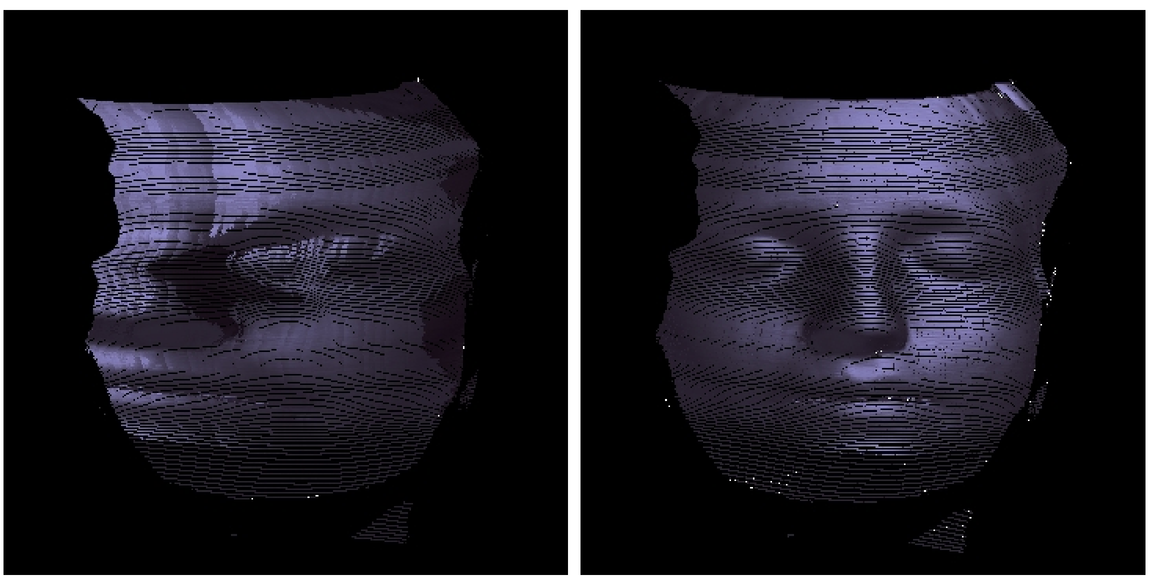


(a) Orignal Model **(b)** Shaded Point Clouds

Figure 4.2: (A) Original Woman Face model (B) Shaded Point clouds

r as proposed by [MN03]. The Spool based algorithm can be seen in procedure (SpoolMethod()). Instead making KdTree for each upcoming scanline, spool based method waits until a number of lines defined by a user parameter n to arrive and make Kdtree for these lines. Further for nearest neighbor finding, Kdtree is searched within an optimal radius r . The rest of the algorithm works as stated before. Each spool is independently processed and does not effect other spool processing. For optimal value of n , the working of algorithm was analysed with different values. From the observed results it can be said that $n < 3$ i. e., 2 result in poor quality and gives visible edges on the surface between each spool data. Further, it fails to perform accurate shading when the surface geometry is suddenly changed. Using $n > 3$ gives good results in terms of normal estimation accuracy and shading quality, however, gives visible delays if n is used significantly higher. From the observed results, it can be said that $n = 3$ is an optimal value in terms of quality and speed.
A reasonable objection can be made here that online preview functionality aimed to provide user a real time preview which is not the case in spool based method. For justification of this method, it should be reminded that the considered scanner generates scanlines with very high frequency. The delay between each scanline is merely observable by the naked human eye. Further, the spool based method with spool parameter $n = 3$ would update the display every 30 ms which is remarkably high. Figure (4.3) shows the results of the same data set which was used in basic algorithm, (a) with $n = 2$ and (b) with $n = 3$. The spool based method results in a

```
Procedure CreateSpool
Input : Points Clouds Data PC
foreach ScanLine S in PC do
    if count < n then
        temp := S
        return
    Tree := MakeTree(temp)
    foreach Point P Where P ∈ temp do
        KNN:=FindNearestNeighbors (Tree)
        Normal:=EstimateNormal (KNN)
        Normal:=CorrectNormal (Normal)
        AssignNormal (Normal,P)
        DisplayPoint (P)
```



(a) **(b)**

Figure 4.3: Woman Face model with Spool based method (a) Result with $n = 2$ (b) Result with $n = 3$

accurate normal estimation and requires significantly less time for shading than the basic scanline method. However, spool based method still does not responds in a real time. The amount of delay is minimum however, still can not be called real time or online preview. The delay in data processing is not a matter in terms of 3D scanned point clouds since, the 3D point sets are always in a large numbers. The displayed result was scanned in 6 seconds and the shaded model was generated in 8.5 seconds which is quite close to the scanned time. To overcome this delay some steps can be taken at implementation level.

4.3.5 Implementation Level Improvements

The 3D scanners with preview functionality discussed in section (3.4), suffer from the same delay in preview problem. Since, the scanned point set data is always generated in a big amount and which is dependent upon the surface size, therefore, the delay in the online preview is acceptable. However, for the considered 3D scanner and proposed HMI technique, current scanline being sampled is very important since it does not only inform about the scan data but it also informs about the part of surface under camera focus. Therefore, the delay which seems quite minimal must be removed. The spool based method results good shaded models in minimal time delay but still can not be said perfect. On the other hand, the delay in the preview is not acceptable for a better HMI technique. Therefore, a simple technique is proposed which should keep the continuity of the preview system and provide shaded preview as well. The technique can be seen as a variation in the spool procedure. The proposed method is that the number of scanlines which have already been processed should be displayed with the shaded points and the upcoming scanlines if generated during previous spool data processing should be displayed on the screen without shading. The raw format data would not contain any visible information about the scan data quality however, would still give the feel of continuity in the process which is very important for the HMI techniques discussed in the further part. Figure (4.4) shows the result of a simulation using proposed shading method.

4.4 HMI Technique

The second part of this thesis work proposes a HMI technique for the scanning process of flexible laser scanners. As discussed before, the HMI technique aims to provide the user information about human controlled parameters which plays vital role in scan data quality. This section is further divide in two parts. In the first part, brief information about these parameters will be given with their analysis i. e., how they influence the scan data quality. Later, proposed HMI technique will be presented, which is inspired from game visualization technology particularly FPS games.

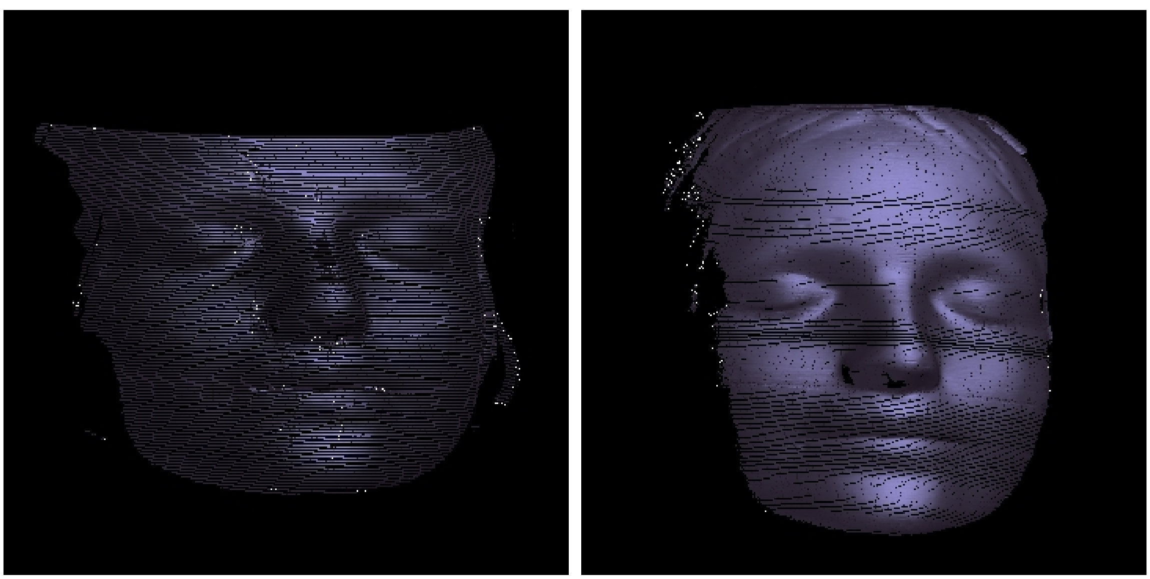
Figure 4.4: Half shaded model of a woman

4.4.1 User Controlled Parameters

The flexible scanners intend to give the user flexibility over the size and the complexity of the scanned surfaces in parts by looking at the result of the previous attempts on the screen. However, the flexibility comes with cost of uncertainty in data. Since human control over machine is not perfect due to a number of reasons. An objective of this thesis was to analyse these user controlled parameters which plays significant role in acquired scan data quality. If compared with the box machine based scanners which are totally controlled by machines, it is analysed that there are three main parameters which are now in the hands of the user.

