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# Framework for Enhancement of Image Guided Surgery: Finding Area of Tumor Volume

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**Abstract:** The advantages offered by Image Guided Surgery (IGS) to medical professionals during a minimally-invasive surgical operation are overwhelming. Although a sophistication growth in imaging techniques can provide the surgeon with high quality guidance but there is still a need for more improvement in IGS application such as: computational time which impedes its full deployment in intra-operative surgical interventional, segmentation, registration, visualization, IGS application software and instrumentation. This paper presents a model for a more effective computational scheme by looking at possible computational improvement at all stages of IGS procedure but focusing on two aspects of IGS relating to intra-operative surgical intervention. The implementation of such improvement will result into fast and better anatomical segmentation and fast computational scheme. The other problem discussed in this paper is to find a suitable method to determine the tumor volume in an accurate way that will help surgeon to remove it precisely.

**Key words:** Image Guided Surgery, Minimally-invasive Surgical Operation, Intra-Operative, Surgical Interventional, Segmentation, Tumor volume.

## INTRODUCTION

Image-guided surgery (IGS) or Computer-aided surgery (CAS) is the general term used for any surgical procedure where the surgeon employs tracked surgical instruments and computer technology in conjunction with pre-operative or intra-operative radiological images for pre-surgical planning, and intra-operative surgical interventions in order to indirectly guide the procedure. IGS is mostly deployed in minimally invasive operation and encompasses the use of radiological images for post operation monitoring, treatment and medication to patients (Wikipedia, 2010).

IGS had dominated the surgical operation theatre (OT) since it successfully lead to the removal of a needle in a patient's hand in January 1896 at Birmingham UK (Beaulieu *et al.*, 2008). IGS in its various forms (Registration, Visualization, and Segmentation) is indispensable since the adoption of minimally invasive method of surgical operation (Gamage et al., 2008; Frank Sauer, 2005; George Hanna, Alfred Cuschieri, 2001), in disfavor of traditionally more invasive method. This is because of the latter's advantages, which includes efficacy, reduced cost, less lesion, minimal discomfort to the patient, surgeons' safety, less operation time, decreased hospital stay, less post operation medication, and quick healing time (Beaulieu *et al.,* 2008; Eran Shlomovitz, 2006; Ziv Yaniv, 2009; Andinet Enquobahrie, 2007; Menchetti, 2008). Recently; imaging techniques have grown greatly in their sophistication and can provide the surgeon with high quality guidance [10] at many stages of intervention. However, IGS is yet to reach the expected level of surgical interventional assistance anticipated by medical professionals, computer engineers, and scientist due to lack of reliable, robust, real-time, and yet cheaper software and hardware that are needed in IGS (Beaulieu et al., 2008; Yaniv and Clearly, 2006).

As argued by (Simon et al., 1998; Chauhan, 2010; Bosnjak et al., 2007; Scheres; Kim; Hadi Rezaei et al., 2009; Baumhauer et al., 2009; Abhilash Pandya, & Greg Auner, 2005) and (Yuichi Tamura et al., 2005) that IGS is still being confounded by many setbacks, and having studied the current IGS paradigm and found it to have contributed immensely to the relative inefficiency of IGS procedure due to it cumbersomeness and tediousness of the mathematics of image segmentation, registration, and visualization. This paper proposes a more computational effective IGS model by redesigning the whole IGS traditional system spanning image acquisition post-op. This of course furthers upon the work of (Hawkes et al., 2005) whose model was limited to patient registration aspect of intra-op intervention. The paper also suggests the evolution of a better image segmentation, registration, and visualization schemes, and more sophisticated IGS software that will incorporate more of the needs of medical professionals or limit the hitherto level of manual intervention in minimally invasive operation, more advanced navigation systems which will be an advancement to the efforts of (Salajegheh, 2008) and (Tran, et al., 2009) plus a better computational platform for overall system efficiency.

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The paper will discuss the concept of determining the tumor volume and proposing a suitable method to precisely determine the tumor volume, which will help the surgeon in doing accurate removal for tumor.

