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# Design and Development of Customized Surgical Guide for Parkinson's Disease

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***Abstract*—Parkinson's disease (PD) is a neuro degenerative brain disorder that progress slowly in older people. Most people's symptoms take years to develop, and they live for years with the disease. Currently there is no cure for Parkinson's disease, but medication and therapy is used to treat its symptoms. Deep brain stimulation (DBS) is a surgical therapy used for the treatment of Parkinson Disease. Because deep brain stimulation implantations and other stereotactic and functional surgical procedures require accurate, precise, and safe targeting of the brain structure, the technical aids for pre-operative planning, intervention, and post-operative follow up have become increasingly important. This paper presents a conceptual model of the Customized Surgical Guide for Parkinson's disease.**

***Keywords*—Stereotactic frame, Deep brain stimulation, Parkinson's disease, Virtual Surgical Planning***

## I. INTRODUCTION

Implantable neuro stimulation devices have become increasingly important as tools for the improved treatment of neurological disorders. Technological advances have made it possible for patients suffering from a wide range of neurological symptoms to receive effective relief by means of cochlear implants, cortical and deep brain stimulator, and systems for spinal cord, vagus and gastric nerve stimulation. Parkinson's disease (PD) is a neurodegenerative brain disorder that progresses slowly in most people. In short, a person's brain slowly stops producing a neurotransmitter called dopamine. With less and less dopamine, a person has less and less ability to regulate their movements, body and emotions. Parkinson's disease itself is not fatal. Currently there is no cure for Parkinson's disease, but medication and therapy is used to treat its symptoms. Surgery can be an effective treatmentoption for different symptoms of PD, only the symptoms that previously improved on levodopa have the potential to improve after the surgery. Deep brain stimulation (DBS) is a surgical therapy used for the treatment of Parkinson Disease (PD). During DBS surgery, a special wire, called a lead, is inserted into a specific area of the brain. The lead, which has four electrodes, delivers electrical currents to precise brain locations responsible for movement, regulating the abnormal brain cell activity that causes symptoms such as tremor and gait problems. Understanding DBS and how it may work to suppress symptoms requires a basic understanding of brain function gears. The brain is a complex organ with billions of cells and cell connections called synapses. These cells are connected to each other by axons or "pipes" that send messages back and forth..

## II. EASE OF USE

### *A. How DBS works*

Understanding DBS and how it may work to suppress symptoms requires a basic understanding of brain functional gears. The brain is a complex organ with billions of cells and cell connections called synapses. These cells are connected to each other by axons or "pipes" that send messages back and forth. Communication is facilitated through a series of circuits that are organized to sort and process information. The connections in the brain circuits are similar to the electrical wiring in your house or car. If one circuit malfunctions, it can disrupt the entire system. Research has shown that in PD there are faulty signals in several brain. Several approaches were proposed to understand the influence of local damages on the dynamic behavior of gear transmission circuits. These faulty or disruptive signals seem to underpin many of the symptoms of PD (e.g. slowed movement, tremor, and stiffness). When electricity is introduced into the circuit it "disrupts the disruption" and in some magical way restores order, and improves disabling symptoms. The electric current is thought to inhibit cell firing, excite the axons (the pipes), and release a chemical called calcium from brain cells called astrocytes. Calcium seems to trigger a series of reactions that lead to the release of chemicals called neurotransmitters and the stimulation of blood flow.This symphony of changes elicited by electrical stimulation in some unknown way acts to combat the symptoms of PD.

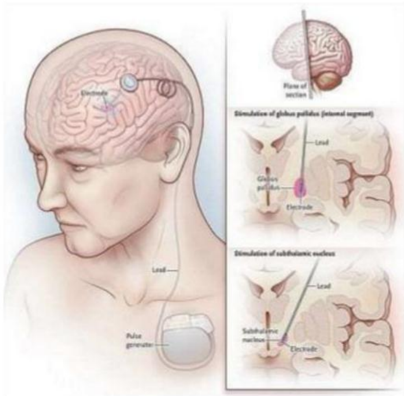

Fig. 1 :- Deep Brain Stimulation

### *B. Design Concept*

Design concept of a new stereotactic head frame was based upon previous work done by Leksell stereotactic arc system and will form the basis of the future development of an improved stereotactic system called as " CUSTOMISED SURGICAL GUIDE ". Customized Surgical Guide ( CSG ) is jig which is design & developed by an engineer using CAD & Rapid Prototyping with the help of surgeons input to be used for surgery.

