Teeth Shape Modeling Pipeline for Oral Healthcare Appliances Development

(Invited Paper)

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***Abstract*—We present a modelling pipeline for the simulation of different teeth and gums geometries. The generated models may be used for various simulations with the end goal to development of novel consumer oral healthcare devices. The pipeline is implemented in a processing framework which is easily extendible and allows scripting to generate various output models with incremental changes.**

I. Introduction

Oral healthcare consumer devices have come a long way from the classic, flat-trimmed manual toothbrush. Several devices have been introduced which allow people to preventively take care of their oral hygiene, reducing the likelihood for more extensive dental treatments. Such devices range from custom engineered tooth brushes, with specific brush head patterns, brushing at frequencies which maximize the speed and effectiveness of the cleaning. While classic tooth brushes focus mainly on cleaning the more accessible tooth surfaces, a key source of dental plaque accumulation are the inter-dental and gum-tooth interfaces. For these areas devices have been proposed such as the Philips AirFloss or specific tooth brush heads focusing on the cleaning of these curved spaces. However, due to the great inter- and intra-subject variation of teeth geometry, developing devices that are as efficient as possible in all scenarios is a difficult task. Two approaches can be taken here. Either one targets one device that is as efficient as possible for most individuals or the manufacturing of personalized devices fitting the specific needs of an individual is considered. Both approaches require the analysis of several shapes and their variations; therefore, a framework facilitating this generation is valuable. In this paper we present such a framework.

II. Related work

Several frameworks have been presented for oral healthcare analysis purpose. Most of the previous work focuses on orthodontic simulation and treatment planning[1]. For most alignment treatments, the planning is performed on a dental cast, traditionally a plaster model and more recently, digital casts. Although orthodontists perform most of the treatment planning on the static surface of the dental cast, some treatments require planning for teeth removal/trimming for the planned alignment to fit the subject's jaw. In those cases a more complex framework is required, where the teeth are manipulated individually and a treatment planning is fully simulated on the framework. For surgical planning, data acquired in CT scans is commonly used given available high resolution [2]. For the automatic segmentation of teeth from dental casts, several approaches have been proposed [3][4][5]. In this paper we present an end-to-end pipeline with the focus on the modelling variations in teeth geometries and exporting the models to be used for simulation and testing of oral healthcare appliances.

III. Framework Pipeline

Our proposed pipeline consists of a series of operations. The key operations performed for any analysis are: automatic segmentation, manual segmentation, arch calculation, teeth geometry analysis and gum deformation analysis. Although the framework is implemented using fast compiled algorithms, we expose most of the operations using a simple to use API in LUA[6]. This allows researcher to generate scripts which consistently model several geometries. We will next describe in more detail each one of these steps.

Automatic Segmentation: In the case a single manifold surface is loaded, an automatic segmentation is performed, separating the individual teeth and the gums. The segmentation algorithm performs the surface analysis based on a medial point cloud approach [7]. This approach allows the separation of the individual teeth based on point medial point density properties and extracts the teeth around the high curvature found on the tooth-gum intersections.

Manual Segmentation: To allow flexibility in the modification of the automatic segmentation results, a manual step is added to the pipeline. In this step, the user can add, remove or edit the resulting segmentations from the automatic step. This editing is done by defining several control points along the tooth-gum intersections which can be defined by the user. The teeth contour is performed using mesh geodesics and is provided in a simple to use user interface where a sequence of points is placed by the user.

Teeth and Gum Geometry Analysis: Once all the required elements for analysis have been defined, we are ready to apply

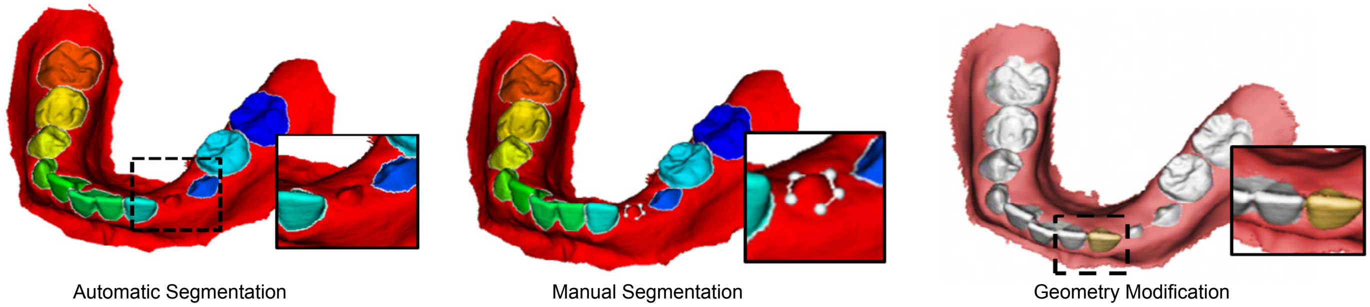

Fig. 1. Pipeline steps: a) Dental cast surface automatic segmentation result; b) Manual segmentation interactive corrections. c) Interactive/scripted geometry modifications

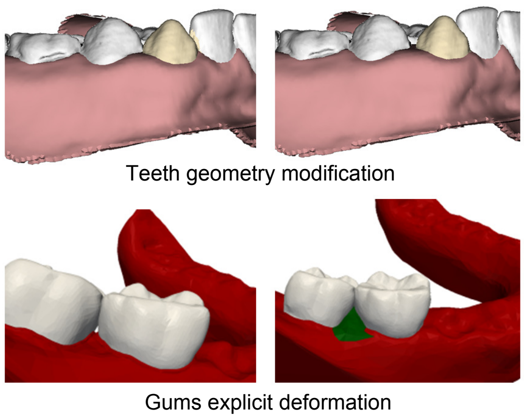

Fig. 2. Examples of geometry modifications. Top: Teeth geometry modification with implicit gum deformation following tooth motion. Bottom: Gum explicit deformations on inter-dental space and around tooth-gum interface region

different modeling algorithms to the teeth and gum geometry. A key distinction between the gum and teeth are their rigidity properties which are taken into account in this step. Moreover, if the teeth and gums are segmented from a single manifold surface, changing the geometry of a tooth, can lead to holes in the mesh (gums). Therefore, the gums are implicitly and explicitly modified. The first happens whenever any tooth is displaced and the latter is configurable by the user. The gum deformations are performed with a thin-plate splines algorithm where the source and target deformation points are points around the tooth-gum intersections. For any tooth user change, the gum geometry is automatically updated. For the purpose of modifying the inter-dental space and teeth-gum interface, the user can model changes on the gums. One change is the simulation of the sulcus - the anatomical interface between gums and teeth and the height of the gums in the inter-dental space.

IV. Implementation

The implementation is via open source frameworks and toolkits. For the visualization and 3D interaction, Visualization Toolkit (VTK) is used. For the window system, we make use of the Qt framework. The programming platform is C++, extended with LUA scripts providing the possibility of scripting operations.

V. Discussion

The presented framework can be applied in research activities towards the development of novel oral healthcare appliances. The framework allows the user to use data from different sources such as segmented CT scans or scanned dental casts. The LUA API provides the flexibility for researchers with different backgrounds to collaborate towards a better understanding of dental properties and to generate several models with consistent variations.

VI. Conclusions

The research and development of novel oral healthcare appliances requires extensive research on different teeth and gums geometry configurations. In this paper we presented a flexible and extendible framework for modelling the geometry of the gums and teeth.The framework provides the required flexibility for both algorithm developers and oral healthcare researchers to collaborate towards a better understanding of dental properties towards the development of novel healthcare devices.

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