A 3D LASER SCANNING DEVICE FOR OBJECT RESTORATION USING POINT CLOUD REGISTRATION

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Certification

This thesis entitled **"The Design Development and Implemention of a 3D Scanner**" was carried out by **Ahmed Abba Sheik** with the matriculation number LCU/PG/001770 in the **Department of Computer Science, Faculty of** Basic Medical and Applied Sciences, Lead City University, Ibadan, Nigeria under my supervision and that this work has not been previously submitted.

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Dedication

I dedicate this Thesis report to Almighty Allah whose love, mercy and guidance has sustained me through this Research report and for the knowledge and understanding provided to complete it. I also dedicate this thesis to my mother, Hadiza Abba Hassan for her support and caring throughout this thesis

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Abstract

3D scanning of environments and the objects have a lot of practical uses. During the last decade increased performance and reduced cost has made them more accessible to larger consumer groups. The price point is still however high, where popular scanners are in the price range of 300,000 NGN-500,000 NGN. The objective of this thesis is to investigate the current 3D scanners in the market, considering both time-of-flight and triangulation in terms of accuracy and limitations and compare there results to build a more cost effective model of the 3D scanner at the end of the thesis. For validation purposes the constructed 3d scanner will be put through tests to measure its accuracy and ability to create realistic representations of its environment.

The constructed model produced significantly less accurate results and scanning time was much longer compared to a popular competitor. This was mainly due to the cheaper camera sensor used for the model and not the mechanical construction itself. There are however many applications where higher accuracy is not essential and with some modifications, a low cost solution could have many potential use cases, especially since it only costs 1% of the compared product.

Keywords: Triangulation, 3D scanner, Time-of-flight, Laser scanner
Word count 185

Table of Contents

Chapter One
Introduction

3D laser scanning device: is a device used for capturing and analysing data of a given object or environment, to get its exact shape, size, colour and other attributes, and then representing the collected data visually in a 3d model. The data is obtained from the environment or object using a straight guided laser light in the form of a point cloud data, a PCD or ply file and then saved as a 3D STl file, this form of data will be used to create the 3D models by sending the object signals directly to a software which will translate the visuals and display it in a 3D format.

Different types of scanners have been built worldwide, each with its advantages, disadvantages, purposes and cost. Hence the purpose of this thesis is an attempt to create an advance laser 3D scanning device that is cost effective without compromising the quality of scanned data and also capable of collecting data in both 360 and 180 degrees in its environment.

1.1 Background to the research problem

"Over the last decades, 3d laser scanning has been the most developing and popular type of remote sensing, there has been many models of 3d laser scanning devices that has been developed over the decades but each with its own flaws[1]".

A 3d laser scanner in general is a scanning device that can analyze and capture the accurate shape, color and size of an object using a laser point or a laser line which will be pointed at the intended object and then a specialized software cad will use triangulation or time of flight to record data and calculate the point where the object surface came in contact with the laser's light, each angle of the object's data points will be recorded until a 360 degrees scanning is completed in the process of the scanning, which will result in thousands of data points, this pieces of data points recorded together it is what is called point cloud.

"The Charge -Coupled Device, or CCD, while invented in 1962 by researchers trying to figure out a way for semiconductors to store data, CCDs have become a ubiquitous component of consumer electronics such as digital cameras and scanners, as well as more sophisticated applications such as the Hubble Space Telescope, the Mars rovers, and the satellite systems circling the earth[2], another invention based on the CCD is three-dimensional laser scanning[3]"

"A **3D scanner** can be based on many different technologies, each with its own limitations, advantages and costs. Many limitations in the kind of objects that can be digitized are still present,[4]".

A 3d scanned visual display or a 3d model is often captured by any camera capable of recognising an object in details. each of the devices used to capture a 3d model often has its limitations, for example optical technology encounters difficulties with objects that are transparent but has accuracy and good resolution, structured light 3d scanning technologies has good speed and a good resolution but it has issues to work outside with, while a contact based 3d scanning devices has good ability to scan transparent and reflective surfaces but has inaccuracy while working with freeform shapes. during the few recent year's studies have shown that objects captured with 3d scanning devices can be improved with lasers, multiple censors and the ability to capture from all sides, increases the possibility to capture the objects or environment efficiently.

3D technology today has a role to play in almost each and every industry in the world, from medicine to infrastructure, transportation, designs, constructions, engineering and even movie fictions, 3d technology is used to construct models for use and it is adopted as the most modern and accurate form of data display of objects.

The main purpose of this project is an attempt to try and create an improve version of a 3D laser scanning device and analyze some of the gaps and limitations of all the modern laser 3d scanning devices.

Some of the laser scanning devices that will be looked into in this thesis are: LASER triangulation 3D scanning technology, structured light 3D scanning technology, photogrammetry, contact-based 3D scanning technology, and LASER pulse-based 3D scanning technology.

1.2 Statement of the Problem

There have been numerous researches about how to improve and build a cost-effective 3D laser scanning device. A research was carried where they tried to replace the items that cost more in a 3d laser scanner, like the laser-source and high-resolution web cam with IR distance sensor[5,6]. In the process a distance sensor is designed and fabricated to plot 90*90 for example, 8100 points on the object to be scanned, and then an algorithm using concept of point cloud is used to create a mesh. This mesh is rewritten in the format of '.STL file' which is generated in python language. The result yielded in the research was that the scanning device obtained was still considerable accurate, within 1mm, and 70 to 75% economical than commercia scanners. Also, a lot of similar researches have been carried out. The famous David laser scanner available for commercial use[7]. A lot of research has been devoted towards 3D embedded systems design and the design and development of a 3D laser scanner in general. However, no research has been reported on a comprehensive review of all the 3D laser scanning device technologies available today and a future way forward on how to scan all the edges of an object or environment with just a single go without compromising its overall performance, cost, accuracy and speed to achieve the best possible data cloud of the object or environment[8,9]. Even though earlier studies on 3D laser scanning device have recorded tremendous success on all the improved 3d laser scanning technologies we have today; failure on a comprehensive study on all these technologies have resulted in each having its on limitation. "A 3D scanner can be based on many different technologies, each with its own limitations, advantages and costs[11,12,13,14]"

1.3 Research Questions

Below is a list of questions the thesis will answer at the end of the thesis.

- What makes a modern 3D laser scanning device to capture and print with less errors?
- How can we improve a 3d laser scanning device to enhance qualities of object pictures taken in broad daylight and in darkness?
- How can we capture objects in all angles using a modern 3D laser scanning device when is capable of rotating in both 360 and 180 degrees?
- How do modern 3D laser scanning devices work in general?

1.4 Main Objective of study

1. Identify and implement the best possible model of the most recent 3D scanner.
2. Design and develop a 3D scanning system for object restoration.
3. Analyze the restored object to determine the accuracy and performance of the system.
4. Compare the results from (3) with existing systems.

1.5 Scope of the Study

The scope of this study is limited to the aspect of 3d laser scanning technology that has been explored in the last decade, it does not explore any study or hypothesis beyond these years, and focuses primarily on the gaps of building a cost-effective 3D laser scanning device without compromising its speed, efficiency, and the overall quality of scanned data.

1.6 Significance of the Study

The comprehensive study and analysis of 3D laser scanning technology can be a learning paradigm to further research on 3D laser scanning devices and a good reference to those who have interest in the study of visualization of objects in general and other groundbreaking technologies such as the charge -coupled devices, or CCD, 3D models, Laser technology, scanning devices, triangulation technology, time of flight technology, point cloud, and other numerous technologies that is going to be explored throughout the study. The project's goal is designed to help fill in the gap of building an cost effective 3D laser scanning device at the same time without compromising its speed, efficiency, and the overall quality of scanned data. It is also designed to help researchers and manufacturers improved their overall knowledge on visualizing technologies and its important role in future plans and also a means for a break-through on 3D laser scanning technologies.

The results of the study will be of great benefit to the following:

1. Researchers: Data given at the end of the thesis will provide researchers with information on how to design and implement a low-cost effective 3D laser scanning model without compromising quality of scanned data. The result will enable researchers to identify the limitations and gaps of each of the 3D laser scanning technologies. Data gathered at the end of the thesis will be another break-through opportunity to further newer studies on 3D scanning devices.

2. Manufacturers: The results of the study will help manufactures of object visualizing devices and 3D laser scanning devices to evaluate the quality of future products and help them in building efficient and effective 3D laser scanning devices.
3. Industries and institutions: This study will help industries, companies and institutions in acquiring cost effective 3D scanning devices in the future.
4. Future studies: This study will foster new ways of enhancing knowledge, skills and strategies in the design, development, implementation and evaluation of future 3D technologies

1.7 Operational Definition of Terms

The following central terms are operationally defined based on their usage in the study:

- 3D: three dimension is the representation of all the angles of an object visually through the use of a specific device.
- Triangulation: this is a type of technique that is used to accurately measure the angle between points in a triangle formed by using three control point.
- Time of flight: this is a type of light detection technology; it uses the distance a light travel to and for from an object to calculate its angle
- CAD file: computer aided design file is a form of digital file use to store 2d or 3d designs or any form of data
- STL file; this is a form of computer aided design file
- CCD: Charge -coupled device: is a circuit that is used to display images

Table 1.1: Project plan

Activity	*Duration(weeks)*	*Date of completion*
Introduction/literature review	*12*	

Research design/methodology	*6*	
Preliminary Experiment	*6*	
Experiment Work	*8*	
Data collection	*6*	
Analysis of Result	*6*	
Thesis writing	*8*	
Submission for examination	*2*	

Table:1.2 Equipment and materials required

Arduino Uno chip board	To store and transfer values
Webcam	To be use for the object capturing
Laser module-red line	To be use for the object capturing
Power supply cables	To supply power
Wooden Crystal	To serve as a frame
stepper motor	For the rotation of the device
Plain woods	To serve as a frame support
Screws, Tapes, Gums	To bind the different materials together

Endnotes

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Chapter Two
Literature Review

2.1 Conceptual Review

In Modern-day engineering, the term `3D laser scanning' is used to describe a single device technology, but the term initially originated from three related technologies but with separate meanings. The first, "laser" more general meaning is the cordinated Deflection of laser rays, visible or invisible. Scanned laser rays are used in stereolithography technologies, in rapid prototyping, in laser engraving machines, in machines for material processing, in confocal microscopy, in laser shows, Laser TV, barcode scanners and others. The second "3D Scanning"more specific, meaning is the controlled steering of rays or beams followed by a distance measurement at every pointing direction. This method, often called 3D object scanning or 3D laser scanning, is used to Promptly capture shapes of real-world objects, structures, and landmaps, while the term 3D alone refers to having a three dimensional space in a Symmetrical setting in which three values are needed to determine the Position of an element, i.e. something that has length(depth), width and height.

In this chapter, a brief background to the history of 3d laser scanning will be given, starting from the brief history of the origination of each of the individual term of "3D laser scanning device" and how the different technologies evolved with time to become the single sophisticated 3D laser scanning technologies we have today will be presented. The theoretical background in areas of interest will also be presented, the theory will provide understanding in the used methodology to come and the reasoning behind the experiment, findings and discussion. Moreover, this chapter connects to scientific articles and journals to contribute further in the learning process for the curious.

The conceptual review attends to identify in-depth analysis of the concepts under study, the theoretical review serves to guide the identification and analysis of all relevant theories on which the study will be based and better simplify the perception of the study, the empirical review will discuss the various relevant studies that have been conducted on the variables under study, while the research conceptual framework will attempts to explain the relationship between variables under study.

2.1.1.1 Laser

The name "LASER" is an acronym for Light Amplification by the Stimulated Emission of Radiation[1]. Albert Einstein first theorized about the process which makes lasers possible called "Stimulated Emission."Stimulated emission is the process by which an atomic electron interacting with an electromagnetic wave of a certain frequency may drop to a lower energy level, transferring its energy to that field[2]. Albert Einstein first explained the theory of stimulated emission in 1917[3,4], which became the basis of Laser. He suggested that when the population inversion exists between upper and lower levels among atomic systems, it is possible to realize amplified stimulated emission and the stimulated emission has the same frequency and phase as the incident radiation[5]. However, it was in late 1940s and fifties that scientists and engineers did extensive work to realize a practical device based on the principle of stimulated emission. Initially, the scientists and engineers were working towards the realization of a MASER, a device that amplified microwaves for its immediate application in microwave communication systems[6,7,8].

A laser is a device that emits light through a process of optical amplification based on the stimulation emission of electromagnetic radiation[9], a laser differs from other sources of light in the sense that it emits light coherently[10]. Spatial coherence allows a laser to be focused to a tight spot, enabling applications such as laser cutting and lithography[11,12,13]. Spatial coherence also allows a laser pointers. Lasers can also have high temporal coherence[14], which allows them to emit light with a very narrow spectrum, i.e., they can emit a single colour of light. Temporal coherence can be used to produce pulses of light as short as a femtosecond[15].

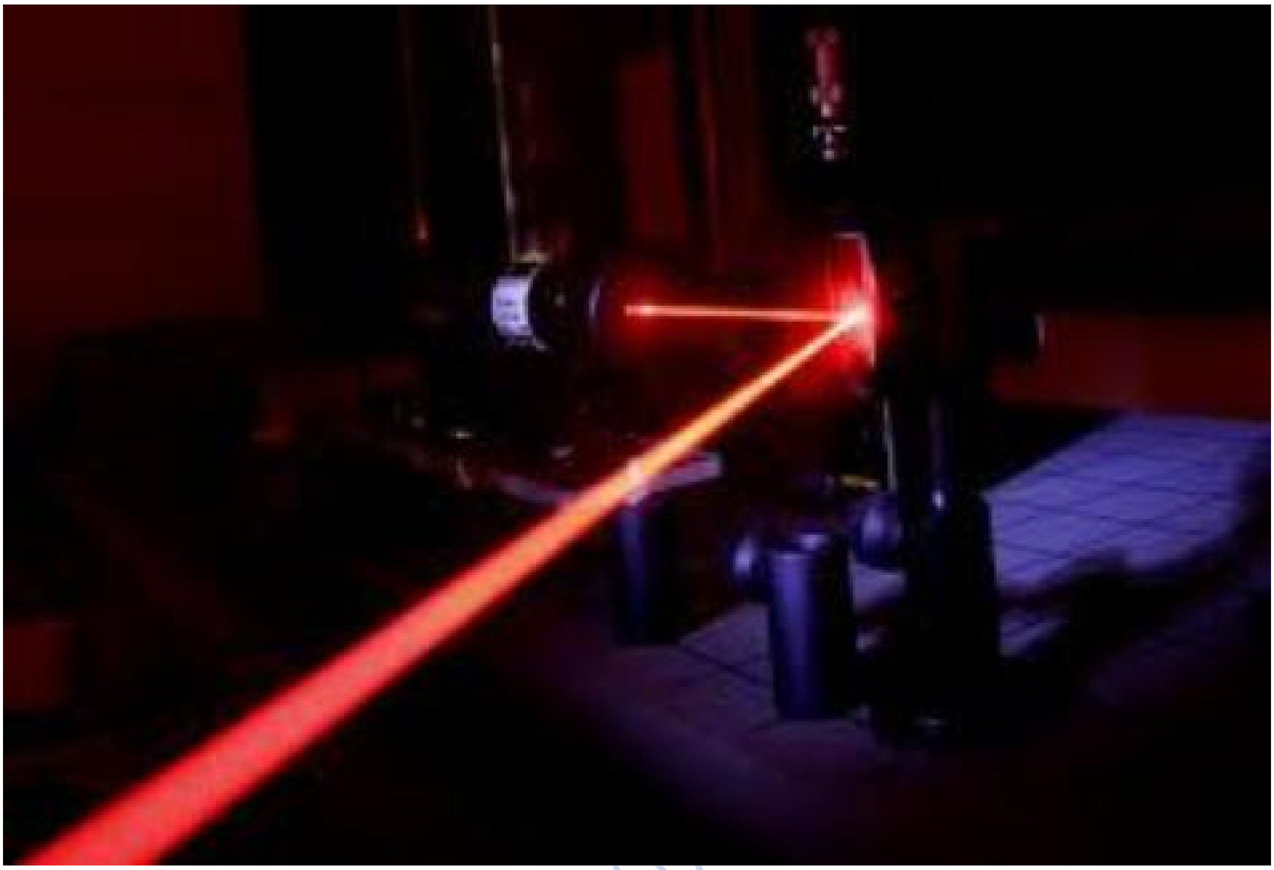

Figure 1: A laser beam

Source: 3D Laser Scanning, 2018

Lasers have provided the most popular method for 3D scanning over the last couple decades, almost to the point where they've become synonymous with definitions you'll find online[16]. Yet the technology has changed a lot from the 20th century to today, including what systems are used and what its used for.