### *Current Image-Guided Surgery Model:*

Neuro-surgery is one of the areas in surgery where the use of IGS is indispensable because the brain is intricate, delicate, sensitive, tender, yet central to human functioning, hence a surgeon must maintain a precise sense of complex three-dimensional anatomical relationships. Accurate visualization is crucial in minimally-invasive operation because in some cases visual landmarks are relatively rare, and at times they are completely missing within gray colour images presented from the radiological unit. Damage to eloquent portions of the body especially brain anatomy can severely impair the patient. The current mode of operation for surgeries is called image guided neuro-surgery (IGNS). This is essentially a virtual reality (VR) system where the trajectory of a tracked tool is displayed in orthogonal medical image space as well as three dimensional (3D) models of various structures or the use of endoscope/ laparoscope enables rendition of internal organs. However, being able to project and perform surgery using orthogonal scans produces a significant mental load and hence recently, augmented reality (AR) systems capable of overlaying registered 3D models on video images have been developed (Hadi Rezaei et al., 2009).

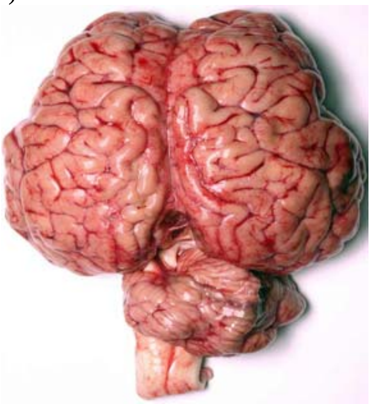
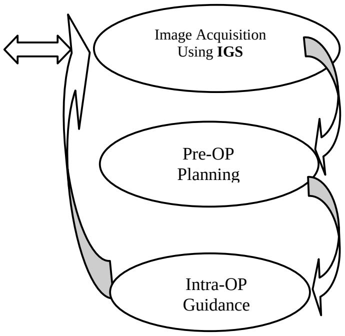


**Fig. 1:** A Picture of Human Brain

The current IGNS model can be depicted as made up of four stages linked up in a continuous chain. At each of the stages forming the model, one or more computation or application of certain mathematics based procedure is executed before moving on to the next stage. The stages are listed in order of execution as follows; (a) image acquisition, (b) pre-operation planning, (c) surgical interventional stage, and (d) post-operation monitoring. The diagram of this model is as shown in figure 2a and it flowchart in figure 2b.



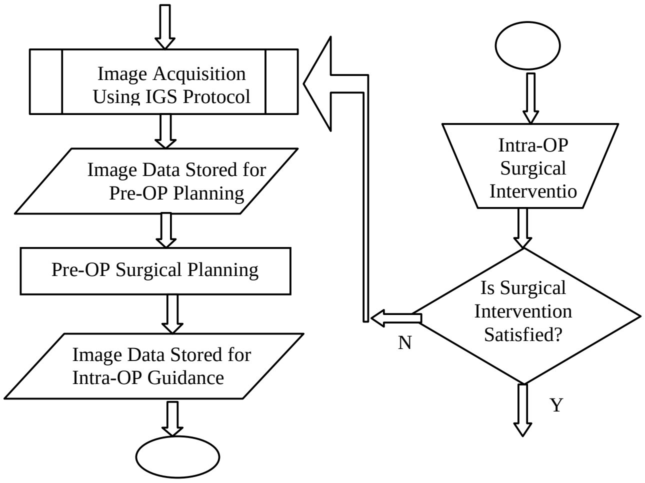


**Fig. 2a:** Pictorial Representation of the Current IGS Model
**Fig. 2b:** Flowchart Representation of the Current IGS Model

Stage (a): Patient’s image is acquired based on IGS protocol using MRI/ MRA scanner owning to its capability for better tissue/ atrium and blood vessel imaging. The IGNS protocol employs some aspects of patient registration methods like patient layout, imaging modality, field strength, scan sequence, slice thickness, et cetera needed to correlate the reference position of a virtual 3D dataset with the patient's reference position which will be useful at other stages of IGNS. An MRI/ MRA scanner with its images are shown in figure 3.