Scanning Speed

The speed at which a scanning device generates data plays an important role in scan data quality. However, in this matter, the scanning speed with which a user swaps the scanner on the object surface is considered. There are different effects of a scanning speed of a scanning device and the scanning speed of the user on the scanned data quality. With respect to the considered scanning system, it can be compared as the gaps between the sampled data point within a scanline is due the scanning system and data processing techniques, however, the distance between the scanlines is partially controlled by the user's scanning speed. If the scanning process is seen as a spray paint on a surface, the more part of a surface remains under the focus of the spray paint, it would get more amount of paint. Same in the case of 3D scanning, if user scans over a surface in a slow speed then the data would be overlapping and considerably dense. On the other hand, a quick surface scan will result in gaps between the scanlines and more overload to the post data processing phase. For being at the safe side, it can be said that the slow scanning process is more accurate than a quick scan if the data processing time at the post scanning process is not a big matter. Further, during scanning there are multiple parameters which the user has to observe such as, the two laser lines from a laser beam and camera laser which frequently change their positions due to hand movements and surface features. A quick scan will fail to observe and maintain other parameters. Both scanning quickly or a very slow scan would cause trouble in the data processing phase. Unfortunately, there is not any measure which can be used to judge the speed. The decision should be taken at the scanning time by the user himself. Figure (4.5) shows two shaded data sets of the same object with



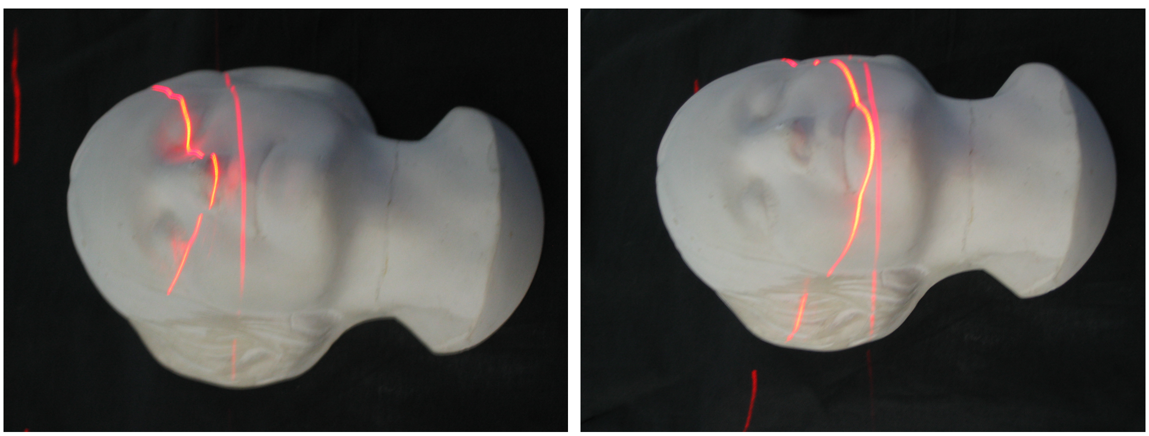
(a) **(b)**

Figure 4.5: Woman Face model with different speeds (A) A quick scanned data (B) Slow scanned data with considerably more points

slow and fast speed scanning. Visible gaps between the scanlines can be seen in the fast scanned data.

Distance

The importance of the distance between object and the scanner is a technical issue. The considered flexible 3D scanner works with both optical methodology and tactile methods. As discussed in section (2.2) the camera device mounted on the scanner head captures images from the object surface. Since, the quality of these images are important for the contour extraction, where the captured image is processed, therefore, the camera device as well as laser device which projects the laser line on the surface should be at the optimal distance. If the distance to the object is very small it would result in uncertainty in the data since, the observed point of both camera device and the scanner device would be different. On the other hand the camera device mounted on the scanner head has a fixed range and can not capture quality images if taken from out of range distance. Therefore, the need of the optimal distance is given importance. During scanning the two laser lines projected from



(a) (b)

Figure 4.6: Woman Face Object with laser Lines (a) Laser lines have gap indicating wrong distance (b) Overlapping laser lines indicating optimal distance

both laser devices are equipped in a way that when the optimal distance is reached the two lines overlaps each other. Figure (4.6) shows the two lines on same object with two cases. Figure (4.6(a)) has distance between the two laser lines which is an indication of wrong distance between scanner and object. Figure (4.6(b)) is taken during the same scanning process and the two laser lines are overlapping from the middle which means scanner and object have optimal distance. The laser lines does not look straight because of the object surface as well as the cylindrical lens in front of them.

Angle

The third main parameter which plays an important role in scan data quality is the angle between the scanner head, particularly equipped camera and the object. There are two factors that must be discussed here. The first effect of the scan angle can be described as if the angle between the surface normal being scanned and the viewing of the camera device is minimal the captured image quality would be better. Apart from this the main issue, the matter which makes the angle important for HMI technique is that, during the scanning process the user has to monitor that if camera can actually see the projected laser line from the object surface. The geometry of complex surfaces makes it impossible for the camera to capture laser line. During scanning process the user has to monitor this factor as well. The optimal approach in this case is that if the camera can not see the laser line with the optimal angel as stated before, the angle should be increased rather having a hole in the acquired data.

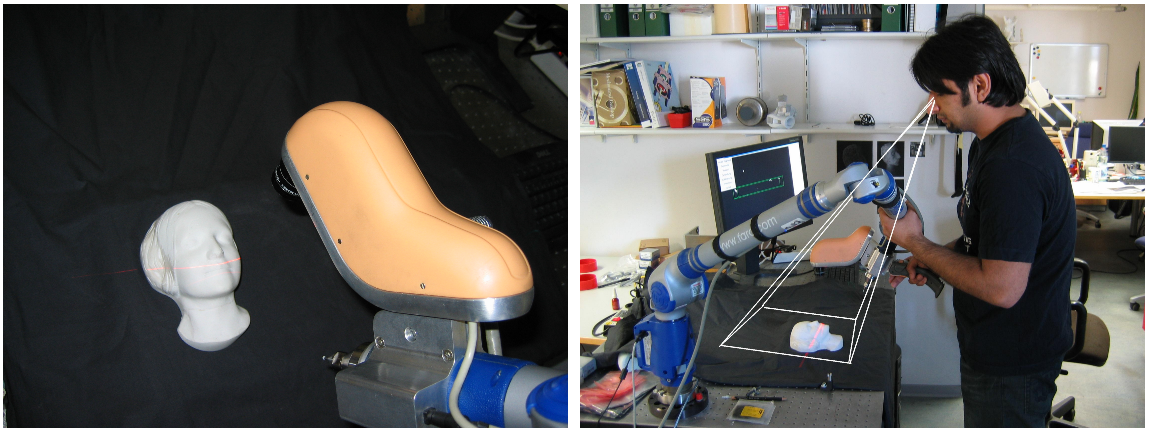
4.4.2 Proposed HMI Approach

In this thesis, the use of game visualization techniques for the given problem is proposed. The first person shooter games aim to provide the user information necessary at the middle of the screen and give realism to the generated scene by giving missing information through other means such as background sounds. This thesis propose to provide the first person perspective view of the scanning process of the user using the scanner on the attached display. The problem statement of this work clearly states two basic ingredients of the solution,

(a) Transmission of the user controlled parameters to the user during scanning process.

(b) Ergonomic HMI technique which should avoid the need of simultaneous monitoring of object and screen.

Before justifying and describing the first person perspective view of the scanning process, having a look at the original first person perspective view of the scanning process is inevitable. The figure (4.7) shows the perspective view of the user in (b) from the side view, and (a) from the perspective view. The foremost reason for flexible laser scanner to have an agitative scanning process is that the user has to frequently change the focus from the screen to the object/scanner. The reason behind this need to fluctuate the focus is that the amount of information presented at the screen with or without online preview functionality is not enough for a successful scanning process. The other information which the user has to monitor during scanning is not available on the screen that is why the user is forced to look back at the scanner. The first person perspective view of the user shown in figure(4.7(a)) contains that information.



(a) (b)

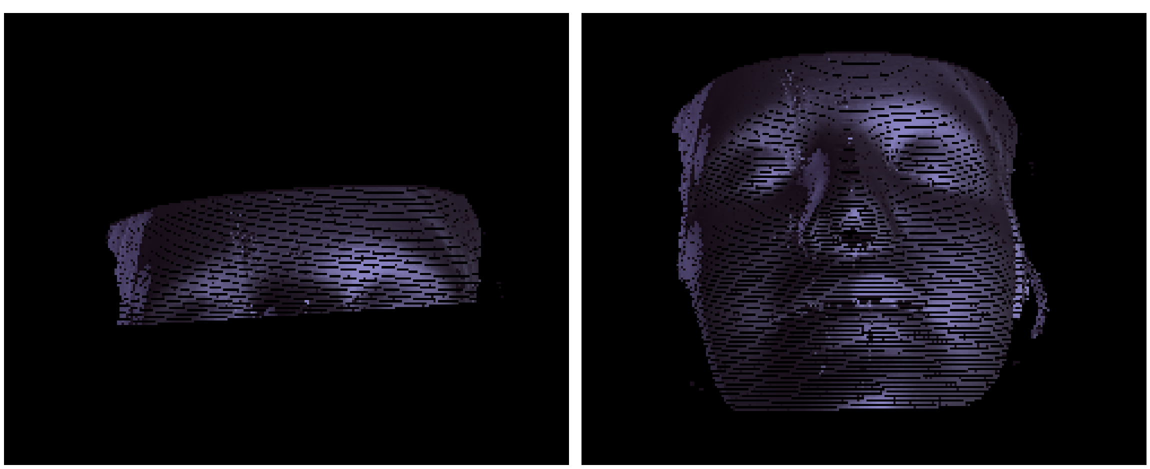
Figure 4.7: FPS view of the scanning process (a) First person perspective of the scanning process (b) Shows the viewing frustum of the user

The proposed solution is based on the idea that providing the same view on the screen would reduce the need to look at the object simultaneously. The required information which the user seeks from the viewing frustum shown in figure (4.7(A)) has already been discussed in previous section i. e., the scanning speed which indirectly tells how much object has been scanned already, the distance between the scanner head and object which user perceives with the help of two laser lines on the object surface and finally the angle between camera viewing and surface normal. This information which is distance, speed and angle has different units of measures. If presented in the written form on the screen, it will further increase the focus fluctuation within the screen and providing three measures with different units does not make sense. To solve this problem, FPS games technique is adopted. Since, the FPS keeps the user's focus at the middle of the screen and conveys the information through other means which does not needs focusing, therefore, it significantly matches the given problem. In the following section proposed solution is discussed that how the first person perspective view on the screen with online preview functionality serves the purpose with respect to the three main parameters discussed in previous section.

