A Review of various 3-D Modelling Techniques and an Introduction to Point Clouds

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Abstract. The substantial lead of 3D models and computer graphics over 2D images is no mystery. Apart from being a hot topic in scientific and engineering society, 3D data models are found to be of widespread usage in fields like virtual reality, e-commerce, robotics, auto-pilot vehicles and other dominant techniques to successfully overcome the limitations of 2D projections, with their demands increasing with every passing digital age. This research paper is divided into 2 parts: the first part enlightens us about the various 3D modelling techniques with advantages, limitations and applications of each one of them while the latter part of the paper introduces the latest pioneer in the field of 3D modelling titled as ′Point Clouds′, an open source project capable of carrying out tasks like 3D classification, 3D detection, 3D segmentation, augmentation, flow estimation etc. To conclude our work, we outlined the various features of the Point Cloud Library along with their uses and future research summons.

Keywords: 3D Modelling, Point Clouds, Virtual Reality, augmentation.

1 Introduction

The technological shift in the past few decades hasn’t and will not go unnoticed. [1] described about the new inventions that were part of the various digital reformation waves chronologically including the new findings in the fields of software and mobile development. One such reformation was the advent of 3D modelling in the field of data acquisition and modelling. Enriched with better understanding of geometric shapes, size, scaling and surrounding environment as studied by [2], 3D data modelling techniques have taken over 2D coordinates and image representation methods without any discretization. As depicted by [3], 3D data modelling techniques secured their place in various areas of applications like autonomous driving, robotics, remote sensing and medical treatment (See Figure 1) in a very short span of time just because of their excellent cognitive ability to represent and solve real-life scenarios.

The digital data collected through 3D models can be preserved and represented in a variety of formats some of which include depth images, meshes, wireframes and grids. One such format

THEETAS 2022, April 16-17, Jabalpur, India

DOI 10.4108/eai.16-4-2022.2318159

which is nowadays widely used because of its ability to stores initial geometric information in 3D space without altering the original layout is Point Cloud. [4] defined a Point Cloud as a set of a large number of scales: a set of data points or links in three dimensional space whose measurements are usually made with 3D laser scanners and Light Detection and Ranging technology (LIDAR) finding immense usage in the field of robotics, industries, object detection, its segmentation and anatomy, autonomous driving cars etc.

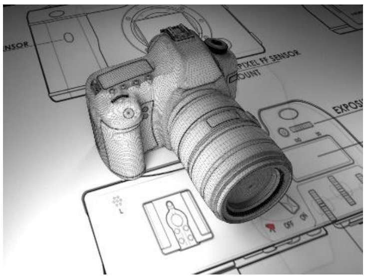

Fig. 1. Illustration showing 3D Model of a Camera.

The structure/outline of this paper is as follows. Section 2 presents the outcomes of the Literature Survey performed undertaking this research along with the fields of application of 3D modelling and Point Clouds. Section 3 describes some of the most widely used 3D modelling techniques along with their advantages and limitations. Section 4 depicts how Point Clouds are used for generate a 3D model. Section 5 attempts to provide a logical conclusion as to why Point Cloud representation of 3D models are better than some described in Section 3 along with the future scope of this research.

2 Literature Survey/Review

[5] carried out a PRISMA systematic review to determine and quantify the use of 3D printing solutions during the COVID19 pandemic along with pre-clinical evaluations and approvals.

[6] provided a detailed study of the uses of 3D modelling, scanning, segmentation and printing in various areas of Forensic Science such as Documentation, Human identification, Dental Anthropology and Anatomy, Bite Marks and pattern analysis, Forensic Facial Reconstruction etc.

[7] designed a fully automatic data registration system to execute all the necessary steps for 3D data modelling in an automated fashion with minimal human intervention along with several other applications of proposed system in 3D data modelling of cultural heritage objects.

[8] described how 3D modelling assisted the overall discovery process and implementation of challenging ideas by Aerospace Engineers. Advanced, efficient, and an accurate view for aerospace engineers can facilitate communication and learning, which increases collaboration within the industry and helps delivering highest quality products to their clients.

[9] documented how easily, independently and cost effectively 3D surfaces and objects are converted into their accurate 3D models using laser scanners and 3D modelling softwares.

They also discussed how their production company was awarded a contract to create a clever 3D model built as an As-built gas processing plant located in Haughton, LA in 2011. The scanner produced models within 1/4 of the accuracy and gave the contracting company a complete survey as it was designed as an easy-to-manage asset management model.

