Simulation of Haptic Feedback Useful in Laparoscopic Surgery

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Abstract - In this paper the technique for Simulation of Haptic feedback has been developed, which enhances the skill of Surgeon during Laparoscopic surgery. In simulation of haptic feedback H3DAPI is used to create 3D representation of human tissue, in which X3D is used to add physical properties and dimensions to tissue and laparoscopic tool (Stylus). Laparoscopic surgery simulation bridges the gap between training and performing the real time surgery. In this work, both haptic rendering and deformation modelling shows the critical areas of any surgical simulation. By adding sense of touch Haptic technology extensively increases the quality of interaction .The main objective of Simulation during laparoscopic surgery; Surgeon should able grasp tissue with less force and handling of soft tissue with laparoscopic stylus Result of this will help to reduce the pain of patient, shorter recovery time, less scarring. Result of deformation of tissue indicates that haptic feedback has been successfully simulated.

Index Terms - Deformation, Haptic feedback, Haptic simulation, haptic device, Haptic rendering, H3D API Laparoscopic surgery, Soft tissue, Stylus, X3D

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1. INTRODUCTION

Laparoscopic surgery; also called Minimally invasive surgery (MIS\Band-Aid surgery or Key hole surgery is the modern surgical surgery in which operation in abdomen are performed through small incision (Usually 0.5 to 1.5 cm) as opposed to the larger incident needed in the laparotomy[7].Laparoscopic surgery include operations within abdomen and pelvic cavities. Because of this smaller incision involved, it offers many benefits to patient including the reduced pain, shorter recovery time and less scarring [3],[4],[5].Conceptually laparoscopic approach is intended to minimize post-operative pain and speed up recovery times, while maintaining an enhance visual fields for surgeons.

Due to improve patient outcomes, in last two decades laparoscopic surgery has adopted by various surgical specialist including Gastro intestinal surgery, gynaecological surgery and Uriology.

The restricted vision of this, difficulty in handling of instrument, lack of tactile perception and limited working area which leads to technical complexity .Clearly laparoscopic surgery is advantageous in term of patient outcome; procedure is more difficult from surgeon perspective.compaired to traditional open surgery: Surgeon must use tools to interact with tissue rather than manipulating directly. With their hands. This results in an

inability to accurately judge how much force is applied to tissue as well as risk of damaging tissue by applying more force than require. This limitation also reduces tactile sensation, making it more difficult for the Surgeon to feel tissue. The main objective of this work is to developed haptic feedback simulation which will improve practical skill of medical surgeon [2], [4]. A particular advantage of this type work is that Surgeon can perform more operations of similar types with less fatigue [6]. In this work, we developed 3D model of tissue using H3DAPI, runs on all popular platforms including Windows, Linux and Mac. It Combines graphics-haptics into one platform and also adds haptics to existing 3D models which enables rapid programming of haptic applications using X3D and Python. Complex surgical cases require planning that includes visualization of the approach, tissue exposure and execution of the defined procedure. If advanced visualization software is not available to the surgeon, they may be relegated to traditional cross sectional scan views or snapshots of volume rendered images. Using the capabilities of X3D, surgeons can analyse patient volumetric data from their office or home computer to plan their operation, make measurements and label objects. This technology would be relevant to all areas of surgery. The objective of this work is achieved by 3 DOF Novient Falcon Haptic devices. More laparoscopic procedure in surgical areas, makes the purpose of Haptic Virtual reality environment very natural because of similarity of monitor based navigation and using similar equipment. Simulator creates new training opportunity to surgical procedures which are otherwise impossible to realize and can measure the operating skill of surgeon using by computer based tracking system. To evaluate specific surgical performance. Using simulator for planning actual surgery will reduced errors and make the surgeon feel more secure

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when performing real operations. It is also possible to practise and evaluate both new and ordinary operating methods, which is impossible today due to safety of patients. Instead of training on animal cadavers or other live or dead objects, the training room can be moved from operating room to Virtual Reality (VR) simulator [14]. This can save considerable amount of expense in long run for hospitals and any organisations [6]. Haptic VR environment can be introduction of robot assisted surgery .By using this one can increase precision and safety and decreased the operating time. Virtual environment is mostly used for surgical simulation. Because of complex nonlinear, viscoelastic, anisotropic and nonhomogeneous behaviour present in human tissue it is demanding.