Scanning Speed

There are two sources which can inform about the scanning speed of the user. The movement of the scanner itself is a major source for the scanning speed. However, there are some concerns which does not allow to use this source. The scanner is controlled by the human hand which is not perfect in terms of intended movement and resultant movement. Since the 3D scanner is a flexible device, therefore, it responds

to the very small vibration in the human hand as well. Using scanner movement speed as the scanning speed will result in very inaccurate results since, not all the scanner movements are important. Second source of information for scanning speed is the generated scanlines. As described in the previous section, the scanning system keeps on generating data even if kept on the same part of the object. Therefore, if scanner is slowly moved there would be less distance between two consecutive scanlines, on the other hand, in a quick scan this distance would be relatively high. Using this distance to compute the scanning speed has several advantages such as no response to the unwanted vibration of the hand or environment.
For the scanning speed and covered distance, the proposed solution adopts the same visualization technique introduced by FPS games. The FPS games adopt the strategy that the currently focused object remains at the centre of the screen and the surrounding objects are moved in perspective projection. Since, the perspective projection is similar to the human eye viewing, therefore, it helps putting focus at the current object by reducing the size of the objects farther to viewing plane and increasing the size of objects closer to the viewing plane. For the current scenario, the current generated scanline is used as the current focus. As a new line is generated, it is placed at the center of the screen and the previous scanline moves away in opposite to the scanning direction. If the user slowly moves the scanner the generated scanlines has less distance therefore the generated view scrolls very slowly. On the other hand, a fast scan scrolls the view very quickly and indicates a very fast scanning speed. Figure (4.8) shows two screen shots of a scanning process with the current scanline at the middle of the screen. There is a small disadvantage in using the current scanline



(a) **(b)**

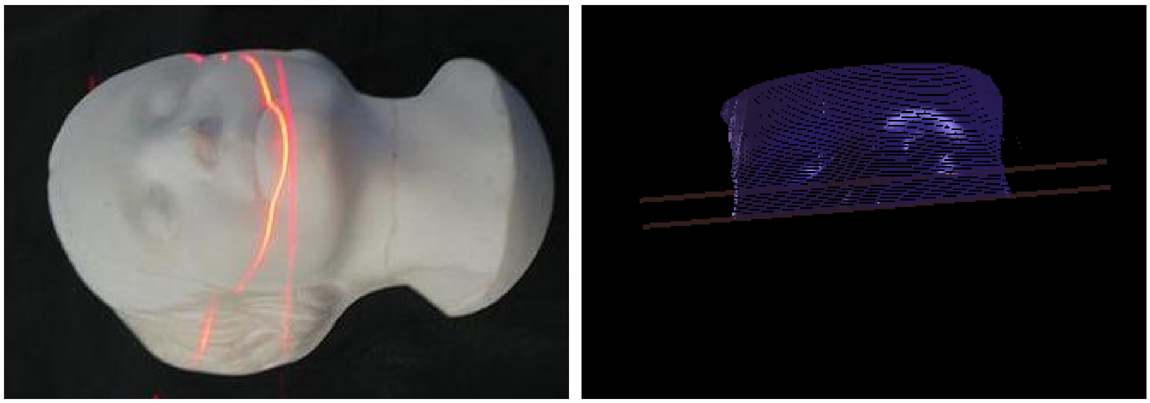
Figure 4.8: Woman Face model with current scanline at the middle of the screen

at the center of the screen. The the mean point of the current scanline is used as the center of the current scanline which creates a smooth effect in focus transition of one scanline to another. However, in case of a error data, when the number of points in a scanline are significantly lower than the previous scanline, it results in a disturbance in the view since the whole view transfers to the mid of the error scanline. This error is accepted as a limitation in the proposed solution since it is inescapable and the number of scanlines with low point counts are rare.

Distance

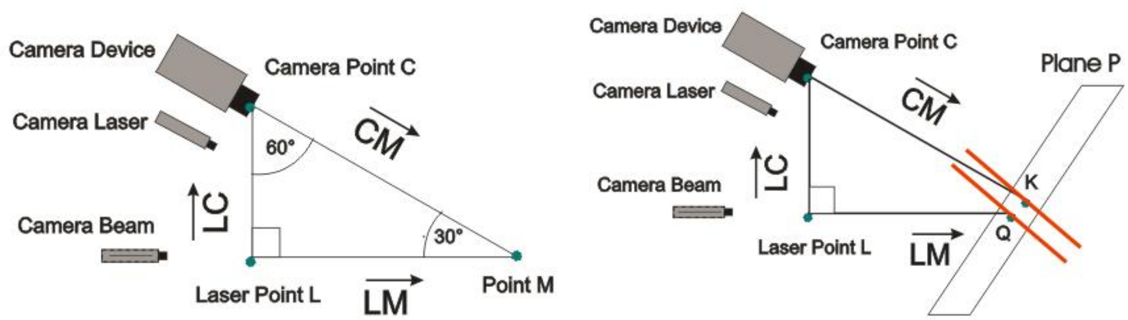
The current system is aware of the fact that the distance between the object and the scanner is an important factor in scan data quality. The two laser lines on the object surface already inform the user about the distance between object and scanner. During the scanning process, the distance between two laser lines takes the most attention of the user and maintaining this distance is given priority over the other parameters. In normal life the distance between two points can be measured in different units such as meters or centimeters depending upon how much is the distance. However, the distance between the two laser lines changes very frequently that if presented in the written form, it would result in disturbance and will require much more focus than the preview of the point clouds. The proposed solution for this problem is again adopted from the FPS games. The FPS games, particularly shooting games always have a crosshair which indicates the line of sight of the weapon in the hands of protagonist. This idea is adopted for the two laser lines. Instead of converting it into some other crosshair symbol, the same two red lines are used as crosshair. The distance between the two red lines on the screen is identical to the distance at the object surface by the laser lines. Figure (4.9) shows the two red lines on the object surface and on the screen respectively. To accomplish the corsshair visualization technique, the line of the sight of the camera laser as well as laser beam is necessary. This information is provided by the scanner hardware. The figure (4.10 (a)) shows the line of sight of the laser and the camera. The idea behind the two laser line has a complexity at implementation level. On the original object, the laser lines can be seen on the object surface since the object may not be properly scanned but still collides with the laser lines. However, on the screen only scanned data is available and the laser line position can not be calculated without information about the further object geometry. To accomplish this, a plane P is defined using a point n and a normal vector $\vec{a}$ which is opposite to the viewing direction.

The point n could be used as the the mean point of the current scanline. To calculate the position of the laser lines on the object, two rays are shot from the camera and the laser points. The direction of the two laser rays LM and CM is available through the scanner itself. Points where the two rays intersect with the



(a) (b)

Figure 4.9: Distance between object and scanner in original and on the screen



(a) (b)

Figure 4.10: (a) Line of sight of the camera laser and the laser beam (b) Camera and Laser line calculation for screen view

plane P , two lines are drawn in the direction d which can be calculated by,

$$\vec{d} = \quad CrossProduct\left(L\vec{M}, C\vec{M}\right) \tag{4.2}$$

Since the intersection points K and Q on the plane P would be almost on the middle of the scanline, the drawn line is expanded in both positive and negative direction of $\vec{d}$. It can be said that, when $K = Q$ the distance between the scanner and the object is optimal. Figure (4.10(b)) shows the procedure in pictorial form.

Angle

The most sensitive and difficult to visualize parameter is the visualization of angle between the viewing direction of the camera device and the surface normal. The units used for angle measurements are radian and degree, however, they are quite difficult to visualize even if provided with the exact measurement in written form there is no clear idea what the exact direction the scanner should be moved to. To solve the angle visualization problem, the main idea from the FPS games are adopted. The FPS games always show a weapon in the hands of the protagonist or main character which moves with it within the scene. Since, the user who is scanning the object judges the angle by looking at the scanner and the object itself, therefore, an identical 3D scanner model is placed on the screen as well. The 3D model is placed in the scene such that, the laser point is taken as the origin for the 3D scanner model. Therefore, setting the exact location for the 3D model in the scene is not a big problem. However, the orientation of the 3D model of the scanner needs to be the same as for the original scanner. Figure(4.11) is a screen shot of the FPS scene with all three functionalities. There are different ways to set the orientation of the rigid bodies in 3D space. As shown in figure (4.10) there are two important direction vectors $\vec{LM}$ and $\vec{CM}$ which can represents the orientation of the original scanner. The third axis can be easily computed using the cross product of the two given axis. To set the exact orientation, the front, up and side vector of the 3D model should be aligned with $\vec{LC}$, $\vec{LM}$ and $\vec{LC} \times \vec{LM}$ respectively . Setting the orientation of 3D objects can be handled in different ways. Euler orientation representation leads to find the angle between the original axis and the object axis and rotate the object on three different axis. However, this rotation representation suffers from Gimbal lock in which case when two axis are aligned it loses its one degree of freedom. It can be assumed that this problem would occur since the scanner is flexible and can be moved freely in all directions. The other approach to set the orientation is using Quaternions which does not suffer from Gimbal lock, however, increases the computational complexity. Two over come both Gimbal lock and complexity problem, matrix computation technique is adopted. The matrix computation technique is easy in rigid bodies rotations when the orientation is described in terms of direction vectors rather than angles. The orientation of the model can be set by multiplying the viewing matrix with the rotation matrix M_r

$$M_r = \begin{bmatrix} X_x & X_y & X_z \\ Y_x & Y_y & Y_z \\ Z_x & Z_y & Z_z \end{bmatrix} \tag{4.3}$$