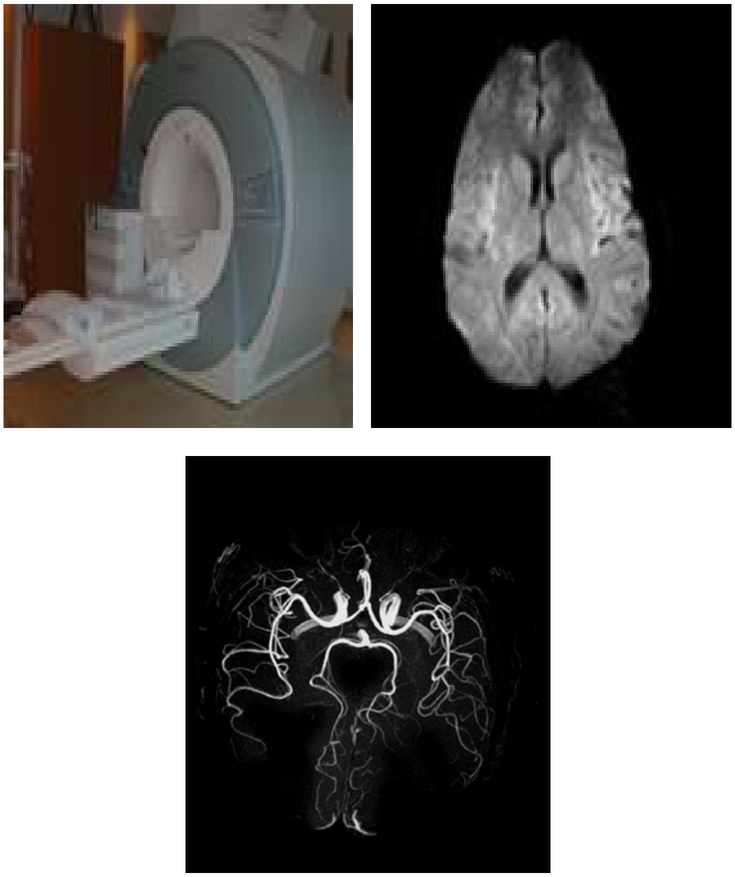


**Fig. 3a:** A Typical MRI/ MRA Scanner. 3b: Axial view of MRI Brain Image. 3c: MRA image of Brain Atrium and Blood Vessel

Stage (b): With the aid of IGS software, the image acquired in (a) is used in planning and practicing the surgical intervention needed ahead of the actual operation (Beaulieu *et al.*, 2008) and at times it is used to simulate the intended surgical operation. At this stage surgeons make use of the registration information followed in stage (a) to accurately plan the interventional procedure.

For instance, imaging modality and field strength determines the spatial contrast resolution of the image and these should be known by surgeons. Also slice thickness affects contrast resolution and its the knowledge enables surgeon to partially determine tumor size. In addition, he needs a clear view of the 3D virtual image before him (visualization) and a clear distinction between the target region and the adjacent tissues (segmentation) to avoid the risk of post-surgical morbidity by accidentally damaging adjacent structures.

Stage (c): The surgical intervention stage sees the full deployment of all IGNS knowledge and tools in the OT. Here the patient and surgeons come in contact thus most of the patient registration information in the two previous stages are used on the patient at this stage and the navigational and visualization equipments are used to their fullest to aid interventional procedure. At this point, integration of medical images and other sources of information such as tracked instruments are accomplished (Yaniv and Clearly, 2006). More so, the earlier segment of the target area is strictly enforced. For apparent lack of ability to see widely and work freely in a minimally invasive operation, and seemingly lack of accurate knowledge of the size of the target tissue (especially in brain tumor removal) and in order to avoid post-operation morbidity, the surgeon uses his medical knowledge to decide whether or not the extent of removal is adequate or not. Hence assuming it is not – occurrence of post-op morbidity or some kind of side effect may be expected, the patient would have to complain and be referred for scanning again. This is the critical point in this model where insufficient knowledge of target area size leading to incomplete or unsatisfactory intervention may result in relapse. Figure 4 shows neuro-surgical operation in progress.

**Fig. 4:** Neuro-surgical Operation in progress.

Stage (d): Assuming the patient survived the operation, the post-operation use of radiological images is meant to administer medication, and check patient's recovery process especially if the patient complains of the same illness or any operation related illness. Again the knowledge of patient initial registration information, image segmentation and visualization are used in recapturing his image again.

### *Proposed Image-Guided Surgery Model:*

The ineffectiveness and awkwardness of the current IGS model is hitherto presented in the last section. The main cogs are: analytical software impediments, and imperfectness that may result at the end of the intervention due to inability to 'see and evaluate' the site once the intervention commences (rescan intra-operatively). Figure 5a and 5b diagrammatically depict the idea of the proposed IGS model and its flowchart which is partially based on the researchers' idea in combination with the pieces of ideas from (Simon et al., 1998) and (Okker et al., 2004).