2.1.1.2 3D Scanning

"EVEN THE BUILDERS OF THE GREAT PYRAMIDS USED 3D ENGINEERING[17]".

3D scanning services dated way back to as far as the times of the ancient Egyptians civilization, much farther than you might probably think[18]. Just how far? It is stated that the ancient Egyptians worked out a procedure for 3D when they Wanted to replicate the people who have passed away to the afterlife within their community.

And so they derived up a technique in which they made plaster casts of their dead's mummified heads. This was very novel for Civilization in general as the Resources that is used in this process is required in order to come up with a considerable degree of accuracy included in linen and plaster[19]. Both of these were very hard to come by at the time and so only the most wealthy in the society were able to scan people in such a expensive and time consuming method[20]. So although 3D laser scanning services feels like the latest technology, it has been an interest of mankind that has been in development for a very long while. As such one of the best ways to appreciate and understand its significance and complexity is by looking back and going through the various steps that have made it possible to reach the extent that it has achieved [21].

One of the key players in the development of sophisticated 3d laser scanning services, is the introduction of laser technology[22]. As we read above laser technology originated in the 1940s, while 3D scanning technology could be tressed back to the times of the ancient Egyptians, now the question is where and when did this two-technology got Combined together to have what we have today as 3D laser scanning devices.

The 3D scanning device is based on the Charge -Coupled Device, or CCD, The Charge - Coupled Device, or CCD was invented in 1962 by researchers trying to figure out a way for semiconductors to store data[23], CCDs have become a ubiquitous component of consumer electronics such as digital cameras and scanners, as well as more sophisticated applications such as the Hubble Space Telescope, the Mars rovers, and the satellite systems circling the earth[24]. A charge-coupled device (CCD) is a light-delicate integrated circuit that stores and displays the information of a picture in a way that each picture component within a picture is changed and represented into an electrical charge, the intensity of which is identified within the color range. A CCD camera utilizes a solitary preparing unit to change over all the pixel signals, while every pixel in a CMOS has a singular charge to voltage convertor which offers a higher handling speed to the detriment of greater complexity.

After the invention of the first 3D scanning device in the 1960s with the help of the CCD, although the first 3D scanning device was a breakthrough but has too many short comings, such as; it is bulkier in size, it is slow, it requires a lot of time and storage facilities, it is not possible to capture and object in one go with the device and the overall device quality wise is poor[25]. "At that time they relied primarily on the coordinated use of projectors, cameras and lights, and as you probably may also surmise, they required a lot of effort and patience for operators to produce, with a considerable degree of precision, results that could be used for a certain helpful intended purpose. There was a long way to go."

3D scanning technology remained quite primitive for a number of years, up until the mid 80's when some researchers and tech people began to figure out how to incorporate the use of laser-beams, white light and neat shadowing tricks to come up with more precise results in considerable less time[26,27,28].

With the developments of digital devices, it was feasible to develop 3D scanning devices for an exceptionally concept model. In the middle of 1980, some industry developed a contact probe to create a accurate model to be created, but it was so late[29,30]. Therefore, experts started developing optical technology. Using light was much faster than a physical probe. This also allowed scanning of soft objects which would be threatened by probing. At that time, three type of optical technology were available: Point, Area and Stripe.

Point, which is like an actual test in that it utilizes a solitary perspective, repeated continuously. This was the slowest approach as it included loads of actual movement by the scanner. Area, which is technically difficult. This is demonstrated by the lack of robust area systems. Stripe, the third system was soon found to be faster than point probing as it used a band of many points to pass over the object at once, which was accurate too. Therefore, it was satisfied with two demands for speed and precision. Soon Stripe was the way forward but it was clear that the challenge faced was with one of the software, to capture an object in 3d, the sensor would have to make several captures from different angles. The challenge was in joinin those scans together, remove the duplicated information's and move out the surplus that inevitably gathers when several million points of data is collected at once[31]. "The early scanners used lights, cameras and projectors to perform this task. Due to limitations of the equipment it often took a lot of time and effort to scan objects accurately. After 1985 they were replaced with scanners that could use white light, lasers and shadowing to capture a given surface[32]."

By the 90s there was a high race between researches, industries and tech people in developing a more efficient 3D scanner, some of the early key players in this race are; Cyberware, REPLICA, Digibotics, Immersion and Faro among others.

By the mid 90s, these early scanners have developed into a full body scanner[33]. In 1994, 3D Scanners launched REPLICA - which allowed fast, highly accurate scanning of very detailed objects. REPLICA marked serious progress in laser stripe scanning. Meanwhile Cyberware were developing their own high detail scanners, some of which were able to capture object colour too, Digibotics also introduced theirs which is a 4-axis machine, that could provide a fully 3D model from a single scan, but it was based on laser point - not laser stripe and was thus slow. Neither did it have the six degrees of freedom necessary to cover the entire surface of an object, neither could it digitise color surface. but despite this progress, true three-dimensional scanning - with these degrees of speed and accuracy remained elusive[34,35,36,37].

[38]Moreover, these scanners where relatively expensive, Immersion and Faro Technologies introduced newly low-cost manually operated scanners. This model of scanners could indeed produce complete models of 3D scanners, but they were relatively slow, more especially when the object to be scanned are were detailed. This is when 3D models became united in their race for a scanner, which was: by far accurate, fast, capable of capturing colour surface, really 3D dimensional and realistically low priced.

In 1996, 3D Scanners took the key technologies of a manually operated arm and a stripe 3D scanner - and combined them in ModelMaker. This incredibly fast and flexible system is the world's first Reality Capture System. It produces complex models and it textures those models with colour[39].

Figure 2, Manually operated arm and strip 3D scanner

Source: 3D Scanning Embedded System Design, 2017

One of the things that influenced the rapid development of 3d scanners was also the field of medicine mainly Anthropometry. According to[40and41] many new technologies and tool continue to revolutionize our lives, some of this technology requires a multidisciplinary research approach as the accelerating power and presence of technology has produced unlikely partnerships between disciplines as each adapts new technologies for use in their own field or an emerging one. One of such technology is the 3D laser scanning technology, Because of the diversity of its application, laser scanning technology encourages a multidisciplinary research focus and collaboration across academic disciplines and industris. Many of the applications of the 3D scanning technology focus on anthropometry, or the study of the size and shape of the human body[42].

Anthropometry or the investigation of human body measurement initially started in the 1870s when Quelet wanted to know the measurement of the normal size man to create a better fitting outfit for Napoleon's soldiers[43]. However, anthropometry didn't turn into a perceived discipline until the 1950's[44] with scientists using measuring tape, weight scale, spreading caliper and sliding compass as estimation tools. These methods of studying anthropometry were subject to both unreliability of the measures and observer error[44,45]. The 1960's saw the introduction of new scanning technologies, which at last reformed the study of anthropometry. The main function of these scanning devices is to measure the surface topography of the human body. One of the first large scale research efforts to make use of the newer 3D laser scanning technology was the CAESAR Project (Civilian American and European Surface Anthropometry Resource)[46]. CAESAR was the result of a comprehensive research project that brought together representatives from industry including apparel, aerospace, and automotive in order to assist these industries with their ergonomic needs by making anthropometric measurements over large populations of citizens[48].

3D scanning was not that popular beyond the engineering fields until the 90s. Which should be anticipated as laser scanning would not have progress successfully until the hard drive storage and bandwidth has been increased to be able to fully store the large amount of point cloud data that comes with 3D scanning.

Even in today's times, point cloud data are too bulky to be transferred over common platforms like e-mail or FTP format, but are rather delivered through an external hard drive or thumb drives primarily because the data files are so Enormous.

[49]A point cloud data ccould be anything ranging from 10 to 100 GB's, meaning most CAD programs aren't able to handle it. The secret behind successful 3D scanning is managing the point cloud data and the developed model. The scan collects the acquired data and places it from the cloud point in the Operator's selected software computer. The advantage is that both of the components can be able to be visualized

ultimately maximizin the ability for clash detection, which is the main system that allows for fast turn-around time on every new project.

Before 3D scanning was named that 3D scanning, it was called 'range scanning', described by the Stanford University team as 'a grid of distance values that tell how the point on an actual item is from the gadget that makes the scans.' Range scan information was regularly shown as a high contrast black and white picture, with pixel glow reflecting distance.

By the 90s computer Engineers had a good grasp of what they want to achieve, and how to go with the idea, they were just restricted by their equipment's. The pioneers of 3D scanning were working with simple camcorders, camera tubes rather than sensors, and CPU ceilings of 512 KB and capacity storage limited to 5 MB. Average image resolution is 512 x 512 pixel. Hence, early scanners were for the most part restricted to surface inspection,measurements, and deformation analysis.

Although laser scanning technology was much faster and more efficient than other scanning methods, it still took considerable time and was very Costly. [50]Researchers and 3D scanning models could not figure out how to efficiently combine multiple 3D scans of the same object to create a more efficient data set for 3D models. That didn't happen until the mid 90s, when two researchers from Stanford University, Greg Turk and Marc Lavoy were able to successfully combined 10 scans of a clay bunny, picked up by one of the researchers in a shop and predicted its clay texture and shape would be an ideal model to scan in 3D. The model consists of about 69,451 triangles. The Stanford Bunny served as a benchmark for testing computer graphics algorithms for many years, including polygonal simplification, compression, and surface smoothing.

Figure 5. The Stanford repositions

Source: Wikipedia

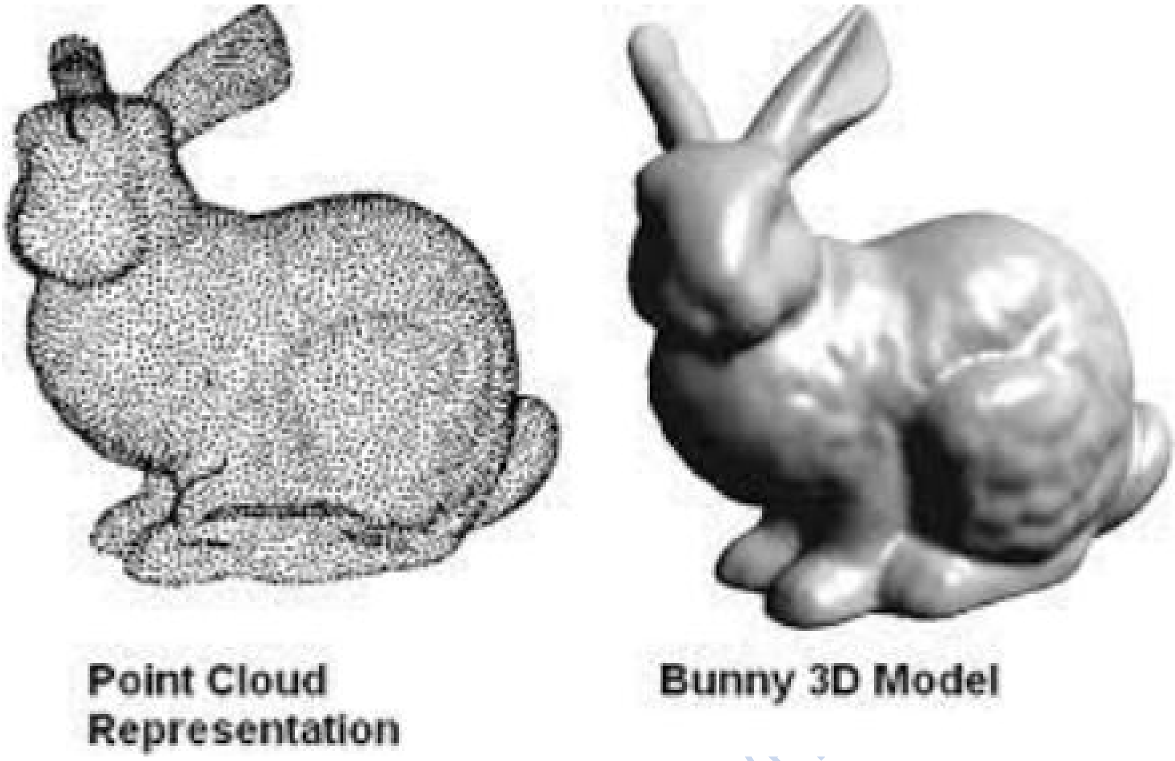

Figure 6. The Stanford point cloud representation

Source Wikipedia

2.1.1.3 3D scanner design patterns

There have been numerous forms of 3d laser scanning devices designs and techniques used by industries and researchers over the years, but they all follow one of the three categories the three principles of data collection and interpretation which is the laser triangulation phase shift, and time of flight.

[51]tested the time-of-flight technique with C programming language, which use either some kind of light or radiation to detect an objects reflection in order to proe it and used it to design the embedded platform for laser/camera settings with WiFi wireless communication under Raspberry Pi 3 model platform. raspberry pi 3 and software for processing the gathering data

after scanned is completed with 3D scanner. With this experiment a certain level of 3D scanning technology was achieved; however, the overall performance of the platform was not very impressive, other technologies not to be explored together with the materials used to enhance the overall platform.

2.1.1.4 Computer aided design (CAD)

Computer aided design, also known as computer aided drafting, (CAD), is the use of computer device to support in the design, simulation, modification, or analysis of an object. CAD is widely use in almost every field today, for example in medicine it is use in developing things like prosthetics and artificial limbs to get a more accurate measurement of the client's need before going on to develop the actual limb, in Architecture and Civil engineering field is use to develop a proposed design or model of a structure or building with a CAD software known as AutoCAD, in military it is used in the aid of designing a weapon or vehicle model and so on.

The history of CAD computer aided design started back as early as the 50s, closely with that of CAM computer aided machine, they are mostly mentioned together as CAD/CAM, due to CAM has increasingly used CAD for a long time now even though the two terms describe different things.

CAM is established based on Computer Numerical Control (CNC) where programmed system softwares dictates the movement of factory tools and machinery. The most popular used CNC programming language in building CAM is the G-code. While CAD is a software program used in creating electronic files for print, developing and other manufacturing operations. CAD arrival has increased the productivity of designers though improving the quality of designs amongst other benefits. The CAD software is used to support both designers and engineers across a wide range of fields, including medicine, auto mobile and aviation.

The term CAD or Computer Aided Design was first introduced and used by Douglas T. Ross, in the early 1950s[52]. Douglas, was a researcher at MIT (Massachusetts Institute of Technology), he was working with computer display systems and military radar technology[53].Douglas worked on projects that pioneered early CAD technology – such as the APT (Automatically Programmed tools), which led to the creation of Automated Engineering Design (AED). Douglas would host conferences at MIT to discuss the expanding technologies with other early practitioners in the industry.

2.1.1.5 CAD meets CAM

CAD and CAM first came together when CAM Utilised CAD design to create its instructions, to control automated machine tools. These tools could subsequently create physical items directly from design files. Pierre Bézier created the pioneering surface 3D CAD/CAM system, UNISURF, between 1966-1968, while working for the French car manufacturer, Renault. His invention was designed to aid the design and tooling of cars by integrating drawing machines, computer control, interactive free-form curves, surface design and 3D milling for manufacturing clay models and masters[54].

One of the main uses of what may be called CAD was deployed by Patrick Hanratty at the General Motors Research Laboratories[55]. Hanratty created Design Automated by Computer (DAC), which is believed to be the principal CAD system that elaborate interactive graphics. This was the first business CAD/CAM system software, and involved a mathematical control programming instrument named PRONTO, which he created in 1957. As such, Hanratty is often referred to as ‘the father of CAD/CAM[56,57,58]. Hanratty is generally credited as "the

Father of CADD/CAM." In 1957, while working at GE, he grew PRONTO (Program for Numerical Tooling Operations), the main commercial CNC programming system.

Five years later, the first true CAD software came to light, developed by Ivan Sutherland and presented at the Massachusetts Institute of Technology (MIT) in the early 1960s as part of his PhD thesis an was called "Sketchpad" Sketchpad was especially innovative CAD software because among its features are; the first graphical user interface, where Sutherland interacted with the computer graphically by using a light pen to draw objects displayed on a computer's monitor

2.1.1.6 CAD/CAM in the 1970s

In 1970, Hanratty founded his own company named ICS, with its own CAD/CAM drafting system software. The business was a failure as the system worked oonly on a smaller 16-bit computer system which was not widely used nor accessible to the mainstream market. However, in the following year, he founded MCS (Manufacturing and Consulting Services) which invented the Automated Drafting and Machinery (ADAM). About 90% of Up-to-date commercial drafting is said to be traced back to this product.