Where the vectors X, Y and Z represents the desired orientation of the 3D model. For the 3D model of the scanner this orientation can be set by computing X, Y and

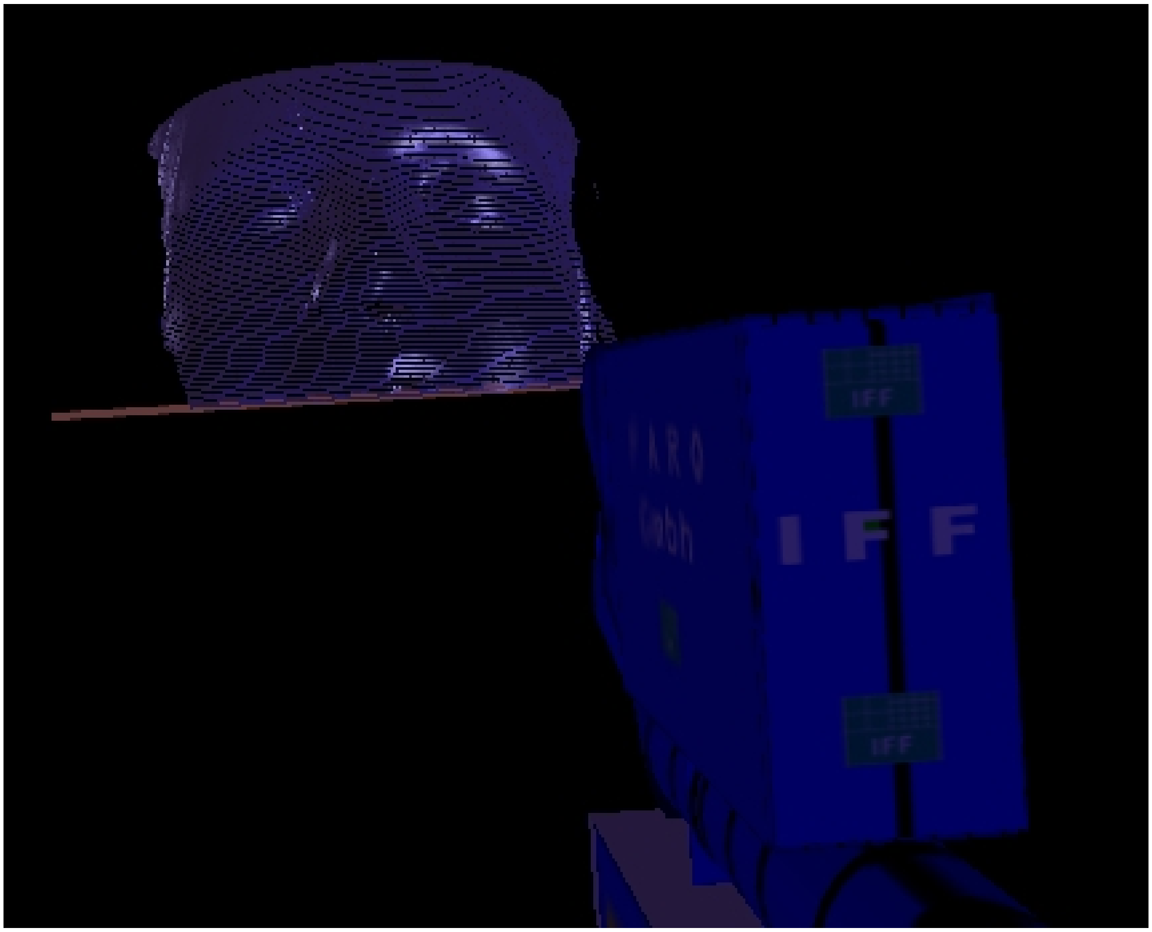


Figure 4.11: Screen shot of the proposed method

Z vectors from the given data shown in the figure (4.10). With the given information the rotation matrix can be formed as,

$$M_r = \begin{bmatrix} d_x & d_y & d_z \\ LC_x & LC_y & LC_z \\ LM_x & LM_y & LM_z \end{bmatrix} \tag{4.4}$$

Where $\vec{d}$ is computed using equation (4.2).

4.5 Summary

In this chapter, the proposed solution to the given problem is discussed. First, the basic idea for the online preview functionality using KdTree for nearest neighbor searching and plane fitting method for normal estimation is presented. Further, the proposed different variations in the basic algorithm to improve the algorithm speed by maintaining the necessary amount of quality is presented. In the second part, the proposed HMI technique using FPS games visualization techniques is discussed. The proposed idea aims to provide the same amount of information on both first person perspective view of the user and the screen. For this purpose, first the information which the user seeks by looking at the object and the scanner is analysed. Further, the technique to provide this information in the screen to minimize the changes in the focus is presented.

Chapter 5

Implementation

5.1 Software

In this chapter, the practical implementation of the theoretical concept discussed in previous chapter will be presented. The implementation is performed in visual C++ 7.0 using Microsoft Visual Studio 2005 Professional edition.

5.1.1 Simulation

The implementation is performed on the acquired data which is stored in files. Fraunhofer institute of factor operation and automation has developed *.IFF files which stores one scanning process. The IFF contains multiple scan operations of an object. Further, the scan operations can be extracted and stored in separate files called SCN files. A SCN files contains the data with the same structure shown in figure (2.7). The data is extracted from the file and stored in dynamic data structure. To store the data in dynamic data structures , KdTree and plane fitting method functionality is adopted from the pointCloud library developed by Micheal Schiller and Christian Teutsch in IFF Magdeburg. To evaluate the proposed method in streaming environment where data is generated with a certain time delay, the extracted data is simulated such that a new scanline is extracted every 10 ms from the data structure and given to the processing unit which further perform shading and rendering steps for online preview.

5.1.2 Graphical User Interface

The implemented software is a GUI (Graphical User Interface) application. The GUI is made in Trolltech QT version 4.2 library[1]. Figure (5.1) shows a screen shot of the

[1] `www.qtsoftware.com`

application during simulation.

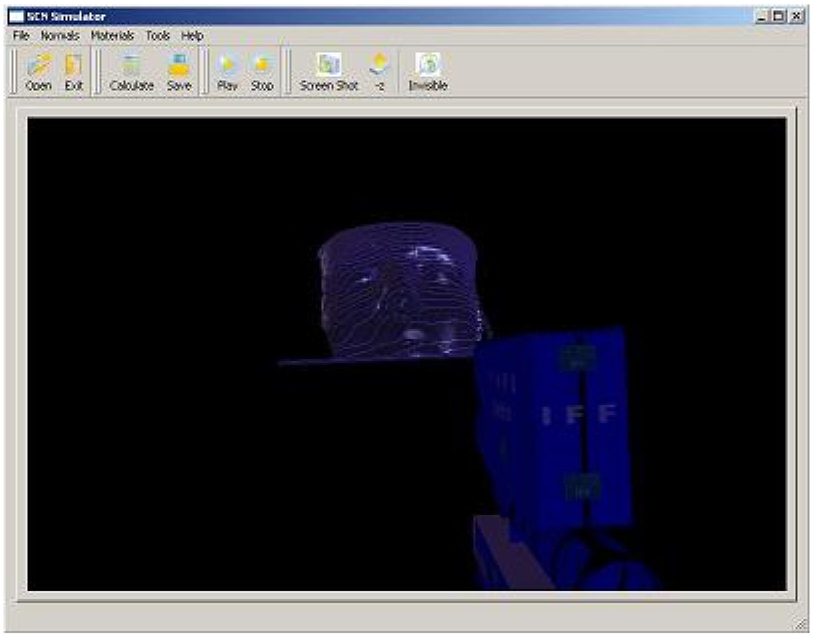


Figure 5.1: Screen shot of the developed application

The application supports basic GUI functionalities such as open SCN files, selection between normal estimation algorithms and saving calculated normals in a file. The normal selection dialog is shown in figure (5.2).

5.2 Rendering

For rendering of the 3D point clouds data, OpenGL[2] library is used. The OpenGL library supports Gourad shading model by default, therefore, separate shading model was not developed.

5.2.1 3D Model

The 3D model of the flexible scanner head was designed and developed in the Autodesk 3D studio Max[3]. The texture and the shading of the 3D model was performed in 3D studio max and later imported in OpenGL by the 3D engine developed for this purpose. Figure (5.3) shows the [4] 3D model used for simulation. The scanner head

[2] `www.opengl.org`
[3] `www.autodesk.com`

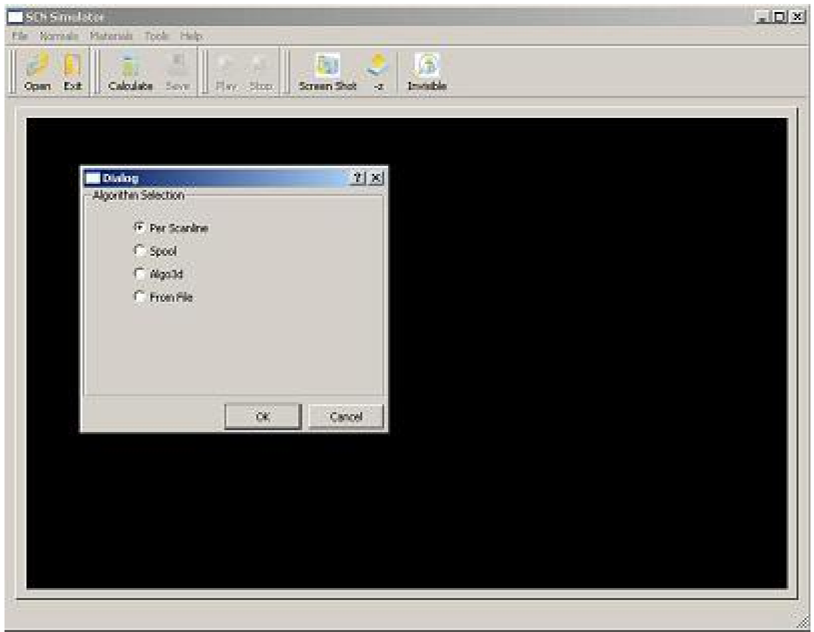
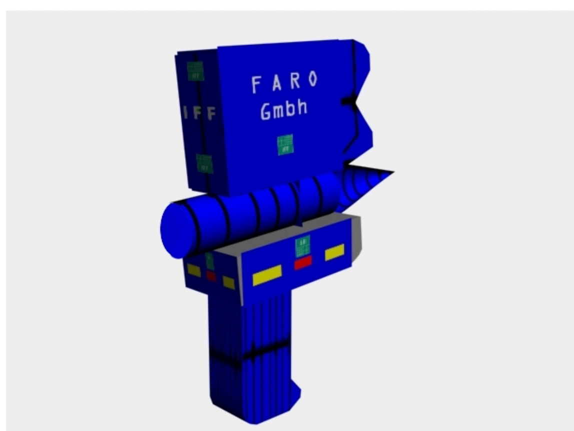


