Title:
SimplyNURBS: A Software Library to simplify the use of NURBS Models and its Application for Medical Devices

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Introduction:

Nowadays, there are many software libraries (both open source and commercial), which make available the basic features to manage NURBS surfaces. In this paper we consider open source libraries, such as NURBS++, OpenCASCADE and AYAM, for the development of a modeling system specifically conceived to design prosthetic socket. Even if these libraries are broadly used and include many basic operations on NURBS models, they still have some criticalities. For example we have experienced the use of NURBS++ library to develop the first release of the above-mentioned socket modeling system, named Socket Modeling Assistant-SMA. Even though this library makes available features for NURBS creation and management, it has some lacks with regards to its usability. Fig. 1. shows two examples of criticalities related to the creation of a close surface along u and v directions and to the fitting of the socket surface. Fitting accuracy could be improved by increasing the number of points but this can cause computing performance drop during the interaction with NURBS models.

Furthermore, the development of NURBS++ has stopped since 2002. Other libraries (e.g., AYAM) have been investigated to face identified criticalities. Therefore, we have envisaged the need of a library which permits to manage NURBS surfaces in a completed and easily way and merges the features of mentioned libraries. In particular, it should make available following features:

- NURBS surface generation from fitting of point clouds.
- Closed surface.
- Direct interaction and modification using surface points.
- Data Exchange using different format (e.g., iges and stl).
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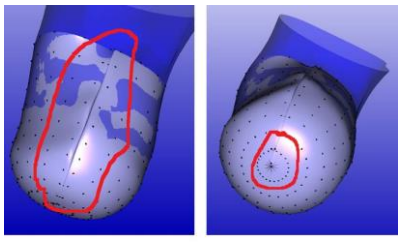

Fig. 1: Problems with: a) surface closure; b) accuracy.

Main Idea

The main idea is to develop a software library, which offers a similar solution to the commercial SMS NLib library [5] [8], but based on a small set of libraries under GPL license. The new suite, named SimplyNURBS, has been developed upon existing free software libraries among which AYAM [7], OpenCASCADE [6] and NURBS++ [4]. These software libraries were separately tested but none of them made available all features we need. The library has been mainly designed to meet the requirements of the considered application field, but it can be used for other applicative fields. SimplyNURBS is based on a layered structure. Fig. 2 shows the architecture and main feature are the following ones:

- **Mathematical Kernel**. This part is completely written in ANSI C, and it has been extracted from the AYAM, which is a free 3D modeling environment to manage the mathematical model of NURBS surfaces.
- **Interaction paradigm**. It permits to modify NURBS surface acting directly on the surface point and without the use of the control points. This feature is based on a part of code extracted from NURBS++ and specifically updated for our purpose. Furthermore, this module permits to introduce another way to interact with 3D models using hand-tracking and haptic devices.
- **Fitting**. It permits to create a curve/surface interpolating points cloud. An algorithm has been developed to extract an ordered point cloud from a set of raw data (e.g., 3D scan or MRI volume). Therefore, the actual computer's power permits to define a NURBS model from the ordered points cloud in real time, and thus, without a complex approach to define the mathematical representation.
- **3D Rendering**. A set of methods has been developed to permit 3D rendering of the models. These modules are based on OpenGL primitives. Furthermore, an interface has been developed to use NURBS models within virtual environments based on Visualization Toolkit (VTK) [9]. The implemented interface permits to manage the 3D rendering in a very simple way avoiding involvement on low-level software development.
- **Data exchange**. This module has been developed using OpenCASCADE in order to obtain data exchange translators for IGES and STL. In fact, both AYAM and NURBS++ do not include this feature that is meaningful for our application field. This part of the suite is entirely developed using C++ language.

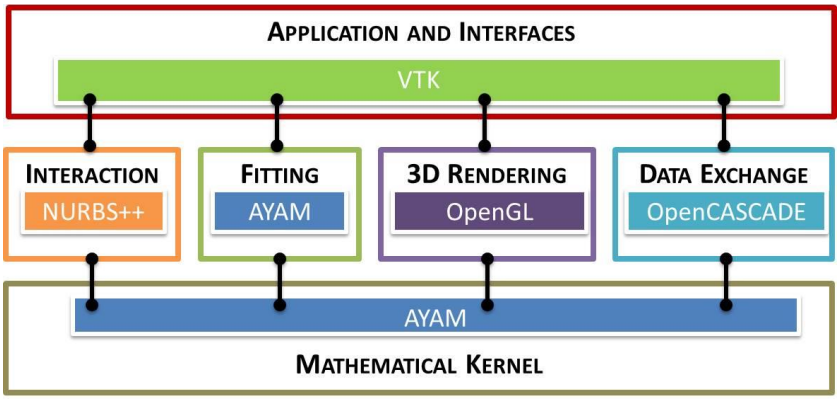

Fig. 2: SimplyNURBS architecture.

SimplyNURBS has been used to implement the new release of SMA, a virtual laboratory, which allows the prosthetist to design the socket of both transtibial and transfemoral prosthesis around the digital model of the residual limb, acquired by MRI. It embeds a set of design rules and procedures (e.g., how to modify the socket shape) that emulate the operations performed by the prosthetist during the traditional manufacturing process [2], [3].

