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Review of Visualization Techniques in Computer Graphics

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***Abstract*— Surgical simulation has many applications in medical education, surgical training, surgical planning, and intra-operative assistance. However, extending current surface-based computer graphics methods to model phenomena such as the deformation, cutting, tearing, or repairing of soft tissues poses significant challenges for real-time interactions. This paper elaborates various methods currently used for surgical simulations. Reading a large quantity of research papers and capturing the essential information from them is a very challenging task. This paper aims to categorize the concept of various approaches related to area of interest. Also analyzes the current situation of model modification in development of visual technology. The relevant components are depicted in detail. This paper presents a survey of work done in eight different visualization categories within computer graphics research community. The research has a long history and wide range of approaches. This paper organizes the diversity of research by using various algorithms and methods. This paper also suggests important areas for future research.**

***Keywords*—Two Dimension(2D), Three Dimension(3D), Artificial Intelligence(AI), Binary Space Partitioning (BSP), Carnio Maxillo Facial(CMF), Compute Unified Device Architecture(CUDA), Digital Image Correlation(DIC), Finite Element Method (FEM), Graphics Processing Unit(GPU), Light detection and Ranging (LIDAR), Magnetic Resonance Imaging (MRI), Mass Spring Method(MSS), Scale Invariant Feature Transfer(SIFT), Virtual Reality(VR).**

I. INTRODUCTION

Visualization is any technique for creating images, diagrams, or animations to communicate a message. Visualization today has ever-expanding applications in science, education, engineering (e.g., product visualization), interactive multimedia, medicine, etc. Typical of a visualization application is the field of computer graphics. Visualization techniques are used to create computer-generated images that aid in the communication, processing, and understanding of information.

These techniques build upon algorithms from computer graphics to render images of information, to enable interactive navigation and exploration of information, and to integrate and augment information from the real world. The following is an introduction to fast growing fields of visualization categories for the computer graphics programmer. These categories are indicated in table1.The computer graphics techniques themselves will not be discussed, but the way these techniques are applied will be explained. This discussion will also explain related work, algorithm/methods and future challenges. New procedures to visualizations high CPU usage and large memory requirements are a frequent occurrence. The reader is encouraged to consult the papers listed in references for information on specific algorithms, scientific applications and advanced topics.

II. VISUALIZATION CATEGORIES

1. Geometric Modeling

Geometric modeling is collection of methods used to define the shape and other geometric characteristics of an object. This modeling is used to construct a precise mathematical description of the shape of a real object or to simulate some process. Xiufen ye [1] discusses virtual human soft tissue model and its deformation under external forces. Human soft tissue modeling is implemented using mass spring method, deformation using runge kutta 4th order method, where as incision and cutting using beizer curve. Bo Zhu [7] proposes a novel approach to model elastic behavior of organs with complex surfaces in surgical environment. The organ deformation is implemented using surface mesh and soft tissue deformation using particle based simulation framework.

Algorithms/Methods: The main idea of MSS [1] is, to discretize the simulated object with masses between which composite linear elastic spring model is adopted.

When a particle moves under a certain external force and produces stress, other adjacent particles will move under this stress to generate deformation. MSS gains the advantages of fast computing, simple implementation, low computational complexity and better ability to adapt the changes of soft tissue topology. Particle-based method [7] has proven to be a powerful tool in real-time surgical simulation for its simplicity and high efficiency. Particle-based simulation methods have been proposed over the past decades to alleviate the simulation problems brought by meshes in the area of computation physics and computer graphics. For its simplicity in topology and data representation, particle-based methods are suitable for simulating the elastic and plastic bodies in real-time applications.

Challenges: The above mentioned methods need to be applied to more complex and heterogeneous models which is still a challenge, hence there exists a research gap in this area although it is less significantly used.

2. Volumetric Modeling

Volumetric modeling deals with scalar valued functions defined on 3D space. The synthesis, analysis and manipulation of sampled computed and synthetic objects are contained within a volumetric data set. Lenka [2] proposes Interactive simulation of object cutting using dynamic branch grid algorithm. E.A.Audenaert [3], discusses 3D Anatomical & geometrical description of soft tissues (orthopedic) used in orthopedic surgical applications & muskoskeletal biomechanics. Ingela [23] describes Computation of enclosed volume using Triangulated surface representation (256 marching cube). Chuhua Xian [28], Wei Zeng [29], Meng-fei Li [39] emphasizes on hexahedral and tetrahedral mesh representations to decompose and visualize volumetric meshes, this is positive in this area compared to other papers. Jun Zhou [30] discusses 3D models of trees from freehand sketches.