2. HAPTIC TECHNOLOGY

It is a tactile feedback technology which takes advantage of the sense of touch by applying forces, vibrations or motions to the user. Haptic devices may incorporate tactile sensors that measure forces exerted by the user on the interface. Haptic technology has made it possible to investigate how the human sense of touch works by allowing the creation of carefully controlled haptic virtual objects. These objects are used to systematically probe human haptic capabilities, which would otherwise be difficult to achieve. Haptic interfaces for medical simulation may prove especially useful for training in minimally invasive procedures such as laparoscopy.

By using haptic technology Surgeons are trained by conducting virtual reality operations. It helps in minimizing mistakes and trains them to become better. Surgeon can feel and used real tools and can perform operation for unlimited time to get perfections without cutting anybody.

There are two main types of haptic feedbacks

- Tactile Feedback:-Tactile or Touch feedback means sensation felt by skin. It allow user to feel things such as texture of surface, temperature and vibration.
- Force Feedback : - Reproduces directional forces that can result from solid boundaries, the weight of grasped virtual object, mechanical compliance of an object and inertia [2],[12].

Haptic feedback helps Surgeon to feel tissue characteristics and identify pathological conditions .Haptic feedback describe sensory feedback resulting from both tactile and force information. Both are necessary to form typical sensation felt with human hand. Tactile feedback keeps grip force minimal during precision gripping than force feedback [14].

3. SOFTWARE FOR SIMULATION

H3D API:-It is used to develop the visual simulation. Its open source application .H3D Viewer is used to view X3D files with Haptic content using H3DAPI. It uses the open standards OpenGL and X3D with haptics in one unified scene graph to handle both graphics and haptics. It enables rapid development of haptic applications using X3D and Python. It supports a wide range of haptic devices in the market.
H3DAPI is the ideal tool which combines the sense of touch with vision, and the support for many industry and de facto standards (OpenGL, X3D, SensAble OpenHaptics) and hardware in the marketplace
Haptic Device: - Novient Falcon (Figure 1) 3Degree of freedom haptic device is used to produce haptic feedback which is used for simulation. This Haptic device produces only three (x, y, z) ways of feedback, but delivers 6-DOF position information (x, y, z, pitch, roll, yaw) from the sensors to the VR simulator. The Falcon has removable handles, or grips, that the user holds onto to control the Falcon. As the user moves the grip in three dimensions (right-left and forwards-backwards, like a mouse, but also up-down, unlike a mouse), the Falcon's software keeps track of where the grip is moved and creates forces that a user can feel, by sending currents to the motors in the device.

Fig 1 Novint Falcon Haptic Device

The Falcon's sensors can keep track of the handle's position to sub-millimetre resolution, and the motors are updated 1000 times per second (1 kHz), giving a realistic sense of touch. The surfaces of virtual objects feel solid, and can have detailed textures applied to them. The weight and dynamics of objects can be simulated so that an object's

inertia and momentum can be felt. Currents are sent to the motors at the 1 kHz servo rate to present the user with an accurate sense of touch. In this way, a force can be applied to the grip in any direction, up to the maximum force (over 2 pounds of force), every 1/1000 of a second.
The Falcon in essence is a consumer robot. It consists of its grip connected via three arms to a roughly conical body. The body contains 3 motors, each attached to one of the Falcon's arms by a cable that is wrapped around a capstan on the motor. As each of the 3 arms moves, an optical sensor attached to each motor keeps track of the movements of the arm. A mathematical function called a Jacobian is then used to determine the position of a three-dimensional cursor in Cartesian coordinates based on the positions of the arms. The position of that haptic cursor is therefore controlled by the Falcon's movements, and is used by the Falcon's software to determine the forces to be applied to the user.

4. Tissue Modelling

H3DAPI is open source software used for Haptic Simulation. It is designed to support a special rapid development process.

