International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 08 | Aug - 2021 ISSN: 2582-3930

IMPLEMENTATION OF 3-D PRINTING IN DIAGNOSIS OF INTERNAL ORGANS

S. Ravichandiran[1], K. Suresh[2], P. Sasvath[3], S. Rutharesh[4], K. Gowrishankar[5]

[1]U.G Student, Department of Biomedical engineering, Rajiv Gandhi College of engineering and technology, Puducherry

[2]U.G Student, Department of Biomedical engineering, Rajiv Gandhi College of engineering and technology, Puducherry

[3]U.G Student, Department of Biomedical engineering, Rajiv Gandhi College of engineering and technology, Puducherry

[4]U.G Student, Department of Biomedical engineering, Rajiv Gandhi College of engineering and technology, Puducherry

[5]Assistant professor & Head, Department of Biomedical engineering, Rajiv Gandhi College of engineering and technology, Puducherry

---***---

Abstract - 3D printing, or added substance fabricating, is the development of 3 planar objects from a computerized 3D model. The expression "3D printing" can allude to an assortment of procedures wherein the substances are fused or hardened under control to create the object by including the fluids or grained powder fused of various layers. Clinical utilizations for this method, both genuine and potential, can be sorted out into a few general classes that include developing of living tissues, creation of tweaked prosthesis, inserts, human organ models and research in pharmaceutical industries in regards to sedate dose structures, conveyance, anddiscovery. This paper gives a short survey of 3D imprinting in medication, which can give numerous advantages, including: the customization and personalization of clinical items for demonstration, modelling and analyzing purposes with a couple of contemplations in regards to future bearings in this significant field.

***Key Words*:** 3-D printing, medical imaging, Image processing, Diagnosis.

1.INTRODUCTION

Among the diverse assembling forms that are presently embraced by the business, the 3D printing is an added substance procedure. It is a procedure through which a three-dimensional strong item, for all intents and purposes of any shape, is produced beginning from a computerized model. Clinical 3D printing was at one time an aggressive unrealistic fantasy. Be thatas it may, time and speculation made it genuine. These days, the 3D printing innovation speaks to amajor chance to assist pharmaceutical and clinical organizations with creating progressively explicit medications, empowering a quick creation of clinical embeds and changing the way that specialists and specialists plan methodology. Thisinnovation has different applications, and the quickest developing advancement in the clinical field has been spoken to by the appearance of the 3D printing itself. The survey paper explains briefly about the history of imaging, 3-D printing technology its advances and merits in medical applications. About the IOT, it is the connectionof two or more devices and share data between themselves. These data's that are shared can be human fed or fed via other external sources.

2. LITERATURE SURVEY

2.2 3-D PRINTING TECHNOLOGY

Charles Hull concocted 3D printing also called "stereolithography," Hull has been certifiedin material science. He was dealing with plastic items manufacturing from photopolymers at the UV Products organization in US. Stereolithography uses a stl document configuration to decode the data in a computerized model, permitting these directions to be imparted printer. The shape and the guidelines from stl record may use directions, for example, the specifications of the article that needs to be printed.

Later 3D Systems organization had beenestablished, which concocted the principal printer, called a "stereolithography contraption." In 1988, they presented the main industrially accessible printer named SLA-250. Since then many different organizations have created 3D printers for business purposes. The works of Hull,just as advanced ones made by different analysts, has upset assembling, and is ready to do likewise in numerous different fields.

3D printing, or added substance fabricating, is the development of a three-dimensional item from a computerized 3D model. The expression "3D printing" can allude to an assortment of procedures wherein material is fused or hardened under control to create a 3-planar object, with included materials, (for example, fluids or powdered grains fused),

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 08 | Aug - 2021 ISSN: 2582-3930

ordinarily by several layer. The schematic diagram given below explains the 3D printing technique.

One of the key preferences of 3D printing is the capacity to create exceptionally complex shapes or geometries that would be in any case difficult to build by hand, including empty parts or parts with inside support structures to diminish weight. Combined affidavit demonstrating, or FDM, isthe most widely recognized 3D printing process being used starting at 2018. Hence, 3-D printing is very helpful in various fields due to its accuracy and time management.