Meng-fei Li [39], defines Facial hexahedral mesh of Patient specific using harmonic fields. George [22] explains cutting of 3D mesh using FEM model.

Algorithms/Methods: Dynamic branch grid algorithm [2] illustrates surface model which is polygonal set of volumetric data, when an element is cut it is replaced by number of superimposed elements. 3D anatomical description [3] is used in orthopedic surgical applications and muskoskeletal biomechanics, they mainly use metallic markers to mark muscle tissue, vascular and nerves. Muscle tissues are represented as solid volume, vascular and nerves are indicated through mathematics.

Triangulated surface representation [23] uses T-shell data structure based on marching cube concept, it maintains a look up table with area and volume for triangulated digital surfaces. Automated decomposition of volumetric mesh [28] using 3D hexa & tetrahedral meshes is to decompose volumetric mesh into semantic components. Each feature boundary lines are identified. Each splitter is decomposed into 2 graph cuts. Splitter element group are used to obtain inner volumetric elements. To visualize density of colon volume [29], the volumetric colon unfolding (colorectal cancer) is implemented using harmonic differentials to know densities. Meng-fei Li [39], defines Facial hexahedral mesh of Patient specific using harmonic fields. It avoids element flipping and preserves element angles. Fractals [30] are used to create 3D geometry from 2D mesh, one should have botanical knowledge & tropism to create branches (Algorithms).The majority of current surgical simulators use the finite element method (FEM) for Volumetric modeling [22]. FEM is a mathematical model to solve complex problems. The number and quality of the finite elements have a direct impact on simulation performance and stability. From the viewpoint of dynamics simulation, this approach is closely related to the virtual node algorithm and the XFEM. Moreover, the similarity of shapes allows us to easily build a hierarchy of coarse voxels based on fine ones.

TABLE I
FIELDS OF VISUALIZATION CATEGORIES

Sl.No	Visualization Categories	Description
1	Geometric Modeling	*Geometric modeling* is a 2D modeling of human organs or solid objects.
2	Volumetric Modeling	*Volumetric model* mainly deals with three-dimensional model constructions.
3	Application Oriented	*Application oriented* papers rely on VR simulators or GPU accelerated simulation.
4	Deformation Based	*Deformation category* includes skinning,stretching,transformations,topology modifications etc.
5	Data visualization & Collision detection	*Data visualization* category deals with representation of complex data sets.
6	Rendering & Camera Vision	Papers on *rendering* category explain displaying of data subsets.
7	Virtual Surgery & Applications	*Virtual surgery* category includes VR simulators either for bone drilling or 3D kidney model.
8	Soft Tissue Based	*Soft tissue* category includes tissue classification, tissue development, its properties and reconstruction method.

This simplifies the construction of physical models based on volumetric images. The voxel based approach is particularly suitable for medical simulation, because it can directly use 3D medical data, which defines the finest level of detail. Arbitrarily coarse levels of detail can be generated recursively by doubling the voxel size at each level. The deformations and to apply the viscoelastic response, a regular grid of arbitrarily coarse deformable hexahedral elements is generated, hierarchically built on top of fine voxels. In order to reflect the fact that the coarse voxels may be partially empty, a non-uniform stiffness and mass distribution is used. This allows adjusting a tradeoff between accuracy and speed of the dynamics while preserving a high visual quality of the simulation.

Challenges: Interactive simulation of object cutting using dynamic branch grid algorithm need to replace separate cells rather than removing of cells. 3D Anatomical & geometrical description of soft tissues (orthopedic) need to include general description of soft tissues i.e. about nerves and vessels. Automated decomposition of volumetric mesh requires validation for complex form features. 3D models of trees from freehand sketches require additional features like move rotate and bend branches of tree. Hence literature review in this category shows that there is a research gap in evaluation/validation of these models.