Fig. 2 :- Leksell stereotactic arc system [1]

### *C. How shape Decided*

To decide the shape we went through Literature study, Radiography of the human head, Image Processing in Mimics, Virtual surgical planning and Modeling in 3matic software. There have been different researches to design a frame to guide an electrode used in Deep brain stimulation such as Zeppelin Micro Stereotactic System, Micromar Stereotactic AIM system, IMRIS Surgery and Imaging Tools, Inomed Stereotactic System etc. And here we focused on Leksell Stereotactic frame as it is the latest one and then the modification was done on the basis of its drawbacks. This device used a "target-centered" arc–radius system which allowed amovable probe carrier on the arc to move along the arc to any location and still be able to terminate at the desired target.

*Anatomy of Brain*

There are three brain targets that have been FDA approved for use in Parkinson's disease [20]. In Fig. 3, the thalamus which is one of the three targets occupy a central location among the subcortical nuclei. As noted, the Thalamus is actually two mirror image ovoid masses that occupy each lateral wall of the third ventricle.

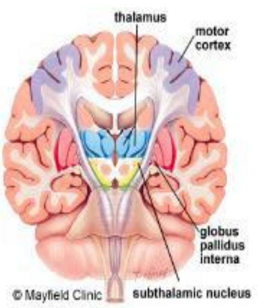


Fig.3 :- Different target areas of Brain [20]

*Image Processing*

3-D imaging is essential for a successful stereotactic procedure. And to perform the design and modeling of the Customized surgical guide, the CT/MRI of patient is taken and the image processing work is done with the help of Mimics software. Mimics interactively read CT/MRI data in the DICOM format. Segmentation and editing tools enable the user to manipulate the data to select bone, soft tissue, skin, etc. Once an area of interest is separated, it can be visualized in 3D. After this visualization, a file can be made to interface with STL+ or MedCAD. CAD data, imported as STL files, can be visualized in 2D and 3D for design validation based on the anatomical geometry. Here, Mimics software is used for image processing that includes orientation of the image, defining the mask, editing mask and converting 2D to 3D image is done to separate the different parts of the head and to get the target location for path generation.

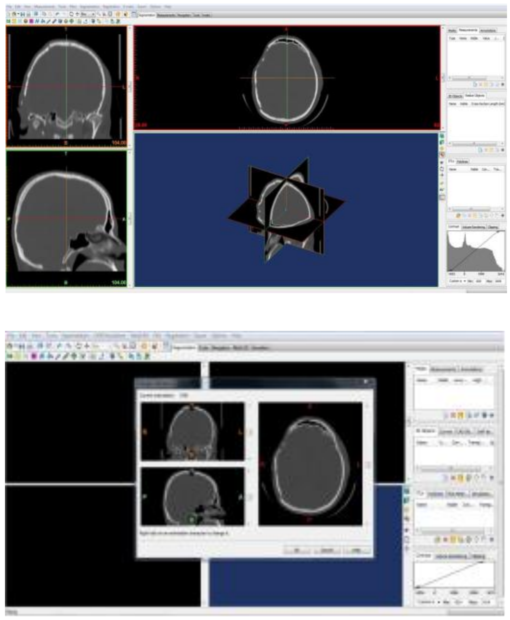

Fig.4 :- MRI image of the head and Orientation of image

*Orientation of the Image:-*

Fig. 4 shows the orientation of the image which was developed after arranging the CT/MRI of the patient in the DICOM file format. In the figure the colored letters located on each view shows the orientation of the images i.e., **P:** Posterior, **A:** Anterior, **L:** Left, **R:** Right, **T:** Top and **B:** Bottom. In Mimics, Thresholding is used to create a first definition of the segmentation object. The object can be defined based on one lower threshold, or based on a lower and a higher threshold.

