# Haptic AR Dental Simulator Using Z-buffer for Object Deformation

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**Abstract.** Dental surgical simulator could be one of the efficient tools to learning and practicing dental surgical skills. To these simulators, the visual and tactile feedback is desirable to be processed in real time. And, in the dental operation, the hand position during operations is one of the skills to learn and practice. Therefore, we develop the dental surgical simulator which use virtual tooth surface model for processing real time rendering. And we develop a display system which allow users to training dental operation by a right hand position.. The tooth model is deformed by cutting and drilling operation using haptic device. And the display is set close to user's hand position and shows combined image with virtual tooth model as a surgical target and a real tooth model as other parts of the patient dental model. The system uses a collision detection and deformation method by using Z-buffer for virtual objects. This method enables users to view the complex shape of virtual tooth model by the surgical operation tasks and practicing dental surgical tasks. We developed prototype system and confirmed about the capability of our system.

**Keywords:** Collision detection, dental surgical simulator, augmented reality, GPU.

## 1 Introduction

In dental surgery, most surgical training methods use plastic tooth or live patients. These methods are good for improving surgical skills, for example, the use of surgical tools and surgical procedures. But it is difficult to do repetitive practice, because of the need for new plastic tooth or patients for each task. Therefore, several types of dental surgical simulator have been proposed [1], [2]. These simulators allow users to training dental surgical methods by using visual and haptic rendering [3], [4]. Most of systems use the volumetric implicit surface model for simulating dental surgical operation, such as cutting and drilling a tooth. Therefore, to reducing the rendering cost is one of the challenging issues. And to training complex tasks, some of the dental simulators use unique interfaces [5], [6], [7], [8]. However, most of these simulators use a typical computing display system. Therefore, the user cannot experience the actual hand positions or body posture required during dental surgery.

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In this paper, we describe about our preliminary work of a dental surgical training system. Our system allows users to operate the surgical tasks by using haptic device. The system uses surface polygon model as a tooth model. And the deformation of a tooth model is generated by using GPU architecture. And our system set a display screen close to user's hand position for learning about real hand position and the body posture. The display screen shows combined image with virtual tooth model as a surgical target and a real tooth model as other parts of the patient dental model. In order to adapt to any head position of the user, the system measured the head position of the user and the position of the real tooth model. We make a prototype system which is implemented our deformation algorithm for dental tooth model on our display screen system.

## 2 Deformation Algorithm

Our system uses a deformation algorithm for rendering a tooth model to operating surgical tasks, cutting, drilling and so on. In order to reduce the computation time to rendering it, our system use a coordinate system organized the depth direction as a drilling direction. And our system use Z-buffer that is stored depth map in the coordinate system. Figure 1 shows the abstract of our algorithm.

### 2.1 Generating Depth Map

Generally, Z-buffer is used to rendering only the model showed from a viewpoint in 3D graphic scene. To use the Z-buffer, the system is enable to process many polygons simultaneously and reducing the rendering time. In our algorithm, it is used to measure the deforming volume by user's interaction. At first, the region of manipulation is defined by the virtual tool and the tooth model. And the coordinate system is defined in this region and stored the depth map. Figure 2 shows summary of this process.

### 2.2 Generating Depth Map within Collision Detection

In order to generate the depth map after the deformation by drilling with a virtual tool, it is stored amount of changing the depth map when the virtual tool drills it. This is used to change the shape of tooth model and calculate parameters to generate tactile feedback. This depth map is a simple two-dimensional array, and this process is executed by GPU.

### 2.3 Deforming Tooth Model by the Depth Map

The deformation tooth model is generated by the following process. At first, in order to be assigned vertex of the tooth model to Z-buffer, it uses a conversion method to change the vertex with world coordinate system, which constructs Z-buffer. And it acquires z value from the pixel, which contains the vertex in Z-buffer. The deformation volume is defined from this volume and it is reconverted to the vertex position in world coordinate system. All of this process is executed in the high-speed transaction by using the parallel processing in GPU.