2.2 3-D PRINTING IN MEDICINE

The two most important uses of 3-D printing in medicine are as follows:

A. Bio-printing of Tissues

Organ failure because of maturing, infections, mishaps, and birth deserts is a basic clinical issue. Recent approach for treatment of organ disappointment depends for the most part on transplantation of organs from living orexpired donors. But, there is a constant lack of human organs for transplantation. In 2009, 154,324 patients in the U.S. were sitting tight for an organ. Only 18% of them got an organ for transplantation, and 8,863 of them with 25peoples every day passed on while on the holding up list. In 2014, roughly 120,000 individuals inthe U.S. were anticipating an organ transplant.Organ transplant medical procedure and follow-upis likewise costly. An extra Treatments dependent on tissue designing and regeneration are sought after as a reason for the shortage organ giver. The conventional tissue building methodology is to segregate undifferentiated cells, blend with development factors, increase them in the research center, and put the cells with platforms that immediate cell expansion and separation into working tissues.

Though in the earliest issue is that organ transplantation includes the regularly troublesome errand of finding a giver withtissue match. This issue could probably be killed by autografting to construct a substitution organ. This would limit the danger of tissue dismissal by our immune system. Stages, bio-printing gives extra significant points of interest past this customary regenerative technique (which basically gives framework bolster alone, for example, exceptionally exact cell position and high computerized speed control, goals, cell fixation, volume drop, and distance across of cells printed. Organ printing exploits 3D printinginnovation to deliver cells, biological substances, and cell-loaded biological substances exclusively or couple in various layers, straightforwardly making 3-planar histological structures. Various materials are accessible to manufacture the frameworks,contingent upon the ideal quality, porosity, and tissue types are generally viewed as reasonable for creating soft histological structures. For example, the picture given below shows a 3Dprinted vertebral column.

Despite the fact that 3D bio-printing frameworks can be laser, inkjet or expulsion based, but inkjet printing is most common. This technique stores "bioink" beads of biomaterials onto a substrate as indicated by advanced guidelines to imitate human tissues or organs. Various simultaneousprint heads may utilized for storing diverse cell types (organ, vein, muscular cells), a vital element for manufacturing entirely different typesof histological structures. The procedure for bio- printing has risen:

- Make sketch of an organ with blood flowdetails.
- Create bio-printing procedure strategy.
- Detach foundational microorganisms.
- Separate undeveloped cells into organ-explicit cells.
- Get ready ink supplies with organ-explicit cells, vein cells, and bolstermedium and put in the printer.
- Print and place the printed organ in a reactor.

Laser printers can be utilized in the process, where laser vitality is utilized to energize the phones in a specific example, giving movement access in surrounding. In spite of the fact that histological structures developing by printing are still in its earliest stages, numerous examinations have given verification of idea. Specialists have utilized printers to make different sorts of prosthesis and implants. Usage of Inkjet printing innovation to fix cartilage. Utilization of a printer and tomographic pictures of aviation route empowered them to manufacture an absolutely demonstrated, bioresorbable tracheal support that was precisely embedded in an infant with tracheobronchomegalies.

B. Surgical planning

The differences and complex nature of the structures utilize 3D-printed models perfect for careful readiness. With substantial plan of subject's life systems accessible to doctor for recreating medical procedure is desirable over depending exclusively on conventional image examines, which aren't as educational because of their 2D visual representation. The utilization of printed models for careful preparing is additionally desirable over preparing on corpses, which present issues concerning accessibility and cost. Cadavers likewise regularly do not have the proper pathology, so they give to a greater extent an exercise in life structures than a portrayal of a careful patient. The Figure shown below is a 3-D printed head used for surgical preparation of head.

Additive printed neurological anatomicalprints can be especially useful to professionals by giving a portrayal of the absolute convoluted structures of the subject. The complicated, at times clouded connections between nervous system and skull can be hard to decipher dependent on radiographic flat visual data. A little blunder in exploring this mind-boggling life structures can have conceivably obliterating consequences. A sensible model mirroring the connection between a sore and typical cerebrum details may be useful in deciding the most secure careful hallway and likewise be helpful for the surgeon to practice testing. Complex spinal disfigurements can likewise be concentrated using a additive printed model.