Its combine

* X3D
* Python

The X3D file format is used by H3D as an easy way to define geometry and arrange scene-graph elements. Such as a user interface. H3D has a full XML enabled X3D parser and automatically supports predefined.X3D nodes as well as any new nodes developed for your application / toolkit. Soft tissue modelling completed in X3D, Tissue properties are defined in X3D file (Figure 3)

```
<Transform rotation="1 0 0 -0.5">
  <DeformableShape DEF="DEFORM_SHAPE" >
    <CoordinateDeformer >
      <GaussianFunction width="0.05" containerField="distanceToDepth"/>
    </CoordinateDeformer>
    <Appearance DEF="LOCAL_APP" >
      <ImageTexture url="plastic_1.jpg" />
      <Material/>
      <SmoothSurface stiffness="0.03" />
    </Appearance>
```

Fig 3 Tissue properties defined in X3D file

5. Haptic Rendering

H3D Viewer customized to work with a wide variety of virtual reality display systems and easy to customized haptic device settings and graphical render settings. H3DLoad Settings define display type, the haptic device, the stylus shape of the avatar and the starting viewpoint of the scene program in X3D/XML files.

Haptic Rendering Algorithm: - Haptic rendering consists of collision-detection, force-response and control algorithms which are processed in high-frequency servo rates. Haptic rendering algorithm use to determine the force and torque values depending on the haptics device position and all the shapes added to the scene. These algorithms are variants of a proxy-based model. The probe is the real position in the 3D space of the haptic device while the proxy is the virtual position of the Device, the representation of the tool on the screen. The proxy based rendering technique involves having a virtual representation of the haptics device called the proxy which always lays outside the geometry surface [10],[11]. This means that when a shape is touched the proxy stays on the surface of the object, even if the haptics device actually has penetrated the surface. Forces are then generated to bring the haptics device out of the surface, towards the proxy, and usually some kind of spring force between the proxy and haptics device is used (Figure 2).[13]

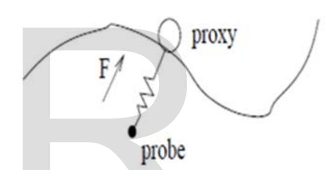

Fig 2 Proxy based method

F --> Force

Haptic rendering algorithm user can be chosen by Open Haptic Framework.

As part of the design of the framework, a haptic rendering algorithm which perfectly fits in dynamic environments is needed because of the nature of deformation shapes. It is an open source solution which is the key element of the framework. Also it is device independent; therefore the Falcon haptic device can be easily integrated.

6. Simulation and Deformation using haptic tool

A framework for haptic simulation is presented by combining haptic rendering, deformation modelling and open source tools. To view simulation soft tissue is modelled. Soft tissue in H3D Viewer (Figure 4). The placement of the stylus in the virtual environment follows directly the orientation and translation of the tip of the tool

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on the haptic device. The algorithm only lets you feel the haptics in three ways, xyz-space. H3D API scene graph is built up by scripting languages like Python and X3D. To view deformation, a deformable object having mechanical behaviour is used and force is applied to understand the motion and view deformation of the tissue.

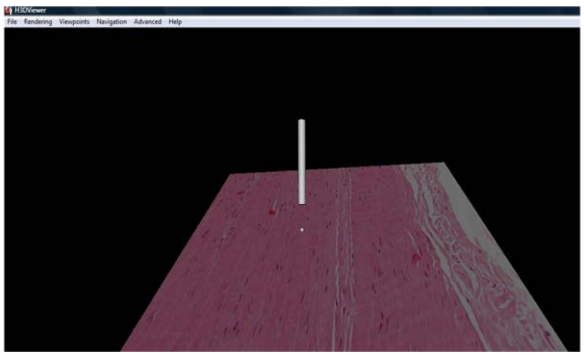

Fig 4 Soft tissue model in H3D Viewer before deformation

Soft tissue deformed visco-elasctically when they are pushed or pulled by surgical instruments. Depend upon surgical instrument soft tissue deform. By Applying force using Stylus, soft tissue deformation will displayed. The depth of deformation depends upon tissue properties and location of stylus. Deformation of human tissue by applying force on Stylus is example of local deformation.