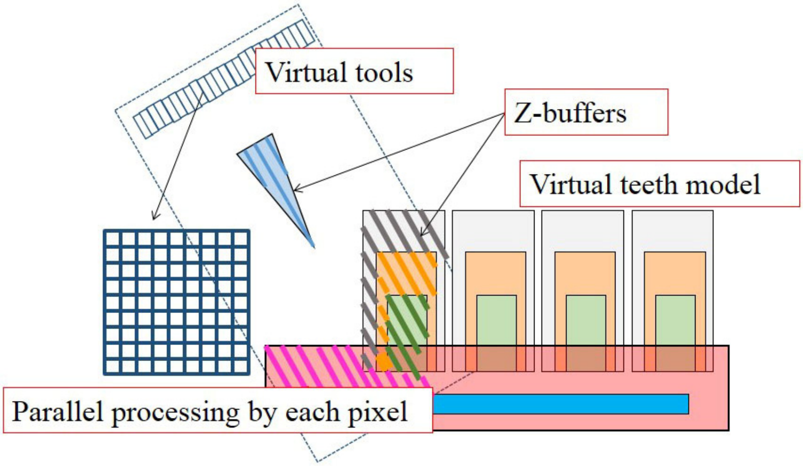


**Fig. 1.** The abstract of our algorithm

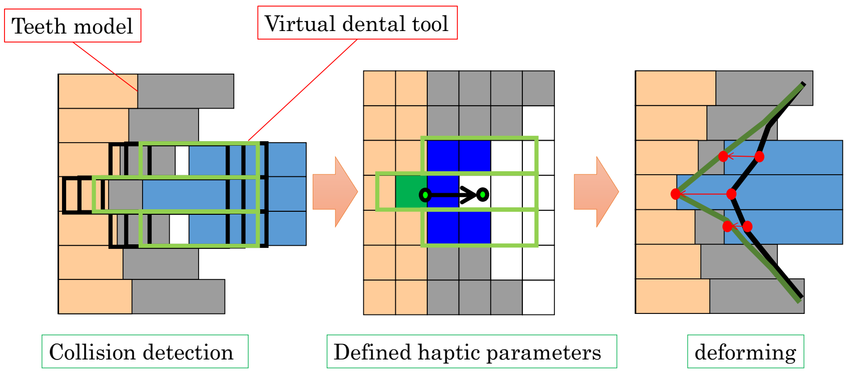


**Fig. 2.** Our deformation process

### 2.4 Subdivision Surface of a Tooth Model Deformation

To adapt this deformation process, our algorithm uses a method which changes the vertex point of a tooth model to deform it. In this algorithm, the surface of model is extended to a direction of deformed region and it is not enable to deform to other direction. To solve this problem, our system uses a subdivision surface algorithm to divide the extended surfaces. A summary of this method is that generates middle point to the edge between 2 vertexes with length more than a certain threshold.

Figure 3 shows this process. For example, in a case of adjacent surfaces, 1,2,3, and 1,3,4, it generates new vertex as index 5 on a side between index 1 and index 2. And it searches another surface which share the same vertex and side to generate same vertex, 5. Finally, these surface data is divided into 4 surfaces data. These data is stored only the index number of three vertex points. And the order of this three points is located in a clockwise direction.

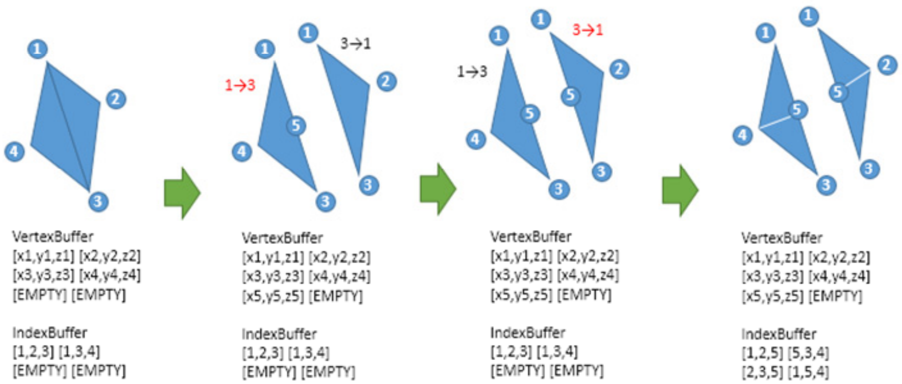


**Fig. 3.** A process of subdivision surfaces

## 3 Display System

The real surgical environment is usually such that a patient is lying in front of a dentist while the dentist operates. In such a situation, the position of the dentist hands and the body posture of the dentist are different from those in traditional dental surgical simulation. For example, Figure 4 shows a typical hand position in dental surgical operation. It is needed strict movement to manipulate a dental tool for operating surgical tasks. The dentist put their hand on the patient teeth or gum as the fulcrum.