The best additive printed structures with the correct pathology for preparing specialists in doing endoscopies are additionally crucial, because colon and rectal diseases are the subsequent driving reason formalignancy related passing.

3.METHODOLOGY

The capacity to create complex shapes and levels of underlying subtlety included here. The proposed strategy is completed in different strides to deliver the last 3D printed model as given in the following steps (Figure 3.1).

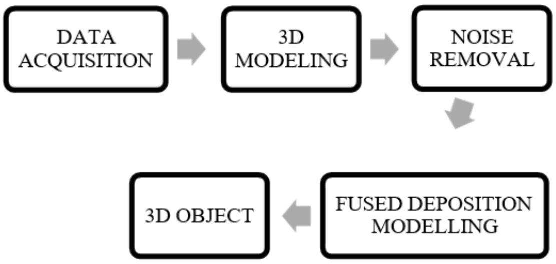

Figure 3.1: Various stages of 3D printing

3.1 DATA ACQUISITION

Advanced procurement of information from the different imaging modalities for input to picture archiving and communication system (PACS) is canvassed in detail in this section. Image acquisition is the initial purpose of information passage into a PACS, and in that capacity, mistakes produced here can proliferate all through the framework, antagonistically influencing clinical tasks.

Picture securing from the naturally computerized modalities, for example, CT, MRI, furthermore, US ought to be a direct advanced DICOM catch. Direct computerized interfaces permitcatch and transmission of picture information from the methodology at the full spatial goal and full piece profundity of gray scale inherent to the methodology. In the frame grabbing strategy, as in printing a picture to film, the picture quality is restricted by the cycle to only 8 bits (or 256 gray values) while most modalities have the capacity to gain in 12, 16, or even 32 bits for shading information.

Modality	Image Matrix Size	Grayscale Bit Depth
Computed tomography (CT)	512 × 512 pixels	12–16 bits
Digital angiography (RA) and digital fluoroscopy (DF)	512 × 512 pixels or 1024 × 1024 pixels or 2048 × 2048 pixels	8–12 bits
Magnetic resonance imaging (MRI)	256 × 256 pixels	12–16 bits
Nuclear medicine images (NUC)	64 × 64 pixels or 128 × 128 pixels or 256 × 256 pixels	8–32 bits
Ultrasound (US)	64 × 64 pixels or 128 × 128 pixels	16–32 bits

Figure 3.2: Imaging modalities and their resolutions

Hence, direct catch of computerized information from the inalienably advanced modalities is the favoured technique for securing. Figure 3.2 records the cross-sectional modalities usually interfaced to PACS alongside their natural document sizes and bit profundities.

Usually, the data is obtained through DICOM file format, which is a standard medical image file format that is used in various medicalsectors. In this methodology, the data in this DICOM file and NRRD file are analyzed to create a 3D model.

3.1.1 DICOM FILE

Imaging modality conformity with the Digital Imaging and Communications in Medicine (DICOM) standard is critical. DICOM comprises ofa standard picture design just as a network communication convention.

Consistence with this standard empowers an open engineering for imaging frameworks, spanning equipment and programming elements and permitting interoperability for the exchange of clinical pictures and related data between divergent frameworks. DICOM comprises of a standard picture design just as a network interchanges convention.

Figure 3.3: An Example of a PACS tool for readingthe DICOM header

3.1.2 NRRD FILE

NRRD ("nearly raw raster data") is a library and record design for the portrayal and handling of n- dimensional raster information. It is planned to help logical perception and picture preparing applications.

NRRD is a file format for putting away andenvisioning clinical picture information with ".nrrd" file extension. Its fundamental advantage over DICOM, the standard record design for clinical imaging, is that NRRD documents are anonymized and contain no delicate patient data. Besides NRRD documents can store a clinical sweep in a solitary record, while DICOM informational collections are generally included an index or catalogues thatcontain handfuls if not many individual records.

This instructional exercise will show youhow to make a NRRD record from a DICOM informational collection produced from a clinical sweep, for example, a CT, MRI, ultrasound, or x- beams. The general format of a NRRD file (with attached header) is:

```
NRRD000X
<field>: <desc>
<field>: <desc>
```

```
# <comment>
<field>: <desc>
<key>:=<value>
<key>:=<value>
<key>:=<value>
# <comment>
<data><data><data><data><data><data>...
```

3.2 3D MODELLING

3D modeling is that the method toward utilizing programming to create a numerical portrayal of a third-dimensional item or form. The made item is known as a 3D model and these 3- dimensional models are utilized in an assortment of enterprises. It tends to be shown as a two-dimensional picture through a cycle called 3Ddelivering.