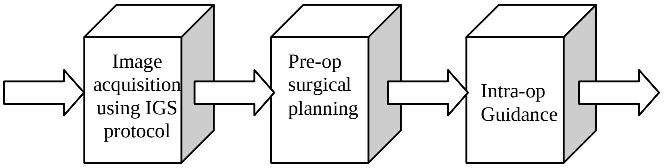


**Fig. 5a:** Pictorial Representation of the Proposed IGS Model

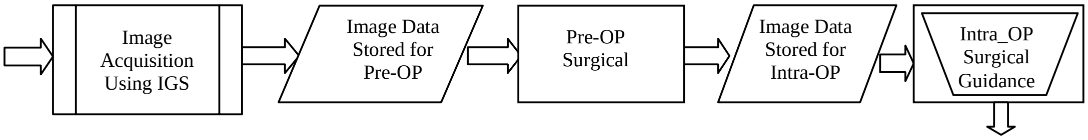


**Fig. 5b:** Flowchart Representation of the Proposed Model

The proposed model advocates for more improvement in the software use from stages (a) to (c). This could be in form of visual enhancement and image segmentation algorithms and target-area estimation algorithms. Secondly it supports the use of radiographic equipment in the OT for intra-operation visualization and segmentation to evaluate target-area which could eliminate the cycle as depicted in figure 2, and lastly the introduction of a more advanced data processing platform for real-time medical image processing.

In term of the expected improvement, the proposed model is aimed at (i) improving operations in stage (b) in terms of spurring ideas about the creation of more efficient software which will have the capability to incorporate more activity that are currently manually executed, and better visualization and segmentation algorithms; (ii) introduce innovative ideas in stage (c) by supporting the idea of having MRI/ MRA machines as part of OT equipments; (iii) improved navigation system to aid visualization; (iv) enhanced segmentation algorithm to assist surgical intervention; (v) enable real time surgical interventional; (vi) and possible elimination or reduction in the role of stage (d). As seen from the flowchart diagram of the proposed model, stage (c) is made up of two processes in one. This signifies the combine use of computerized techniques (like intra-operative imaging, segmentation, target-area evaluation) – these are the area in which the authors are presently researching – and manual operations in the OT.

In term of the advantages of the proposed model, it would engender improved surgical intervention and less time, that is, surgeon should be able to quantitatively, accurately, and instantaneously appraise the extent of work done and immediately know what is left. It will further reduce cost of treatment because patients and surgeons can walk out of the OT without fear of relapse.

### *Finding Area of Irregular Shapes:*

The idea of finding the area of irregular shapes (of unfamiliar types)/ wobbled edge circles of the type in figure 1 had been receiving attention from mathematicians, engineers, and scientists ever since. In addition to aforementioned earlier quest, the twenty first century is faced with increase in automation, tele-guiding, and use of robots in many fields of human endeavour. All these require specific and unambiguous instructions for optimal performance especially in medical and military fields plus space exploration and nuclear technology. The well-know Simpson's rule for determining the area under a curve in Cartesian plane, stemming from integral calculus has already been established (Stroud, 2007; Spencer et al., 1983; John Berry, & Patrick Wainwri, 1991; Weltner et al. 1986). Likewise, many complex 2D/ 3D figures consisting of intricate merger of regular shapes have had their parameters determined through careful separation and determination of the properties of individual components that make up the figure (Kreyszing Erwin, 1993; Spencer et al., 1983; Stroud, 2007). The above two approaches does not satisfy the type of irregular shape in this discussion. In our case, the source of data is the MR image which shows timorous section on a slice as a 2D snaky-edged circle and whose accurate determination of it area would influence precise calculation of the tumor volume and shape. Another method of old for finding volume of an object is to pour a liquid or sand into the object and later pour it into standard measuring device in order to know the volume (http://www.audiogearreviews.com/tech/how-to/calculating_volume/calulating_volume-irregular.asp). This method could be erroneous if the compressibility of the poured is not taken into consideration and altogether unsatisfactory as it is mostly applied to hollow shaped object. Yet we find a different method though not in common use but can be extremely accurate for equally determining volume of hollow objects as explained by (Andinet Enquobahrie, 2007), It involves the use a sine wave generator and a test fixture. Again we come across graphical methods of calculating the area of irregular shape lands usually employed by Surveyors and Civil and Agricultural Engineers in (http://biosystems.okstate.edu/Home/fharry/4112/500_Information/). Of the many approaches to solving the problem of determining the area under arbitrary close shape is the popular Fractal Analysis Algorithm (Khan M. Iftekharuddin, 2005) originated by Benoît Mandelbrot (http://en.wikipedia.org/wiki/Beno%C3%AEt_Mandelbrot). Furthermore, (http://www.westone.wa.gov.au/toolbox6/ hort6 /html/resources/depot/hort_file/ calc_area/area_fs.htm) described an approximation method for determining the volume of irregular shaped object by finding the average of its radii measured at different but close intervals, and the calculate the volume having previously calculated the area using the average radius.