Figure 5.2: Screen shot of the developed application with normal selection dialog box



(a)

Figure 5.3: (a) 3D model of scanner used in implementation

shown in picture is different from the IFF scanner head. This model is used due to simplicity in shape.

[4]The scanner head is made by FARO technologies Inc. Image source www.faro.de

5.2.2 3D Engine

Since, OpenGL does not support 3D model files directly, therefore, 3D engine is developed to give the 3Ds[5] file support. The 3D engine supports 3Ds files with image textures of different image formats (JPG,BMP,GIF,TIF). To parse the 3Ds model fie, lib3ds library is used. The 3D engine supports two types of rendering, when supported from the graphics hardware, it uses VBO (Virtual Buffer Object) of OpenGL which stores data in graphics card memory and supports fast rendering. On an old graphics card, when VBOs are not supported, it switches to normal mode and uses RAM memory. To support the textures in OpenGL SDL [6] library is used, which converts the image files into OpenGL textures.

[5] 3Ds is the standard 3D model file extension made by Autodesk 3D studio Max

[6] www.libsdl.org/projects/SDL_image/

Chapter 6

Evaluation

In this chapter, the evaluation results of the proposed technique will be discussed. The evaluation criteria is based on qualitative and quantitative results. Since, the proposed technique is divided in two sections, the evaluation is presented in two parts as well i. e., the online preview algorithm and HMI technique. This chapter will first describe the testing environment and later discuss the results in details.

6.1 Testing Environment

The developed application was tested on a standard PC (Intel Pentium 4 - 3.2 GHz Processor , 3.2 GB RAM) with a state of the art 3D Graphics Card (ATI RADEON 9600 Series AGP, 256 RAM).
The algorithm is tested on different datasets from five different objects. The flexible scanners are used in different domain where objects varies with respect to their size and surface properties. For Example, the entertainment industry uses small character models made of Plaster of Paris [1]. The surfaces are less complex and do not reflect excessive amount of light. Three objects of this nature with different sizes are evaluated. The industrial domain uses 3D scanners for quality assurance and measurement of different objects. The type of objects used in this domain normally have a complex surface made of shining material such as metal. Two objects are used to generate data sets of this nature.
The algorithm is evaluated with two different criteria. The qualitative assessment and the quantitative assessment. The qualitative assessment is done to evaluate the algorithm for the question such as; does it serve the purpose?, Does the shaded preview of the scan data is capable of conveying information about the scan data quality.

[1] Plaster of Paris is a type of building material based on calcium sulfate hemihydrate. It is created by heating gypsum to about 150 °C Source as per date 12-Feb-2009: `http://www.lafargeprestia.com/caso4___h2o.html`

In the the quantitative analysis, different parameters are presented in tabular form which reflects the accuracy and speed of the algorithm in numerical form.

6.2 Comparison Criteria

The purpose of the online time preview functionality was to present the scan data quality of the acquired data to the user during scanning process. There are several elements of the scan data quality which could be useful if provided to the user during the scanning process. The assessment of the acquired results is based on following parameters

The distance between the scanlines which indicates the data density, should be presented to the user so that a user can increase or decrease the scanning speed at the run-time.

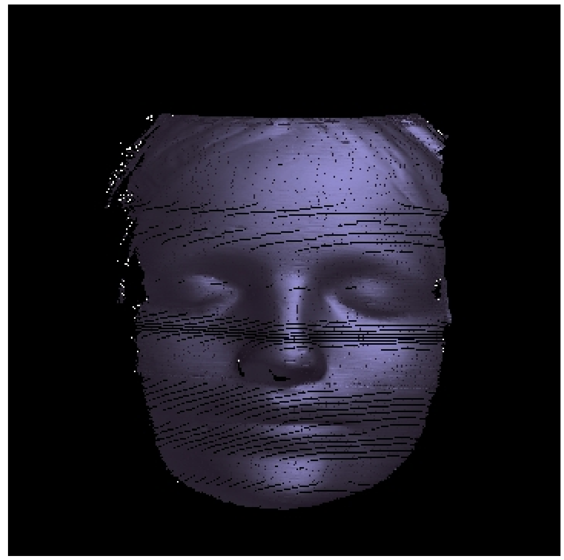
The holes in the data are normally formed when camera is unable to view the projected laser line or the distance between the two laser lines is large. Information about a hole in the scanned data itself is not important during scanning because the user can only take actions once the scan pass is complete. However, when the number of holes in the data is high, then quitting the scanpass to perform after removal of the cause does help in reducing the scan time. For small objects when the whole surface can be scanned in one or two scanpass, the online preview of the holes in data is not very important. However, when scanning a large object where one scanpass will be relatively longer, quitting a scanpass with wrong result in between is the right choice rather having a longer unfruitful scanpass.

The environment conditions, such as light/dust and the accuracy in the human hand movements play an vital role in the scan data quality. The online preview functionality is expected to inform user about the disturbance in data due to any of the above said conditions. The quality of the results are judged on the above discussed parameters.

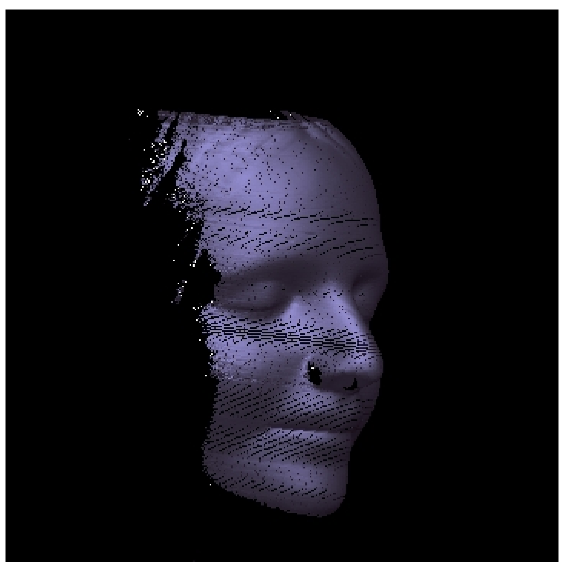
6.3 Qualitative Assessment

In this section, the quality of the results is examined. For the discussion, three different objects are selected according the surface complexity. However, the results of the other datasets are available in section (B). The datasets are taken from three different objects with simple, moderate and high level complex surfaces. The quality of the shaded models is normally good. The figure (6.1) shows a woman face model, the model is made of Plaster of Paris which does not reflect a considerable amount of light. The surface complexity is minimum, however, at the area near lips and under the nose, it is difficult for the camera and laser beam to cover that part of surface.

(a) Original Women Face Model



(b) Shaded Point clouds data



(c) Side View of the Same Data set

Figure 6.1: Original and the resultant model of the women face model (a) Original Model (b) Shaded Scanpass data with 364370 points and 337 Scanlines

The resultant shaded model is an example of a good shaded model. In the resultant shaded model, data density can easily be seen at the start of the surface near the forehead, however, during the scanning the scanning speed is reduced (intentionally) which can easily be identified at the surface. There is a part of surface which could not be seen by the camera device, therefore it leaves a hole in the data. The small area under the nose has a hole, the side view of the model shows it more clearly. The overall data has frequent changes in density level which is important for the user to know during the scanning process. The small holes in the data are visible, however, they are not strong enough to force the user to stop the scanpass. The proposed online preview functionality serves its purpose for this dataset, however, the surface complexity and amount of light is ideal in this model.
To assess the results of the algorithm in more difficult conditions, an industrial equipment is used as moderate level candidate. The surface geometry is relatively more complex than the previous object and this object is made of metal which reflects a significant amount of light. The results in figure (6.2) show that the proposed technique is capable of achieving desired results even in relatively difficult conditions. Two different datasets were used in this evaluation. The figure (6.2(c)) shows the result of a dense data set. The white coloured points are those which could not find any neighbour with the given radius. As can be seen in the picture, most of the white points represents error in the data. Since, the dataset in the figure (6.2 (c)) is of relatively high quality, another dataset was taken from the same object to evaluate the results. The result of the second dataset is presented in figure(6.2(b)). To change the data density at different surface position the scanning speed was changed intentionally during the scanning process at different times. The resultant dataset clearly provides the information about the change in data quality due to the difference in scanning speed. The scanlines at the end have more gap than the previous scanlines. As a solution for the current situation, a user would ideally rescan the parts where the scan data quality was decrease due to the scanning speed.