Soft tissue after deformation in H3D Viewer (Figure 5)

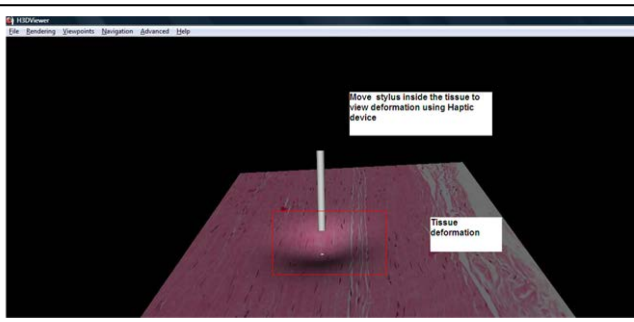

Fig 5 Soft tissue after deformation using Haptic device

Magnitude of deformation can be determined using below;

Depth =Ao + A2 (Radial distance)2

A0 =AP

A2 = -AP/ (Radius of influence)2

AP = vector is from coordinate of Stylus tip to contact point (A)

Radial influence = distance of each neighbouring vertex within the radius.

Using this we can calculate the direction and magnitude of interaction forces between Stylus and deformable tissue. It calculates the reaction forces that are sent to haptic device as force command to convey the tactile feeling of soft tissue surface. The size of region that is deformed is depending upon the material properties of tissue and amount of deformation depend upon tip location of instrument.[9]

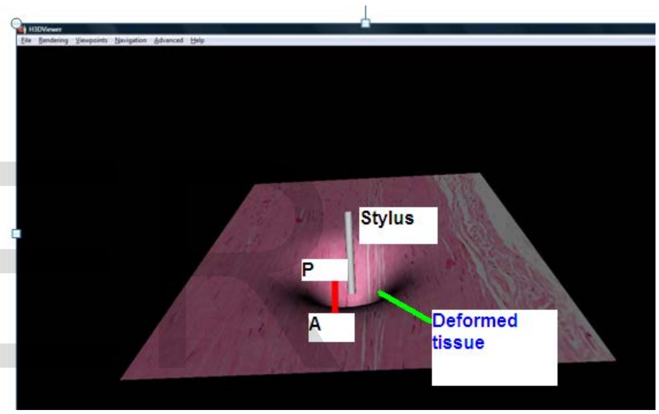

Fig 6 Soft Tissue deformed

7. Conclusion

In this paper Focus of our study is concentrated on How Simulation of Human tissue would be useful during actual laparoscopic surgery and same can be useful for other medical surgery too. Using algorithm the collision of virtual instrument with 3D object would be check in the scene as generic stylus of force feedback device which is manipulated by the user. Afterward by using the force command to haptic device for displaying the tactual feeling of deformable soft tissue surfaces. Using this Surgeon can analyse impact of various force value during surgery on human tissue. It can be tried out and easy to use for several surgical tools that are typically used during a Laparoscopic surgery. Using extra force during surgery can cause serious damage to tissue or an organ of human body. By using this Haptic soft tissue simulation will optimize surgical tool design and understanding tissue injury mechanism. The Modelled soft tissue model and used of Stylus convey user the actual amount of force require during surgery. In future work we will try get all data captured during the Simulation e.g. Force feedback value and validate with giving input as various Force values which would result in showing depth of tissue deformed. Also we will try to get above values using various algorithms.

8. Future work

Next step will include better appearance modelling which is an extreme importance to present realistic scenarios. Also Non linearity deformation needs to be included due to nature of soft tissue. Additionally the graphical user interface might support X3D scene graph in the framework. By modelling, grasping and cutting, even more medical procedures can be simulated and different tools might be integrated. An important part of training is the measure of performance thus statistics will be of paramount importance for medical surgeons in Virtual environment. Adding a sense of depth perception to the model, which will greatly enhances Surgeons understanding of the actual scenario.

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