In this research all manual editing functions are performed on the active mask. We can draw, erase, or restore the image with a certain threshold value indicated below and Fig. 5 shows the process to calculate the 3D mask.

First the image was converted into 3D to take it as a reference for modeling. And then the editing of mask was done to remove the unwanted parts from the model produced with the help of the Edit mask command.

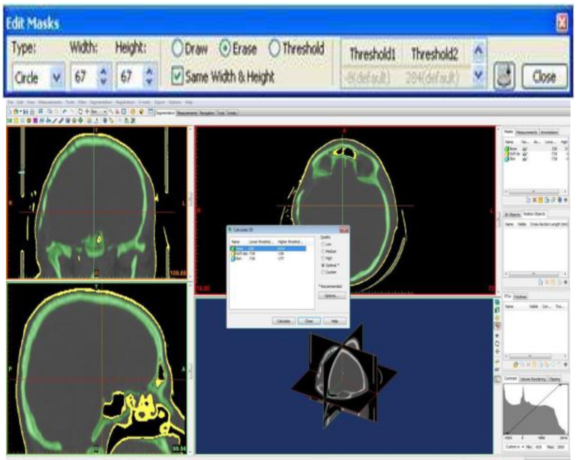


Fig. 5 :- Calculated 3D Mask

## VIRTUAL SURGICAL PLANNING

In this research the main challenges were to find the location of the screw position on the head to hold the guide, the location of the target where the electrode is going to be inserted and the path generation from where the electrode is going to pass and burr hole is going to be drilled. The Virtual surgical planning is mainly the preoperative planning which is done to design the CSG with the help of CT/MRI scans used in Mimics and 3matic software.

### *Screw Positioning*

The frame is attached to the skull using screws. The best placements for the screws are given by the surgeons as the surgery takes place in conscious state. Areas that should be avoided are in the center of the forehead, in between the pupils where ventricles behind the skull bone increases the risk of the skull bone breaking from the force of the screws. The area in the back of the head near the neck should also be avoided because of the muscular attachments located in that area. Screwing into those muscles causes extra pain to the patient.

With the study it is known that there is a lot of problem arising in drilling the screw. So, the research gives the new guide in which there is no use of screws which reduces pain and discomfort to the patient as well as it reduces the planning and operationtime.

### *Location of the target*

The stereotactic neurosurgery access to all parts of the brain which is necessary. The surgeons enter the brain in different areas depending on what target they aim to reach. The frame must allow access to these areas. To get the entry area in the head through skull to insert the electrode, drilling is done to burr hole. So, to get the location of the position to drill hole, a specific coordinates is required.

The coordinates of the target i.e., sub-thalamic nucleus is taken with surgeons input with respect to the Mid-commissural point (MCP) present in the brain. The mean is calculated for the same and taken as the reference to take out the parts from the CT/MRI scan of the patient brain.

### *Path generation*

After getting the coordinates of the target points. In one of the paper [10] a doctor named Dr. Okun represented the path to insert the electrode and gave the permission to use the path defined in the paper. There are many ongoing studies that will help to refine target choice for individual patients.

### Image Processing for Bone, Soft tissue, Skin, Brain and Parts of brain

Image processing was done for bone, soft tissue, skin and brain. The thresholding values for head was set and the editing and converting the image in 3D was performed. All the mentioned parts of head was separated and 3D model was formed in which the main role is of brain.

After the formation of the 3D model of the brain, the different parts of the brain were separated with the help of the coordinates which we got from the virtual surgical planning and from the images of the brain anatomy.