[10] provided a detailed study regarding how 3D modelling forms the basis of modern Computer Graphics. Three-dimensional modeling, engineering graphics, operating systems with 3Ds Max, AutoCAD, COMPAS-3D, Blender can be learned in the Stepic tutorial. Coursera and edX forum offers a basic study of 3D modeling and photographic engineering by learning Autodesk Fusion 360, Blender and more.

The medical science center of the University of Bern, Switzerland, and the Zurich metro police service decided to examine and validate modern, non-invasive, three-dimensional texts and analytical methods which for example can make it possible to find out what tool may have been the weapon involved, what injuries were created, to whom the footprints of the shoe might belong to or any damage caused by any obstacle.

3 Three-Dimensional Modelling Techniques

[11] defined 3D modelling as *an approach in computer graphics to generate digital presentation of any object, space or surface deigned by a technical expert using designated set of software to manipulate points in virtual space into a mesh*. The final output of a 3D modelling process is usually a digital object which is able to fully animate, making it an important character in animation process and special effects.

The term “3D modeling” refers to *the process of creating a three-dimensional representation of an object using special software the output of which is a template, called a 3D model conveying the size of the object, its shape and texture*. We can create 3D models of existing objects, as well as designs that have not yet been created in real life.

[12] further adds that in construction, 3D workplace models can be used to control the machine. These simulations include points, lines and areas that make up the visual environment. They use link data that identifies the location of the horizontal and vertical points relative to the reference point. Thanks to this geographical relationship, we can view representations from various angles.

Machine control uses a variety of stop sensors to give machine operators feedback on such things as target distances and the location of the bucket or blade. Machine operators can refer to the 3D model to ensure that they complete the task accurately. GPS technology enables employees to locate replica points in a location, and sensors on the machine tell them where they are compared to model points. These control processes help employees to translate the 3D model into reality by directing the tools to create lines, points, and locations as described in the model. Teams can also use 3D models in projects, design and environmental compliance reviews. These models also help during pre-bidding, allowing contractors to evaluate various designs and pass on ideas.

Some of the widely used 3D modelling techniques as discussed by [13] are enlisted in the Figure 2 followed by a brief description on each one of them.

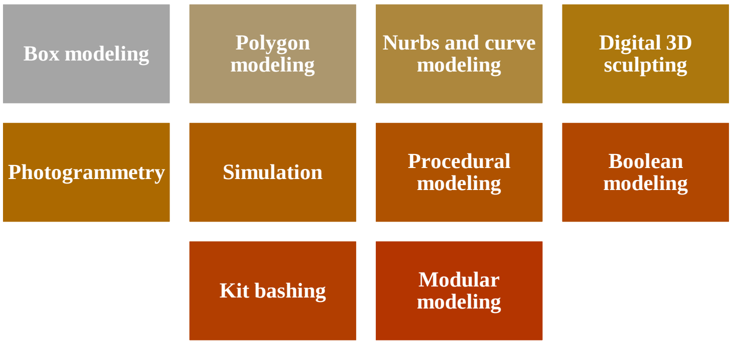

Fig. 2. Some widely used 3D Modelling Techniques.

3.1 Box Modelling

The main principle of Box Technique is to create a 3D model using primitive and classic shapes like cube, sphere etc. An illustration of Box Modelling is shown in Figure 3. To handle some initially unstable meshes, a sub-division surface is added to the original mesh in the form of added geometry between edges, surfaces and vertices bringing about the stability and roundedness to the surface of the object to be modelled.

Applications: Architectural visualization and modelling hard surfaced man-made objects.

Research Application: [14] used Box Modelling technique to rebuild the floristics of various fossil remains establishing the potential of this technique in paleontological analysis.

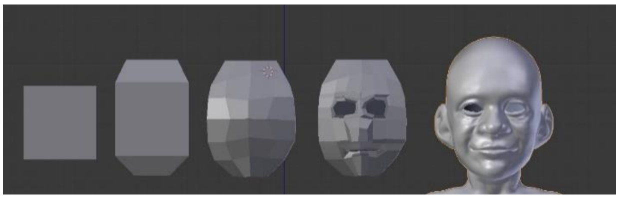

Fig. 3. Illustration of modelling a face using Box Modelling.