SimplyNURBS is used to create and manage 3D models of socket and residual limb. SMA embeds an interface with SimplyNURBS in order to automatically build 3D models from MRI volume and to model the socket shape. Simply NURBS tools have been mainly used to:

- Create the external skin and bones models through surface fitting of the points cloud automatically extracted from MRI images.
- Manipulate the socket shape interacting directly with surface points through a set of interactive tools that emulate the traditional tasks performed by the prosthetist. Among them, the most important is the Sculpt tool. It permits the technicians to manage the critical zones of the socket surface in order to obtain the most ergonomical shape for the socket. It emulates the operation of adding or removing materials usually performed by the technicians on the plaster cast to create load and off load zones. Another one, named NURBS modeling tool, permits to shape the upper part of the socket directly acting on the surface points. In this way the technicians do not need to know details about the underlying mathematical models.
- Export and import the geometric models of the socket and residuum in IGES or STL formats. The system generates the geometric models in IGES format required by the FEA system to automatically execute the simulation and analyze the socket-residual limb interaction [1]. Furthermore, STL file of model will be used to get the real model of the socket using 3D printer.

A set of tests has been carried out to evaluate the new modeling suite implemented using SimplyNURBS.
Fitting has been tested with different dataset of point clouds. First, we considered sets of MRI images acquired for different patients and we automatically reconstructed the 3D NURBS models. Later, they have been used to generate the NURBS surface, which describe the socket shape. The results reached so far have been compared with those of previous version. It has been highlighted that all NURBS surfaces were properly created and problems have been solved (Fig. 3). In addition, the correct import of modes in IGES format has been verified.

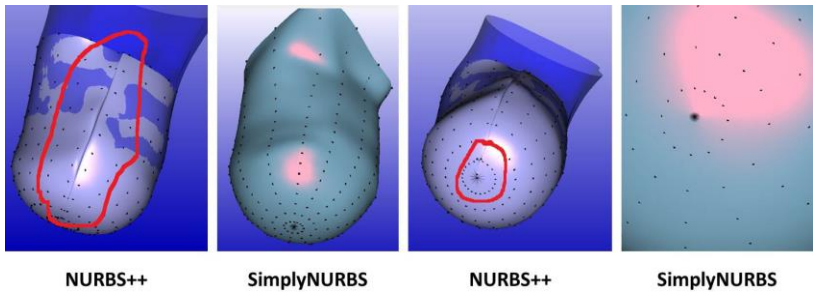

Fig. 3: Comparison between NURBS++ and SimplyNURBS.

Conclusion:
The new library has been tested implementing the new version of SMA. It permitted to realize a modeling system that meet all the requirements and permits to generate the geometric models of the socket that are more accurate and usable by FEA software (i.e., Abaqus). In fact, the system allows the automatic generation of the geometric models required by the FEA system to analyze the socket-residual limb interaction. Furthermore, it's very important highlight that the standard version of VTK doesn't contain a module to use NURBS models in exhaustive way. Thus, with the use of SimplyNURBS, we could make available a free solution, which can be added to the next releases of VTK.
Finally, SimplyNURBS, has been initially developed for application in the prosthetic domain, but it can used for other applications, which usually require computer-aided tool to model products around the human body, or anatomical district and organs. In fact, the authors have planned to use the library to develop application for 3D clothing design and simulations.

References:
[1] Colombo, G.; Facoetti, G.; Morotti, R.; Rizzi, C.: Physically based modelling and simulation to innovate socket design, Computer-Aided Design & Applications, 8(4), 2011, 617–631. http://dx.doi.org/10.3722/cadaps.2011.617-631

[2] Colombo, G.; Facoetti, G.; Rizzi, C.; A. Vitali: Socket Virtual Design Based on Low Cost Hand Tracking and Haptic Devices, in Proceedings of the 12th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry, 2013, 63–70. http://dx.doi.org/10.1145/2534329.2534351
[3] Facoetti, G.; Gabbiadini, S.; Colombo, G.; Rizzi, C.: Knowledge-based system for guided modeling of sockets for lower limb prostheses, Computer-Aided Design & Applications, 7 (5), 2010, 723–737. http://dx.doi.org/10.3722/cadaps.2010.723-737
[4] NURBS++, http://libnurbs.sourceforge.net/old/, Lavoie, P. .
[5] Piegl, L. A.; Tiller, W.; Rajab, K.: It is time to drop the "R" from NURBS, Engineering with Computers, 30(4), 2014, 703–714. http://dx.doi.org/10.1007/s00366-013-0318-x
[6] OpenCASCADE, http://www.opencascade.org/, S.A.S., O. C.
[7] AYAM, http://ayam.sourceforge.net/ayam.html, Schultz.
[8] SMS Nlib, http://www.smlib.com/, Solid Modeling Solutions.
[9] VTK - Visualization ToolKit, http://www.vtk.org/, Kitware Inc.