The different parts of the brain were separated for the path formation in the 3matic software. The given parts are the tissues through which the electrode will pass and get in contact with the target i.e., Subthalamic Nucleus:-

1. Thalamus
2. Caudate Nucleus (CN)
3. Nucleus Ventro Caudal Thalamus (Vc)
4. Nucleus Ventral Intermedius Thalamus (Vim)
5. Nucleus Medio Dorsal Thalamus (MD)
6. Nucleus Ventral Oral Posterior (Vop)
7. Nucleus Ventral Anterior Thalamus (Va)
8. Subthalamic Nucleus (STN)

All the above parts are present in one part of the brain i.e., thalamus. Thalamus is the main tissue through which the electrode passes and reach to the target for the treatment of Parkinson’s disease.

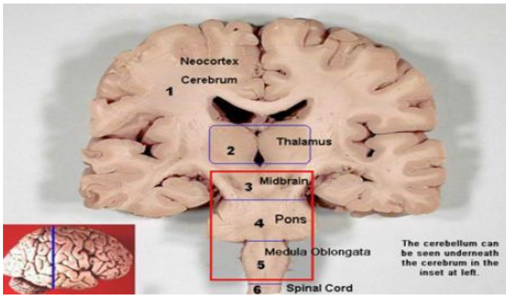


Fig.6 :- Different Parts of Brain[4]

All the parts of the brain were separated and converted into STL file so that it can be imported in the 3matic software for the path formation of the electrode with the help of which the Customised surgical guide was designed.

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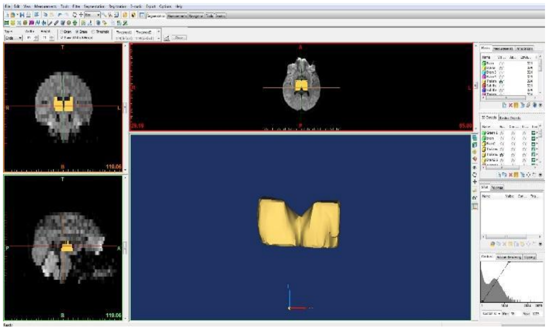

Fig.7 :- 3D Model of Thalamus

## III. DESIGN PROCESS OF CUSTOMISED SURGICAL GUIDE

3MATIC :- 3-matic is unique software that combines CAD tools with pre-processing (meshing) capabilities. To do so, it works on triangulated (STL) files and as such it is extremely suitable for organic/freeform 3D data, like the anatomical data coming from the segmentation of medical images (from Mimics). We call it Anatomical CAD. Import your anatomical data in 3-matic to start doing real Engineering on Anatomy, like thorough 3D measurements, design an implant or surgical guide, or prepare the mesh for finite element modeling.

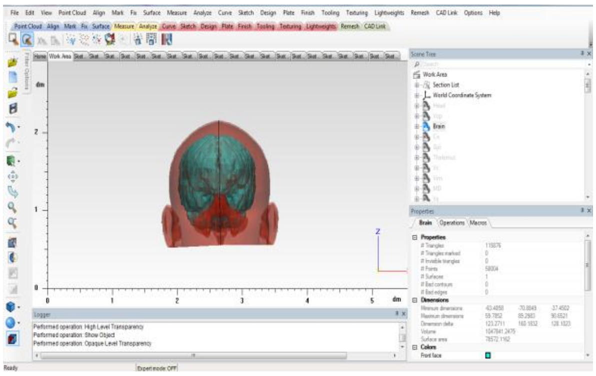

Fig.8 :- Imported STL of skin and Bone

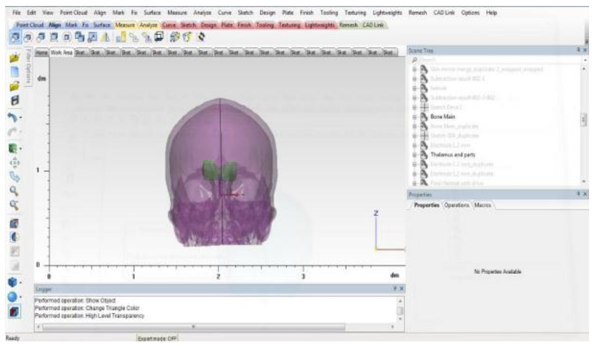

Fig. 9 :- Imported STL of Skull and Thalamus

After all the parts were imported in 3matic, the DBS lead was designed. DBS lead (thin wire) has four electrode contacts i.e.