3.2 Polygon Modelling

The main principle of Polygon Modelling is to start with a vertex and then build the model edge by edge before moving on to a piece. An illustration of Polygon Modelling is shown in Figure 4. Similar to Box Modelling, Polygon Modelling tend to make use of subdivision process to smoothen or even out the geometry of the object under consideration.

Applications: Visualizing 3D models of statues, ornaments etc.

Research Application: [15] designed polygon meshes built out of triangles, hence naming their methodology as DELTA which found its application in modelling Landscape, animal head, Grecian urn, prosthetic medicine and menger sponge.

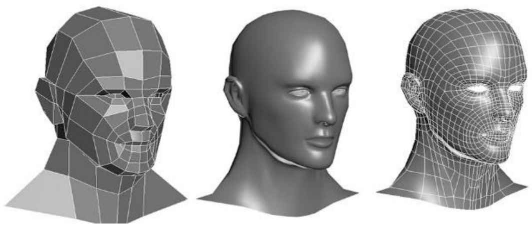

Fig. 4. Illustration of modelling a face using Polygon Modelling.

3.3 Nurbs and Curve Modelling

The main principle of this modelling technique is that we make use of control points to create surfaces using a set of curves and then move on to create bridges among multiple curves rather than working on vertices and edges. An illustration of Nurbs and Curve Modelling is shown in Figure 5. By adjusting the control points with operations like scaling, moving, rotating etc. smooth curved 3D models can be designed.

Applications: Engineering and softwares like CAD etc.

Research Application: [16] made use of NURBS modelling along with operations like slicing and layering to improve the real-time accuracy of high-order derivatives of the curve interpolation process.

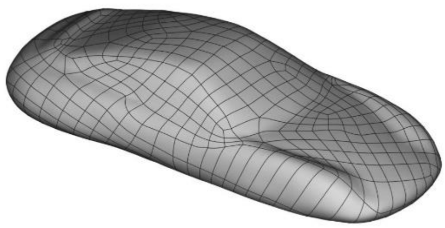

Fig. 5. Illustration of modelling a car using Nurbs and Curve Modelling.

3.4 Digital 3D Sculpting

Sculpting make use of artistic approach like brushes with influence areas to go ahead with the shaping process using vertices, edges and faces. An illustration of Digital 3D Sculpting is shown in Figure 6. The output of sculpting is a non-uniform mesh having poor performance accuracy. However, a mesh with great workability can be obtained through a process called re-topology which makes use of multiple re-meshing algorithms.

Applications: Visualizing a character, animal or creature.

Research Application: [17] tested the scanned data against Digital 3D Sculpting Modelling to examine and attempt to reconstruct the Tomb of Sir John Nivelle situated at Durham Cathedral, United Kingdom.

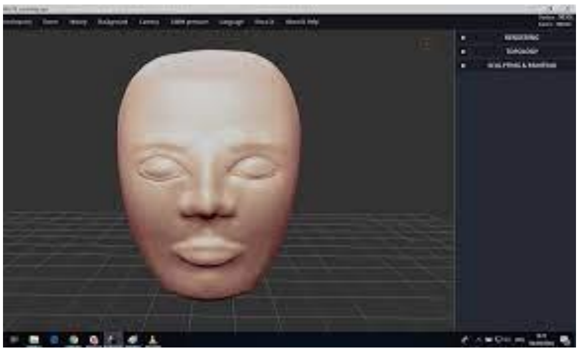

Fig. 6. Illustration of modelling a face using Digital 3D Sculpting.

3.5 Photogrammetry

The main principle of this technique is to trace an object multiple times from various camera angles and under different lighting conditions using a camera and feed the scanned data to a set of code which generates the 3D representation of the object as the output as shown in Figure 7. The added advantage Photogrammetry offers over the techniques covered so far in this paper is the generation of UV maps which can be further enhanced through processes like re-meshing and re-topology to get a more accurate representation of the object.

Applications: Visualizing old buildings and forts.

Research Application: [18] made use of Photogrammetry to study and analyze various structures and field surveys.