2.1.1.7 The First Modern CAD Program

From the year 1960 to 1980, Aerodynamic industries and manufacturing firms such as Ford and Lockheed Martin invested deeply in CAD Programs to be in-house use. Big manufacturing companies like ford and Lockheed Martin were among the few than could afford the new technology until the early 1970s. In 1973, After Hanratty founded his MCS, and produced the program known as "Automated Drafting and Machining." The program only worked on a smaller 16-bit computer, however it also featured many of the commands used by modern CAD programs today. Instead of numerical inputs, users operate a small table of drawing commands using a regular keyboard. This program initially only came with an 11-inch screen, but MCS company gradually increased the size of the screen over the years[58].

2.1.1.8 CAD/CAM hits mainstream manufacturers

CATIA one of the leading companies for CAM/CAD and computer-aided engineering was first founded as a multi-platform suite in 1977, while, in 1980s, IBM founded its first affordable desktop computer to the mainstream market. Increasing access to technology had a huge impact on the development and spread of CAD/CAM systems to the mainstream market as more and more companies join the processes.

In 1980s, John Walker founded the company Autodesk, which in 1982 launched its CAD software (AutoCAD) for the Ppersonal Ccomputer in the same year. After three years, the software expanded to offering 3D modelling, and in 1992, AutoCAD became accessible for Windows[60]. By 2007, Autodesk had sold about eight million copies of the CAD, making it one of the leader companies in the industry.

Another major turning point for both CAD and CAM was the move from UNIX to PC in the 1990s, which made the process accessible to millions of engineers as well as general consumers who would have previously been unable to afford the software.

2.1.1.9 AutoCAD software

AutoCAD was first introduced by the company Autodesk Co, in the year 1982, and till date it still stands among the most widely used CAD software globally. In 1986 it was named the world's best CAD program by "PC World" magazine, a trend that continued for the next 10 years as Autodesk kept upgrading and introduced more and more advanced versions of CAD software throughout the decade.

In 1993, Autodesk introduced a 3D CAD program for DOS-based computers. As PCs became more widely available and used throughout the 1990s, so did the use of CAD software[61]. By the 21st century, many 3D drawing and modeling programs were created mainly for architecture and designs, including Autodesk's Revit. Revit and other similar modeling software's combined design, drafting and building-information modeling (BIM) to create more sustainable and efficient buildings.

2.1.1.10 Expense

When it comes to CAD development cost remained, the expense involved in building and maintaining the programs remained one the biggest drawback of the CAD evolution throughout the 20^{th} century, mainly the high cost and limited availability of personal computers and software's during the early years of its Introduction. [62]In the early 1970s, Dr. Hanratty's 16-bit CAD program sold for around of $125,000. By 1982, Autodesk was able to sell CAD programs for under $1,000. By 2000, Autodesk's Chief Architect program, which combined 2D and 3D CAD options for professional Operators, could be acquired for around $895. By 2010, a simple CAD software programs can be acquired for as less as a few hundred dollars, making them accessible to most computer users.

2.1.1.11 Uses of AutoCAD

AutoCAD programs offers a diverse advantage over the traditional hand-sketching plans and proposals. It helps both the manufacturer and the designer or client visualize the finished outcome. By seeing what the outcome will look like ahead of work, and changes are able to made easily before heavy work and investments will be made. Researchers and Engineers can use various CAD programs to analyze the quality of a product's design to ensure that it is structurally sound and that it will keep up to need before implementation. CAD also speeds up the design process making products less cheaper to make and be implemented in less time.

2.1.1.12 Uses of CAD/CAM

As CAD/CAM continues to evolve, it has been adopted and used in almost every industry today, from Aviation, to Medicine, Dentistry, Architecture, Civil Engineering, Movie industries, among others. Some of its application include:

1. Aerospace manufacturing, CAD/CAM is in almost every aspect of plane manufacturing to prepare and detail every aspect of production in other to avoid errors in the process where every single detail matters.

2. In Architecture, Digital designs developed using CAD software programs are regularly used in both the interior and exterior designs in architecture, helping bring thoughts to life.

3. In dentistry, CAD/CAM is regularly used to construct both complex and simple oral prosthetics, as well as other medical tools and equipment.

4. CAD/CAM technology is also regularly used in the fashion industry to optimise the use fabric and minimize waste products.

5. CAD/CAM is also widely used in security to solve crimes, as forensics teams use the process in injury analysis, postmortem identification and age estimation.

2.1.1.14 Innovations

CAD/CAM since it emerged commercially in the 1970's to 1980's has Significantly progressed from its separate origins and became a very extensive tool in the Engineering industry. The technology evolved from just being used in drafting simple wireframe geometrics to more considerable advanced modeling, as the production of technology continues to move at a rapid pace, CAD/CAM has had the opportunity to be developed and integrated within a stream of advanced technologies. From the cloud computing to Internet of

Things (IoT), CAD/CAM continues to be revolutionized within the mainstream of the manufacturing industris, which in turn, enables it to be used to create other innovations.

2.1.1.14 History of CAD Highlights:

Program	**Date**	**Creator**	**Description**
Blueprints	1861	Alphonse-Louis Poitevin	The first blue-prints was invented by Alphonse-Louis Poitevin using iron ferro-gallate and light. His method let designers and manufacturers to make copies of architectural drawings, thereby reducing the chance of losing information or making errors when transferring designs between team members.
Pronto	1957	Dr. Patrick J. Hanratty (the "Father of CAD")	PRONTO was the first commercial, numerical-control programming system. It sparked everything that is CAD.
Sketchpad	1960	Ivan Sutherland	Sketchpad was one of the first design systems to use a graphic user interface. Using a light pen on a CRT display, users could constrain properties in a drawing. Sketchpad also created the use of "objects" and "instances."
DAC (Design	1963	Dr. Patrick J.	Dr. Patrick J. Hanratty, General Motors, and IBM partnered to create DAC, an early graphic CAD system. Computer scientist Douglas T. Ross coined the name CAD (computer-aided design).

Automated by Computer)		Hanratty, General Motors, and IBM	

DAC (Design Automated by Computer)	1963	By: Dr. Patrick J. Hanratty, General Motors, and IBM	Computer scientist Douglas T. Ross coined the name CAD (computer-aided design).
CADAM (Computer-graphics Augmented Design and Manufacturing)	1965	By: IBM/Lockheed	CADAM introduced CAD to aerospace design.
CADD (Computer-Aided	1966	By: McDonnell Douglas (now merged with Boeing)	McDonnell Douglas and

Design & Drafting)			other manufacturers started releasing internal CAD systems like CADD, which was used for parts layouts and geometry work.
PDGS (Product Design Graphics System)	1967	By: Ford	Ford developed an internal CAD system called PDGS.
Digigraphics	1967	By: Itek	Itek released Digigraphics, one of the first commercial CAD systems. The system cost $500,000.
Computervision (now under PTC)	1969	By: Philippe Villers and Martin Allen	Computervision sold one of the first commercial CAD systems to Xerox.
ADAM (Automated Drafting and Machinery)	1971	By: Dr. Patrick J. Hanratty	This interactive graphic system was written in Fortran and designed to

		work on virtually all mainframe computers. Approximately 90 percent of today's commercial drafting programs can be traced back to ADAM.
Synthavision	1972By: MAGI	Synthavision was the first 3D solid modeling system. It rendered images with ray-tracing.
Unigraphics (now NX)	1973By: United Computing	Unigraphics provided 2D modeling and drafting. It was a high-end, easy-to-use software used by many corporations that set a new gold standard for CAD software at the time.
NURBS (Non-Uniform	1975By: Dr. Ken Versprille	While working under

Rational B-Splines)			Computervision, Dr. Ken Versprille introduced NURBS to CAD. NURBS helped define surfaces and is still widely used in engineering today.
GLIDE (Graphical Language for Interactive Design)	1977	By: Charles Eastman	GLIDE had many of the same features as modern BIM.
CATIA	1977 1981	By: Dassault Systèmes	CATIA, a multi-platform CAD software still in use today, introduced engineers to 3D modeling.
IGES (Initial Graphics Exchange Specification)	1980	By: U.S. National Bureau of Standards (now National Institute of Standards and Technology)	IGES is a neutral CAD format that lets users transfer their 3D designs between different CAD software programs. Once STEP was

			released, IGES was no longer updated, but it is still accepted in many places.
GEOMOD	1981	By: SDRC (Structural Dynamics Research Corporation)	SDRC developed GEOMOD, their geometric modeling product. Featuring NURBS (Non-Uniform Rational B-Splines), this model generator was based on precision and accuracy.
Autodesk/AutoCAD	1982	By: John Walker	ohn Walker founded the company Autodesk, which released AutoCAD. AutoCAD was the first CAD software made for PCs instead of mainframe computers.
Radar CH	1984	By: Gábor Bojár	

(later ArchiCAD)		This was the first BIM software available for personal computers.
MiniCAD (Now Vectorworks, Inc.)	1985By: Richard Diehl/Diehl Graphsoft	MiniCAD was the best selling CAD software for Mac computers.
AutoCAD 3D	1985By: Autodesk	Autodesk started offering 3D modeling systems.
Pro/Engineer (Now PTC Creo)	1988By: PTC	This was the first mainstream CAD program that brought the ideas of Sketchpad (interactive, easy to use, fast) to life. Based on solid models, history-based features, and the use of constraints, it transformed the CAD industry. It was written in UNIX's X-Windows,

			making it faster and more user-friendly.
CADENAS	1992	By: Juergen Heimbach	Founded originally as an engineering firm, CADENAS realized the potential of the engineering IT age and eventually founded eCATALOGsolutions.
Building Design Advisor	1993	By: Lawrence Berkeley National Laboratory	This BIM system could perform simulations to determine how buildings and components function and give feedback to design teams.
AutoCAD R13	1994	By: Autodesk	This version made AutoCAD 3D compatible.
STEP (Standard for the	1994	By: ISO (the International Standards Organization)	STEP took over for

Exchange of Product Data)		IGES as the new format to use when transferring 3D models. The initial 1994 release of STEP made it an international standard for models, and it's still the most used format today.
eCATALOGsolutions	1995By: CADENAS	CADENAS entered the native 3D CAD model market with its eCATALOGsolutions digital product catalogs that featured multiple native CAD formats for the first time.
SolidWorks	1995By: Dassault Systèmes	SolidWorks allowed more engineers than ever to take advantage of 3D CAD technology.
Solid Edge	1995By: Intergraph	Made as a PLM

		(Product Lifecycle Management) software, Solid Edge was a response to the success of SolidWorks. It functioned on Windows and provided solid modeling, assembly modeling, and 2D orthographic views.
CATIA Conferencing Groupware	1996By: Dassault Systèmes	This was CATIA's first internet-ready system, and it allowed teams to review and annotate CATIA models simultaneously. It was quickly followed by Unigraphic's iMAN web author and CoCreate's Openspace Web.
Inventor	1999By: Autodesk	Inventor was more

		intuitive and simpler to use, and it allowed designers to create complex assemblies in record time. It is still in use today.
Revit	2000By: Revit Technology Corporation	By finding conflicts between BIM objects in models and making necessary adjustments, Revit transformed BIM. Revit is one of the most popular BIM systems used today.
SketchUp	2000By: @Last Software	SketchUp was released as an easy-to-use, 3D modeling tool for several different fields, and it's still widely used today.
AutoCAD 360 (Now AutoCAD	2010By: Autodesk	Autodesk released a

mobile)		mobile version of their system, allowing designers to work outside of the office.
A360 (Autodesk 360)	2012By: Autodesk	This system moved CAD to the cloud and allowed teams to work on the same design simultaneously. Others followed.
3D CAD Models App	2013By: CADENAS	CADENAS released the first 3D CAD models app for manufacturers. The app allows industrial marketers to display their products anywhere and at any time.
Onshape	2015By: John Hirschtick and John McEleney	Onshape is a completely cloud-based CAD system that lets teams

		collaborate on one design simultaneously.
Mindesk	2015By: Gabriele Sorrento	Mindesk lets users view projects through virtual reality.
Microsoft HoloLens	2016By: Microsoft	HoloLens offers full-scale, holographic models.
3DfindIT.com	2019By: CADENAS PARTsolutions	3DfindIT.com is a visual search engine that crawls billions of 3D CAD and BIM models in hundreds of manufacturer catalogs available worldwide.
CAD-to-AR for Inventor app	2019By: Autodesk	CAD-to-AR allows users to view Inventor models in augmented reality.

Source: Evolution of Computer-Aided Design, By David Cohn, Digital engineering, 2018

2.2 Theoretical Review

3d scanning concept The purpose of 3d scanning is to collect data of a real-world object or environment and recreate it in the form a digital 3d model. This 3d model has many applications, ranging from movie productions to industrial design and production quality control. To create a 3d model, the first step is the 3d scan. This results in a pointcloud, often millions of points shaped like the scanned object and placed in a Cartesian coordinate system. These points are often so densely packed that they might appear as solid 3d model (as seen in Figure 9). To capture the color of each sample point a camera can be used. This results in a "RGB pointcloud", a point cloud where each point has a color in the RGB (red, green blue) color scale. When the 3d scan is completed, the pointcloud is analyzed in a computer program to create a surface model from the pointcloud. Simply put and very simplified it's "connecting the dots" to create surfaces These surface reconstruction methods are generally very mathematically complex and are outside of the scope of this thesis. It is however relevant to note that the quality of the final surface model is very much dependent of the quality of the 3d scan.

3d scanning devices can generally be divided into two main groups; contact and non-contact scanners[63]. Contact scanners probe the object using mechanical sensors to measure shapes and distances of smaller objects. Non-contact scanning in turn can be divided into active and passive scanners. Active scanners emit various kinds of light while passive scanners do not emit anything themselves but rely on ambient light

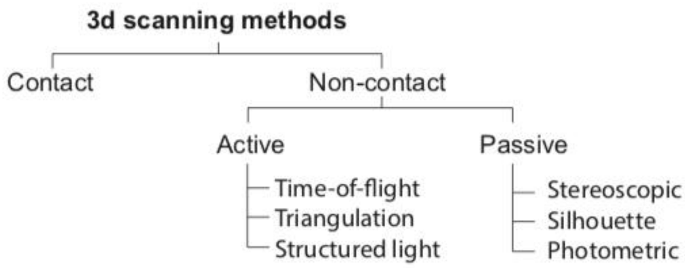

Figure 3: Illustration of 3d scanning methods.
Made in Illustrator

Non-contact active methods Time-of-flight (TOF) scanners pulse a laser beam onto an object and calculates the time between emitting the light and receiving the diffuse reflected light. The equation for the distance is therefore[64];

$$d = \frac{c \cdot t}{2}$$

d= distance
c= speed of light
t= time of flight

There are several methods for transmitting and analyzing the reflected light, mainly to reduce noise and increase accuracy. The range limitation of the system depends how much diffuse light is reflected back to the sensor.

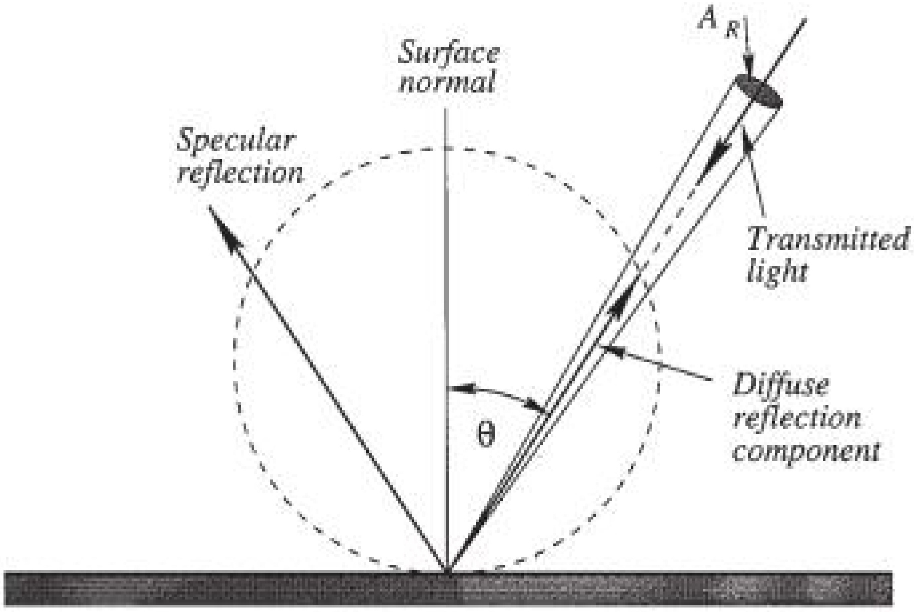

Figure 4: Illustration of the principle of TOF scanning.
Source: Adams 2010

As the amount of reflected light varies with both angle Θ and the reflectance of the material scanned, range limitations are often specified to a specific reflectance and angle instead of an absolute range. For example: “range of 0.6m - 30m with upright incidence to a 90% reflective surface”. As the speed of light is nearly 300 000 km/s, the TOF for a 1 cm measurement would be approximately 6·10-11 seconds. According to the theorem of Nyqvist frequency the sample rate must be at least twice the sampled frequency. In the above example this would require at least a 1.2 THz analogue to digital converter (ADC) or several coupled Ghz ranged ADCs[65]. Triangulation is commonly used where very precise and short range measurements are needed, such as verification of machined parts. The method utilizes at least one laser and image sensor placed with an offset to each other. The laser commonly projects a point, line or pattern on the scanned object and the image sensor captures its offset from the image center.