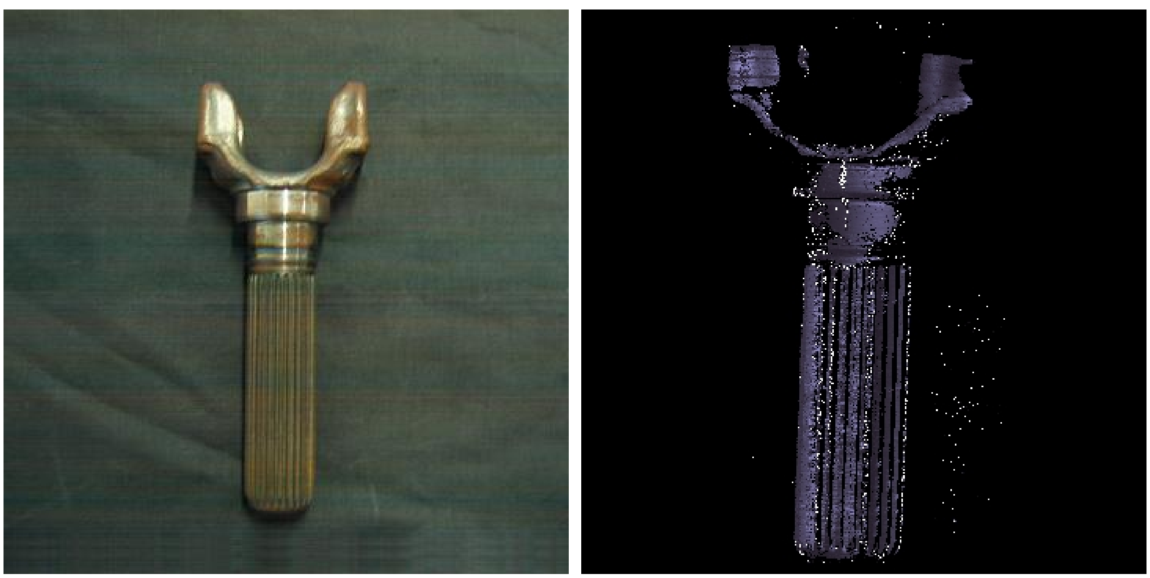
6.3.1 Assessment in Critical Conditions

The three results provided in the previous section are from two different objects with different surface properties. The datasets contains optimal amount of points with less amount of errors. The proposed technique has shown good results in term of quality for these datasets. However, to asses the response of the proposed technique in severe cases when the surface geometry is exceptionally complex or the human control was not accurate, two more datasets were adopted. The first dataset is taken from an object from a car engine. The objects surface geometry is very complex and contains multiple sharp edges with 2 mm distance.

The object is made of metal and has noticeable shininess. The dataset itself has a

(a) Original Model **(b)** Shaded Point clouds data **(c)** Second Data Set

Figure 6.2: Original and the resultant models of the a car part(a) Original Model (b) Shaded scanpass data with 428945 points and 496 scanlines (c) second data set with 410265 points and 476 scanlines

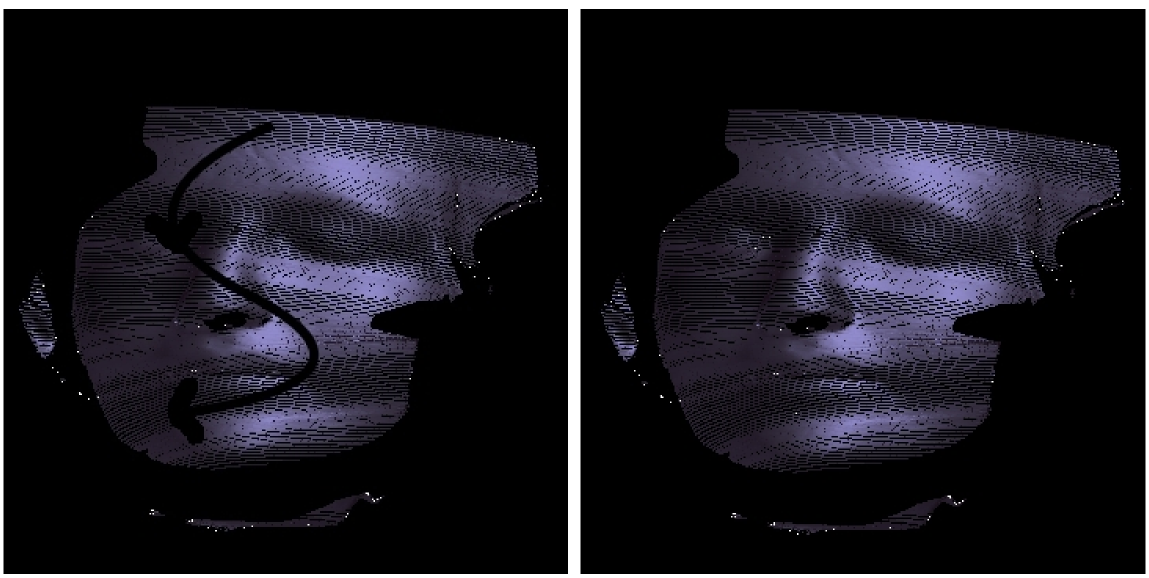


(a) An object from a car's engine with complex surface **(b)** Resultant shaded model

Figure 6.3: An object from a car's engine with complex surface (a) The originial model (b) Shaded model of a dataset with 134489 points and 523 scanlines

number of problems. Since, the laser line projected on the surface must be captured by the camera device to generate data points, therefore, the data between the sharp edges of the surface could not be generated. The scanlines have discontinuity between

them and the points within a scanline itself has visible gaps. However, the resultant model shows the true picture of the scan data quality. The surface before the sharp edges has relatively better shaded view. However, the shaded model does fulfils its purpose for online preview. The error and holes in data are visible and despite the fact that the scanlines have gaps within points, proper shading is visible where the data is presented with minimum continuity. The proper shaded view of the error data with visible holes defends the credibility of the technique with error data.
The second dataset belongs to the same woman face statue used in previous examples (see figure (6.1a). Instead of using an object with complex geometry, the second object is selected to evaluate the proposed technique in conditions when the human hand control is not very accurate. Since, the flexible laser scanner's data acquisition process is very sensitive to the scanner movements, therefore it is expected from the user to have a careful scanning process to generate quality point clouds. However, to assess the proposed technique for the worst scenario, the scanner is moved in zig zag path to intentionally generate errors in the data. Figure (6.4(a)) shows the dataset with



(a) Direction of the human hand path during scanning

(b) Resultant shaded model

Figure 6.4: Shaded model of the woman face with zig zag scanning pass (a) The scanning path of the human hand (b) Shaded model of the dataset with 242 scanlines and 226474 points

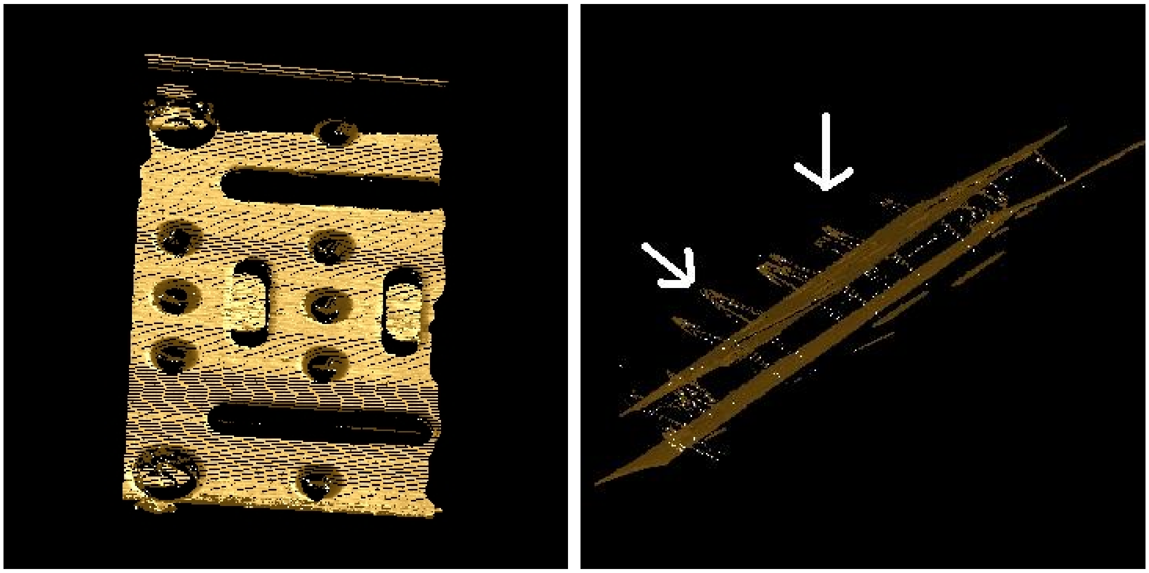
the path on which the scanner was moved during scanning. The resultant data has visible artifacts generated by the scanner movements. The shaded points clouds do not only show the quality of the data but also represents the error caused by the inaccuracy in the human hand control (see figure(6.4(b)).