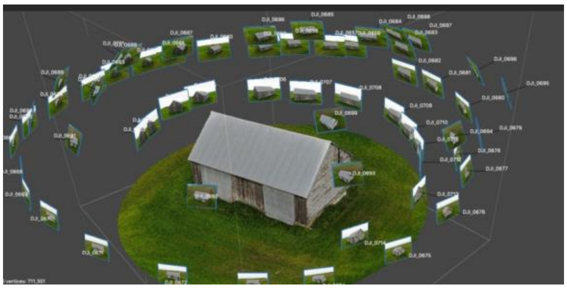

Fig. 7. Illustration of a drone modelling a house from different angles using Photogrammetry.

3.6 Simulation

Simulation depends upon fine tuning the parameters to create a visual of an object rather than dealing with raw manual inputs like vertices and edges. The main principle of Simulation is to create a virtual environment, assign values to different parameters of the object and feed this data to a system which then calculates and notes how the object is reacting and moving in each frame we run the simulation for. An illustration of simulated plane environment for a training pilot is shown in Figure 8.

Applications: animations, VFX, gaming, pilot/driving training under a simulated environment.

Research Application: [19] made use of Scene Simulation modelling technique based on Multigen Creator and Vega Software to visualize various complex structures.

Fig. 8. Illustration of a pilot is trained to handle a plane under Simulated environment.

3.7 Procedural Modelling

This type of modelling is broadly classified into 2 class described as follows:

- **Tool Based Modelling:** The main principle of this modelling is to provide a set of values as input to a program and for each execution the program generates a different model as an output, even for the same set of inputs provided.
- **Shading:** In this type of modelling, the complexities in the geometry of the objects are better studied using Vector Displacement. These vectors expose the complexities in the geometry of an object along a sphere or a plane.

Applications: Modelling the design of a multi-story building/structure before it is actually constructed. Figure 9 illustrates a sample output for procedural modelling.

Research Application: [20] generated building shells with high visual detailing along with massive urban models and virtual reconstruction of various archaeological sites.

Fig. 9. Illustration of 3D model of a tree using Procdedural Modelling.

3.8 Boolean Modelling

Used in co-operation with Box Modelling, Boolean Modelling starts with a primitive model and then move on to detailing by just adding or cutting shapes to/from the primitive model using operations like difference, intersect and union(See Figure 10) thus helping in realizing shapes that would have been time consuming using other models.

Applications: Architectural visualization and modelling hard surfaced man-made objects.

Research Application: [21] constructed 3D models of heterogeneous material objects using a CAD based modelling approach along with introducing a new reasoning Boolean operation.

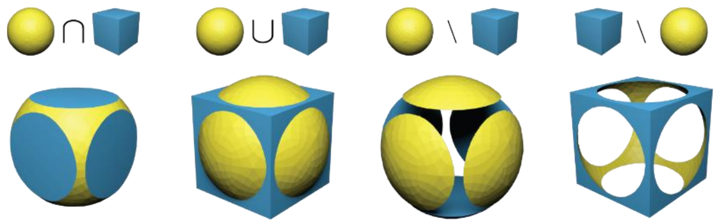

Fig. 10. Illustration of various operations of Boolean Modelling.

3.9 Kit-Bash Modelling

This type of modelling is usually used to enhance the detailing provided by some other type of modelling keeping in mind ratio of frequency details. It permits to explore how distinctive portions could get in-shape together while not having a whole picture of what the final piece will appear to be. Some of the widely used kits used for Kit-Bashing are illustrated in Figure11.

Applications: Visualizing hard and organic surfaces like robots, forest etc.

Research Application: [22] incorporated Kit-Bashed Code in GIGAMacro images machine which allowed collections to capture lots of high-resolution, high focal-intensity pictures with minimal manual attempt.

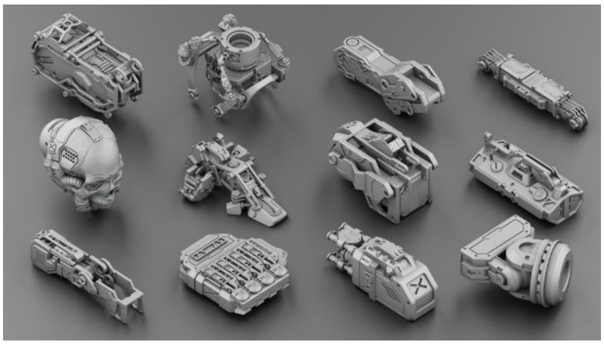

Fig. 11. Illustration of various tools/kits usded Kit-Bash Modelling.