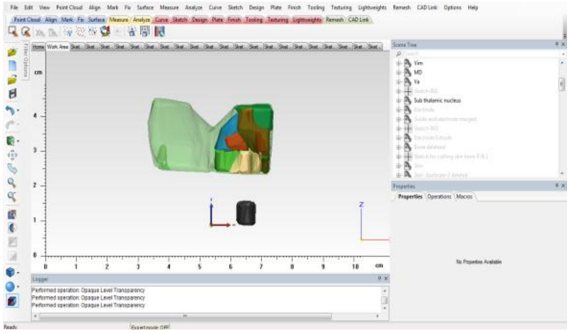

Fig. 10 :- Imported STL of Thalamus & its parts and Sub-Thalamic Nucleus

electrode contacts i.e. implanted in, or as close as possible to the intended brain target area.

*Virtual Surgical Planning In 3matic And Placement Of An Electrode :-*

In 3matic, the placement of the electrode was done with the help of the image which we got from the Virtual surgical planning. In this the electrode was placed as such as it passes through the parts as reviewed from the paper [21]. Below Fig. 11 & 12 gives the path to the target got from planning and the path generation which was done as a part of the project in 3matic.

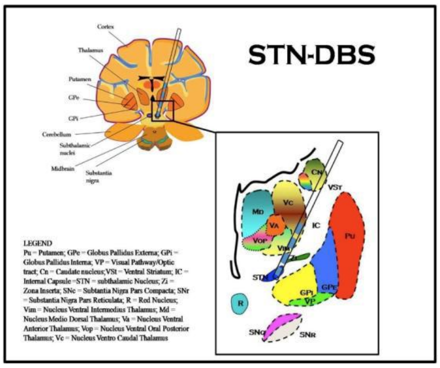


Fig. 11 :- Path of the electrode to pass [21]

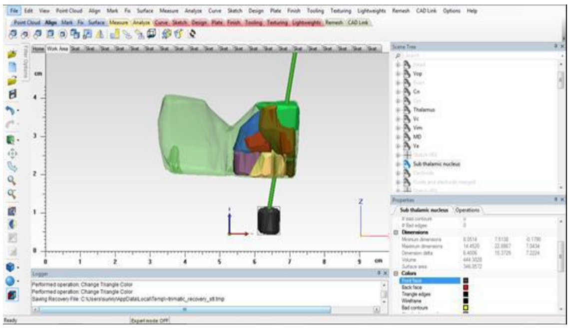

Fig. 12 :- Path generation of electrode through desired parts

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*D. DESIGN PROCESS*

After analyzing the previous models, the drawbacks of the frame based stereotactic frame was found regarding accuracy, stability, drilling the hole etc. So, it was decided to make the model that snugged fit to the contour of the head so that there is no screw positioning and no drilling in head which gives better accuracy, better stability, lightweight feature, less operating time and is cost effective.

Main Commands used to design the guide were sketch, cut, wrap, extrude, Boolean subtraction, split, align, interactive translate and rotational translate.

*For designing the guide here is some of the important steps used in it:-*

*Sketch*

The Sketch was taken parallel to the view with the reference of the head imported from the Mimics software and the coordinates were noted. After the sketch was formed it was moved to the proper place from where the cut was performed to make the guide of the shape of the contour of the head.