3. Application Oriented

Application oriented is a user-oriented Computer Graphics System which primarily has been designed to aid the application programmer, and not just the sophisticated computer graphics user. The system has been designed to provide a very simple interaction capability, where the interaction is based on a variety of input devices and a simple input/output graphics command language. Lin [27] uses triangulated surface model to build bone model of CMF structures. Dong [4] and Yo [40] provides virtual haptic feedback for needle insertion into liver model, however [4] includes registration with CT & ultrasound, which is not present in [40]. Yanxiang [6], Ding [42] and Hadrien [47] speaks about GPU simulation based on CUDA sim, however methods used are different. [6] Uses algorithm based on network models, [42] uses parallel computing for irregular volumes & [47] for complex surgical procedures. [42] Sounds best paper as it is cost effective.

Algorithms/Methods: Figure1 shows VR simulator for ultra guided needle insertion in liver [4] uses SIFT algorithm for realistic needle insertion which involves registration with computed tomography (CT) and ultrasound, provides visual and haptic feedback. A biopsy takes a tissue sample from the body for analysis. This procedure's success depends on the biopsy needle's correct alignment with both the ultrasound probe's scanning plane and the target lesion, which requires extensive training and practice. The system first stitches together the ultrasound volumes with different scan angles to generate an ultrasound panorama. It registers the resulting stitched volume with the corresponding computed tomography (CT) volume to obtain a correlation. It extracts anatomic surfaces from the CT volume for both visual and haptic rendering while using the stitched volume to simulate the ultrasound imagery. GPU accelerated biochemical network simulation [6] uses CUDA sim (python package) for running parallelized algorithms on network models. Reconstruction of old complicated CMF fractures [27] make use of triangulated surface model to implement bone model. Needle insertion with image guidance [40] uses ultrasound and 3D model for liver deformation simulation. particle based multiple irregular volume rendering[42] makes use of CUDA to render regular and irregular volumes.GPU based soft tissue deformation with cutting and haptic feedback[47] uses interactive simulation of complex surgical procedures.

Challenges: virtual haptic feedback for needle insertion [4] need to include labeling of anatomical structure. Bone model of CMF structures [27] should improve navigation systems. Hence there exists a research gap in these methods.

4. Deformation Based

Deformation is a geometric technique used to model simple deformations of rigid objects. It is based on the idea of enclosing an object within a cube or another hull object, and transforming the object within the hull as the hull is deformed. Martin, Jonas [9], discusses Interactive simulation of deformable bodies using 3-fold body representation: cubic, tetrahedral and triangle meshes. Ibrahim Alhasim [13] defines Stretching different parts of shape i.e. shape variations. Jun Feng [37] explains multi resolution statistical deformable model using liver deformation. Y.Lafon [38], debriefs about effects of posture on anatomical structures of trunk. P.Jimenez [45] enlightens survey on model based deformable objects.

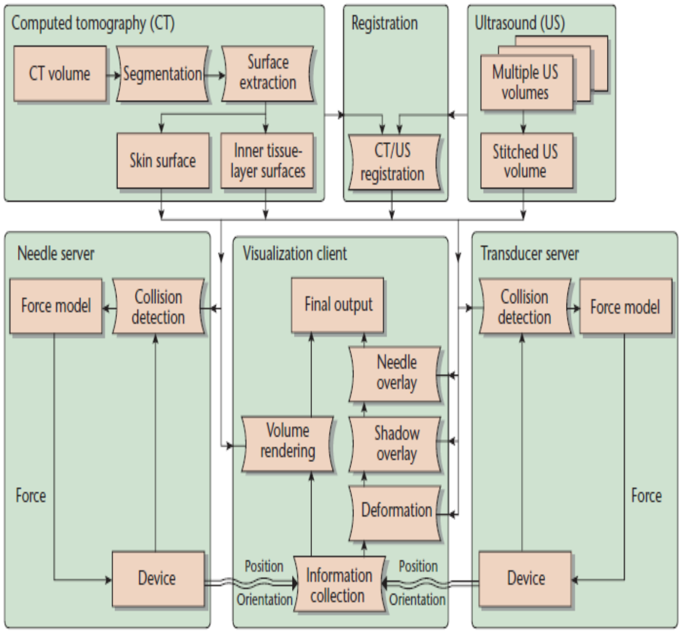

Figure 1. The framework for a VR-based simulator for ultrasound-guided needle insertion in the liver. The simulator provides realistic visual and haptic feedback.

