3D VISUALIZATION OF DENTAL DATA FOR VIRTUAL TREATMENT PLANNING

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ABSTRACT:

Dental rehabilitation treatment planning includes the qualitative evaluation of all available data (eg. Panoramic x-rays, periapical x-rays, models of dental arches, intra-oral photographs, periodontal and dental measurements, registrations of occlusal relationships etc.) and choice of the appropriate strategy. For this planning to be effective both accurate 3D geometrical information and proper use of multi-modal / multi-source images are important. Virtual treatment planning could be an important step towards decision making, since it permits the testing of alternative strategies, exploiting the quality of the digital data. In addition, the educational value of such a process is of great significance.

In this paper a methodology to 3D reconstruction of dental arches through our developed low-cost prototype laser-scanning device is presented. The derived 3D models, interrelated through the occlusal registrations, are enhanced by texture from panoramic and periapical x-rays, after their photogrammetric processing.

At a subsequent phase, the dental 3D data are being projected in a stereo mode, through our low-cost Stereo-3D visualization system. A dual graphics card, two data projectors, and a silver painted screen are used for this, and the whole system operates on developed software and is based on polarization effect.

1. INTRODUCTION AND AIM

Medical imaging is the most important source of anatomical and functional information, which is indispensable for today's clinical research, diagnosis and treatment, and is an integral part of modern health care. Current imaging modalities provide huge floods of data, which can only be transformed to useful information if automated. That is, the inherent (highly resolved both spatially and radiometrically) information cannot be recovered, understood and exploited, unless highly sophisticated algorithms can be devised. Therefore, both medical imaging and the automated interpretation of imagery are of central importance today.

Most of the clinically evolving abnormal situations are actually evolving in space, ie. they are 3D processes. There are numerous parameters inherent to these 3D processes that have in general been understudied and have the potential to better delineate the actual pathologic process and probably contribute significant prognostic information. Therefore, accurate 3D-information extraction is fundamental in most of the situations.

Such conclusions inevitably underline the importance of the technology transfer across disciplines. Indeed, it is this technology fusion among different disciplines that has changed enormously medical diagnosis and treatment in recent years. In this quest for more accurate 3D reconstructions and more robustness of the automated processes, Photogrammetry has an important role to play. Photogrammetry's comparative advantage is the ability to produce process and exploit in 3D, big amounts of high-resolution data in a geometrically consistent, robust and accurate way.

Management of patients with complex dental needs necessitate the simultaneous interpretation of non-homogenous data, in order to achieve a stage of differential diagnosis, which will allow an individualized treatment planning development. At the same time, the potential outcome of a selected treatment planning, affect the longevity of the rehabilitation. In other words, the prognosis of a treatment strategy depends not only on the stage of health at the time of data interpretation, but also on the decision parameters that have been incorporated into the applied therapy; not to mention biological complications (Bergam, 1996), or aesthetic parameters and patient expectations (Molin, 2000, Lang et al, 1996).

This fact has been long recognized by many researchers, the following being only a small sample of a vast literature : "*Crucial factors influencing success or failure have to be recognized and biological and technical aspects governing these factors have to be respected and counted.*" (Hammerle, 1994). All available data (eg. models of dental arches, panoramic x-rays, periapical x-rays, intra-oral photographs, periodontal and dental measurements, registrations of occlusal relationships etc.) has to be included in the qualitative evaluation of and choice of the appropriate strategy.

Dental rehabilitation treatment planning is based on information evoked from different sources and targeting on long term successful therapeutic applications. One source of fundamental morphological data comes from diagnostic casts. Dental diagnostic casts are offering multiple 3-D information, regarding tooth morphology and alignment, location in the arch, edentulous spaces, occlusal curves etc. Radiographic data also provides a major second source of invaluable information. *"Radiographic examinations (panoramic, periapical etc.) offer information regarding the patient's condition that is not available through clinical examination or history. This radiographic information should be used to supplement other clinical information to aid in diagnosis and treatment planning.*" (White SC et al, 2001).

Over the last few years computerized image processing techniques have been implicated in treatment planning, targeting almost exclusively osseointegrated implant treatment modalities, in order to improve human image interpretation and planning performance. (Cucchiara et al, 2001, 2004, Brief et al, 2002, Schicho et al, 2002). This led to what is today known as "Virtual treatment planning".

Currently developed virtual reality technologies use mainly computer tomography data, by which approach volume rendering and voxel based modeling of dental implants is introduced, which allow interactive 3D manipulation of the atomic model and real-time manipulation of virtual implants (Seipel et al, 1998). However, osseointegrated implant treatment modalities represent only a very limited fraction of daily applied dental therapies.