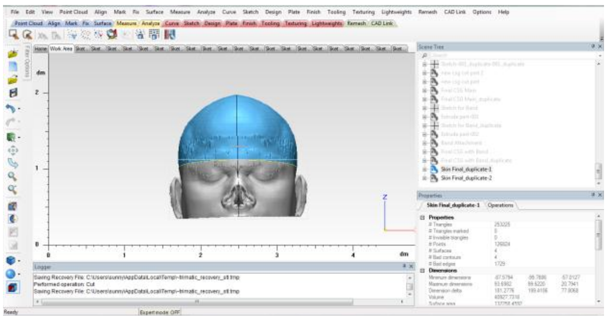

Fig. 13 :- Cut Part of the Head

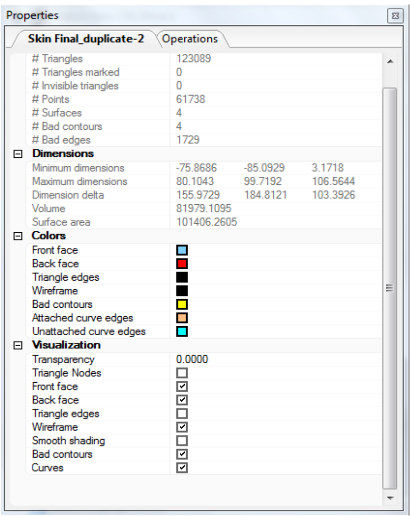


Fig. 14 :- Cut Part Properties

The Fig. 13 shows the cut part of the head which is going to be wrapped with the same to get the snugged pack contour to design a guide. Fig. 14 shows the properties developed after the cut was performed.

*Wrap*

The wrap operation will create a wrapping surface of the selected entities. The wrap function is useful for medical parts, to filter small inclusions or close small holes. In this project wrapping is done to get the snugged pack contour for the further design process.

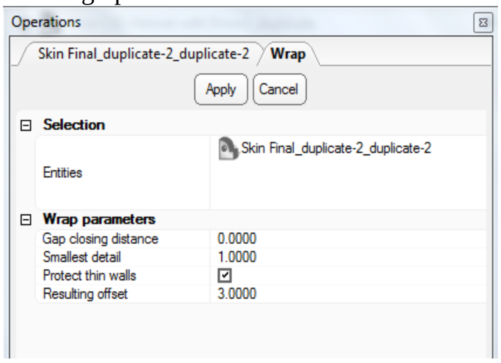


Fig 15 :- Wrap operation

The above Fig. 15 shows the wrap operation in which we can see that the entity is selected, then the gap closing distance was taken zero as the gap closing distance determines the size of gaps that will be wrapped away via the operation. So, with this it is known that the gap has to be taken zero as we want snugged pack design. Smallest deal is taken one as it referred to the size of triangle on the newly created surface. And at last the offset was set to 3 mm which determines the thickness of the guide. Fig. 16 shows the wrapped part of the cut part of the head and Fig. 17 shows the wrap properties after the operation.

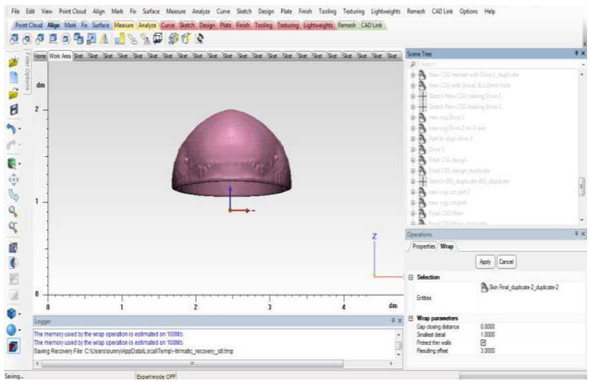

Fig. 16 :- Wrapped part

After the wrap was performed, the part was edited by taking the head as the reference by using Boolean subtraction with the help of which the wrapped part was divided into two. And then with the split command one of the part was deleted and the main contour was ready for the further design.