When combining this offset with the focal length between the image sensor and the lens, the distance can be calculated.

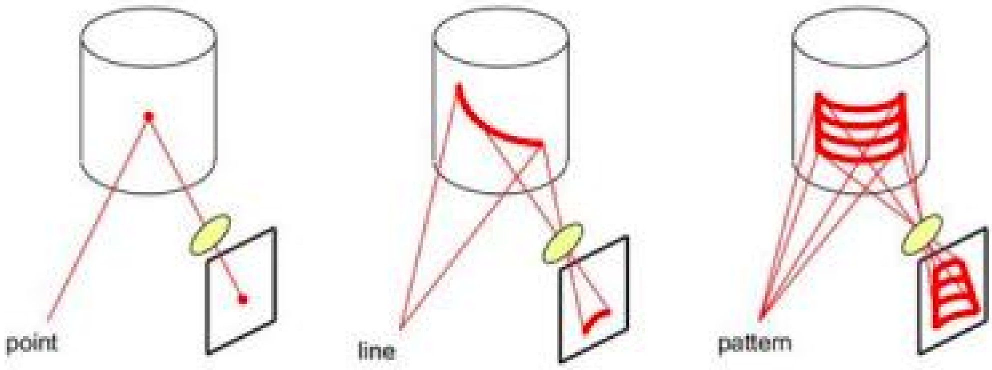

Figure 5 : Illustration of the principle of triangulation scanning.
Source: János 2008

Structured light on the other hand uses light to project various striped images on the scanned object. Initially the cameras take photos with the light source turned off to capture the colors of the object. During the second stage the projector is turned on and projects one or more patterns on the surface which the cameras registers. By analyzing the distortions in the patterns the 3d geometry can be determined. The concept of using cameras and projector enables this method to quickly scan objects but due to the use of visible light is more sensitive to ambient light, reflections and shadows compared to triangulation[67].

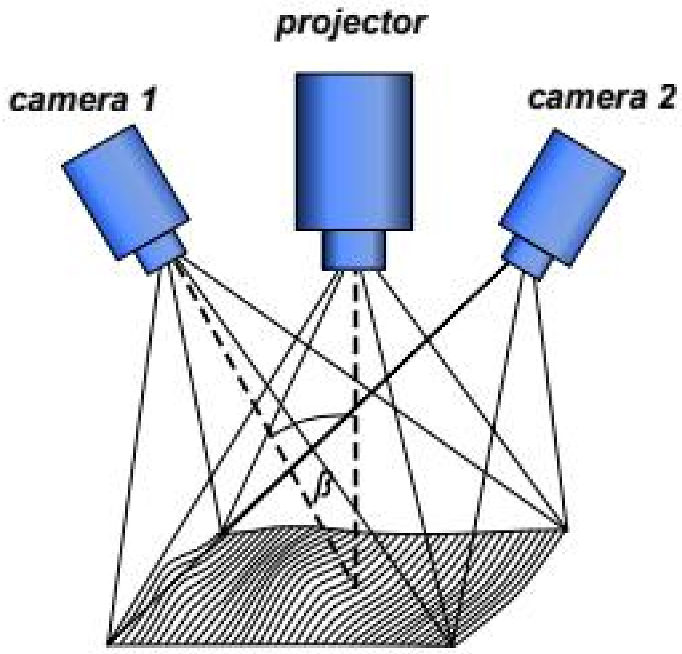

Figure 6: Illustration of the principle of structured light scanning.
Source Vanessaezekowitz 2008

Table 2.1: Product comparison between popular products of each type

Product	HandySCAN300	Go!SCAN 50	Faro 3D X 30
Technology	Laser triangulation	Structured light	Time of flight
Accuracy	0.040 mm	0.100 mm	2 mm
Samples per second	205 000	550 000	122 000
Scanning area	225 x 250 mm	143 x 108 mm	360° by 300° @ 30 m radius
Price approx.	400,000 SEK [iReviews 2014]	+200,000 SEK [Aniwaa 2016]	300,000 SEK [Pobonline 2011]

Non-contact passive methods

Stereoscopic scanning is based on the same principle as the human vision, by observing an object with two slightly offset cameras we can calculate the depth of object. Both triangulation and structured light can use the same principle of two cameras, but plain stereoscopic 3d scanning is passive in the sense that no external light (only ambient light) is projected onto the object.

Photometric scanning; requires only a single hand-held camera and computer software to create a 3d model with high surface texture quality. Several overlapping images are taken of the object so surface normals can be calculated by analyzing the shadows. Using these surface normals a 3d object can be created. By placing up to 100 cameras in a fixed position surrounding an object, an "instant" 3d scan be completed. This is useful when doing high resolution scans of people.

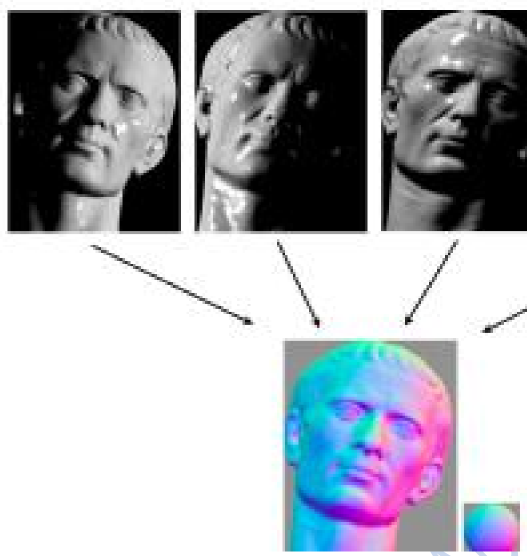

Figure 7 Illustration of the principle of photometric scanning.
Source: [Meekohi 2017]

2.2.1 Reverse engineering

When we talk about reverse engineering, just as the named stated is the act of performing engineering backwards, which is to engineer or program an object or software backwards to understand the particular aspect of the object, it is also known as backwards engineering, reverse engineering can be performed for many different reasons across different fields such as: computer sciences, electronics, medicine, chemical engineering, software engineering and others.

Reverse engineering can be done for many purposes, some are Saving money: finding out how to utilize some resources in a machine can spare people from using expensive products to build another. Upgrading reversing an already existing machine or software can help researchers have better understanding on how to increase its usability. Competitive intelligence, industries perform reverse engineering in competitors product to understand what competitor is initially doing, to upgrade their own product.

Each discipline of engineering has a different definition for RE[69]. Computer engineers and computer scientists, for example, refer to RE when they speak of determining the algorithmic functionality of a software package when they have no prior knowledge of the original software design.

RE in terms of generating computer-aided design (CAD) models from existing objects and components

We are going to focus on reverse engineering in the field of software engineering, the idea of reverse engineering came into software engineering is done to better understand how to improve the understanding of the existing original codes for later maintenance or improvement of the software, applicable information can be gotten to make a decision for software development and visual representations of the code to provide a substitute views regarding the original code, which will help to find and fix software bugs and weakness. Reverse engineering is also known as computer-aided reverse engineering or CARE in the field of software engineering.

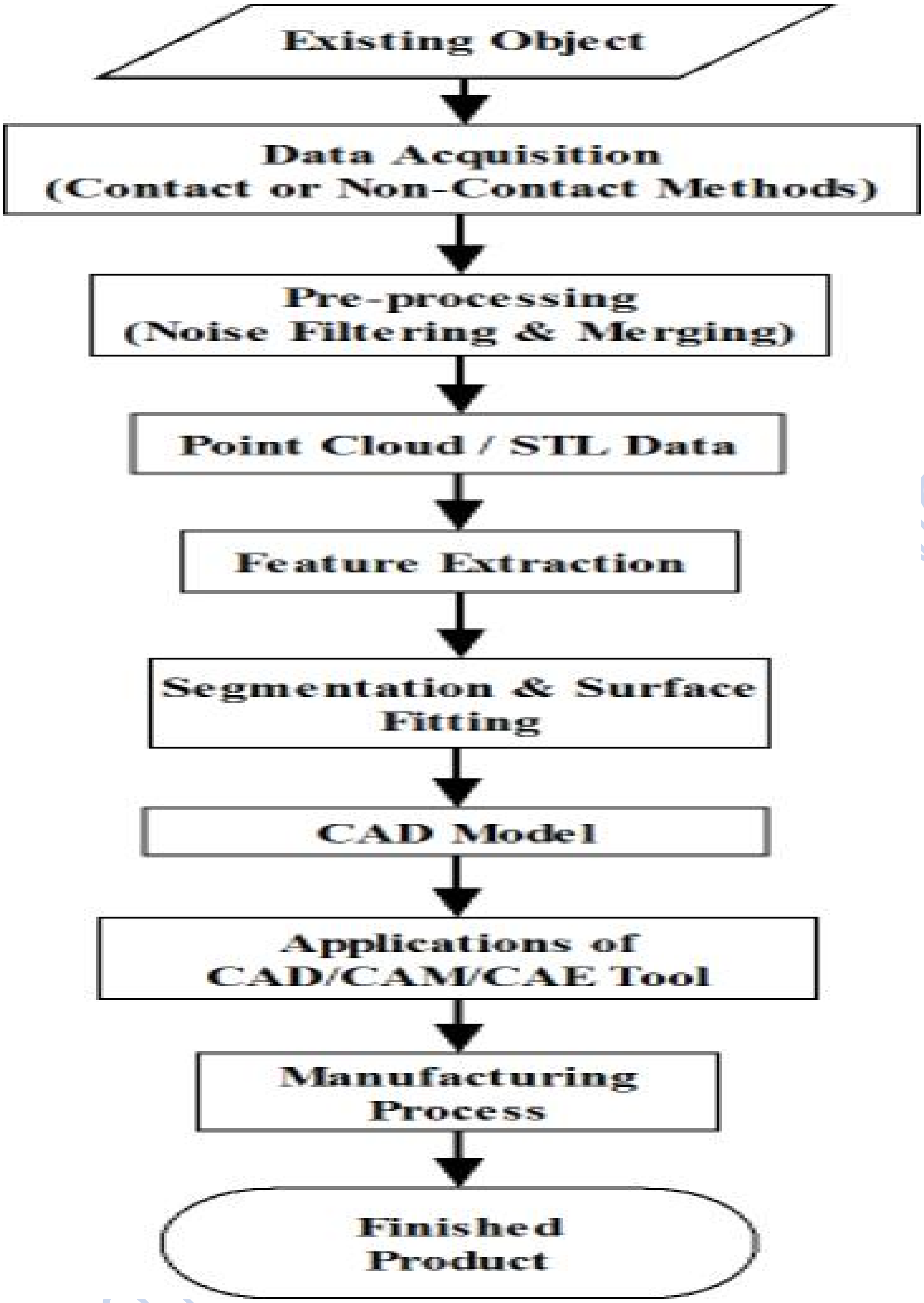

Figure 8. Basic flow of reverse engineering

Source: 3D Scanning Embedded System Desig, 2017

Software reverse engineering is a method in which a machine algorithm program, (string 1 and 0 usually sent to the logic part of a processor) converts a machine code of a program back in to its original programmable language statements, which is normally known as the source code.

programming reverse engineering is done in other to get the original source code of a software program. In doing so researchers can be able to figure out how a particular part of the software program works and performs different operations. It is done in order to improve the software functionality or to fix errors and bugs in the program, and also to find malicious pieces of data in the software if there is any in the program. Generally, most of the times reverse engineering is done in older industries on machines that the manufacturers are not there anymore to explain how that software was programmed. But as of recent, reverse engineering is found to be done in any type of computer hardware and software. With reverse engineering technicians or researches can be able to access the important Contents, like the data formats used and algorithms used by the initial programmer to implement the software and other ideas of the company will be revealed to the 3rd person. Although in doing so without authorization by the company or programmer is a violation of the security and privacy of the

manufacturer company.

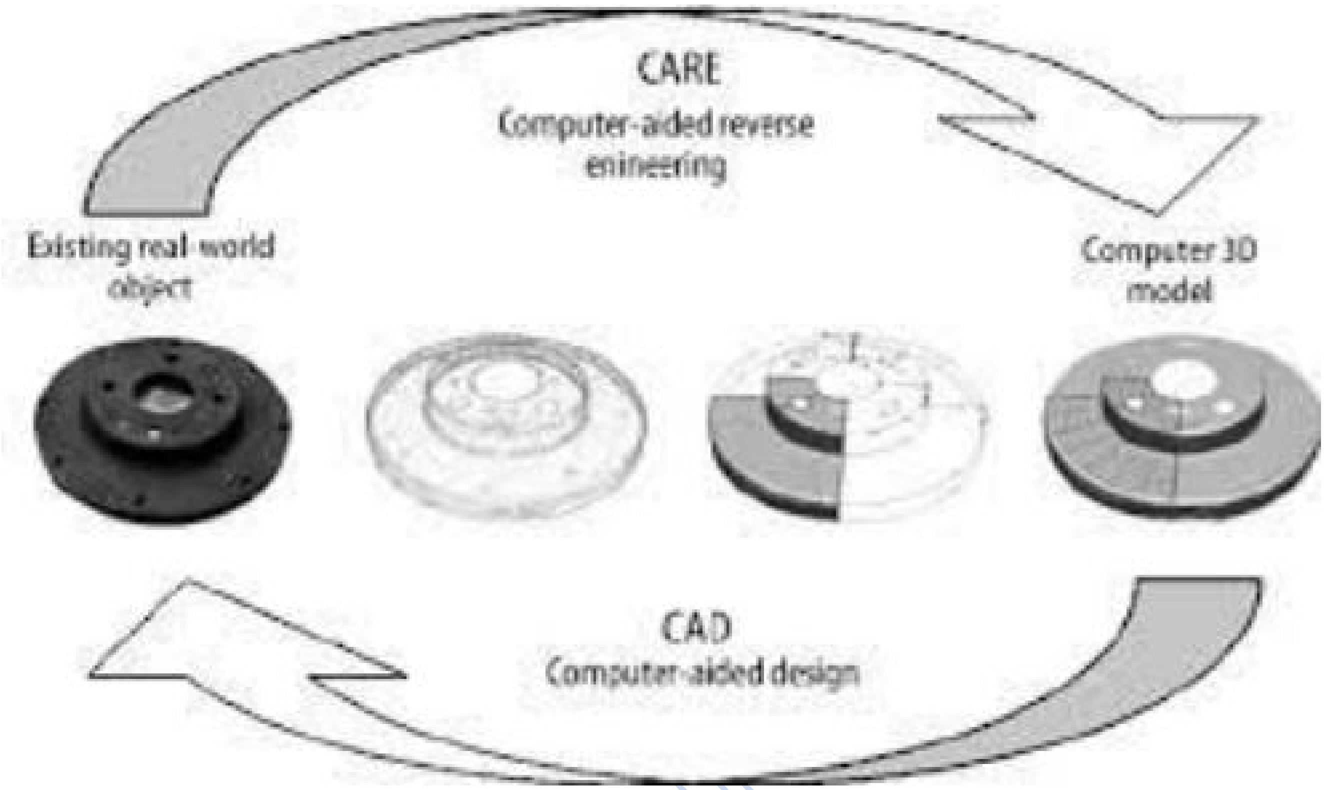

Figure 9 Computer-aided reverse engineering (CARE) process

Source: David & Koschan, Andreas & Abidi, Mongi. (2007)

The ability to generate a CAD model from an environment or real-world object is what is known commonly known as computer-aided reverse engineering[70]. The CARE technique includes creating a point cloud of a real-world object, in this manner gaining near exact measurements of the object. The CARE then detects features, edges and surfaces from the point cloud, and then lastly the CARE will use the data to generate a complete model description of the environment or real-world object.

The advantages of being able to create a full CAD model of an present object are many[71]. gave some examples; allowing for quick inspection and validation in real time, allowing for better collaboration between companies and aiding in recovering of lost or missing documentations of processed parts. With help of either stand-alone software or plugins for existing software such as AutoCAD, users can generate meshes or detect features in the point cloud utilizing CARE. The mesh generating method analyzes the whole point cloud and creates a 3D mesh or NURBS-file that can be used in other applications. The feature detect method generates a solid 3D geometry representation from the specified point cloud object.