Benjamin Gilles [11] discusses a new approach that combines the advantages of both skinning and physically based deformation. Martin, denies [8] defines robust interactive cutting based on adaptive octree simulation mesh, it defines use of Z-curves to update & store simulation elements. Christian Dick [14] debriefs about hexahedral multigrid approach for simulating cuts in deformable objects.

Algorithms/Methods: Interactive simulation of deformable bodies [9] uses 3- fold body representation i.e. deformation is done using cubic mesh, collision is achieved using tetrahedral mesh and visualization is obtained using triangle mesh. Stretching [13] illustrates shape variations using grid construction & texture synthesis making use of stretching algorithm. Multi resolution appearance models such as liver model [37] captures most significant deformation and variation model of organ shapes. Anatomical structures of trunk [38] shows 3D effects of 4 full trunk postures on skeletons and organs using MRI scanner. Types of deformation [45] are explained using algorithm which includes path planning, folding/unfolding, topology modifications and assembly.

Paper [11], discusses a new approach that combines the advantages of both skinning and physically based deformation. Instead of the vertices of a mesh, the degrees of freedom are a sparse set of coordinate frames, which parameterize material points using an advanced skinning method called dual quaternion blending. It presents a new type of deformable model using continuum mechanics applied to objects undergoing skinning deformation fields. This approach allows the creation of sparse mesh less models with arbitrary constitutive laws, and have been demonstrated it using St. Venant-Kirchhoff materials. The models are robust to large displacements and deformations. Adaptive octree based approach [8] for interactive cutting of deformable objects. This technique relies on efficient *refine*- and *node split*-operations. These are sufficient to robustly represent cuts in the mechanical simulation mesh. A high-resolution surface embedded into the octree is employed to represent a cut visually. Model modification is performed in the rest state of the object, which is accomplished by back-transformation of the blade geometry. This also proposes to use a *Z-curve* to store the vertex correspondences per simulation element.

Figure2 shows a Z-curve (or space-filling curve) *f:* R*n*→N is a mapping from a multi-dimensional data domain to a one-dimensional *hash value*. Its main advantage is that spatial locality is well preserved, resulting in reduced cache misses and thus a more efficient access. *Z*-curves are widely used in computer graphics, e.g., to visualize scalar fields, to speedup fluid dynamics, or to detect collisions. Hexahedral multigrid approach [14] for simulating cuts in deformable objects is carried out using splitting cube algorithm, this simulates cuts using co-rotational formulation of strain at high computational efficiency. It is a best method as it includes co rotational formulation of strain at high computational efficiency.

Challenges: 3-fold body representation [9] should consider stiffness tensor to reflect embedded material and also should address topological changes. In frame based elastic models [11] stiffness and weight to be exploited. Shape variations [13] using stretching algorithm fails to include stretching of arbitrary surfaces. Literature review in this category shows that there is a research gap in stiffness and stretching of arbitrary surfaces. Robust interactive cutting [8] should include progressive cutting to handle collisions and self collisions. Hexahedral multigrid approach [14] needs extension of splitting cubes.

5. Data Visualization & Collision Detection

Data visualization representing data graphically and interacting with these representations in order to gain insight into the data. Data visualization is a related subcategory of visualization dealing with statistical graphics and geographic or spatial data (as in thematic cartography) that is abstracted in schematic form. Collision detection typically refers to the computational problem of detecting the intersection of two or more objects. Collision detection methods primarily address the problem of rigid bodies, recent approaches have started focusing on deformable objects. Deformable collision detection is an essential component in interactive physically-based simulation and animation which is a rapidly growing research area with an increasing number of interesting applications.

