# Modeling Inlay/Onlay Prostheses with Mesh Deformation Techniques

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**Abstract.** This paper presents a method for effectively modeling the outer surfaces of inlay/onlay prostheses restoring teeth that are partially destroyed. We exploit 3D mesh deformation techniques: direct manipulation free-form deformation (DMFFD) [9] and multiple wires deformation (MWD) [10] with three kinds of information: standard teeth models, scanned mesh data from the plaster cast of a patient's tooth, functionally guided plane (FGP) measuring the occlusion of the patients' teeth. Our implementation can design inlay/onlay prostheses by setting up various parameters required in dentistry during visualizing the generated mesh models.

**Keywords:** Prostheses modeling, inlay/onlay, mesh deformation.

## 1 Introduction

Many artificial teeth prostheses are composed of cores and crowns [1]: the cores directly contact the abutment to increase the adhesive strength to the crowns that are revealed to the outside sight when the artificial teeth prostheses are put in. Inlay/onlays can be regarded as a kind of single crowns, which are used for reconstructing only one tooth that are partially destroyed. In general, a tooth adjoins with adjacent teeth and also contacts other teeth at the opposite side when the upper and lower jaws occlude. The adjoining surfaces at the adjacent side are said to be adjacent surfaces, and the contact surfaces at the opposite side during the occlusion are called occlusal surfaces. The inlay is a prosthesis fabricated when little dental caries or established prostheses are on the two surfaces, while the onlay is a prosthesis fabricated when its cusp in tongue side exists soundly but other parts are destroyed.

In modeling inlay/onlays with CAD/CAM and computer graphics techniques, the most important subject is how to model their 3D shapes same as the dentists want to form. That is, the adhesive strength to the abutment must be maximized. Furthermore, the appropriate adjacency with neighboring teeth and the accurate occlusal strength to the opposite tooth has to be guaranteed. Previous researches for modeling inlay/onlays can be divided to two categories: 2D image-based [2-5] and 3D mesh-based [6,7].

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Our method adopts the mesh-based modeling approach similarly to the GN-1 system [7]. In this paper, however, differently to taking a side view of 3D scanners for producing mesh models in the GN-1 system, an inlay/onlay is modeled by dividing its surface into two parts: an inner surface adhering to the abutment and an outer surface revealed to the outside sight. The inner surfaces of inlay/onlays are modeled same as the results of Yoo *et al.* [8] with the 2D Minkowski sum: compute a new model that is the expansion of a terrain model with expansion values given by users. This paper focuses on modeling the outer surface, which is just the union of two subparts: the adjacent and occlusal surfaces, by deforming the corresponding standard tooth according to the inherent features of each tooth.

## 2 Modeling the Outer Surfaces of Inlay/Onlays

The standard teeth models include the information of axes and geometric features for all teeth in the upper and lower laws. First, the standard teeth are transformed and aligned to the patient's teeth by referencing the arrangement information of the former such as adjacent points, tongue side points, lingual side points, and the positional information of the latter. And then, adjacent surfaces are generated with the technique of direct manipulation free-form deformation (DMFFD) [9] to a standard tooth by considering the contact points. On the other hand, occlusal surfaces are generated by applying the technique of multiple wires deformation (MWD) [10] to the two corresponding polygonal lines that are, respectively, extracted from a standard tooth and FGP.

The DMFFD [9] is an extended version of free form deformation (FFD) [11], which directly controls the points on the mesh for the deformation. For an arbitrary point $X$ and a set $P$ of control points, they define the deformation equation as the following matrix form $X = BP$ . Here the matrix $B$ is obtained by the B-spline blending function with the three parametric values that are determined from the given $X$ . Then, the transformed point $X'$ is represented as $B(P + \Delta P)$ , that is, $\Delta X = B\Delta P$ . For moving a given point $X$ in the amount of $\Delta X$ , the amount $\Delta P$ for moving control points can be inversely computed as.

$$\Delta P = B^{+} X \ . \qquad (1)$$

In the above equation, the $B^{+}$ is a pseudo inverse of the matrix $B$ . If we apply FFD to $X$ with the computed $\Delta P$ , $X$ is transformed into $X'$ . Hence, it is possible to deform a mesh intentionally, if we apply FFD to all vertices of the mesh after computing $\Delta P$ for each vertex with the same method.

The deformation technique of multiple wires deformation (MWD) [10] is used for more naturally deforming the wired curves representing geometric features of cusp, ridge, fissure, and pit, which are extracted after scanning the FGP. A wired curve is represented as a tuple $< W, R, s, r, f >$, where $W$ and $R$ are the free-form parametric curves that are the same in an initial state, $s$ is a scalar for adjusting the radial size in the curve circumference, $r$ is a value representing the range effecting the curve circumference, and $f$ is a scalar function defined as $f : R^{+} \rightarrow [0,1]$ . The function $f$ guarantees the $C^1$-continuity at least, and satisfies the properties of $f(0) = 1, f(x) = 0$ for $x \geq 1$ and $f'(1) = 0$ . Our implementation uses the $C^1$-continuous function $f(x)=(x^2-1)^2, x\in[0,1]$ as in [10]. As $R$ is deformed into $W$, an arbitrary point $p$ on $R$ will be deformed accordingly. Let $p^R$ be the point nearest to $R$, and $p^W$ be the corresponding point in $W$. Then, $p^R$ and $p^W$ have the same curve parametric value. When $W$ is deformed, the point $p$ moves to $p'$ as.