2.2.2 Point cloud

Point cloud is a bunch of small pieces of data points or clusters that carries pieces of information which when merged together gives a 3-D shape or object. Each point cloud the cloud will consist of a large number of points, sometimes in millions each containing either a data relative to the origin that is taken from, i.e. the position that was scanned.

To be able to achieve a complete three-dimensional model of an environment or real-world object, several scans of each of the sides, edges and corridors of the object is needed to be completed to avoid an incomplete point clouds data.

To achieve a full three dimensional scan of a room or object several scans are required in order to avoid incomplete point clouds in the process of scanning which will lead to and incomplete 3D model of the scanned object. To obtain a complete point cloud, each of the several scans need to be noted down or registered. Registration is the process where two or more point clouds are aligned into one single cloud[72]. Registration of scans can be performed in two ways, by either registering one scan successfully at a time and then alignin them and be added to the registered point cloud or all the scans will be aligned and registered at once.

[73]Even though a point cloud is not a real surface representation, but sometimes a very sparse approximation of the surface at certain well-defined points, , [74]gave us some reasons why point cloud representation is considered. Firstly, point clouds are most often the output created by 3D scanners. Secondly, the point cloud can be the base of most of the following

surface representations. Another reason to incorporate the point cloud is the increased popularity because of the ever-increasing memory capacities in today's computers.

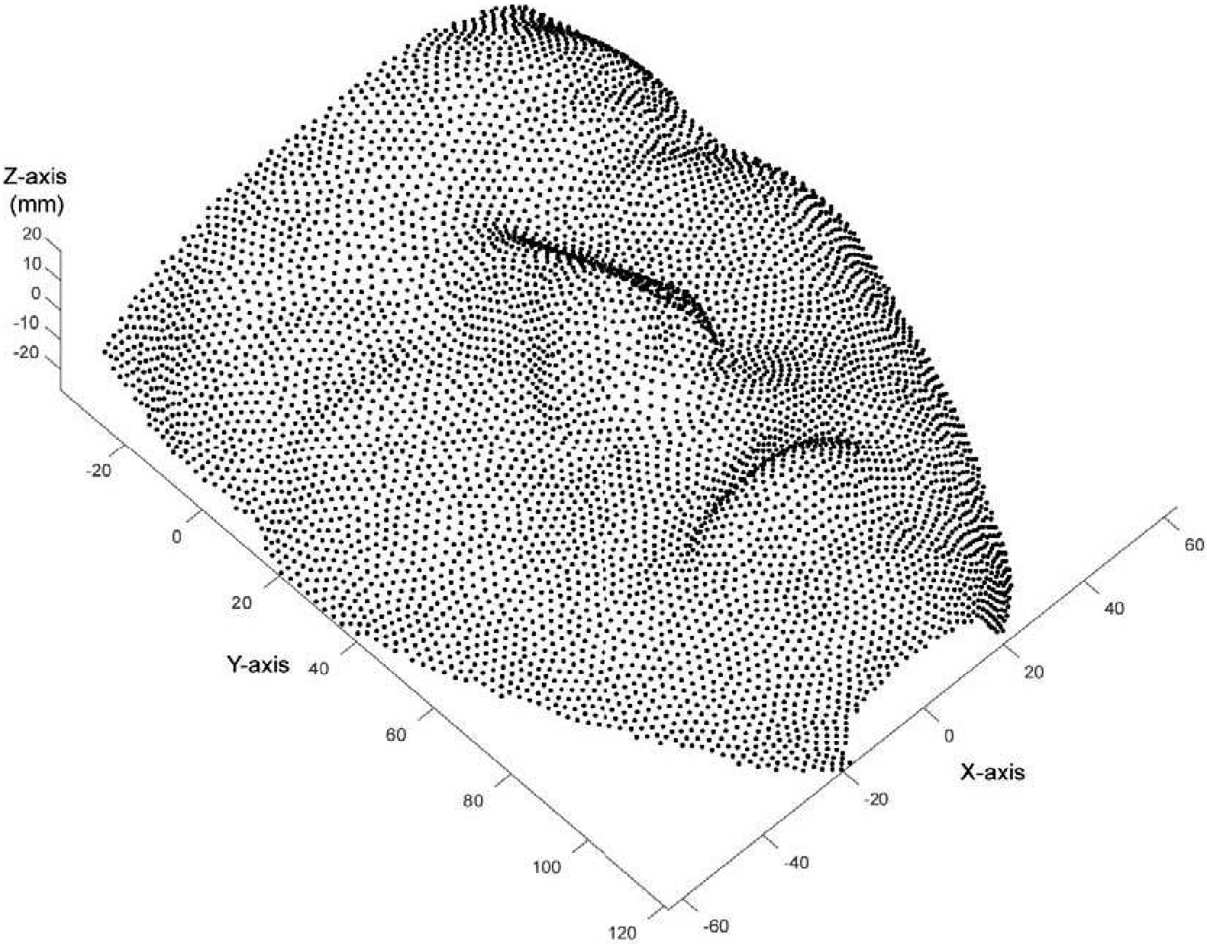

Figure 10. An example of a 3D face represented as a point cloud

Source Fabry, Thomas & Smeets, Dirk, 2010

2.2.3 Applications of point cloud

There are Various uses for point cloud, available already in several softwares. The use of point cloud mainly to aid in design purposes are quite new, although the literature available in this regard is quite limited[75]. The Possible point cloud applications given below has several Volume of Prior researches carried out in the aforementioned topic and further research will likely yield additional applications.

2.2.4 Visualization

When it comes to visualization of an idea or a real-world object, point clouds is going to be the excellent choice for visualization. In point cloud, there is a high level of details in point cloud which increases the Possibility of more people to understand the model. With point clouds even a non-expert in design could be able to visualize a model as same mental of reality, as point clouds are a representation of a reality. Point clouds data can be combined with CAD models, like 3D and 2D models, called hybrid models. Hybrid models can also assist in planning of layout, though they increase the chance of a successful proposal layout. Visualization can also be taken even further, by creating a solidified movie of the point cloud data together with hybrid model where the

camera view will be moving forward and backward through the environment for a more qualitative scan. For a more greater immersive effect, 3D models can be utilized.

Other application of point cloud includes: Clash detection, Discrete Event Simulation, Standardized work and work routines, reverse engineering among others.

2.2.5 3D scanning technologies

The basic principle of 3D scanning is to use a 3D scanner to collect data about a subject. The subject can be:

- an object
- an environment (such as a room or even a landscape)
- a person (3D body scanning)

Some 3D scanners can simultaneously collect shape and color data. A 3D scanned color surface is called a texture.

3D scans are compatible with Computer-Aided Design (CAD) software and also 3D printing, after preparing the 3D model via specific software. A 3D scan can give a lot of information about the design of an object, in a process called reverse engineering.

While 3D vision is second-nature to humans, using cameras to generate an image with depth information is more challenging. Several methods have been devised to extract depth information from camera images. One of the most popular techniques is **Laser Triangulation.**

Laser triangulation: One of the most popular techniques used in 3D scanning is the Laser Triangulation**. L**aser triangulation is a technique that uses machine vision to capture 3D dimensions of a real-world object by pairing a laser beam source with a camera, the laser beam and the camera are both aimed at the inspection surface, then the laser projects its beam onto the surface and measure the deformation of the laser ray. (as shown in Figure 1), nevertheless by assuming a known angule (α) between the camera sensor and the laser source, it is possible to measure depth differences at angle (a) using trigonometry.

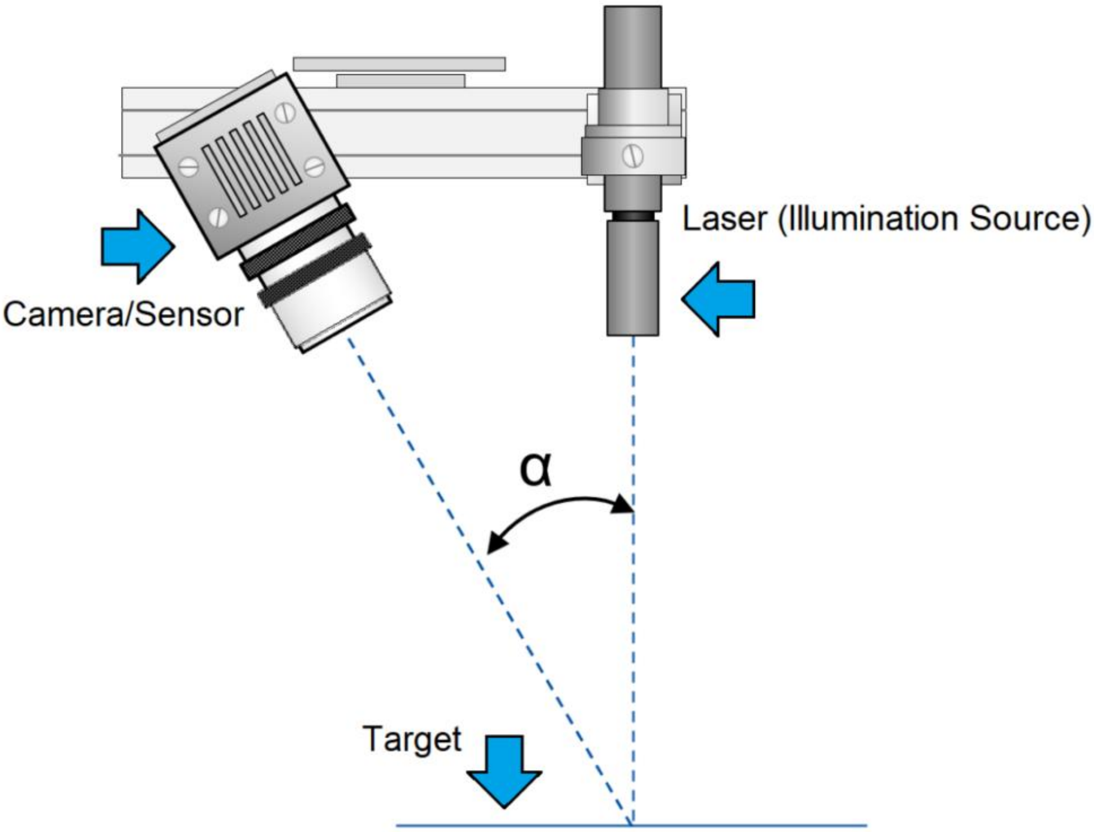

Figure 11: laser illustration:

Source: 60 Years of CAD Infographic: 2014

Laser Triangulation Set-upUsing the fixed angular offset of the camera and laser positions, it is possible to derive the linear distance between the inspection surface and the camera's sensor.

Laser triangulation sensors use the reflected light from the laser source to determine the position of a real-world object by measuring the reflected light from the object i.e., using the time it took the laser beam to travel to and from the surface. Laser sensors can be classified into two categories based on their performance and applications; High quality lasers are generally exploited in position and displacement monitoring applications that high precision, stability and low temperature.

While Proximity type laser triangulation sensors are use to detect the Presence of an element, or applied in counting applications. They are the least expensive also compared to other high-quality technologies

2.2.6 Characteristics of Laser Sensors

Measurement Range

Measurement range, also known as span, is the functional distance between two measurement endpoints by which the sensor will dependably measure displacement. There are different types of laser triangulation sensors available today, of which each is built to measure from a specific measurement range. As longer measuring distance require more resources and attention, most sensors work in a the shorter the sensor measurement range the more accurate the laser. This is due to the more shorter the measurement range the more detector pixels per unit distance within the sensor, which turn gives a more accurate result than long range laser which has to distribute detector pixels along the way. Distance measurement laser sensor mostly focuses on longer ranges, whereas laser displacement sensors often concentrate on short range measurement. Within a Precise range model, as the target material approaches the far end of the measurement range, the accuracy tends to slightly reduce, while still remaining within specifications. Normally, laser calibration certificates are given out to users from the manufacturers upon request.

Standoff Distance

Laser triangulation sensors have a unique operating distance, known as the standoff distance. This point is where the laser is at its sharpest focal point and the reflected spot is in the middle of the detector. How a sensor's optical designed is what will determine its range and standoff distance.

Non-Contact

Laser triangulation sensors are independently non contact by nature, due to laser triangulation sensors using the location of a light spot from the emitted laser beam to make measurements, they accurately measure the position of an object without being in contact with the object. Non-contact measurement facilitates the ability to measure long distances at high speed without the downsides of making damage to the target material or being an obstacle in the target's path. The ability to measure at long distances and high speeds enables laser displacement sensors to be flexible to a lot of applications, including measuring vibrations, measuring sensitive materials, and high speed process applications.

Sensitivity

Laser triangulation sensors have a very high sensitivity when it comes to measuring and object which also makes them stand out from the other high-resolution technologies as in most cases, high sensitivity results in greater resolution.

Resolution

laser triangulation sensors are generally properly designed to provide excellent resolution and stability. Resolution refers to the smallest amount of distance change which can be determined easily. The main factor generally used to determine the resolution of a device is the electrical noise of the system.

Spatial Resolution

Laser triangulation sensors offer a distance that is almost equivalent to the original surface location within the laser range during measurements. Even though these systems sensors cannot accurately detect the position of each feature, they can continuously measure the uneven surfaces. Hence, the laser point must be 25% less than the feature to be measured.

Linearity

Laser triangulation sensors have a good liner balance as in most cases, the sensor's output is completely linear and does not diverge from a straight line in any situation. Nevertheless, there use to be a small deviations from this line which define the linearity of the system.

Advantages and Disadvantages of laser triangulation sensor

Accuracy: one of the major advantages of laser sensors is their high accuracy when measuring as they can resolve measurements of less than one micron with a reduced cost compared to the other technologies[76,77]. Their measurement range is also large, which makes them to meet a wide range of application requirements. Their large operating distance, also makes the adequate standoff to cut down damages that may occur due to contacting shifting objects.

However, laser sensors systems has to be kept clean always and free from dirt as there accuracy may be affected by any external factor easily. laser systems also have electronic components which in turn makes them highly sensitive, and they must be operated in a somewhat favorable temperature. vacuum installations cannot also be carried out with external cooling

Applications of Laser triangulation sensors

- Position Sensing: Laser triangulation sensors is used for navigation and position sensing of objects like, Robot, automatic cars, and drones. It is also used in railroad track alignment, welding head position and pavement of concrete and road profiling.

- Dynamic measurements: Laser triangulation sensors is for dynamic measurements of ultrasonic vibration measurement, spindle runout analysis, Piezoelectric characterization and in-line process monitoring among others.
- Dimensional and thickness measurements: Laser triangulation sensors also plays a vital role in measuring the thickness and dimensions of materials during constructions. It is used for the
- measurement of quality control during concrete block manufacturing, brake rotor thickness, process monitoring of wood thickness and separation distance between rollers.

2.2.7 CONDITIONS THAT IMPACT LASER SENSOR READINGS:

Laser triangulation sensors are accurate measuring machines. All fixing equipment, environmental conditions, material color, sensor alignment, and orientation must be taken into account. Because any little error or alter in setting and implementation may lead error in reading. Some of the most important operating conditions to be taken into account while handling laser sensors are mentioned below:

SENSOR ALIGNMENT*:* It is important that the fixture of the laser sensor is properly aligned and in holes position that mostly comes with the laser stand which are used to mount and secure the laser sensors. Fixtures should be made to match the location of the holes and maintain the laser head Vertical to the target object. Insuring that will produce the best results for the scans.

Mounting: In general, for optimal results, laser triangulation sensors must be mounted in a stand to ensure that the laser beam comes as close to a perfect 90° angle to the surface as possible. By not ensuring that the laser beam is mounted close to a perfect 90° or if the measurable target is not vertical to the laser beam, the reading may be distorted due to a cosine error. Accurate fixturing and the use of a 2-point calibration can help in reducin the cosine error.

Temperature: It is essential to ensure that the fixture holding a laser sensor is well suited for the temperature in the environment. Generally, temperature changes cause expansion and contraction to materials such as steel and aluminum in the surroundings. Some of the mounting materials are made of such materials, when these materials are subjected to a certain temperature is may contract or expand which will probably result in a distance change to the target object. Fixturing material is important to minimize this effect. i.e., a steel mounting block is highly recommended over an aluminum block in high temperature environments because aluminum structures expand more in the heat, which in turn increases the chance of false distance readings.

Vibration: When taking measurement, it is important to ensure that vibration is minimize to as low as possible, as any minor vibration can alter. This can be done by taking extra precautions while fixturing Any vibration will impact the accuracy of the laser and potentially reduce the lifespan of the laser. This is especially important if the sensor is being used for micron to sub-micron resolutions. Any vibration affecting the sensor affects the measurement signal.

