3D Tooth Shape from Radiographs using Thin-Plate Splines

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Abstract. Current methods to produce 3-dimensional tooth root models involve conversion from radiographic means (computed tomography) or creation using computer-assisted design (CAD) software. The former lacks detail while the second is manually fabricated and can bear little resemblance to the original. Thin-plate splines have been used in morphometrics to define changes of shape between subjects of the same species [1]. Herein, we use thin-plate splines to deform a 3D geometric prior model of a tooth to match 2D patient radiographs, producing a "best-fit" patient specific 3D geometric polygonal mesh of the tooth.

Introduction

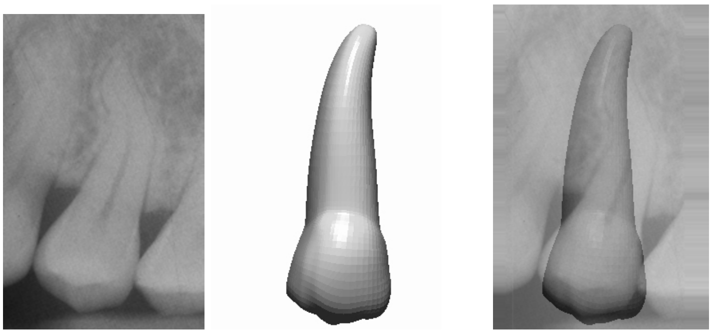
Very accurate three-dimensional geometric crown models are now commercially available from different sources. Destructive scanning methods (Orthocad from Cadent) slice the dental impression of the patient as it is scanned producing a stack of images that are rendered to produce the final model. Laser systems are also used to directly image the stone model of patient's dentition (e-Models from GeoDigm Corp.). A direct imaging method (OraScanner from OraMetrix GmbH) also exists wherein an intra-oral camera capable of generating highly accurate 3D crown models is used after applying an opaquing agent to the teeth. However all these methods provide data on the tooth crowns only and nothing on root form. Therefore, researchers have explored using root information from computed tomography (CT) volumes with crown forms obtained using laser scanning methods[4][5]. Registration of the data sets is accomplished using ceramic markers present in both images.

In this paper we propose to use a patient-specific radiograph and a 3D geometric prior model to produce a "best-fit" patient specific 3D model of the whole tooth using radial basis functions, previously used for volume morphing [3] and to fill in a hole on the skull and fabricate the implant [2]. The rationale for this approach is that 2D radiographs of dental patients are the norm, while there are applications being developed for modeling and treatment simulation that require 3D tooth root information. CT imaging of dental patients is not routine and in most cases the risk cannot be justified.

Of note, there are 3D volumetric imaging devices developed specifically for dentistry recently released (NewTom from Aperio Services) and others being developed which feature a lower absorbed radiation dose but until these devices become widely used, 2D radiographs are the only available source of root morphological information. Therefore, this information can be "fitted" to a geometric model to provide a reasonable shape of the tooth root.

1. Materials and Methods

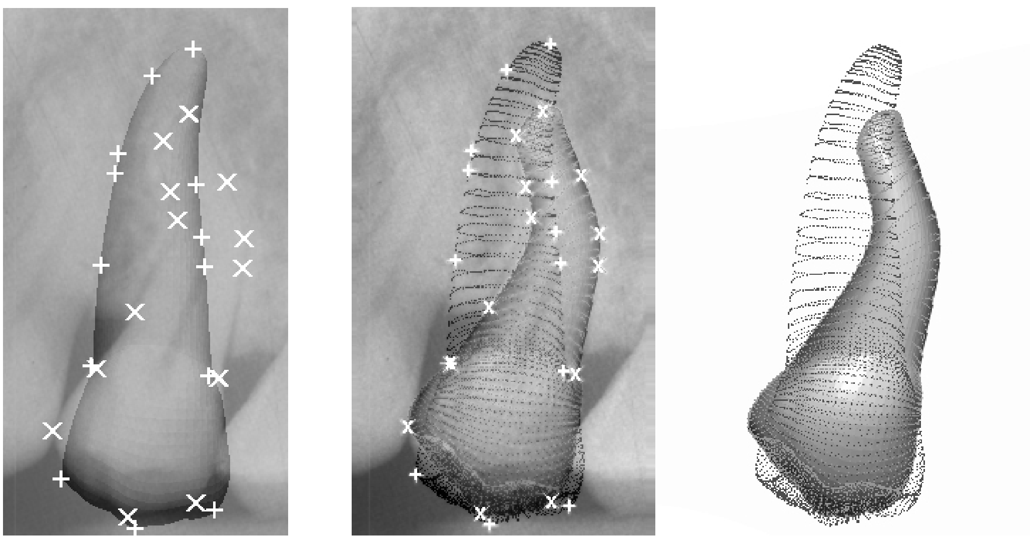
The input data for our interactive 3D computer program is a 2D periapical radiograph of a tooth (Figure 1a) and a generic 3D polygonal surface mesh model (courtesy of 3M Unitek) of the corresponding tooth (Figure 1b). These items are overlaid in close proximity prior to the fitting (Figure 1c).