The clinical business utilizes itemized models of organs; these might be made with various 2-D picture cuts from a MRI or CT check. This 3D model is finally printed using a 3d printer. There is various 3D modeling software available in market. In this methodology, we preferred slicer 3D and blenderto create a 3D model.

3.2.1 SLICER 3D

3D Slicer is a free open-source programming (BSD-style permit) that is an adaptable, secluded stage for picture examination andrepresentation.

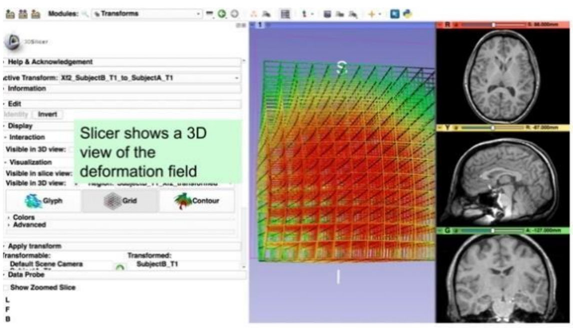

Figure 3.5: Visualizing the transform

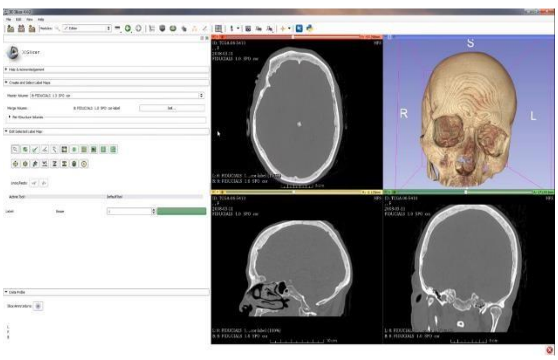

Figure 3.6: Final transformation

3D Slicer gives picture enlistment, handling of DTI (dispersion tractography), an interface to outer gadgets for picture direction backing, and GPU- empowered volume delivering, among different abilities. 3D Slicer has a secluded association that permits the expansion of new usefulness and gives various nonexclusive highlights not accessible in contending tools.

The intelligent representation capacities of 3D Slicer incorporate the capacity to show self-assertively situated picture cuts, fabricate surface models from picture names, and equipment quickened volume rendering. 3D Slicer likewise underpins a richarrangement of explanation highlights (fiducials and estimation gadgets, altered shading maps). Figure 3.5and Figure 3.6 shows the transformation of the imageto a 3D plane.

3.2.2 BLENDER

Blender is a free and open-source 3D PC designs programming toolset utilized for making 3D printed models, movement illustrations, intelligent 3D applications and augmented reality.

This software is similar to the slicer 3D but it is comparatively difficult to create 3D model from scratch. Apart from 3D modeling Blender can bevery helpful in 3D image enhancements. In this methodology it is actually used to perform surface mesh smoothening algorithm through its graphicaluser interface (GUI). Blender supports varied geometric primitives, as well as polygonal shape meshes, quick subdivision surface modeling, Bezier curves, NURBS surfaces, metaballs, icospheres, text, associate degreed an n-gon modeling system known as B-mesh.

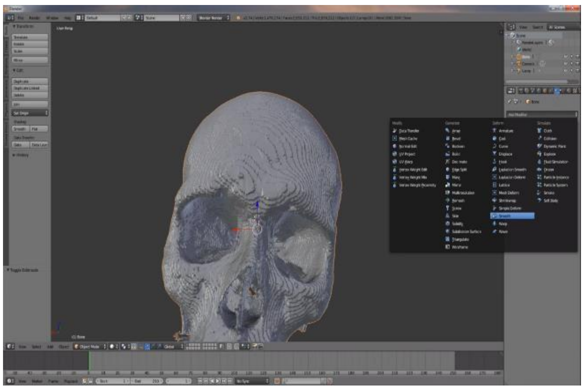

Figure 3.7: Surface smoothening

3.3 NOISE REMOVAL

There are mainly two algorithms are used for creating 3D model and to remove noises produced during 3D rendering of the model. These algorithms are as follows:

3.3.1 MARCHING CUBES ALGORITHM

Marching cubes could be a special effects algorithmic program for extracting a plane figure mesh of associate isosurface from a three-dimensional distinct field (the parts of that area unit typically referred to as voxels).