Reference Surface: It is important to note that the surface that the target rests on must be taken into account to ensure proper readings. If the surface tolerances are too great, it may impact the sensor's readings. For example, if trying to precisely measure the height of a target with one laser sensor and the reference material has variations in warpage or surface imperfections, the laser measurements will reflect these imperfections. This will result in an incorrect height measurement of the target material.

Reference surfaces such as an optical breadboard are used to ensure stable surfaces. Motorized reference surfaces such as linear translation stages are used for precise measurements across the material's profile.

2.2.8 ENVIRONMENTAL CONDITIONS

Triangulation sensors are precise measuring devices so environmental factors must be taken into consideration. For best sensor performance, a sensor warm-up time of at least 25 minutes is required to best stabilize the measurement.

Temperature: The most common environmental problem that can affect the accuracy of a laser sensor is temperature. Not only do the electronics exhibit temperature drift, but as discussed before, expansion and contraction of mechanical components and fixturing can physically change the sensor gap. This is especially true when measuring in the micron resolution level.

It is important to note that laser sensors can only operate within a specific temperature range. In order to increase the lifespan & longevity of the laser, if possible avoid placing sensors in environments at the far ends of the temperature limits. Cooling enclosures or heaters can be used to maintain an adequate ambient temperature.

- **Structured light:** Measures the deformation of a light pattern when projected onto a surface to 3D scan the shape of the surface.
- **Photogrammetry:** Also called "3D scan from photographs", this technology reconstructs a subject in 3D from 2D captures (photos) with computer vision and computational geometry algorithms.
- **Contact-based 3D scanning technology:** Relies on the sampling of several points on a surface, measured by a mechanical, optical, or physical probe.

- **Laser pulse:** Based on the Time of Flight (ToF) of a laser beam. The laser beam is projected onto a surface and recollected by a sensor. The time of travel of the laser between its emission and reception gives the surface's geometrical information to the 3D scanner.

2.3 Review of Related Works

3D scanning technologies has been the subject of discussion and research over the years among academic's scholars and engineers. Numerous qualitative and quantitative studies have examined the 3D technology disclosure and its overall performance in different institution's and manufacturing firms over the last few decades providing mixed, inconsistent and often contradictory results ranging from positive to negative or no relationship and even statistically insignificant relationships. Some of the empirical results of these studies are presented below:

Perform an experiment by testing the active scanning technique which use some kind of radiation or light and detect its reflection in order to probe an object or environment[78]. And then they designed the embedded platform for laser/camera settings with raspberry pi 3 and software for processing the gathering data with 3D scanner. By using only time of flight technique with C programming language is used in the overall design of the device. The experiment found that only a certain level of 3D scanning technology is achieved.

1. 3D Scanning: A Comprehensive Survey, Morteza Daneshmand, Ahmed Helmi, Egils Avots, Fatemeh Noroozi, Fatih Alisinanoglu, Hasan Sait Arslan, Jelena Gorbova, Rain Eric Haamer, Cagri Ozcinar, Gholamreza Anbarjafari

Critically analyzed the overview of the 3D scanning methodologies and technologies proposed in the existing scientific and industrial literature. The aim of the paper is to help make a clearer difference on the relevance and reliability of the possible methodologies and technologies in building a 3d scanning machine choices. The study used a literature review approached to analyze all the existing 3D scanning methods, including close-range, aerial, structure-from-motion, terrestrial photogrammetry, and mobile, terrestrial and airborne laser scanning. time-of-flight, structured-light and phase- comparison design approaches were also studied, followed by comparative and combinational investigations and outlier detection and surface fitting strategies. The study analyzes each of the methods and technologies to find the relationship and flaws that comes with combination and recombination's of the different technologies. Findings of the study revealed that there will be a substantial implication regarding deciding on the best possible plan for performing the task of 3D scanning, as each 3d scanning task comes with its own demands and flaws.

The role of 3D laser scanning technologies by critically analyzing the history and applications of 3d laser scanning[80]. The aim of the article is to present a brief look on the 3D laser scanners and study its limitations in general. The study adopted a literature review method where data is collected from earlier studies and the study found out that Laser scanning technology has matured and developed more especially in the past two decades to become a leading surveying technology for the acquisition of spatial information, while wide industries and fields have evolved to use 3D laser scanning in their various fields. The study showed that the high- quality data produced by laser scanners are more essentially used in surveying' s specialty fields in the last two decades. These fields include topographic, environmental, and industrial. These data collected from this scanners includes raw, processed, and edited dense point clouds; digital terrain and surface models; 3D city models; railroad and power line models; and 3D documentation of cultural and historical landmarks.

An experiment was conducted by designing a 3D laser scanning system is which is composed of a high precision elevating platform and small 2D laser sensor[81]. The aim of the paper is an attempt to designed a 3D laser scanning system with less flaws such as being heavy, cost more, hard to move around and hard to inspect while using it in architecture in general, and specifically in detecting flaws in modern civil architectural structures, while implementing the structure worldwide. Data was collected at the end of the experiment by Conducting a comparative analysis with other non-contact measurement experiments based on the load test, and through this the scanning designed efficiency and feasibility of the new designed 3D laser scanning system was proven. As stated earlier the researchers in the study particularly concentrated on using a 2D laser ranging sensor a sliding mold combination, a bracket, a control box and a computer. The overall scanning system of the device was divided into four parts, which consist of a transmission actuator, a transmission control device, a laser ranging sensor, and a sensor control box. The transmission actuator is driven by a stepping motor to output a high-precision, controllable lifting movement. The drive control unit consists of a stepper motor driver, PLC and related components. The control slider performs a uniform linear ascending and descending motion on the slide rail through the M programming language, while finally the sensor control box is use to switch on and off the device. Using this method and technique the researchers were able to design a 3D laser scanning system with a high precision, miniaturization and lightweight that is able to test measuring structure independently. The results of the study showed that the system achieves 3D modeling of structural inspection objects compared to other detection techniques. It also has stronger environmental adaptability, higher measurement accuracy and it has lower cost compared to the others. The detecting performance of the device is also better than the traditional testing methods and the developed 3D laser scanning system can also overcome the constraints of environmental constraints and hardware equipment, and realize the efficient and accurate measurement of modern structural tests.

2.4 Synthesis of Gaps Identified

S/N	Author, Yearof publication	ResearchTitle	Methodology	Result/Findings	Gap
1	Hong Seonhack・Cho Kyungsoon 2017	***3DScanning Embedded System Design***	The study adopt Regression analysis	The findings of the study are that that only a certain level of 3D scanning technology is achieved By using only time of flight technique with C programming language to test the active scanning techniques.	Further studies need to be carried out to enhance the performance of 3D scanning platform with adapting various technologies
2	Kexin Li, Jun Wang, *K. Li et alii, Frattura ed Integrità Strutturale 202o*	**The development and application of an original 3D laser scanning: a precise and nondestructive structural measurements system**	The study adopt Regression analysis	The findings of the study are that that only a certain level of 3D scanning technology is achieved By using only time of flight technique with C programming language to test the active scanning techniques.	There is a Existing gap between the rapid development of the technologies and the possibilities of processing results (cloud point processing), is a significant drawback of laser scanning technologies.

2.5 Summary of literature Review

This chapter intensively reviewed the literatures on 3d scanning and reverse engineeri

Endnotes

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Chapter Three

Methodology

This chapter will explain the various methodologies that will be adopted in answering the research questions of the study and fulfilling the research objectives. Some of the aspects that will be discussed are; research design, population, sample size, sampling technique, research instruments, method of data collection and method of data analysis.

3.1 Aim and Objectives

The literature review of Chapter 2 leads to the conclusion that there is a need for an cost effective and high quality 3D scanner, This research aims to provide a solution that contributes to address this need. To achieve this aim, three objectives are identified:

I. Review the key subjects related to the 3D scanning and reversed engineering technologies to identify the missing gaps of having a cost effective and high quality scanner.

II. II. Design a new 3D scanner model using common materials to optimize cost for the 3D scanning operations.

III. III. Implement the developed solution in a prototype system and validate the performance of the proposed model experimentally.

3.2 Research process

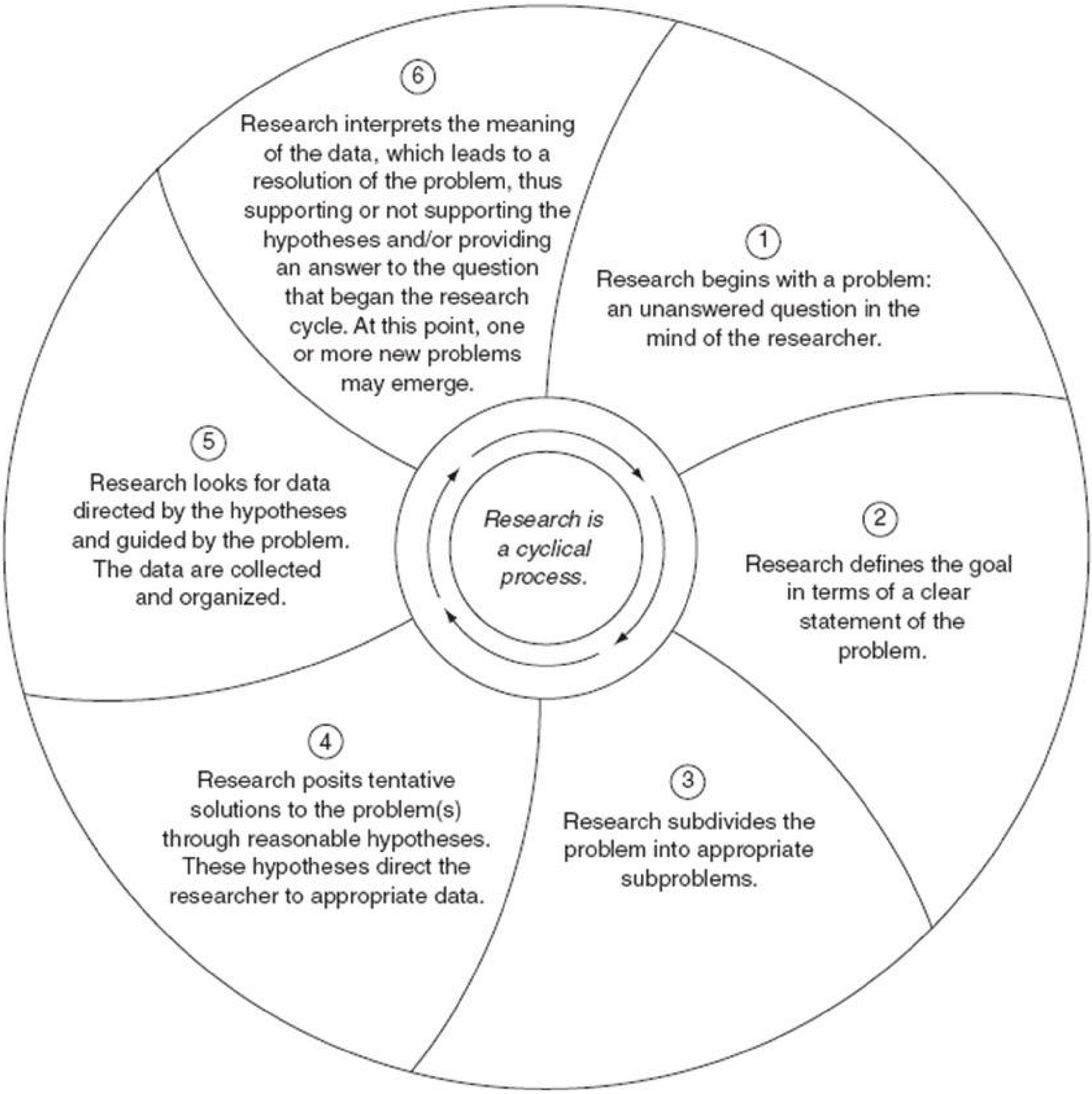

Figure 12. Research cyclical process

Source: Johan Moberg, 2017

The Steps 1 to 3 in Figure 11 have been covered in the literature review and identification of the aim and objectives above. In general terms, the literature review in this research has identified a cost effective problem, for which a new model of 3d device must be developed to solve based on existing theory and new ideas. The model must finally be validated experimentally. This clearly classifies the proposed research as being deductive[1,2]

The rest of this chapter develops the methodology designed to achieve the research objectives and aim above. Figure 12 summarizes these.

3.2.1

Planning for Building		
Objective 1	Objective 2	Objective 3
A thorough literature review on previous laser scanning technologies	Design a new 3D scanner model using common materials to optimize cost.	Using open-source platforms and libraries a prototype model would be implemented and would be evaluated for proposed approach in terms of effectiveness, efficiency and robust

Table 4

3.2.2 **Objective I – Identifying Research Needs**

Objective I is to review 3D and laser technologies and identify the research gap and need in terms of building a cost effective and good quality scanner in the context 3d industry. This objective is also about investigating other industries to identify ideas that could be leveraged. Such objective is typically achieved by conducting a thorough review of literature from various databases of journal articles, e-books, and other library and Internet resources. The literature review is done to (1) assess existing research that directly relates to the identified problem; and (2) explore existing research that partially relates to the problem, e.g. from another industry, but rmains of interest to the problem at hand.

This literature review has been reported in Chapter 2, and enabled a refinement of the research need. It was found that the idea of developing a low cost 3d scanner given an expected model of a scene or object has previously been considered in the 3d industry. But, limitations were identified, specifically the inexistence of methods that consider scanning quality requirements addressing surface completeness specifications, referred to as LOC specifications.

3.2.3 **Objective II – Designing The new Model**

Objective II is to formulate the new design model for scanning optimisation problem in a way that particularly enables to take into account scanning specifications relating to cost of building and the end of the scan result.

This objective is achieved by analysing both the problem at hand and prior work in the field (discovered and analysed as part of Objective I) and derive from those a new design model that solves the cost and quality problem.

Objective two is achieved by caring out three steps:

1. Programming / coding
2. Implementation
3. **Arduino Uno chip board assembling**

Programming /coding

- The coding controls the motion of the lead screw, turntable and stepper motor, the coding is also required for obtaining the values from sensor after scanning, transfer of values from the Arduino uno chip to processor and then to make stl file in required format.

Implementation

- The settings of the code will be adjusted to fit in the process with the scanner assembly. The object signals will be sent directly to the software which will translate the visuals. When scanning procedure is completed, the scanned 3D object will be saved as an 3D point cloud, PCD or a ply file. It will also be saved as an 3D stl.
- **Arduino Uno chip board**. Arduino Uno chip board Is a microcontroller board based on the ATmega328P, the board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. Is an opened source electronics platform based on easy-to-use hardware and software.

3.2.4 **Objective III – Performance Evaluation**

To validate and assess the performance of the proposed new model, experiments must be conducted. For this, it is proposed to implement a hardware prototype, and assess its performance through experiments conducted using both simulated and real case studies[3,4]. The analysis of these experimental results can then be conducted using quantitative and/or qualitative methods[5]. Although quantitative methods are preferred to assess the performance of prototype models, qualitative methods can also be considered. It is worth noting that one but one of the state-of-the-art works on low cost 3d scanner have assessed performance of their approach beyond a basic qualitative assessment of their effectiveness to find a solution. Criteria commonly considered to assess the performance of algorithms typically cover[6,7,8]:

• *Effectiveness:* the model's capability to produce a good solution to the problem;

• *Efficiency:* the model's capability to use as little resources as possible. In the case of computer algorithms, memory footprint and processing speed are commonly considered; and

• *Sensitivity:* the model's stability to changes to its internal parameters. A model that produces very different solutions when its manually-defined internal parameters change even a little can be considered unstable, and difficult to use in practice. More stable models are preferable.

It is proposed to validate the model proposed in this research for automated scanning by considering performance metrics covering all three areas above:

3.3 Research Design

A research design is the overall method one chooses to combine the different elements of the research in a comprehensible and logical manner to ensure that the research problem is well addressed. This research is designed to be categorized into two parts. The first part consists of the literature review and analysis while the second part consists of the experimental design.

3.4 Sample Size and Sampling Technique

In research methodology, the term sample size includes a sub group extracted from the population either selected purposively, randomly or through various sampling technique that is most appropriate for a study

3.5 Description of Research Instrument

Research instruments are statistical tools that are adopted in gathering data, some of which include; questionnaire, focus group discussion (FGD), In-depth interview, content analysis among several others. This study being an *experimetral* research will adopt observation, test and content analysis as its research instrument. because data will be extracted from secondary sources, which will include published journals, papers, text books etc.

3.6 Method of Data Collection

In research methodology, method of data collection involves the various ways or techniques a researcher adopts in gathering data. This study relies heavily on secondary data, as it will extract data from the former reports and account of papers published in all the years covered by the study.