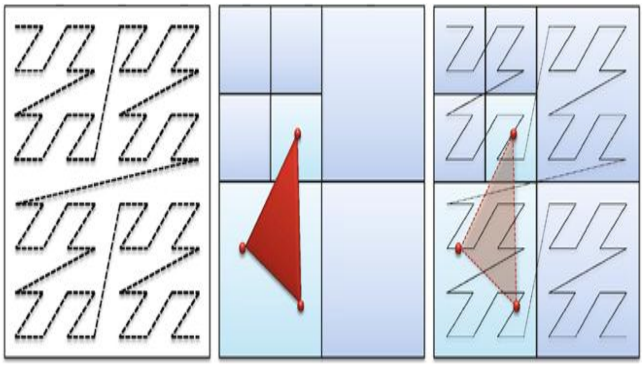

Figure.2. 2D-illustration of the *Z*-curve employed to encode surface vertex positions. *Left*: Conceptionally, the *Z*-curve covers the whole domain of the octree, while preserving spatial coherence. *Middle*: A surface triangle embedded in the octree. *Right*: Each vertex of the triangle maps to a unique location within the sorted list of 1D hash values obtained from the *Z*-curve. All vertices within an octree element can be quickly queried by determining the 1D hash values of its lower left and upper right corner

Yun Jang [12] explains time varying data sets using octree & Binary space partitioning (BSP) tree, while Tim Gregor [34] represents complex objects using signed distance functions. M.Attene [35] illustrates to find whether object is strongly or weakly connected Yin [21] illustrates collision detection using boundary box algorithm where as Marc Gissler [10] handles collision response using spatial data structure algorithm.

Algorithms/Methods: Functional representation of time varying data sets [12] is an encoding technique indicating P-frame (Predictive) and I-frame (Intra) to evaluate time varying data quickly using octree and BSP trees, shown in figure3.

BSP is a method for recursively subdividing a space into convex sets by hyper planes. This subdivision gives rise to a representation of objects within the space by means of a tree data structure known as a BSP tree.

Figure.3.Comparison of octree and BSP tree hierarchy (a) shows the spatial structure using the octree (2,192 cells and 163,715 basis functions), whereas, (b) is the spatial hierarchy with the BSP tree (925 cells and 83,108 basis functions).

Manipulators are used for signed distance function [34] to represent complex objects and scenes. The signed distance function between an arbitrary point in 3D space and a given closed surface returns the minimum distance from that point to the collection of triangles representing the surface. By convention, the sign is positive if the point is outside and negative if the point is inside the region determined by the surface. Scene is rendered using sphere tracing. Solid models are used for weighted topology [35].Solid models are constructed using mesh segmentation algorithm. Weighted arc length are used to find whether object is strongly or weakly connected.

Collision detection walk through [21] in 3D scene is achieved using bounding box algorithm. The core idea of hierarchical bounding box is that, bounding box with slightly larger volume and simple geometric properties is used to describe the complex geometric objects. Collision response is obtained through spatial data structure algorithm [10]. The spatial data structure represents a geographic entity. The entity must be as simple as a point or as complex as a whole map. The entity has global properties, component parts and related geographic entities.

Challenges: The method used in [12] is best as compared to other papers because time varying data sets can be evaluated quickly, but should reduce sudden changes at I-frames.

Signed distance functions [34] can handle complex surface manipulation but should handle merging meshes with implicit surfaces and explicit tools. Weighted topology [35] illustrates to find whether object is strongly or weakly connected, but fails to consider blurred solids. Uniform grids [10] for collision handling using spatial data structure algorithm is expensive in application scenarios where lots of collisions persist over large time intervals, but should adapt culling schemes.

6. Rendering & Camera Vision

Rendering is the process of generating an image from a model (or models in what collectively could be called a scene file), by means of computer programs. This is the process by which a 3D scene is translated into a final 2D image. Camera vision describes the mathematical relationship between the coordinates of a 3D point and its projection onto the image plane. It is mapping from a 3D scene to a 2D image. Its validity depends on the quality of the camera and, in general, decreases from the center of the image to the edges as lens distortion effects increase. Mike Bailey [5] defines GPU shaders for visualization on 3D structures for effects programming. Z Wang [15], Y GAO [18] and Bosjan [44] explain rendering based on GPU, but method used in each is different. Surface rendering [15] based on GPU is done through virtual simulation. Tree leaves rendering [18] is done through visual effects. LIDAR data sets point based rendering [44] is done through remote sensing technology. X Han [16] defines contour force rendering to image perception. M Okada [17] implements sound rendering with fuzzy clustering. Tomasz [43] explains rendering fractal surface points. Camera vision category C Zhang [20] classifies & compares current camera calibration methods with AI.