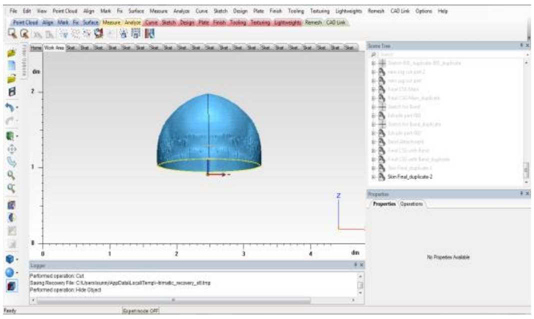

Fig. 17:- Upper Cut part of head

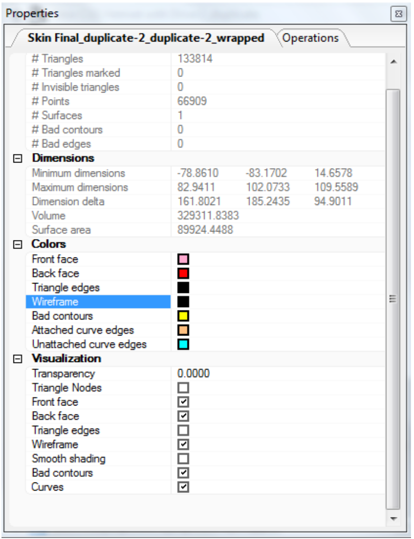


Fig. 18 :- Wrap properties

Fig. 17 shows the upper part of the cut part after performing the different operation. This is then used for designing purpose. And Figure-19 and 20 shows the properties for figure-18 and the properties for skin, after the operation was performed.

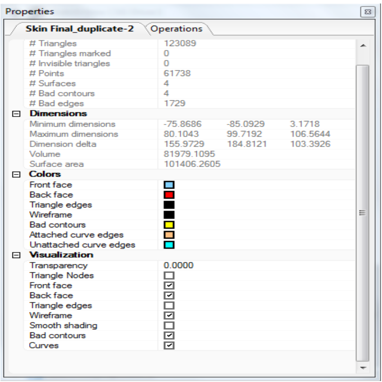


Fig. 19 :- Upper cut part properties

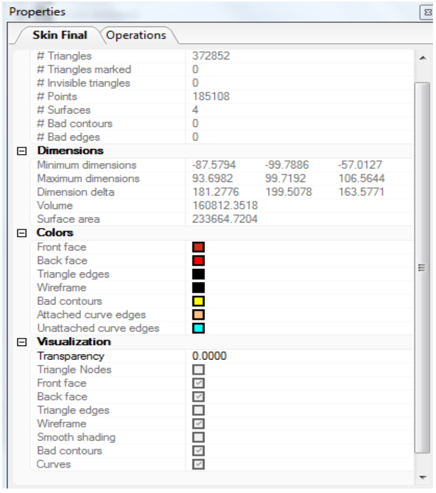


Fig. 20 :- Skin properties

Then after the formation of the contour shaped CSG, it was designed and edited with the help of different commands i.e., sketch, extrude, circle etc. This was done with the help of the reference taken in virtual surgical planning as it requires the location of target for designing the CSG.

Fig. 21 :- Edited CSG

After analyzing, modification was done for the doctors who wants to burr hole prior to the surgery with better accuracy and better visibility. This design is more lighter in compare to any of the frame based Stereotactic frame.

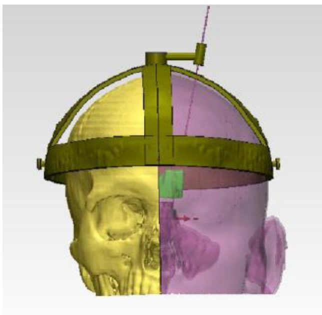

Fig. 22 :- CSG with Skull, Skin and Target

The difference in existing frame and CSG is this that it is made for convenience of the doctors as well as for the patient. Fig. 23 shows the CSG with the electrode and the target.