3.7 Method of Data Analysis

Method of data analysis refers to the many techniques a researcher can adopt in interpreting and analyzing data gathered either from primary or secondary sources. In most cases the method of data analysis a research work adopts largely thrives on which is most appropriate in showing the relationship between the two variables[i].

In analyzing the gathered data, multiple regression will be adopted because it recognized as a method of data analysis with the best unbiased, efficient and adopts a less complex technique in analyzing data.

3.8 Conclusion

This chapter detailed the research methodology set to achieve the three objectives, and ultimately the aim of the proposed research. To achieve Objective I, a thorough literature review was conducted in Chapter 2 focusing on Visualization and reverse engineering technologies and identifying the research gap within the most recent works conducted in the field of 3d scanning technologies. Objective II is to be achieved by designing a new Laser 3d scanning device, that minimises the materials scanning cost to achieve the scanning specifications of the former once. Objective III is to evaluate the performance of the proposed design through adequately designed experiments. Chapter 4 next presents the proposed new Designed prototype (Objective II).

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Chapter 4

Introduction

In this chapter the new proposed model for 3D scanning is presented. The approach aims to generate a scanning result that gives a better quality and with a reduced cost of production as-planned 3D model. the scanner characteristics and the scanning specifications. The model uniquely considers the Level of Surface Completeness (LOC) as a new, yet relevant scanning specification.

4.1 Hardware – Construction overview

The device is roughly 10x20 cm large. The top assembly rotates 360° The main components in top assembly is the IR sensor camera which is responsible for capturing the environment. The focus of the design is small size and convenience to prototype.

4.1.1 The core items needed to build the machine are:

1 x Arduino NANO/UNO

1 x Sharp 0A51SK:

2 x A4988 driver:

2xNEMA17 motors:

1 x SD module:

1 x 12V-2A power supply:

1 x screw PCB connector:

Female pins:

1 x micro-SD card:

1 x drilled PCB:

2 x 47uF cap:

1 x limit switch:

Wires

2 x smooth rods (200mm/8mm):

4 x LM8UU bearing:

1 x lead screw (200mm/8mm):

M3 screws

The design and building of the system are categorized into six parts:

1. Building the frame.
2. Building the 3D scanner schematic.
3. Implementing the 3D scanner schematic.
4. Programming and the coding part.
5. Obtaining the point cloud.
6. Converting the point cloud into STL file using MeshLab

Part one: Building the frame

We firstly fix the NEMA17 motors in place on the frame base. Fix them in place with M3 screws

Figure 13: NEMA17 motors

Figure 14: M3 screws

Next, we now then fit in place the two smooth rods which will be used to as a tool for the sliding of the capturing camera and then we Prepare the Z-axis carrige with the linear bearings, we then Use gum to fit those in place and then, we now add a 8mm nut on the back. We now place the carrige on the smooth rods, add the plastic pulley on the shaft of the motor and put the threaded lead screw. Finally, we then add the turntable on the front motor.

The sensor will give a direct analog output according to the measured distance. Finnaly, we add the limit switch for the Z-axis. This limit switch is used to home the axis at the beggining of the code loop when we start the machine. Now the frame is ready.

4.1.2 Part two: Building the 3D Schematic

Electronics overview. The model mainly depends on ten different electrical components to perform a 3d scan. In the following section their purpose and use will be briefly explained.

This below diagram is what we need for the electronics part.

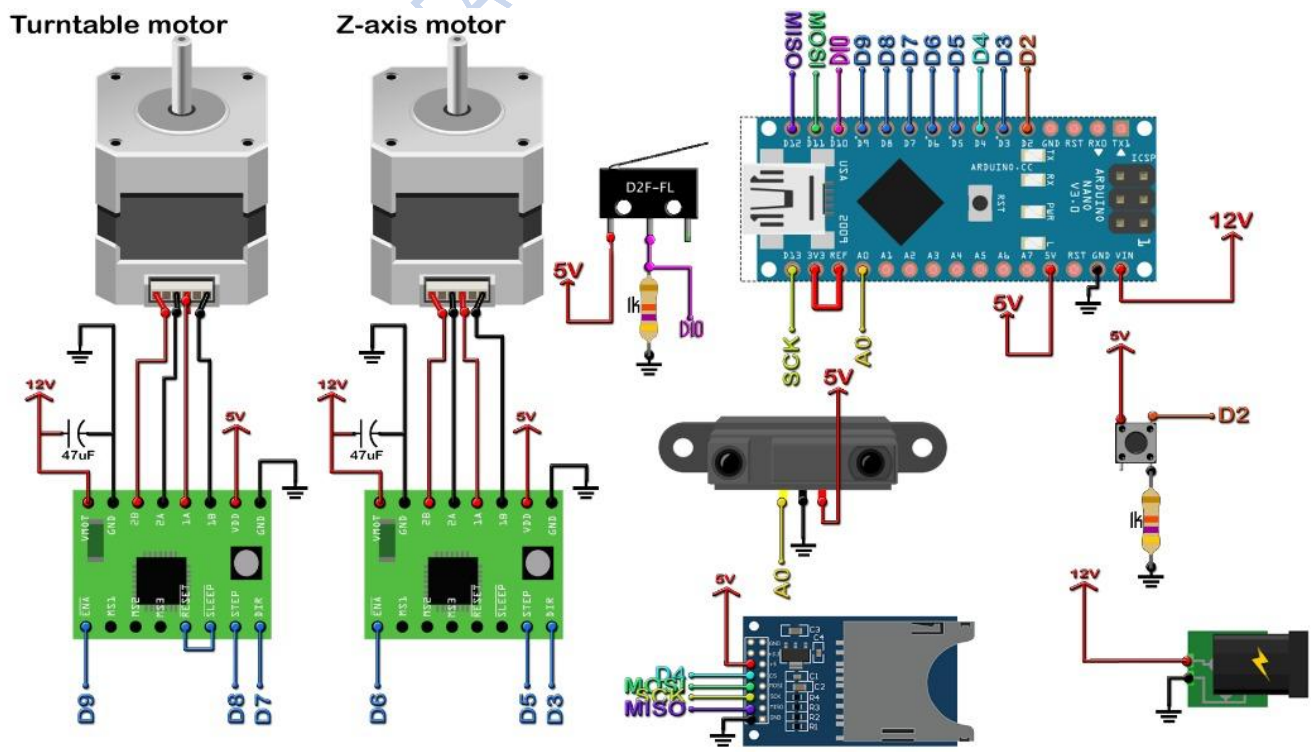

Figure 15: electronics part.

Step motors

Step motors Unlike traditional electrical motors, step motor rotates in small increments. These step motors (Form factor Nema 17, Model: 2BYGHW811) rotate 1.8° per step. This means after 200 steps, the motor made one full revolution. Step motors are commonly used in automation applications where precision is prioritized over high torque or speed.

We have two step motors for this project, the first labelled turntable motor as seen in the diagram above is the one use to control the motion of the turntable, the second motor labelled, z-axis motor is the motor used to control the motion of the z-axis, i.e opposite of the turntable.

D2F-FE switch

On the diagram we have next the D2F-FE switch used for breaking circuit in the system, we connect it with a resistor to reduce the risk of power surges.

Arduino nano board with female pins.

The Arduino Uno chip board Is a microcontroller board based on the ATmega328P, the board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. Is an opened source electronics platform based on easy-to-use hardware and software? We opted for the Arduino NANO with female pins so we could remove it.

The SD card module

SD Card module is a breakout board used for SD card processes such as reading and writing with a microcontroller. The board is compatible with microcontroller systems like Arduino. A standard SD card can be directly inserted into the board, but to use microSD cards, you need to use an adapter. [22]

I R sensor

The sharp A51SK0F is a distance measuring sensor unit, composed of an integrated combination of PSD (position sensitive detector), IR-LED (infrared emitting diode) and signal processing circuit. We opted to the sharp A5 sensor because is easily compatible with the Arduino board.

Step motor drivers

The step motor driver (A4988) is a component designed to optimize and add features to the step motors. Using these step motor drivers, the minimum step angle can be reduced by a factor of up to 16 times. A step motor driver using 16:th step settings has 3200 unique steps per revolution instead of the original 200 of the motor. The use of drivers also reduces vibrations and noise and also adds some safety features, such as over current/voltage protection.

Button

Using push buttons the model can be used without a computer. When the black button is pushed the preset scan program will run.

Part three: Implementing of the 3D scanning schematic

We first made all electronic connections on a drilled PCB. And the inserted the Arduino NANO board with female pins so we could remove it easily, we inserted the SD card module on the side of the board and the rest of the components. The input of 12V was then connected to those two screw PCB connectors, we used 0.1mm wire to make the connections. After that we then added those 47uF capacitors for the motor drivers on the PCB board also. Connect the wires from the motors and sensor to the PCB. After that we then cross check to make sure that the motors rotation is in the desired direction. If not, we will then just reverse the motors inputs.

4.3 Part four: Programming /coding part

The coding controls the motion of the lead screw, turntable and stepper motor, the coding is also required for obtaining the values from sensor after scanning, transfer of values from the Arduino uno chip to processor and then to make STL file in required format.

The code we wrote for the system is simple. Create a loop that will make 360º rotation of the turntable. Each step we measure the distance. The X and Y increment is given by simple trigonommetry as seen below. Next, the x, y and z variable are stored to the SD card divided by a "," character.

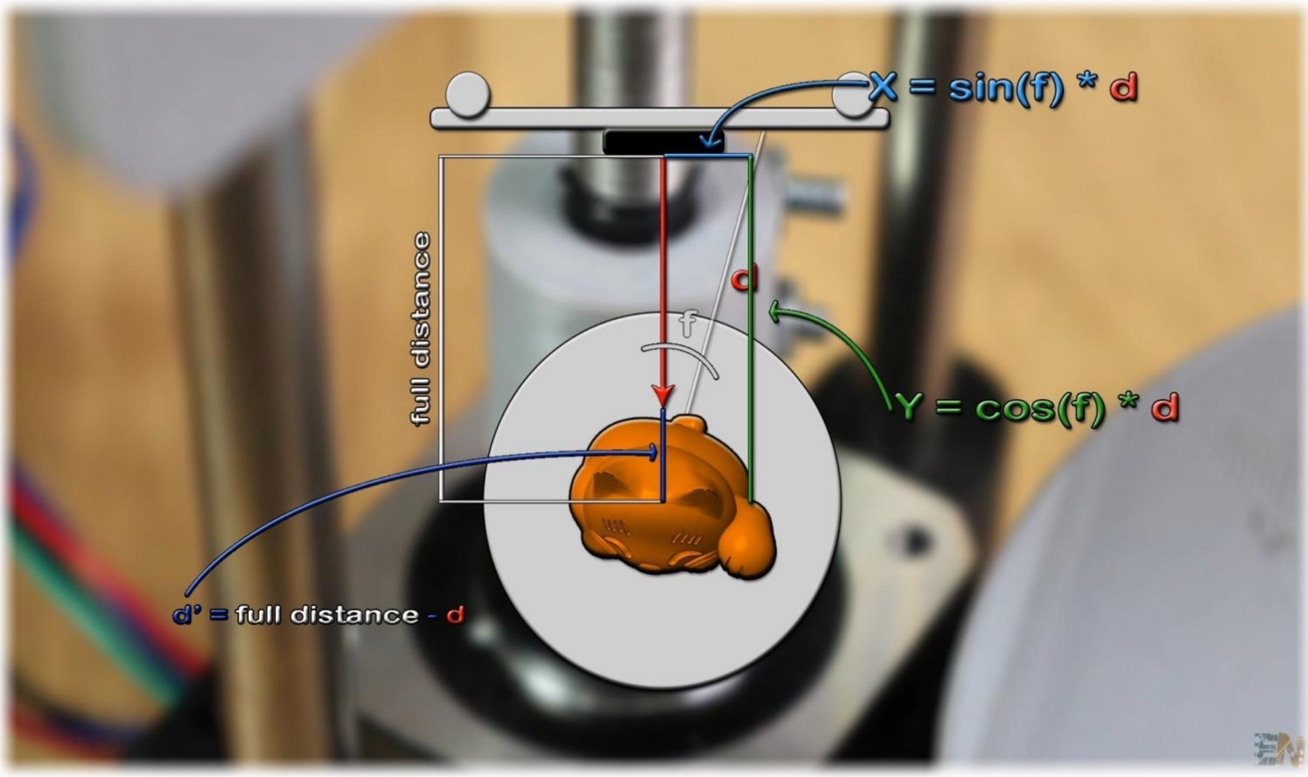

Figure 16: X and Y increment coordinates

Source:

4.3.1 The code

4.4 Part five: obtaining the point cloud

To obtain the point cloud of an object, we first place the desired object on the middle of the turntable. Next, we connect power supply and wait for the system to home itself. When reached, we press the scanning push button and wait for it to complete each circle of the object. Depending on the layer height we choose and size of the object it will take less or more time to complete. Once completed, we then remove the SD card and copy the file to a PC. The file should have the next format. Of which in this case we save the point cloud data in a TXT format. Three columns separated by a comma with the values of the x, y,and z coordinates will be obtained. This are just points in a format of a point cloud. To obtain an STL file, We use a software called MESHLAB software which could be downloaded online

4.5 Part six: Converting the Point cloud to STL file using MeshLab

We first downlad and install the MESHLAB software on the desired system with the default install. Next, we open the meshlab and go to file, import mesh, and the select the scanned point cloud and open the scanned file. In the next window we select XYZ format and as a separator and then select the comma ','. Now the point cloud is open. We next have to give normals to the points. For that we select go to filter, normal curvature and orientation, and compute normal for point set and in this window we modify the settings. For example, we can select 10, as it is a good number. Click apply and close the window.

Software overview

The 3d scanning operation requires 2 different software steps:

1. Arduino uno code written in C for 3d scanning.
2. Merging and meshing of clouds in open source software (MeshLab)

Conclusion

In this chapter, the new model for 3D scanning device, Objective II has been presented. The chapter explains in details how the model is designed, developed and finally implemented. To achieve objective two in this chapter, firstly the frame of the model was built, next the schematic was built and also implemented to fit in the frame, the programming code was also implemented into the system and finally the point cloud data was able to be obtained from the system using a software called MeshLab. Next chapter five next presents performance of the proposed new model (objective

Endnotes

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Chapter 5

This conclusion chapter consists of two parts. The first part reviews the main research contributions. The second part highlights the limitations of the work conducted and provides recommendations for future research to further develop and enhance this research work.

5.1 Research Contributions

This research introduced a new approach for building a low cost 3D scanning device in the context of the industry, aimed at optimizing 3D laser scanning operations.

With regard to scanning quality, the model takes into account a new type of specification that the we identified was lacking from previous models.

In order to achieve the main aim of this research, the following objectives were defined:

IV. Review the key subjects related to the 3D scanning and reversed engineering technologies to identify the missing gaps of having a cost effective and high quality scanner.

V. II. Design a new 3D scanner model using common materials to optimize cost for the 3D scanning operations.

VI. III. Implement the developed solution in a prototype system and validate the performance of the proposed model experimentally.

Objective I is addressed through a comprehensive review of subjects related to the research topic (Chapter 2). The chapter first reviews 3D and laser history, showing that it has gained significant popularity as a visualization technology over the decades. The main applications of laser 3D, its 3D data capturing principles and the factors impacting its measurements are reviewed. The literature review also covers reverse engineering and CCD technology that is similarly identified as a rapidly growing procedural and technological development in the Health&building industris. While CCD focuses on both process and data, this research particularly considers it from the point of view of data and presents the old model as a digital representation of a building that gathers all life-cycle data and information about it. The information contained in BIM models that is of particular interest to this research is the types of objects and their 3D geometry (and potentially their constitutive materials). Finally, the literature review makes the case for effective and efficient methods for 3D scanning and reviews current practice and recent research on the subject. The literature review concludes with the identification of a specific need for building an cost effective and good quality scanning model that take into account not only point-based quality but also criteria for but also surface-related ones, in particular the amount of surface scanned for each object of interest.

The section below reviews all the limitations that can be identified in the work reported here, and suggests approaches to address them through further research.

5.2 Limitations and Future Research

Though the proposed approach for building the model has demonstrated promising results, some limitations of the proposed method can be identified that require further research:

- The implemented model does not currently take into account scanning the desired environment in 360 degrees at a time, in order to generate the point cloud of an object one has to complete the scanning in two sessions. It should nonetheless be straightforward to enhance the system so that it can take into account multiple "floors" where the scanner can be located. Indeed, it was shown how angles can be automatically scanned on top of the rotating motor from. Therefore, instead of selecting one angle, the system could easily consider all of them, and generate potential scanning locations on all those angles, using the exact same approach as presented in this thesis.