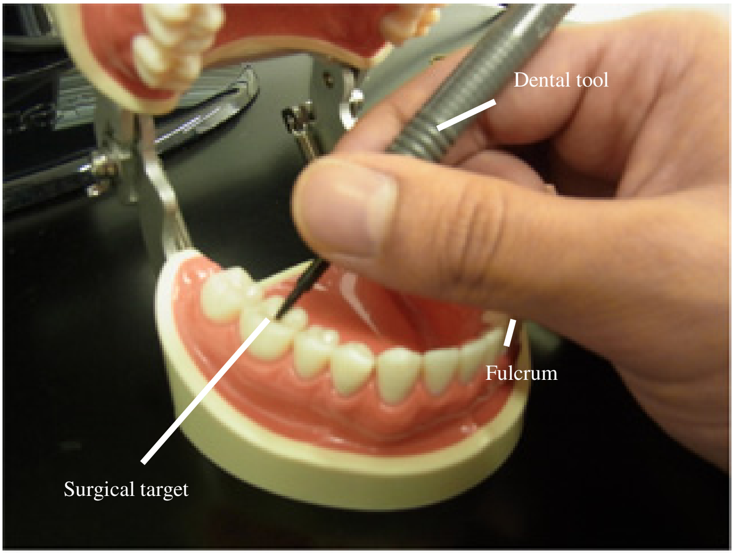


**Fig. 4.** An example of surgical hand position

In order to realize the manipulations with respect to user hand positions and body posture, our system incorporates a half mirror placed horizontally between the head position and the position of the hands, as shown in Figure 5. The system then presents a combined image of the virtual tooth and the tooth model on the half mirror display. Furthermore, in order to adapt the head motion of the user for probing and confirming the surgical target, the system measures the head motion of the user and the tooth model. The virtual tooth are shown on an LCD display that can be adequately viewed by the user. The system set a real tooth model around the surgical target tooth. And the user is able to stabilize their hands against the model to perform the surgical simulation tasks precisely.

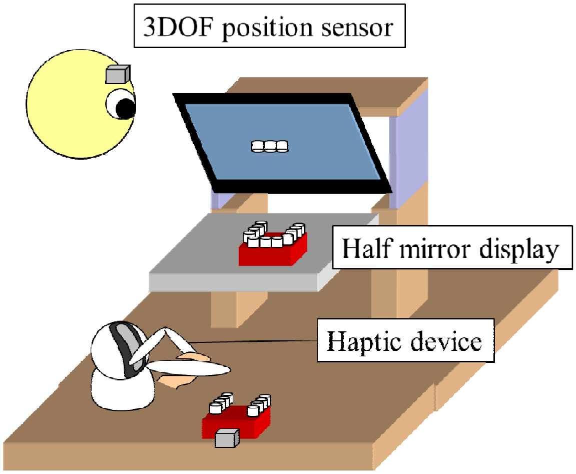


**Fig. 5.** Our dental surgical system

**Fig. 6.** Our prototype display

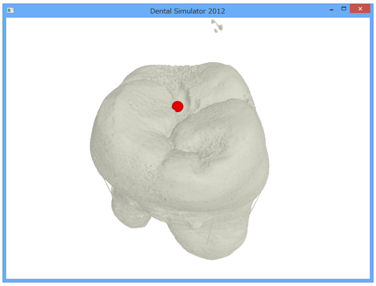


**Fig. 7.** Virtual tooth model

## 4 Prototype System

The prototype display is shown in Figure 6. The proposed system is implemented on a Windows PC, and the system measures the user's head position and real teeth model position using 3DOF magnetic sensors. It shows the users a tooth model and virtual tooth reflected onto the display from the half mirror. Figures 7 shows a virtual tooth model used in our system. This model is created as a surface model by each parts and the system check the collision detection in real time between surgical tools and the tooth model. And it is deformed the shape by user's surgical operation. A usage image of our system is shown in Figure 8. The system measures a viewing position of the user and shows the appropriate view based on that position. Then, the system allows the user to display the virtual and real tooth models simultaneously from any viewing position.

**Fig. 8.** An example of our display system

As a preliminary evaluation about the display system, we have measured the deviation between real objects and virtual objects in the user's view image. We use a cube model as the target model for measuring the deviation precisely. And it is measured from 8 view positions on a horizontal line. The deviation is about from 0.06cm to 1.00cm in these view positions.

## 5 Conclusion

We developed a dental surgical simulator system for learning and practicing dental surgical skills. The proposed system enables the user to view a combined image of virtual tooth and a tooth model. The user can see the combined image from any point of view by tracking his or her head position and the model position. We constructed a prototype system and confirmed the capability and the limitation of this system.

In future work, we will evaluate the haptic feedback module in this system. And we will improve the accuracy of the user's view image.

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