3.10 Modular Modelling

Modular Modelling is more of a modelling practice than a technique. The approach for Modular Modelling is very much similar to Modular programming which states that it is better to break a large problem-space into various smaller solvable problems, the solutions to which are easy to achieve and re-usable.

Applications: Visualizing 3D modelling of a complete city/state as illustrated in Figure 12.

Research Application: [23] used Modular Modelling approach in designing the game ′Jurnal Pahlawan′ by presenting a completely satisfied way of gaining knowledge of media with history contents for kids through this sport incorporating repetition technique of 3D assets for further versions of the game.

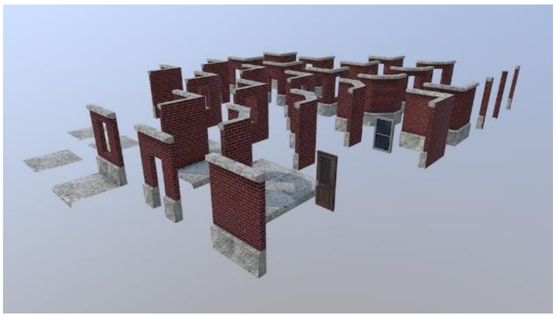

Fig. 12. Illustration of a module can be re-used with or without any modification in Modular Modelling.

Table 1 given below highlights the prime advantages and limitations of each modelling technique described above.

Table 1. Prime Advantages and Limitations of some of the widely used 3D modelling techniques.

Modelling Technique	Advantages	Limitations
Box Modelling	• Generates output faster and comparatively quickly • Easy to use and manage	• Fails to provide precise detailing about the object/structure under consideration
Polygon Modelling	• Easy to furnish and cede • Excels in creating extra unique/organic looking designs	• Imprecise and time consuming • More prone to human-error induction
Nurbs and Curve Modelling	• Generates more organic and uniform characters • Provides more control over the resolutions	• Limitations of the number of shapes that can be rendered
Digital 3D Sculpting	• Fast paced • Offers more variety of sculpting tools like brushes etc. compared to traditional art.	• Less authentic • Lack of organic feel due to absence of detailing.
Photogrammetry	• Highly efficient and reliable • Works well at locations that are unsafe and difficult to access or	• Output is highly affected by weather terrains, lighting conditions and line-of-sight of the cameras.

	capture	
Simulation	• Avoid danger to lives and highly reduce the risks involved • Cost effective • Easy to study and diagnose	• Radical expertise is required to create a simulation
Procedural Modelling	• Meshes are easy to edit, modify and animate • Physical and logical independence among various layers of operations.	• Lack of control on specific details
Boolean Modelling	• Easy to refine • Decisive in nature	• Complex, unfamiliar and time consuming
Kit-Bash Modelling	• Enhanced detailing • More realistic and organic output	• Difficult to comprehend • Radical expertise required
Modular Modelling	• Enhanced reusability • Time consuming	• Lack of realism for organic structures

4 Introduction to Point Clouds

A point-cloud is a group of many small static points virtually existing in a 3-dimensional space, with each one designated with X, Y and Z coordinates. Collectively, they create an identifiable 3D structure and the denser the point cloud is, the more details it provides regarding the object under consideration. Figure 13 provides an illustration of a Point Cloud of a human foot.

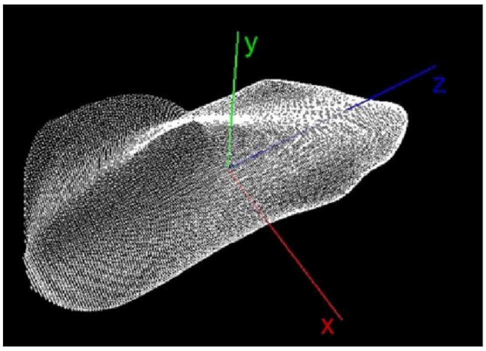

Fig. 13. Illustration of a Point Cloud of a foot.

[24] defined point-cloud basically as *a collection of tiny pixels plotted in 3-D space. It is made up of a mess of points captured by the use of a 3D laser scanner*. If we are scanning a structure, for example, every digital pixel might represent an actual point at the wall or floor the laser beam comes in contact with.

The scanner automatically combines the vertical and horizontal angles created via the laser beam to calculate a 3-D X, Y, Z coordinate position for each pixel to produce a set of 3D coordinate measurements which regularly consists of its shade value saved along with its intensity. This info can then be converted right into a digital 3D model that gives you an accurate distinct photo of our object under consideration.