The uses of this algorithm are essentially worried about clinical representations, for example, CT and MRI filter information pictures, and enhancements or 3-D demonstrating with what is typically called metaballs or other metasurfaces.

The premise of the algorithm is to divide the input volume into a discrete set of cubes By assuming linear reconstruction filtering, each cube, which contains a piece of a given isosurface, will simply be known as a result of the sample prices at the cube vertices should span the target isosurface value. For each cube containing a neighbourhood of the isosurface, a triangular mesh that approximates the behavior of the trilinear interpolates within the interior cube is generated.

Step 1: In scalar field, taking eight neighbor locations at a time, after determining the polygons needed to represent the part of the isosurface that passes through this cube.

Step 2: Create an index to a pre-calculated arrayof 256 possible polygon configurations (2^8=256) within the cube, by taking each of the 8 scalar values as a bit in an 8-bit integer to fuse polygons.

Step 3: If the scalar worth is over the iso-value (i.e., it's within the surface) then the suitable bit is ready to 1.

Step 4: If the scalar worth is on top of the iso- value (i.e., it's within the surface) then thesuitable bit is about to 1.

Step 5: The final value is the actual index to the polygon indices array after all eight scalars are checked.

Step 6: All vertex of the new polygons is placed on the appropriate position along the cube's edge by linearly interpolating the two scalar values that are connected by that edge.

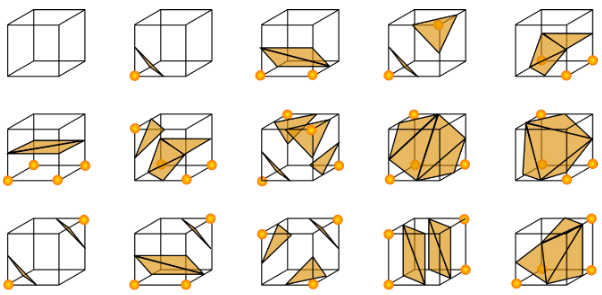

Figure 3.8: The 15 cube configurations

3.5.2 SURFACE SMOOTHENING ALGORITHM

This algorithm is used to smoothen the rough surface or eliminate white noise in an image.In original surface mesh, each node Pi is the solutionof the intersection of a set of planes, S(Pi). Then the QEM of node, Pi, ΔPi , is defined as the sum of squared distances to its planes:

$$K_p = \begin{pmatrix} a^2 & ab & ac & ad \\ ab & b^2 & bc & bd \\ ac & bc & c^2 & cd \\ ad & bd & cd & d^2 \end{pmatrix}, \qquad Q_i = \sum_{p \in S(p_i)} K_p,$$

$$\Delta(p_i) = p_i^T Q_i p_i.$$

Where a,b,c,d represents the coefficients of the plane defined by the equation ax+ by + cz + d = 0with $a^2 + b^2 + c^2 = 1$; $[x_i, y, z_i, 1] = 1$ denotes the augmented coordinate vector of node Pi .

For every component, define the condition of the plane as indicated by the directions of its vertices, and ascertain the lattice kp.

Step 1: For every node of the cross section, discover the entirety of its nearby components; at that point add the lattice k_p of its contiguous components up to get the error matrix Q_i.

Step 2: For every component, project the directions of its vertices to the plane, and afterward lead mathematical distortion autonomously by extending activity;locate the ideal estimation of the shrinking factor k by limiting the all-out quadratic error Δ_e ; lead contractingactivity freely and save the directions of all transitory vertices.

Step 3: For each node of the mesh, calculate the weighted average of the corresponding temporary vertices to urge the position of this node.

Step 4: If the mesh quality reaches the suitable level stop; else, return to step 3 for next cycle.