However, aside from the fact that most of the methods above lead to approximated results, even the more accurate methods as cited above do not fit into the determination of area, volume and structure of brain tumor from the MR image as intended by the on-going research work of these authors because sustaining the exact shape of the tumor is as essential as it area and volume. More so, just like the determination of area under an arbitrary curve is left to be determined using approximation methods like the Simpson's rule, the area encircled by irregular/ snaky edge closed space as in figure 6 is not an exception, hence the need for continuous probe for ways of achieving better results and thus the emergence of the iterative spatial sectoring technique.

The rest of the paper is arranged thus: section two shows the basic concept of iterative spatial sectoring technique, the third section mentions in details the idea of iterative spatial sectoring, the fourth part shows the resulting mathematical model of the technique, section five discusses error elimination technique, conclusion of the paper in section six, and section seven is the reference.

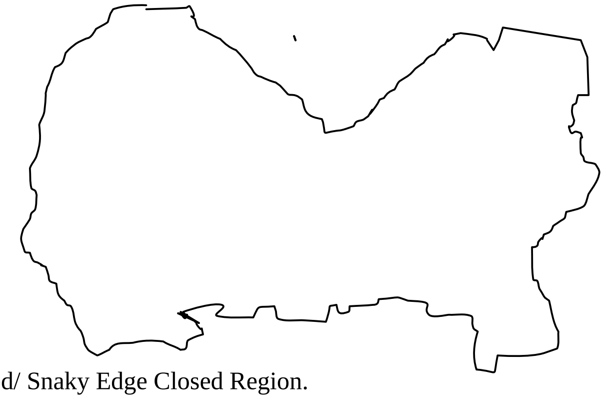


**Fig. 6:** An Irregular Shaped/ Snaky Edge Closed Region.

### *Iterative Spatial Sectoring Technique:*

Owing to the fact that the existing methods of finding the area of irregular closed region relies purely on estimation, an iterative spatial sectoring technique is devised with a preconceived implementation strategy that makes use of today's program codes instead of manual measurement and application of formula like the Simpson's rule. Iterative spatial sectoring is a novel method of determining the area of an irregular close region/shape based on integration of knowledge of basic geometry and integral calculus particularly Simpson's rule. This idea is premised upon two motions that the area of an irregular close space can be divided into sectors of different radii and, when the rough or deformed edges is cut into small segments, it resemble a curve bounding an area in Cartesian plane, the area of individual sectors could be determined just like the area under the curve is divided into smaller rectangles and later add up to find the area of the closed irregular space. Being program code based, the division into smaller sectors would continue iteratively until there is no difference between two successive iterations or the deference is highly negligible.