(a) (b) (c)

Figure 1: (a) Periapical radiograph of the second bicuspid; (b) View of the 3D prior geometric tooth; (c) Both the radiograph and the 3D model overlaid.

In our system the user is asked to interactively indicate with the mouse corresponding landmarks of their choice on both the radiograph (indicated with a “x” in Figure 2a) and a view of the 3D model (indicated with a “+” in Figure 2a). The computer program first computes the thin-plate coefficients from these landmarks for the X and (separately) Y displacements and then warps the image of the 3D model (shaded in Figure 2b) and the 3D mesh (Figure 2c) in X and Y directions (depth information is kept constant) using the thin-plate interpolant. Thin-plate splines minimize a bending energy: $\int\int (f_{xx}{}^2 + 2f_{xy}{}^2 + f_{yy}{}^2)dxdy$, while interpolating values of a set of 2d points (x_i, y_i) named landmarks. The thin-plate spline can be represented and solved using radial basis functions: $f(x,y) = a_1 + a_x x + a_y y + \sum_1^p w_i \cdot U(\|(x_i, y_i) - (x,y)\|)$, with $U(r) = r^2 \log(r)$.

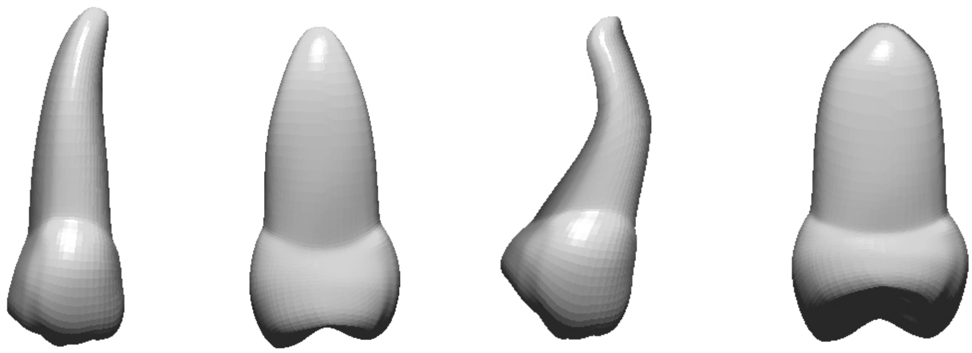


(a) (b) (c)

Figure 2: Landmarks interactively selected by the user in the 3D prior model image (+) and the radiograph (x) are shown in (a). (b) and (c) show the overlaid image of the shell of the tooth 3D model (before fitting) and the shaded warped image of the fitted 3D model.

2. Results

The input landmarks and resulting 3D polygonal mesh can be seen in Figure 2. The prior and fitted 3D models can be interactively rotated to any viewpoint using a virtual trackball interface (Figure 3).



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

Figure 3: Frontal (a) and side (b) view of the prior geometric model from 3M Unitek. Frontal (c) and side (d) view of the 3D fitted model using thin-plate splines.

3. Novelty/Discussion

This new technique uses computer graphics algorithms to combine current patient records in the form of two-dimensional radiographs with 3-D geometric prior models of teeth, producing a "best-fit" patient-specific model (including root information). The resultant 3D model is smooth and conserves the overall shape of the tooth, but is adapted in scale, orientation and shape to fit the X-ray picture and provide patient-specific information.

Additional radiographs from known directions would provide additional depth information but these are generally not available. As such the selected 3d model provides a "best fit" in the presence of this unavailable information. Future research includes fitting the crown models obtained from clinical services and assessing geometric accuracy with micro-CT following extraction of the tooth for clinical reasons.

Acknowledgements:

The research has been funded in part by the Integrated Media Systems Center, a National Science Foundation Engineering Research Center, Cooperative Agreement No. EEC-9529152, Sun Microsystems and the American Association of Orthodontists Foundation.

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