Algorithms/Methods: GPU shaders [5] are reading 3D scalar data into shader (small set of scenes describing graphics attributes). It is implemented using LIC (Line Integral Convolution) algorithm and terrain bump mapping. Virtual simulation[15] which produces different levels of detail surface rendering in automatic way is done using GPU, where as [18] shows tree leaves rendering through visual effects using translucent properties and [44] shows on demand loading of data subsets using point based rendering. Out of these, the method used in [44] is best because it uses remote sensing technology. [16] Discusses polygonal contour curve rendering to perceive shape of images. [17] Explains 3D sound rendering using amplitude panning and hard clustering process. Rendering 3D IFS fractals [43] uses medium power accelerated graphics such that 100 fractals can be kept in video RAM at a time.

Challenges: The above mentioned methods on rendering based on GPU should have broad application in engineering virtual simulation. Camera calibration methods have much scope & therefore there exists a research gap in this area.

7. Virtual Surgery & Applications

VR simulator is only a training tool that must be thoughtfully introduced into a surgical training curriculum for it to successfully improve surgical technical skills. VR simulators allow to navigate around and to interact in a 3D computer simulated environment. Surgeon can have a realistic physical behavior of organs during interaction with surgical instruments. To inform surgeons about the practical issues to be considered, for successful integration of virtual reality simulation into a surgical training program. Virtual Surgery category involves VR simulators for orthopedic drilling [31], kidney reconstruction [32], and spinal bone drilling [33]. Minimally Invasive Surgery (MIS, in german: MIC) is a new kind of surgery which gets more and more common nowadays. Another well-known expression is 'endoscopic surgery'. With this method, a surgical operation is performed by the help of:

- Small,endoscopic,camera
- several long, thin, rigid instruments

Through natural body openings or small artificial incisions ('keyhole surgery').Papers on minimally invasive surgery explains driving motors by L YU [19] for surgical robot system, and Image guidance computer assistance for robotic surgery by SU-Lin Lee [24]. *Neural network* category includes medical image analysis. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. Neural networks are used to model complex relationships between inputs and outputs or to find patterns in data. Neural network papers explain about needle insertion system in to the liver model [25], also processing of medical images using artificial neural networks [26].

Algorithms/Methods: Mithra [31] & Hua Zhanga [33] discusses bone drilling simulations, shown in figure 4, one for orthopedic & the other for spinal bone drilling using visio haptic interaction with virtual bones.

Xiaoning [32] explains VR kidney and its 3D reconstruction seen in figure5 with the help of image registration, segmentation & reconstruction on 3D kidney model. L YU [19] discusses Multi DOF (Degree Of Freedom) fingered mechanism of MIS robot for surgical robot system using driving motors where as Su-Lin Lee [24] discusses computer assistance for robotic surgery using haptic & tactile sensing for visualization and recreation of surgical procedures for robotic surgery through image guidance. Here both methods are equally important.Yo Kobayashi [25] discusses needle insertion system with image guidance and deformation in to the liver model using visco elastic properties. J. Jiang [26] debriefs medical image analysis i.e. processing of medical images through computer aided diagnosis using artificial neural networks.

Challenges: VR simulators for orthopedic drilling should include tapping and screwing motions. Kidney reconstruction method should add physical structure tags on kidney model. There is lot of scope in neural network category. Hence there exists research gap in these areas.

8. Soft Tissue Based

Soft tissue models include skin, muscles, fat…etc. Soft tissue properties should be customized according to the person scanned. Many approaches to soft tissue modeling are based on surface models. Joset [36] and payam [46] discusses classification of tissues one based on activation patterns of neurons & other based on MRI scan. C.V.C Bouten [41] and Alexander [50] discusses about tissue development. [41] Concerns about regeneration of heart valves & arteries where as [50] discusses about continuum model for skin growth. Owen [48] explains the influence on rest of skin on drug penetration & distribution. Christian [49] debriefs about skin macroscopic properties in understanding the failure & damage mechanisms of soft tissues. Kevin[51],J.S.Duffy[52],C.Pailer[53]and Zhang Gao[54] describes mechanical properties of soft tissues.[51] explains with FE modeling, [52] using visco elastic model, [53] explains using indentation device & [54] on tensile testing.