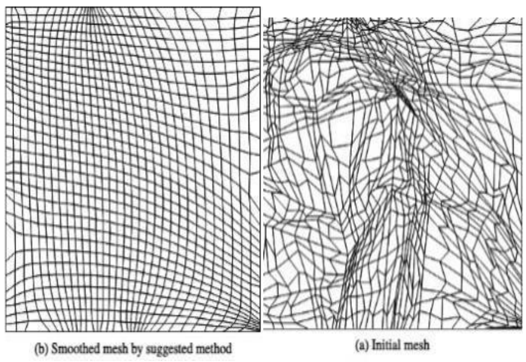

Figure 3.9: Surface mesh smoothening

3.6.3 FUSED DEPOSITION MODELLING

FDM is a 3D printing measure created by Scott Crump, and afterward executed by Stratasys Ltd., during the 1980s. It utilizes creation grade warm plastic materials to print its 3D items. It's famous for creating practical models, idea models, and assembling helps. It's an innovation that can make exact subtleties and flaunts an uncommon solidarity to weight proportion.

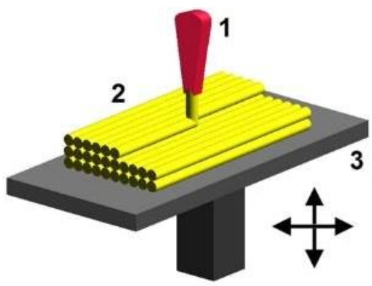

Figure 3.12: Fused deposition modelling

The Figure 3.12 above shows the Fused deposition modelling method. Before the FDMprinting measure starts, the client needs to cut the 3D CAD information (the 3D model) into numerous layers utilizing unique programming. The cut CAD information goes to the printer which at that point assembles the article layer at a time on the fabricate stage. It does this just by warming and afterward expelling the thermoplastic fiber through the spout and onto the base. The printer can expel different help materials just as the thermoplastic. As with every 3D printer, the time it takes to print all relies upon the items size and its unpredictability.

4. RESULT

From the above-mentioned method, the data is obtained from the conventional image sources such as CT, MRI, ULTRASOUND and X-RAY. This data is then transformed into a 3D image using 3D modeling techniques, then various types of noise generated during the 3D modeling is eliminated using the specific algorithms. The final image model is exported for printing process.

We have created 3D printed models with increase efficiency and accuracy from the conventional medical imaging sources. We have produced four types of 3d printed model namely hypothalamic cyst, brain tumor, covid affected lungs and thorax skeleton which are then compared withthe raw data obtained from the imaging sources.

4..1 HYPOTHALAMIC CYST

The image of whole brain scan is compared with diffusion tensor imaging (DTI) for checking a cyst in hypothalamic region with 3D printed hypothalamus. Here the ventricular fibers, optic tract and finally the cyst are created into different segments from the input data. Only the hypothalamusof brain is selected since it is the region of interest and printed the same. Since the hypothalamus region is very tough to interpret for all in the brain scans, printed model will help professionals to analyze the problem to provide required solution for diagnosis and treatment.

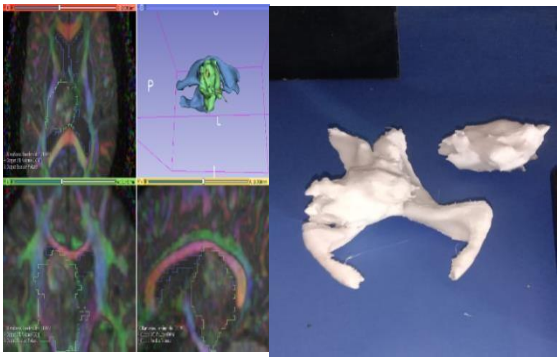

Figure 4.1: Interpretation of hypothalamic cyst

4.2 BRAIN TUMOUR

The tumor in the cerebrum region of thebrain in CT image is compared with the 3d printed brain model. The images in the nearly raw raster data(nrrd) file is segmented to various slices. Each sliceof the tumor is highlighted with a red color to differentiate with the normal brain tissues. Only half the brain is selected since it is the region of interest. The visualization of tumor growth and size in real time will better help the surgeons to conclude the plan quickly and efficiently.