A point cloud can be formed using following 2 methods:

- **Photogrammetry:** In this method, images captured by a drone camera are mended together to create a point-cloud, develop it into a mesh and then finally to a complete 3D model using software like CAD, BIM etc. Larger the number of images, more will be the number of data points and hence more detailed and accurate will be the 3D model constructed.
- **Light Detection and Ranging(LIDAR):** This method make use of infrared laser beams to measure distances based on the amount of time the light beam takes to return back to the source, producing an exceptionally precise view of the area to be modelled.

4.1 Benefits of Point Cloud over other modelling techniques

- Techniques like Photogrammetry automates the cumbersome process of manipulating the X, Y and Z coordinates manually saving hours of time that an operator had to spend manipulating the data.
- Both LIDAR and Photogrammetry excel in generating accurate and precise results due to their ability of collecting information of a large set of data points at once incorporated with features like GPS, geotags etc.
- Due to reduced manual efforts, the overall cost of generating a 3D model using Point Clouds is highly reduced along with diminished risks of encountering costly mistakes, expenses and hiring costs.

4.2 Are Point Clouds and 3D models the same?

A point cloud in general, is a huge collection of data points in 3-dimensional space having X, Y and Z coordinates gathered using Photogrammetry or LIDAR out of an existing structure or object. However, such point clouds are further processed algorithmically to generate solid 3D models. Hence, it is safe to say that *a 3D model is the processed output of several point clouds*.

A point cloud is converted into a 3D mesh using several PCL modules and the resulting mesh is converted into a solid 3D model using softwares like CAD, BIM etc. This conversion is done keeping in the mind the complexity of handling, managing and computing a point-cloud file. Hence a point cloud often acts as raw-input or reference data for a 3D modelling set of code as illustrated in Figure 14.

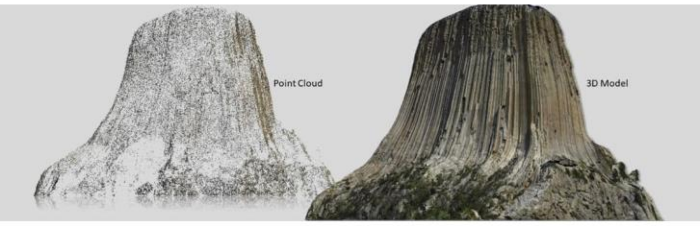

Fig. 14. Illustration depicting the visual difference between a Point Cloud and a 3D Model.

4.3 Point Cloud Library(PCL)

Point Cloud Library(PCL) is a go platform, large scale, Open supply assignment dedicated to the processing of point clouds, working below a Berkeley software Distribution (BSD) license. It has been designed in particular for industrial and clinical research.

It permits free and absolutely felony copying of the source code of the algorithms contained in the library and any modification thereof. [25] further describes PCL as *an advanced and tremendous approach to the challenge of 3D notion, meant to provide support for all the common 3D visualization blocks that an application requires including filtering, feature estimation, surface reconstruction, model generation etc. through a state-of-art algorithms' library*. Due to its immense use in the fields of robotics for its algorithmic capabilities, PCL is supported through an international community of robotics and various other research organizations like AIST, UC Berkeley, TUM etc. The official Logo of Point Cloud Library is shown in Figure 15.

Fig. 15. Logo of Point Cloud Library(PCL)

5 Conclusions and Future Scope of the research

None 3D modelling techniques described above can be described as 'best' on a whole. While describing on what kind of modeling is the most appropriate of a given scenario, we must think about what cease result we are aiming at but in most of the cases the end result is going to be an aggregate and collective efforts of two or more techniques mainly if we are creating a scene that needs to be as realistic as possible.

The PCL presents superior algorithms for point-cloud processing and 3D model visualization running on Open Source License for promoting continuous efforts to improve the efficiency of the algorithms. With the expectancy of sensible packages and libraries in fields like autonomous driving, Point-Cloud understanding has obtained increasing attention these days. In 3D shape classification, point clouds have executed fine overall performance on recognized benchmarks and hence have some out as the new pioneer in the field of 3D modelling.

Acknowledgments

We would like to offer our sincere thanksgiving to the members of honorable management, faculty members and staff members of Gyan Ganga Institute of Technolgy & Sciences, Jabalpur, India for the immense support and trust they shown towards our work.

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