$$p' = p + (p^W - p^R) f(x) . \tag{2}$$

In Equation (2), $f(x)$ is a function with three parameters $R$, $p$, and $r$, where $r$ represents a range. Generally, we define $x = \frac{\left\| p - p^R \right\|}{r}$. We can move the point $p$ to $p'$ by deforming $W$ with an expansion parameter $s$ for changing the wire size.

$$p' = p + (s-1)(p - p^R) f(x) + (p^W - p^R) f(x) . \tag{3}$$

Definitely, the above equation has the property that the expansion parameter $s$ moves the point $p$ in the direction $p - p^R$. This principle of wire deformation is extended for deforming the multiple wires. Let $\Delta p_i$ be the variation value of $p$ when the wire $W_i$ is deformed. Then, the deformed point $p'$ in deforming all wires $W_i, i = 1,\cdots,n$ is written as.

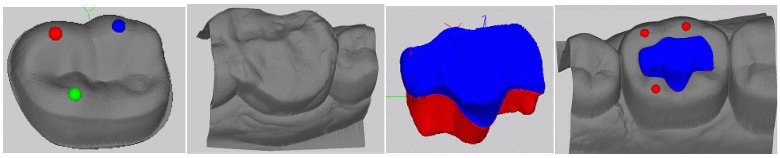
$$p' = p + \frac{\sum_{i=1}^{n} \Delta p_i f_i(x)^m}{\sum_{i=1}^{n} f_i(x)^m} . \tag{4}$$

The parameter $m$ is used for locally controlling the shapes of the multiple wires, i.e., it controls the effects of $W_i$ and $s_i$ during the deformation. For example, the effects of $W_i$ and $s_i$ rapidly increase according to the increasing value of $m$ when $f_i(x)$ approaches to 1.

In modeling the occlusal surfaces, $R_i$ is the curve interpolating all points of the the geometric features lines of cusp, ridge, fissure, and pit. The wired curve $W_i$ corresponding to $R_i$ is determined by more complicated computations; for each segment $L_i$ of the polygonal lines, we compute the intersection line segment $L_i'$ between FGP and a z-axis parallel plane passing $L_i$, cut $L_i'$ so that it has the same x- and y- coordinates with the end points of $L_i$, and finally obtain a curve interpolating all points of the cut line segments. Since the two curves interpolates the same number of points, we can get the parametric value of the curves for any point on $W_i$. In our implementation, we use the Catmull-Rom curve for the interpolating curves, and the one suggested by Singh *et al.* [10] for the function $f$. Our implementation assigns the values 1, 5, and 1 to $s_i$, $r_i$ and $m$, respectively. For the all of points $p$ on the standard tooth, $W$, and $R$, we compute $pR$ and $pW$ and then obtain $\Delta p_i$ with Equation (4). By applying Equation (5) to $\Delta p_i$ of all wired curves and $f$, we can get the finally deformed point $q'$.

## 3 Experiments and Future Works

Our system for modeling inlay/onlays is implemented in the environments of Microsoft Foundation Class (MFC) 6.0 and OpenGL graphics library on PC. Fig. 1 illustrates the designed outer surface for an onlay.



(a) (b) (c) (d)

**Fig. 1.** Designing the outer surface for an onlay; (a) a standard tooth model, (b) a scanned FGP model, (c) a finally designed onlay, and (d) an onlay put in on the abutment

For more accurate modeling, several parameters can be set up through a simple interface as the designed inlay/onlays are visualized. Currently, our implementation gets the adjacent points manually for designing the adjacent surfaces of inlay/onlays. In future, an automatic method for determining such adjacent points is needed to be developed. It is another research subject to simulate the teeth occlusion by using the FGP and the geometric features of teeth.

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## References

1. Yoon, C.G., Kang, D.W., Chung, S.M.: State-of-arts in Fixed Prosthodontics, Jongii Press, Korea (1999)
2. Myszkowski, K., Savchenko, V.V., Kunii, T.L.: Computer modeling for the occlusal surface of teeth, Proc. of Conf. on Computer Graphics International (1996)
3. Savchenko, V.V., Schmitt, L.M.: Reconstructing occlusal surfaces of teeth using a genetic algorithm with simulated annealing type selection, Proc. of Solid Modeling (2001) 39-46
4. Yoo, K.Y., Ha, J.S.: User-Steered Methods for Extracting of Geometric Features in 3D Meshes, Computer-Aided Design and Applications, Vol. 2 (2005)
5. Sirona Corporation, http://www.sirona.com (1985)
6. Nobel Digital Process Corporation, Procera Systems, Nobel Digital Process Corporation, Sweden (2001)
7. GC Corporation, GN-I Systems, GC Corporation, Japan (2001)
8. Yoo, K.Y., Ha, J.S.: An Effective Modeling of Single Cores prostheses using Geometric Techniques, Journal of Computer-Aided Design, Vol. 37, No. 1 (2005)
9. Hsu, W.M., Hughes, J.F., Kaufman, H.: Direct manipulation of free-form deformations, In Computer Graphics (SIGGRAPH '92), Vol. 26 (1992) 177-184
10. Singh, K., Fiume, E.: Wires: A Geometric Deformation Techniques, SIGGRAPH (1998)
11. Sederberg, T., Parry, S.: Free-form deformation of solid geometric models, In Computer Graphics (SIGGRAPH'86) (1986) 151-160