6.3.2 Algorithm Failures

The proposed solution for online preview functionality has shown good results in terms of quality so far. However, there are some shortcomings in this approach which will be discussed in this section. The basic shortcoming in the proposed solution is that it only generates preview from one angle i. e., the perspective view of the user controlling the device. However, the generated data is shaded in form of a 3D model, therefore there are a lot of information which is missing in this view. The very first dataset from a woman face statue presented in the figure(6.1(b)) has holes in the data. Since, the data is only shown from the front side, the holes are hidden from this view. The side view of the same dataset shown in figure (6.1(c)) has more clear view of the holes near the nose area. This drawback of the proposed system can be removed if multiple view ports are generated on the screen which show the same object from different angles. However, multiple views would surely create disturbance in the scanning process.
Apart from the holes in data, the proposed solution fails to convey another set of information about the error in data. The error data which is formed by the shine in the object's surface has a special structure. Since, the shininess of the surface reflects the projected laser line from the surface very strongly, therefore, the camera device wrongly perceives the deformation in the laser line. The reflected laser light is higher than the object surface, therefore, the generated point clouds are a bit higher than the actual surface. Since, the online preview is always generated from the top view of the object, the error data can not be distinguished from the surface. Figure (6.5 (a)) shows a shaded dataset taken from a small shiny piece of metal. The original surface has several round shaped holes in it. The projected laser line is reflected from the shine caused by the small holes. The error data can not be seen from the front view since the error data looks like the part of the surface from the top view. However, when seen from the side view , the error data is visible. This weakness in the proposed solution can only be removed if the error data could be identified from its structure and segmented using different colour in the rest of the data.

6.4 Quantitative Assessment

In this section, the quantitative assessment of the proposed online preview technique is presented. The table (6.1) contains values of different parameters from the resultant data. The table is made from the ten datasets used for evaluation. The table provides information about the number of points and scanlines presented in the dataset. Further there are three more columns which are important to analyse the technique.



(a) Generated Shaded model of a piece of shinning object

(b) Side view of the model

Figure 6.5: Generated Shaded model of a piece of shinning object with 310840 points and 25 scanlines (a) Front view of the model with no indication of the error (b) Side view of the model with visible error data indications

Scanning Time The scanning time refers to the time the user has taken to scan one pass of the surface. The scanning time has its effect on the data density, however, the objects with small surface being scanned may have more data points because the accuracy in the scanner handling is easy for the small surfaces. The data points and the number of scanlines have different effect on the data density. A dataset may have more number of scanlines and less data points, the surface width being scanned decides the number of scanned points in a scan line. The dataset “Small Head 1” has more number of scanlines but 142 scanlines were empty and discarded as the error data.

Shading time Shading time is the most important parameter with respect to the practical online preview functionality. Since, the proposed technique aims to provide the real time preview, therefore, a significant delay between the shaded preview would not be acceptable. The results have shown that the difference between the actual scanning time and the shaded preview is between 2-4 seconds which is in an acceptable range. Since, the method described in section (4.3.5) overcomes this delay at implementation level, therefore, the delay in the full shaded preview can be neglected.

Dataset	Points.	Scanlines	Scanning time (sec).	Shading time (sec).	Adaptive Range. (mm)
WomanFace 1	226754	192	6	7.89	0.65
WomanFace 2	364370	337	8	10.2	0.4
Carpart 1	428945	496	8	11	0.4
CarPart 2	410265	476	8	11.2	0.5
Complex CarPart	134489	523	4	7	0.8
BigHead 1	685557	527	11	14	0.4
BigHead 2	507948	390	11	13.5	0.5
Small Head 1	422103	621	5	7.8	0.4
Small Head 2	378177	460	5	7	0.42
Shiny Metal	310840	253	4	6.9	0.5

Table 6.1: Results of the online preview functionality in tabular form

Search Range For the above presented results, the Kdtree described in section (4.3.4) is adopted. The Kdtree uses adaptive range search query. For the start the KdTree is provided with 0.1 mm range search. However, it adaptively increases its range if the number of searched neighbours are less than 20. The results provided in table (6.1) is based on the average range of each spool. After each spool generation, the Kdtree responds with the average range used for the current spool. The average range of all spools is calculated and presented with each dataset. The observation of the datasets provided during for evaluation has concluded that the range does not go over 1 mm. The presented datasets had all sort of objects with different surface complexities and sizes. The highest range never went over 1 mm.

6.5 HMI Technique Evaluation

In this section, the proposed HMI technique is evaluated. The evaluation of the HMI technique is not based on the real environment because the implementation was done on the simulated data instead of scanning system. The HMI technique presented in the proposed system aims to provide the user information about the parameters which effect scan data quality. The proposed method uses FPS games techniques to provide the information in real time. The ideal form of the visualization was to provide the information on the screen using the same technique which human eyes uses to observe from the actual environment. On the basis of this assumption, the proposed technique aims to provide the exact view on the screen which the user observes by looking at the scanner and object. The advantage of the proposed technique is that, the user can monitor the three parameters which effects the scan data quality as well as the generated preview of the data by focusing on the middle of the screen. Since, the information which the user seeks from the scanner and the object is now available at the screen. It would definitely reduce the focus shifting from scanner/object to screen which was the main cause of having a hectic scanning method. The above made assumptions prove that the proposed HMI technique not only serves the purpose but improve the scan data quality by supporting the user. However, the choice of FPS games techniques can not be justified until the different experiments which were performed in contrast to proposed technique are not discussed. In the following section, the three parameters will be discussed with their experimental technique which were examined before choosing the proposed method.

6.5.1 Scanning Speed

The scanning speed was the first parameter to be analysed and has gone through different experiments for correct selection of visualization technique. The importance of the user's scanning speed has already been discussed. There were two main problems related to scanning speed. The first problem was how to extract the scanning speed from the environment, and second how to convey this information to the user. The extraction of scanning speed was possible through the movements of the scanner head or the generated scanlines. The choice of the generated scanlines as the source for data generation has already been justified in section (4.4.2). The scanlines generation frequency does not responds to the scanner movements which are more vibrant and its more smooth since its controlled by the machine. The next problem is to provide this information to the user. For this purpose, the first technique which was examined is to write down the scanning speed on the screen. The written form of data during in a frequently changing environment always has some limitations. First, the parameter which should be used to inform user about the scanning speed is confusing. The scanner generate data in frequency units which are measured in Hz and the distance between the scanlines are measured in milimeters or centimetres. Furthermore, the distance between the scanlines and the delay between subsequent generated scanlines are very minimal and changes very frequently. In a real time environment, the frequently changing parameter with minimum delay would be unable to monitor if used in written form.
The other prospective method was to use colours to indicate the user about the optimal speed. A small box or light could be displayed on the screen and turned red or green to inform about the optimal speed. However, the next problem is that how to calculate the optimal scanning speed. The optimal scanning speed varies from surface and environment properties. A scanning speed may be optimal for a smooth surface and on the other hand very quick for a complex surface. No assumptions can be made about the suspected surface complexity, it should be left on the user to decide.

Therefore, the colour or the text based approaches were not adopted.
Proposed technique, which is to use the current scanline at the middle of the screen and scroll the data as the new subsequent scanlines are generated serves the purpose without adding extra effort for the user. The user can monitor the scanning speed while monitoring the scan data quality on the screen.

6.5.2 Distance

The most easy to monitor parameter was the distance between the object and the scanner. The object and the scanner distance can easily be extracted for the environment since it is already presented in the form of two laser lines which are projected on the scanner surface. Instead of using written information or the coloured shapes to represent the optimal distance. An idea identical to the current scanning system was examined in which the information could be presented without any extra effort. The first idea which was evaluated was to use the camera point of the current scanline as the viewing point of the user. The basic idea behind it was that the distance to the object and the scanner will be visualized by the size of the scanning results since in perspective project the object which is far from the camera is smaller and the closer objects look bigger. The optimal distance could be informed by using a colour which turns red or green in case of wrong or optimal distance respectively. However, this idea did not produced good view since, the visualization was very disturbing as it responds to every small movements of the scanner head. Therefore, idea of using scanner head camera position as the viewer camera position could not serve the purpose. The next possibility was the use of text based information. The distance between the object scanner or the difference between the object and scanner or the two laser lines should be written on the screen. However, the text based distance visualization had the same limitations as discussed in the previous section. The value of the parameter is frequently changing and does not suit with the real time preview. Therefore, the visualization technique identical to the real system was adopted which the user is aware of from the real environment. The two laser lines which the user seeks to combine during scanning to have an optimal distance, are displayed on the middle of the screen. The visualization technique for the distance monitoring has several advantages over the other examined techniques. The two laser lines distance has already been on the hardware level. The user who is already aware of the scanning process would easily adopt the new technique. Further, the view of the both places i. e., the scanner/object view and the screen has same information now. However, there is a small implementation glitch with the technique presented in the section (4.4.2). Since, the implementation uses mean point of the current scanline for the plane calculation. In the conditions when a scanline is oscillate due to the artifacts in the data as shown in figure (6.5 (b)) the plane would be estimated at the wrong distance. Therefore, the system would fail to provide the exact distance between the two laser lines.

6.5.3 Angle

The most complex parameter to visualize is the angle between the camera viewing and the surface normal. Since, the written information has already proved to be limited in case of real time environment and previous experiments has already proved the usage of written information to be useless. The only option left is to provide the information with the exact technique used in the current scanning system. The user monitors the angle between the camera viewing direction and the surface normal by looking at the both objects. The proposed approach presents a 3D model of the scanner head at the middle of the screen. The idea is to provide the information at the middle of the screen and without changing the format from the actual environment. With the adition of the 3D model of the scanner. The information provided on the screen is now identical to the user's original viewing frustum

6.5.4 Discussion

The proposed HMI technique has proved to be most efficient and ergonomic in all examined techniques. The foremost advantage of the FPS based technique is that the view of the both scanner/object and screen remains same. The user who switched his focus several times from the screen to the object does not realize the difference in the environment. However, there are some disadvantages of the proposed system. The users who has no experience with he FPS games, finds this view disturbing at the start. Even with the same type and techniques from the original environment, new users need some time to adopt this view ad get used to it. Further, there are some implementation level issues which are not generalized for all 3D laser scanners. Since, the amount of information needed to create a first person perspective view varies from the system to system, therefore, the accuracy of the implemented techniques can not be said perfect for all environments.