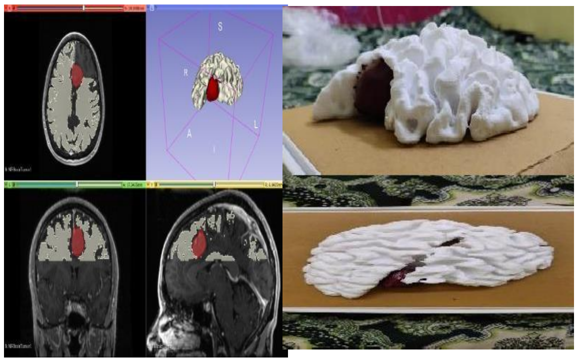

Figure 4.2: Brain tumor interpretation

4.3 THORAX SKELETON MODEL

The CT image of thorax is compared with the printed skeleton of ribcage present in the thoracic region. This region of skeletal system is one of the most complex systems in our body. The data of skeleton is processed from the whole-body CT and printed the same. It is helpful for the learners tovisualize the ribcage in real time.

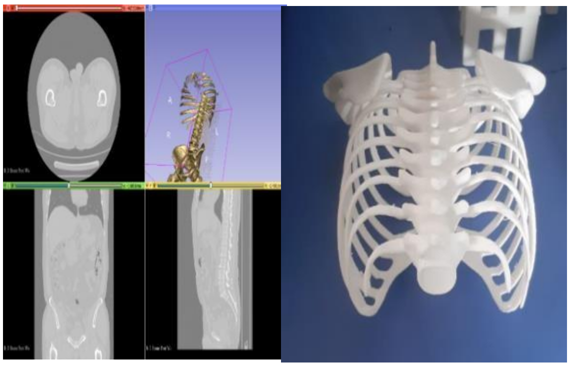

Figure 4.3: Interpretation of thorax skeleton

4.4 COVID-19 AFFECTED LUNGS

Corona virus disease (COVID-19) is an infectious illness brought about by serious intense respiratory disorder Covid 2 (SARS-CoV-2). An enormous report in China contrasted chest CT results with PCR and showed that however imaging is less explicit for the disease, it is quicker and more delicate. Though the images are not much clearer so they are 3D modeled to indicate the damages.

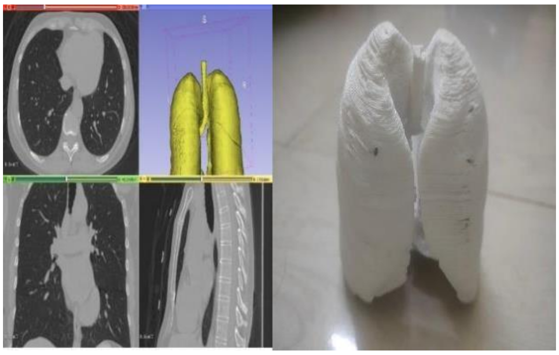

Figure 4.4: Interpretation COVID-19 affected lungs

The image of chest CT data of Covid-19 affected patient's lungs is compared with the 3Dprinted lungs of the same patient. This virus cancause permanent damage to the lungs and otherassociated organs where virus had spread. Thedamage in surface of right lung which is not distinctin the CT data. It can also cause interior damage tothe lungs such as alveoli and trachea. The printedlungs can be helpful for scientists to conduct studyabout impacts of the disease to the lungs. Since nowonly the lungs of the cadaver is studied throughautopsy, so it will be tough to analyze in living patients that can be done by this method.

5. CONCLUSION

3D printing has introduced several benefits and potentialities within the medical field. As theresult, the medical image data obtained from the imaging modalities is converted into a 3D model and the noise produced during the rendering process is removed.

Likewise, the 3d models were produced with a low-cost commodity by using the usual conventional methods at a lower price marginwithout sacrificing the accuracy rate produced from the original previous result. These models are givento a doctor for their appraisal about the model as how its useful for them, what are the details that they could find while viewing it and it's advantages in themedical field in accordance with them.