- The proposed system does not currently consider the level of detail (LOD) specification used in prior research and in practice. However we do not foresee any problem in integrating LOD into the current framework. It is anticipated that points could be filtered out based on the LOD specification at the same stage of the process as when they are filtered out based on the LOA specification. But this remains to be developed and validated.
- Like all previous works that have considered the building an cost effective scanner, this method theoretically also considered having a great quality together with being cost effective. That may be achieved in further research by considering using a better camera with high precision

An important parameter of the proposed model is the density of the scanning object, β. In the work presented here the value of β is specified manually by the user. It may however be possible to define an automated approach to define an appropriate value

This above limitation is certainly significant and requires further research. Although the first four steps of building the model presented in this thesis could possibly remain unchanged.

In addition to the areas of further development suggested above, further experiments should also be conducted using other types of materials and even more complex visualization items. This could help better assess the value of the point cloud generated on newly proposed models for scanning method, particularly in comparison with current available models.

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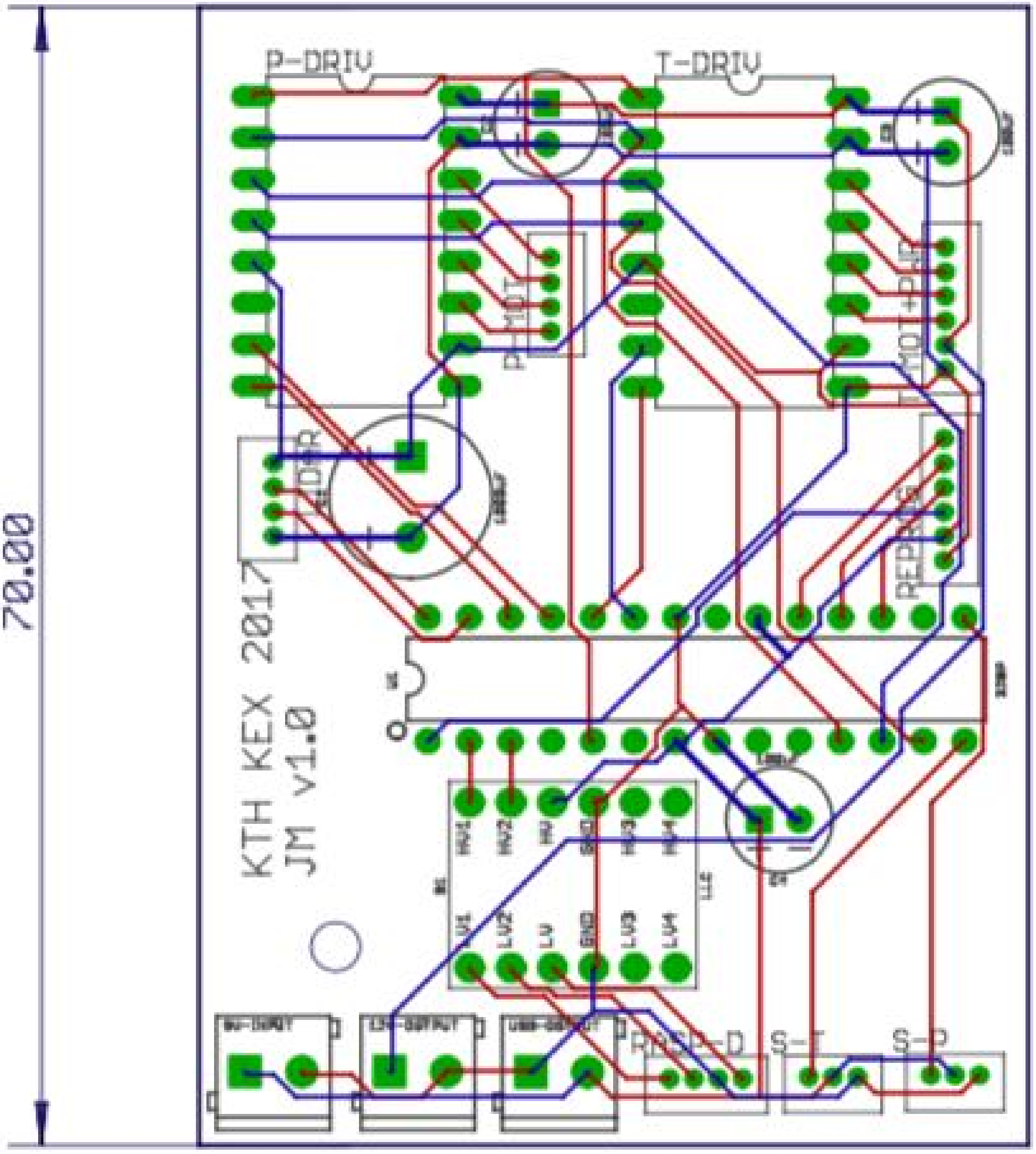
Appendix A - PCB board


70.00
P-DRIV
T-DRIV
KTH KEX 2017
JM v1.0
RASP-D
S-T
S-P

Appendix B - C code for micro-controller Compiled with Arduino compiler ##

Microcontroller code for 3d scanner, This program is compiled with Arduino compiler and runs on ATMEGA329-PU

```
#include <SPI.h>
#include <SD.h>
//Editable variables
int scan_amount = 40;
//Amaunt of scans for each point. The result is the mean. This would increase the delay for
each scan.
String file="scan_001.txt";
//Name of the saved file on the SD card
int z_axis_height = 12;
//in cm //Maximum height of the scaned file
int step_delay = 3000;
//in us //Delay for each step for the stepper motor in microseconds float z_layer_height = 0.5;
//in mm //Layer height. The amount of mm for each layer. int lead_screw_rotations_per_cm
= 8;
//How many rotations needs the lead screw to make in order to make 1cm. int
steps_per_rotation_for_motor = 200;
//Steps that the motor needs for a full rotation.
int distance_to_center = 8;
//In cm. Distance from sensor to the turntable center in cm //I/O
int button = 2;
int limit_switch = 10;
//Turntable driver pins
```

int dir_r = 7;

int step_r = 8;

int enable_r = 9;

//Z-axis driver pins **int** dir_z = 3;

int step_z = 5;

int enable_z = 6;

//Variables File file_values;

//Used for the SD card module

int scan = 0;

//Activate/deactivate scanning

int scan_changed = 0;

//Scan process was changed **float** distance = 0;

//Measured distance **float** angle = 0;

//Rotation angle for each loop (0º-360º)

float x = 0;

//X, Y and Z coordinate

float y = 0;

float z = 0;

int z_loop = 0;

//variable used for the z-axis motor rotation

int r_loop = 0;

//variable used for the turntable motor rotation

float measured_analog = 0;

//Analog read from the distance sensor

float analog = 0;

```
//Analog MEAN
float RADIANS = 0.0;
//Angle in radians. We calculate this value later in Setup loop
int steps_z_height = 0;
//Variable used for the amount of steps in z-axis
int homed = 0;
void setup()
{ Serial.begin(9600);
pinMode(A0, INPUT);
pinMode(limit_switch, INPUT);
pinMode(button, INPUT);
analogReference(INTERNAL);
SD.begin(4);
pinMode(dir_z, OUTPUT);
pinMode(step_z, OUTPUT);
pinMode(enable_z, OUTPUT);
pinMode(dir_r, OUTPUT);
pinMode(step_r, OUTPUT);
pinMode(enable_r, OUTPUT);
digitalWrite(enable_z,HIGH);
//disable the z_azis driver
digitalWrite(enable_r,HIGH);
//disable the z_azis driver
//Calculate variables
RADIANS = (3.141592 / 180.0) * (360/steps_per_rotation_for_motor);
```

```
steps_z_height = (z_layer_height * steps_per_rotation_for_motor *
lead_screw_rotations_per_cm)/10;
/*UNCOMENT this if using limit swithc connected to D10 while(!digitalRead(limit_switch)
&& homed == 0)
{
digitalWrite(enable_z,LOW);
//enable the z_azis driver
digitalWrite(dir_z,HIGH);
//z_azis spin to left (lowering z-axis)
digitalWrite(step_z,HIGH);
//z_azis make a step
delayMicroseconds(step_delay);
digitalWrite(step_z,LOW);
delayMicroseconds(step_delay);
}
homed = 1;*/
}
void loop()
{
//Wait till the push button is pressed
if(digitalRead(button))
{
if(scan == 1 && scan_changed == 0)
{
scan=0;
```

```
delay(3000);
scan_changed=1;
}
if(scan == 0 && scan_changed == 0)
{
scan=1;
delay(3000);
scan_changed=1;
}
scan_changed = 0;
}
//If the scanning proces is ON
if(scan == 1)
{
//We stop when we reach the maximum height
if(z < z_axis_height)
{
for(int loop_cont = 0;
loop_cont < steps_per_rotation_for_motor; loop_cont++)
{
getDistance();
digitalWrite(enable_r,LOW);
//enable the turntable driver
digitalWrite(dir_r,LOW);
//turntable spin to right
```

```
digitalWrite(step_r,HIGH);

//make a step

delayMicroseconds(step_delay);

digitalWrite(step_r,LOW);

delayMicroseconds(step_delay);

angle = angle + RADIANS;

//Increase the angle by one more unit write_to_SD(x,y,z);

//Write x, y, z files to SD card function


//Uncomment this for Serial debug /*

Serial.print(loop_cont);

Serial.print(" ");

Serial.print(angle);

Serial.print(" ");

Serial.print(distance);

Serial.print(" ");

Serial.print(x);

Serial.print(" ");

 Serial.print(y);

Serial.print(" ");

Serial.print(z);

Serial.println(" "); */

}

angle = 0;

//Reset the angle value for next rotation
```

```
/*My threaded rod needs 8 full rotations for 1cm. A full rotation is 200 steps in my case.
We need 1600 for 1cm. So, we need 80 for 0.5mm. The amount is calulated automaically.
Just change the variables at the beginning if you want*/
while(z_loop < steps_z_height)
{
digitalWrite(enable_z,LOW);
//enable the z_azis driver
digitalWrite(dir_z,LOW);
//z_azis spin to right
digitalWrite(step_z,HIGH);
//z_azis make a step
delayMicroseconds(step_delay);
digitalWrite(step_z,LOW);
delayMicroseconds(step_delay);
 z_loop = z_loop+1;
//Increase the loop by 1
}
 z = z + z_layer_height;
//Increase the made z-height by 1 unit
 z_loop = 0;
//Reset the z-axis rotation variable
}
//end of if z_height
//We finished the scan, we stop the drivers
else
```

```
{
 digitalWrite(enable_z,HIGH);
digitalWrite(enable_r,HIGH);
}
}//if scan
}//End ov void loop
//Function that gets the distance from sensor
double getDistance()
{
for (int aa=0; aa < scan_amount; aa++)
{
 measured_analog= analogRead(A0);
delay(2);
analog = analog + measured_analog;
}
distance = analog/scan_amount;
//Get the mean. Divide the scan by the amount of scans.
analog=0;
//reset the andlog read total value
measured_analog = 0;
 //reset the andlog read value
distance = mapFloat(distance,0.0,1023.0,0.0,3.3);
 //Convert analog pin reading to voltage
distance = -5.40274
*pow(distance,3)+28.4823
```

```
*pow(distance,2)-49.7115

*distance+31.3444;

//From datasheet distance = distance_to_center - distance;

//the distance d = distance from sensor to center - measured distance

y = (cos(angle) * distance);

x = (sin(angle) * distance);

/*//For debug

* Serial.print(distance);

Serial.print(" ");

Serial.print(x);

Serial.print(" ");

Serial.print(y);

Serial.print(" ");

Serial.print(z);

Serial.print(" ");

Serial.print(angle);

Serial.println(" "); */

}

//Function that maps the value in a float format float mapFloat(float fval, float val_in_min,
float val_in_max, float val_out_min, float val_out_max)
{
return (fval - val_in_min) * (val_out_max - val_out_min) / (val_in_max - val_in_min) +
val_out_min;
}
//Function that writes the value to the SD card

void write_to_SD(float SDx, float SDy, float SDz)

{

 file_values = SD.open(file, FILE_WRITE);
```

```
if (file_values)
{
file_values.print(x);
file_values.print(",");
file_values.print(y);
file_values.print(",");
file_values.println(z);
file_values.close();
}
}
```

RGB point mapping for 3d scanner, Johan Moberg 19-05-2017 ## MMK 2017:22 MDAB 640

This program runs Python 2.7. Csv, math and PIL libraries are not created or modified by me.

```
import csv
import math
import PIL
## Camera and image parameters ##
hPixels = 1920
vPixels = 1080
CamXAngle = math.radians(62.2)
CamYAngle = math.radians(48.8)
ImXAngle = math.radians(22.5)
ImYAngle = math.radians(24.15)
deltaX=float(695)
deltaY=float(534)
```

```
skipX=float(deltaX/300)

skipY=float(deltaY/80)


ImCenterX = hPixels / 2

ImCenterY = vPixels / 2


StartImageX = ImCenterX

StartImageY = int(round(ImCenterY - deltaY/2))

WidthRange = ImCenterX - StartImageX

HeightRange = ImCenterY - StartImageY

print "Start x", StartImageX,"End x", StartImageX+deltaX

print "Start y", StartImageY,"End y", StartImageY+deltaY

print "Max delta x", deltaX

print "Max delta y", deltaY

print "Skip X", skipX

print "Skip Y", skipY


r=[]

phi=[]
theta=[]

R=""

G=""

B=""


pix = []

fileNames=[]
```

```
alldata=list()

trans=list()


## Imports r, phi, theta. Outputs lists where each row contains: r,phi,theta,z & id no.


def importData():

z=float(0)

i=0

j=0

s=0

fulldata=[]

global alldata

global trans


with open('polar.txt', 'r') as f:

reader = csv.reader(f)

data = list(reader)

print data[5][0]

for x in range(0, 322, 1):

## Creates a list of 322 matrices, each containing 4800 rows containing 4 elements. ##

The 4800 rows in each matrix are sorted after ascending z.

## Example: Matrix 1/322 will contain 4800 rows. In the first row the z value will be the

lowest, and row 4800 will contain the highest in that matrix.


fulldata=[] for x in range(0,4800,1):
```

```
temp = [] r= round(float(data[i][0]),6)

phi = round(float(data[i][1]), 6)

theta = round(float(data[i][2]), 6)

z = r * math.cos(phi)

temp.append(r)

temp.append(phi)

temp.append(theta)

temp.append(z)

temp.append(j)

fulldata.append(temp)

j+=1

i+=1

j=0 s+=1


fulldata.sort(key=lambda x: x[4])

alldata.append(fulldata)

##All data outputs [row(1-322)][array[1-4800][element(1-5)] 59

temp=zip(*alldata)

trans=temp


## Adjust center point of model and image ###


def shiftPoints():


global trans
```

```
print len(trans)
rollOver=False
shiftX=500
shiftY=200
transShifted=[]
i=0

for g in range(0,4800,1):

if (shiftX + i) == 4800:
rollOver = True
i=0

if rollOver == True:
  transShifted.append(trans[i])

if rollOver == False:
   transShifted.append(trans[shiftX+i])

i+=1

trans=[]
trans=transShifted
print len(trans[0])
print trans[0][0]
```

```
print trans[0][:30:10]
print "Finished loop", i


def getPixels():
file_name = "XYZ.txt"
opened_file = open(file_name, 'w')
filename = "image00.jpg"
from PIL import Image
im = Image.open(filename)
pix=im.load()
print "Loaded image ",filename
print "image size:", im.size
j=0
i=0
k=0
counter=0
error=0
for c in range(0,4800,1):
i=0
for v in range (0,322,1):
  r2=trans[j][k][0]
  phi2=trans[j][k][1]
  theta2=trans[j][k][2]
  thetastep=round(4799 - 4799/(math.pi*2)*theta2)
```

```
  if thetastep < 0:
  thetastep= 0
  c=pix[thetastep,i]
x = r2 * math.cos(theta2) * math.sin(phi2)
y = r2 * math.sin(theta2) * math.sin(phi2)
z = r2 * math.cos(phi2)
if (x**2+y**2+z**2) > 0:
 xdir=x/math.sqrt(x**2+y**2+z**2)
ydir=y/math.sqrt(x**2+y**2+z**2)
zdir=z/math.sqrt(x**2+y**2+z**2)

  else:

xdir=math.sqrt(1/3)
xdir = math.sqrt(1/3)
xdir = math.sqrt(1/3)
error+=1
   opened_file.write("%f, %f, %f, %s, %s, %s, %f, %f, %f, \n" % (x,y,z,c[0], c[1], c[2], xdir,
ydir, zdir))
i+=4
if i >= 1200:
i = 1199
 k+=1
counter+=1
```

```
j += 1
i=0
k=0
print "Created", counter, "points"
print "Unit vector errors",error
opened_file.close()
### Main program ###
importData()
shiftPoints()
getPixels()
```