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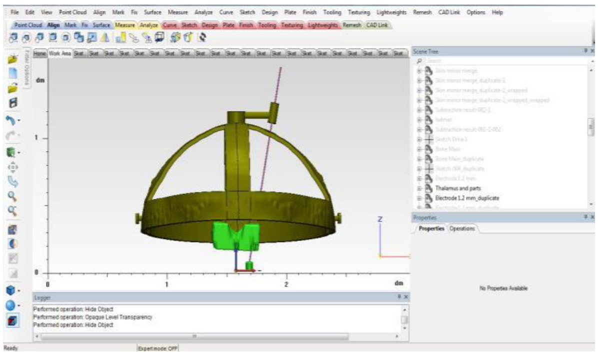

Fig. 23 :- CSG, Electrode and Target

Pictorial representation of the modified CSG :-

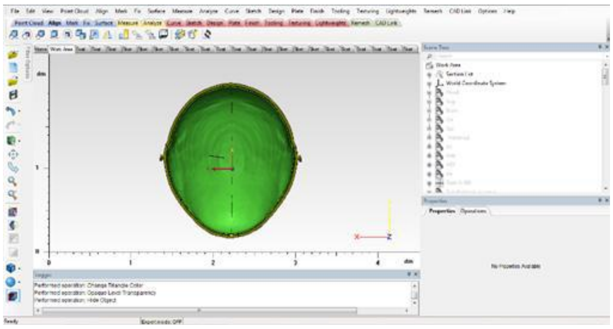

Fig. 24 :- Bottom view to show the Type-C CSG snugged with the skin contour

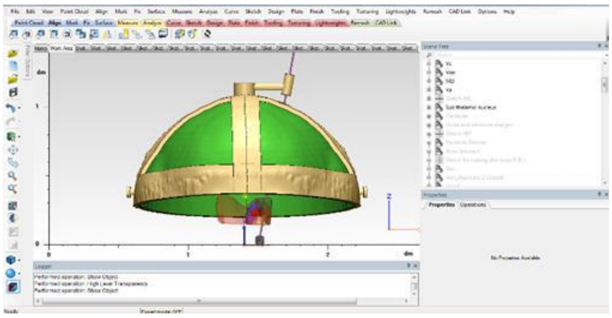

Fig. 25 :- CSG & Electrode hitting the STN & Vim

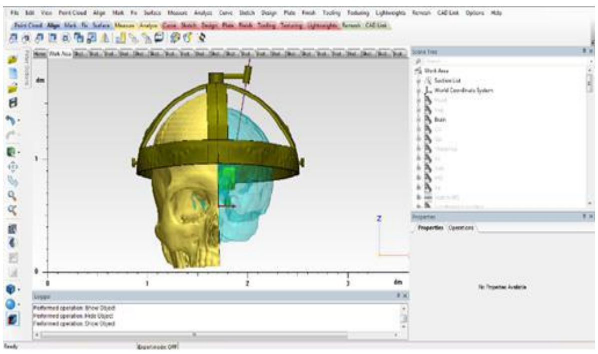

Fig. 26 :- CSG, Left bone, Brain, Thalamus & its parts

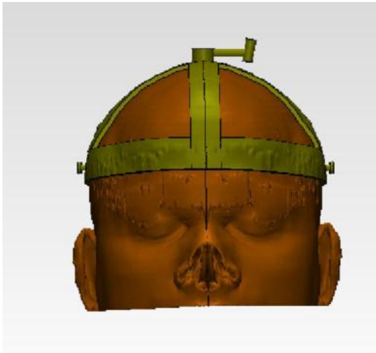

Fig. 27 :- Final Customised Surgical Guide

## IV. RESULT & DISCUSSION:

The research paper represents the methodology and the development of the Customised surgical guide for the Parkinson's disease patient undergoing DBS implantation.

The Final CSG is an array of products designed to accurately provide deep brain access for delivery of various therapies to smaller and deeper targets within the brain. This device is designed to provide more accurate solution as that of the frame based, while allowing more flexibility in imaging and planning for the procedure and providing an enhanced clinical outcome.

Existing Stereotactic frame placement is the difficult task as it requires four drill in the head to adjust the frame and to tolerate the frame is main problem because frame covers maximum part of the face which is more irritating for the patient.

Fig. 28 :- Head Frame [20]

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