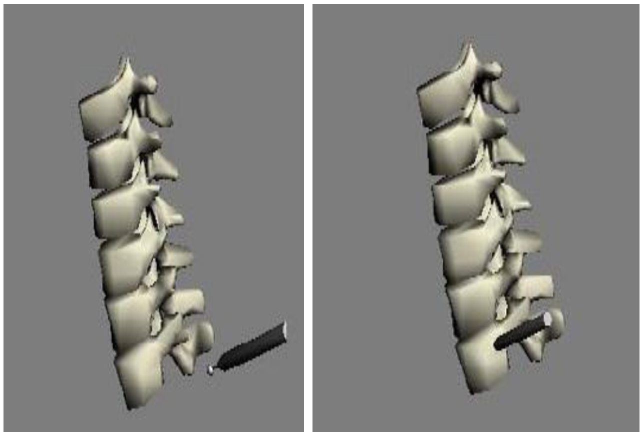

Figure.4. Virtual drilling: (a) drill bit getting close to virtual bone; (b) drilling bit touch the virtual bone.

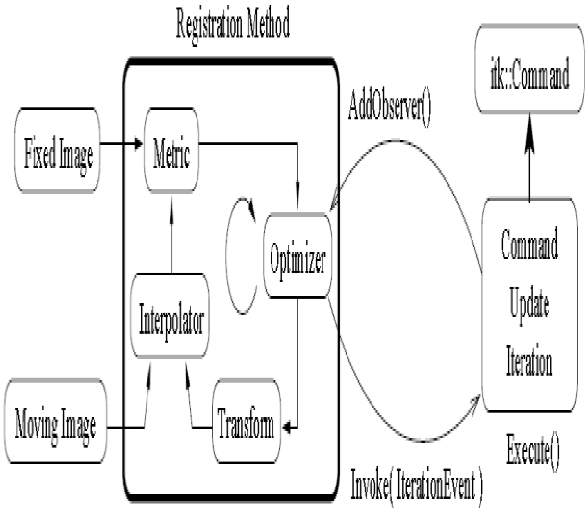

Figure5.Interaction between observer & Registration method

Papers on soft tissues encompasses MRI data for tissue classification[36][46], tissue development and expansion[41][49][50], drug penetration and its impact on skin[48], mechanical properties of soft tissues[51][53], and predicting strain states based on tensile test[52][54]. The mechanical properties are inhomogeneous, i.e. they depend on the position in the material. The perfusion of the organs and their constituting tissues also plays an important role regarding the elastic properties. The diversity of mechanical properties encountered in soft biological tissues is huge.

Algorithms/Methods: Anatomical Region of Interest (ROI) based FMRI Classification analysis [36] shows activation pattern of neurons implemented using ROI based hypothesis. 3D coupled object segmentation [46] using symmetry and tissue type information for segmentation of brain structures that have homogeneous tissues. Substrates for cardiovascular tissue engineering[41] is tissue development pertaining to heart valves, arteries etc.,Interaction between drug, product and skin[48] is modeling transport of drugs which influences on rest of skin on drug penetration and distribution. On the biomechanics and mechnobiology of growing skin [50] uses continuum camera DIC configuration combined with FE modeling which involves bulk mechanical properties of materials. Evaluation of soft tissue properties under controlled expansion for reconstructive surgical use is implemented as quasi-linear viscoelastic model which proposes visco elastic behavior of pig tissue. Measurements of elastic mechanical properties of human skin [53] by indentation test is done using indentation device towards measurement of soft material mechanical properties. Estimating zero strain states [54] of very soft tissue under gravity loading is implemented with tensile test which shows full field deformation behavior of liver tissue in uniaxial tension testing.

Challenges: There is a research gap existing in this area too concerned about tissue behavior and validation.

III. CONCLUSION

This paper has presented many of the techniques that have been used in computer graphics for modeling and deformation, collision detection and rendering, virtual surgery, soft tissue based and applications. While significant advances have been made, there are a number of important areas for future work. Hope this article gives a good clarity with various approaches, so that others may offer their valuable ideas.

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