6. REFERENCES

1. K., H., A., Lim, Z., Y., Loo, S., J., Goldie,J., W., Adams, P., G., McMenamin, "Use of3D printed models in medical education: a randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy", *Anatomical Sciences Education*, Vol. 9, No.3, 2015, pp.: 213–221.
2. J., Garcia, Z., Yang, R., Mongrain, R., L., Leask, K., Lachapelle, "3D printing materials and their use in medical education: a review of current technology and trends for the future", *BMJ Simulation and Technology Enhanced Learning*, Vol. 4,No. 1, 2017, pp.: 27–40.
3. Abeloff, *"Basics of Radiation Therapy"*, Clinical Oncology, 6th edition, Elsevier Publication, Philadelphia.
4. Yousif Mohamed, Y. Abdallah, "History of Medical Imaging", *Journal of Archives of Medical and Health Sciences*, Vol. 5, No. 2, 2017, pp.:275-278.
5. R., Banerjee, M., Pavlides, E., M., Tunnicliffe, S., K., Piechnik, N., Sarania, R., Philips, J., D., Collier, J., C., Booth, J., E., Schneider, L., M., Wang, D., W., Delaney, K., A., Fleming, M., D., Robson, E., Barnes, S., Neubauer, "Multiparametric magnetic resonance for the non-invasive diagnosis of liver disease", *Journal of Hepatology*, Vol. 60, No. 1, 2013, pp.: 69–77.
6. K. R. Rosen, "The history of medicalsimulation", *Journal of Critical Care*, Vol. 23, No. 2, 2008, pp.: 157–166.
7. S., N., Kurenov, C., Ionita, D., Sammons,T., L., Demmy, "Three-dimensional printingto facilitate anatomic study, device development, simulation, and planning in thoracic surgery", *Journal of Thoracic and Cardiovascular Surgery*, Vol. 149, No. 4,2015, pp.: 973–979.
8. Felix Ritter, "Medical image analysis", *IEEE pulse*, Vol. 2, No.6, 2011, pp.:60-70.
9. M., Maruthappu, A., Duclos, S., R., Lipsitz, D., Orgill, "Surgical learning curves and operative efficiency: a cross-specialityobservational study", *BMJ Open*, Vol. 5, No. 3, 2015.
10. D., Bradley, K., E., Bradley, "The value of diagnostic medical imaging", NCMedJ, Vol.75, No. 2, 2014, pp.: 121-125.
11. V., K., Mehta, P., S., Deb, D., Subba Rao, "Applications of Computer Techniques in Medicine", *Med J Armed Forces India*, Vol.50, No. 3, 1994, pp.: 215-218.
12. AmandaSu, Subhi j.Al'Aref, "History of 3- D Printing", 3-D Printing Applications inCardiovascular Medicine, Academic PressPublication, 2018, pp.:1-10.
13. G., T., Klein, Y., Lu, M., Y., Wang, "3D printing and neurosurgery—ready for prime time?", *World Neurosurgery*, Vol. 80, No.4, 2013, pp.:233–235.
14. D., H., Ballard, A., P., Trace, S., Ali, "Clinical applications of 3D printing," *Academic Radiology*, Vol. 25, No. 1, 2018, pp.: 52–65.
15. Cui X, T., Boland, D'Lima DD, Lotz MK, "Thermal inkjet printing in tissue engineering and regenerative medicine", *Recent Pat Drug DelivFormul*, Vol. 6, No.2,2012, pp.:149–155.
16. Anna Aimar, Augusto Palermo, Bernardo Innocenti, "The role of 3-D printing in medical applications: a state of art", *Journal of Healthcare Engineering*, Vol. 2019, 2019, pp.:1-10.
17. M., Randazzo, J., M., Pisapia, N., Singh, J., P., Thawani, "3D printing in neurosurgery: a systematic review", *Surgical Neurology International*, Vol. 7, No. 34, 2016, pp.: 801–809.
18. C., L., Ventola, "Medical Applications for 3D Printing: Current and Projected Uses", *P & T: a peer-reviewed journal for formulary management*, Vol. *39*, No. 10, 2014, pp.:704–711.
19. M., S., Mannoor, Z., Jiang, T., James, "3D printed bionic ears", *Nano Letters*, Vol. 13, No. 6, 2013, pp.: 2634–2639.
20. C., Williams, A., James, M., P., Chae, D., J.,Hunter-Smith, "3D printing in clinical podiatry: a pilot study and review", *Journal of Foot and Ankle Research*, Vol. 8, No. 2,2015, pp.: 41.