6.6 Summary

In this chapter, first the evaluation of the proposed online preview technique is presented. The evaluation was performed on ten different datasets (rest of the results can be found in Appendix B). The criteria for the evaluation was that if the shaded preview presents the information about the scan data quality which could be crucial for the user at the scanning time. The proposed method has shown good results in both normal and complex situations. There is a small glitch in the proposed solution where the technique fails to provide the desired results. However, this short coming can be solved with future work in error identification. Further, in the second section, the HMI technique is discussed with its pros and cons. Since, the proposed HMI technique was not evaluated on the actual scanner, therefore the selection of the FPS games techniques for the current problems is justified by providing the results from the other examined techniques.

Chapter 7

Summary and Outlook

7.1 Overview of the Proposed System

The purpose of this thesis was to propose a visualization and HMI approach to support the data acquisition process of the flexible 3D laser scanners. The proposed solution is consists of an online preview functionality and FPS games visualization techniques based HMI approach. The proposed online preview functionality aims to provide the information about the scan data quality during the scanning process. The basic algorithm proposed for shading the successfully generated scanlines have shown good results in terms of quality. The results have indications that the algorithm successfully informs user about the holes, redundancy and error in the scanned data.

The time consumed for nearest neighbour calculation and shading fails to serve the purpose of online preview. Therefore, to overcome the calculation time, a spool based method was proposed. The spool based method has shown satisfactory results in terms of quality and computation time. Since, the spool based method still does not matches the data generation frequency of the considered scanner. Therefore, to improve the speed of spool based method for online preview functionality, implementation level improvements were proposed which successfully serve the purpose. It is concluded that with the shaded preview of scanned data during scanning process, the scan data quality can be increased due to the rapid interaction of the system.

The flexible scanners do not only differers from the machine based scanners in their functionality. It can be said that by giving the control to the human hand, flexible scanners welcome the uncertainty in the data due to some parameters. It is analyzed that the human control of the scanner effects scanning speed, distance between the scanner and the object and angle between the surface normal and camera view during scanning process. These parameters play an important role in the scan data quality, therefore, they should be monitored frequently. The proposed visualization technique gives importance to these parameters.

The analysis of the HMI technique has concluded that the main reason behind having a hectic scanning process for flexible scanner is that, the user has to monitor a lot of parameters as well as look at the screen for preview of the scanned data. The proposed solution is based on the idea that the amount of information that user finds at screen and scanner/object view must be same. Since, it is not possible to provide the online preview functionality without a screen. Therefore, the information which user seeks by looking at the object is presented on the screen. The idea of using FPS games technique supports this method since it aims to provide all the information on the middle of the screen without having it in the written text form. The three parameters i. e., speed, angle and distance which are measured in form of digits in the normal life are presented to the user without explicitly diverting attention from the main task which is preview of the scanned data.

7.2 Future Work

This thesis can be taken as base for the future work in real time shading of the point clouds and HMI techniques for the hand guided laser scanners.

The online preview functionality in the proposed method is a new contribution in the field of point clouds data acquired from the flexible 3D scanners. To over-come the limitations of the online preview functionality a significant amount of research work is needed. For example, there are always small holes in the data which can be easily filled for the visualization purpose. Since, the proposed method only shade point clouds using Gourad technique. Therefore, adopting a quick technique which gives more detailed information about the scan data quality could be a further work.

The online preview functionality proposes technique for nearest neighbour calculation for the point clouds data. The nearest neighbours of a point is always important to determine if the given point is a quality point or belong to a error data. A proposed future work could be identifying error data during the scanning process and segmenting this data from the original data in the online preview. The proposed method only deals with the error caused by the human controlling of the scanner. However, there are other sources such as surface properties and environmental errors which should be identified and presented with a good visualization technique.

The proposed HMI technique is based on FPS games visualization techniques. The computer games put realism in the scene by using state of the art graphics techniques. However, the proposed method adopts the very basic idea for conveying the information to the user. Future work can be done to put realism in the visualization technique by replacing shapes such as two lines with a better crosshair which provide more accurate information.

Appendix A

Abbreviations

2D	Two Dimensions
3D	Three Dimensions
3DS	3D Studio Max Model File
BMP	Bitmap File Extension
CRT	Cathode Ray Tube
FPS	First Person Shooter
GUI	Graphical User Interface
HMI	Human Machine Interaction
JPEG	Joint Photographic Experts Group
KNN	K Nearest Neighbors
PC	Personal Computer
PNG	Portable Network Graphics
SDL	Simple DirectMedia Layer
SEE	Sensory Environments Evaluation
TIF	Tagged Image File
USC	University of Southern California
VBO	Virtual Buffer Objects

Appendix B

More Results

B.1 Dataset1

Figure B.1: Original Model of a Big human face made of Plaster of Paris

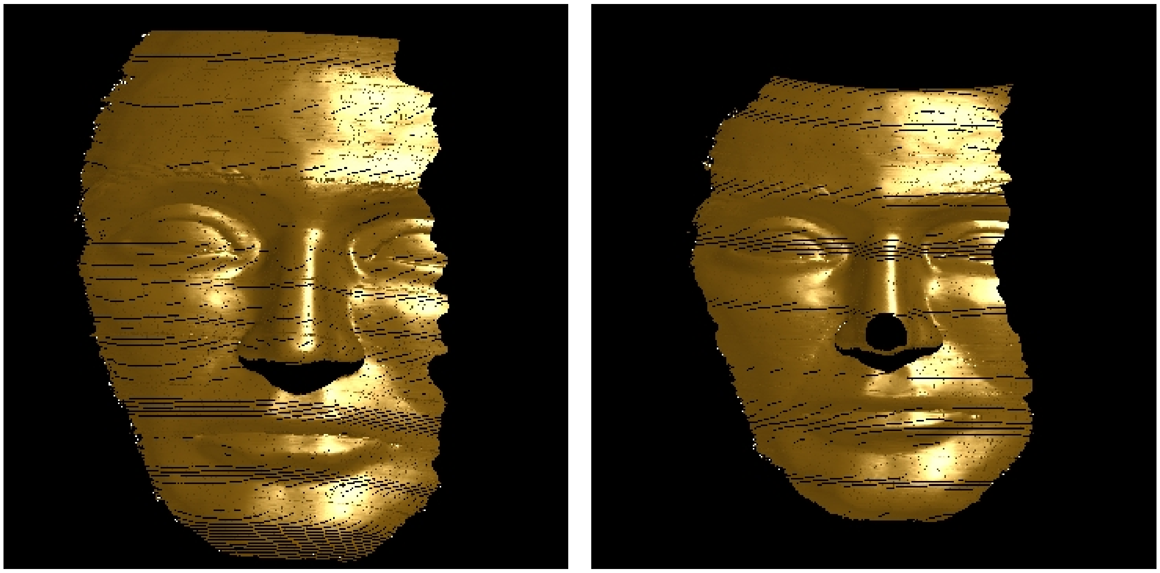


Figure B.2: (a) Points= 685557 Scanlines = 527 Scanning time 11 sec Shading time 14.5 sec (b) Points 507948 Scanlines=390 Scanning time 11 sec Shading time 13 sec

B.2 Dataset2

Figure B.3: A small model of a human head made of Plaster of Paris

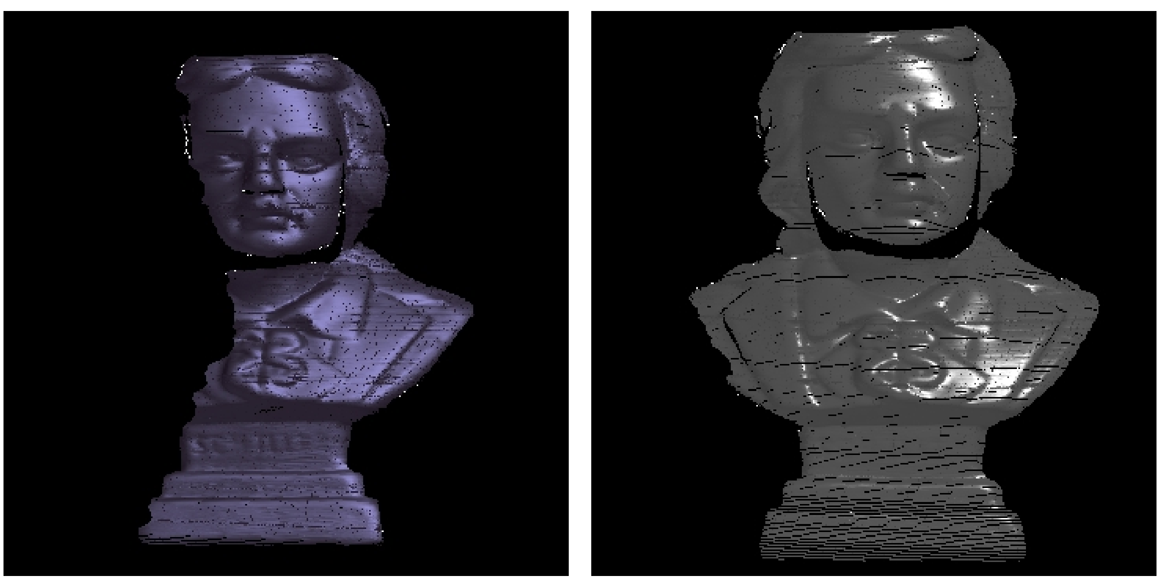


Figure B.4: (a) Points= 422103 Scanlines = 621 Scanning time 5 sec Shading time 8 sec (b) Points 378177 Scanlines=460 Scanning time 5.5 sec Shading time 9 sec

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Declaration

I hereby declare that this master thesis has been written only by the undersigned and without any assistance from third parties.

Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself.

Magdeburg, March 20, 2009

Sohaib Anwar