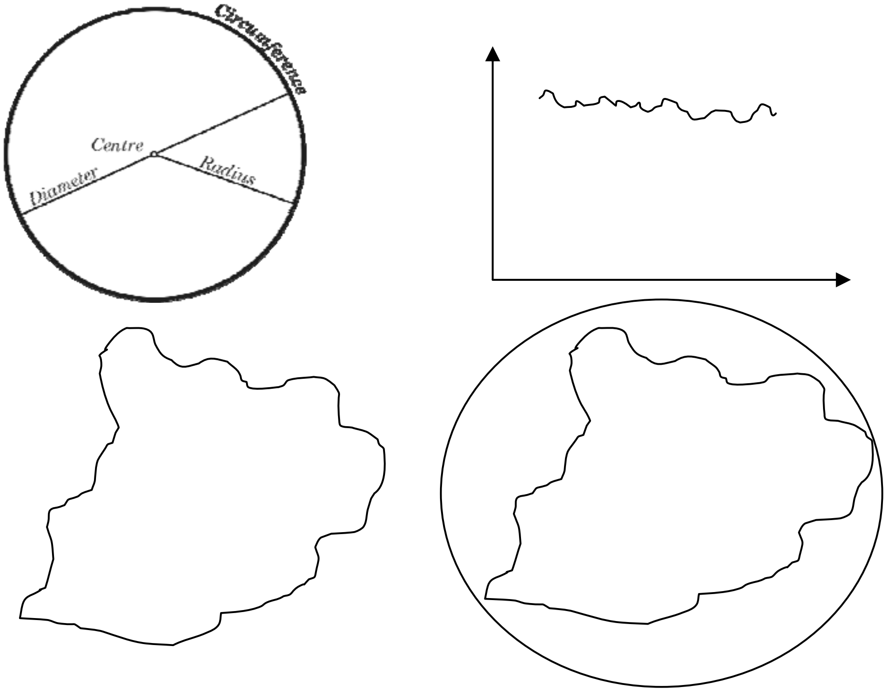


**Fig. 7:** (a) Circle, (b) Determining Area under curve (Simpson' rule), (c) Irregular Shape and (d) Irregular Shape encircled by its circumference.

### *Iterative Spatial Sectoring: Mathematical Model:*

In this approach, an irregular close shape is conceived to be a circle with deformed edges. However, notwithstanding the deformity or shrink, if it perimeter is measured, it is equal to the circumference of the circle that would have been formed should the deformity/ shrink be straighten out. Hence the area of that circle would be the maximum possible area of the irregular closed shape when it becomes regular. Unlike the Simpson's rule which divides the area under consideration into any number of even equally spaced rectangle with odd numbered perpendicular lines, spatial sectoring technique first encircles the space by its circumference as in fig. 7, and then divides it into a number of sector based on calculated shrink ratio. The shrink ratio itself is determined by dividing the area of the would-be circle by a rough area of the closed space. The following steps show the mathematical model of spatial sectoring.

$$Area\ of\ a\ sector\ (R_s) = \frac{\theta}{360}\pi r_n \cdot r_{n+1}$$

$$Area\ of\ the\ irregular\ close\ shape\ (R) = \left(R_{T_x}\right)$$

$$= \sum R_s = \sum_{n=1}^{(W_1-1)} \left(\frac{\pi\theta_x}{360}\right)_n \cdot r_n r_{n+1} + \left(\frac{\pi\theta_x}{360}\right)_{W_1} \cdot r_{W_1} r_n$$

$$Area\ of\ the\ irregular\ close\ shape\ (R) = \left(R_{T_{x+1}}\right)$$

$$= \sum R_s = \sum_{n=1}^{(W_1-1)} \left(\frac{\pi\theta_{x+1}}{360}\right)_n \cdot r_n r_{n+1} + \left(\frac{\pi\theta_{x+1}}{360}\right)_{W_1} \cdot r_{W_1} r_n$$

If the difference between $R_{Tx}$ and $R_{Tx+1}$ is more than a set value: then increase x by 1 otherwise, make $R_T$ biggest value.

The basic iteration steps in spatial sectoring is two, the first step divides the space into a number of sector equal to the product of shrink ratio and 2pie, the second iteration increases the number of sector by increasing 2pie to 3pie. If the comparison of the two results is equal or negligible, the area of the space is determined, however, should there be difference be significant, a third iteration is done by increasing pie by another one step, and so on, hence, an iterative spatial sectoring.

## *Conclusion:*

A novel thinking in IGS has been presented. It is pivoted on the need to have better and faster IGNS process by improving on the available IGS software for the different stages of IGNS, advancing image enhancement and segmentation algorithm, proposing better navigational equipment, introducing imaging modalities into the OT, and running medical data on a more speedy platform like grid computing environment. It is our believe that should some of the above mentioned improvement implemented, it would contribute to the advancement of IGNS and ultimately impact on quality of health services delivery as a whole at less cost to what is presently obtainable. This is especially true if more advanced software and algorithms are employed at stages (b) and (c) as depicted above where manual operations are still prevalent.

The foregoing is a conceptual framework detailing a novel technique for finding the size of space by tumor on a slice in particular, and area of irregular/ snaky/ wobble edged closed space in general. The technique is based on idealistic understanding of methods of finding area under curves particular the Simpson's rule, and geometric way of finding area of a sector. The method is superior to other existing methods for its ability to iteratively get near accurate result with few iteration, and its error correction method. This will help in determining the volume of tumor more precisely.

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