The vast majority of today dental needs are covered by conventional therapeutic approaches, whose complexity increases enormously due to steadily increasing effort for preservation of natural dentition as well as to the continuous individual interest for improved quality of life achievement.

In addition, the available data base of both success and failure correlations from the literature as well as from the individual case, necessitates mastering of treatment planning protocol. Both sources feed reconstructive dentistry to reach technical and biological limits in order to facilitate services covering current scientific and social needs.

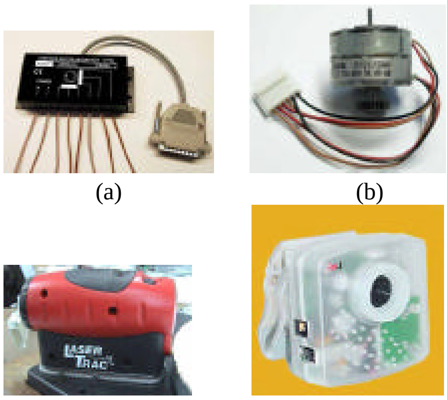
Obviously these efforts involve the solution of many technical problems, and the purpose of this paper is to offer a novel approach to govern these problems. More specifically, the technical problems tackled and the solutions given are:

- 3D reconstruction of dental arches : The dental arches are scanned by our in-house developed, low-cost, prototype laser-scanning device. The output is an extremely dense cloud of points of very high accuracy.
- Multi-source data fusion : The previously extracted cloud of points are used for the registration of multi-source digital medical images, including but not limited to panoramic and periapical x-rays. The aim is to give the means to compare the existing situation (as depicted by existing images) to the planned solution (as described by the reconstructed 3D model).
- 3D-stereo visualization and Database connection : The integrated 3D model with eventual texture from fused images is visualized in both 3D and stereo mode, through our in-house developed, low-cost, Stereo-3D visualization system (OpenView ©). Additionally, links of the 3D models to database information provides for another means to enhance the information provided with any type of data, such as intra-oral photographs, periodontal and dental measurements, medical records, etc.

2. DATA ACQUISITION AND 3D RECONSTRUCTION OF DENTAL ARCHES

2.1 A Brief System description

The rotation unit has been implemented using a rotation disk. A stepper motor device (Fig. 1), with 24 steps/revolution (URL1), has been used for the operation of the disk. In order to get better angular resolution of the rotation mechanism the motor is not directly connected to the rotational axis of the disk, but the movement is transmitted to the axis through special movement transmission belt. The parallel port stepper motor interface unit is been operated through developed Windows applications, in order for the rotation, the laser lighting and image-capturing processes of the system to be fully synchronised.



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

Figure 1: (a) The parallel port stepper motor interface unit
(b) The stepper motor
(c) The laser beam unit
(d) The imaging unit

The laser beam unit creates a straight line curtain, which is projected on the surface. Along this line the 3D coordinates of surface points are been determined. Its switching circuit is been controlled by the computer.

The imaging unit is a Fire-i digital Unibrain Camera, which is based on the Sony™ Wfine color 1/4" sensor CCD and uses a Built-in f 4,65 mm lens with anti-reflective coating. The camera is connected through the FireWire interface port to the computer, providing a maximum of 30fps in 640x480 resolution images (pixel format YUV 4:1:1).

2.2 System Operation and performance

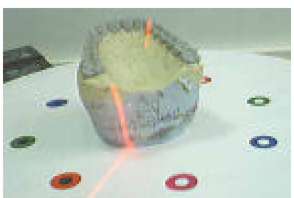
Through a self-calibration procedure, with the use of control points on the turntable, the elements of both interior and exterior orientation are recovered, together with lens distortion parameters, giving an overall accuracy/consistency of the system (s? a-posteriori) of 0,57 pixels, = 2,85μm, with a pixel size of 5μm. The external accuracy against check points is 0,97 pixels, or 4,85μm.

The capturing of the images is done in full synchronization to the rotation and lighting of the laser beam device so that in a single operation cycle the following steps are performed :

Step 1) Rotation by a small angle of the disk
Step 2) 1st Image capture
Step 3) Switching on the laser beam
Step 4) 2nd Image capture
Step 5) Switching off the laser beam

The difference of the two images taken in the 2nd and 4th steps of the processing cycle gives in great accuracy the imaged position of the points that describe the object's surface (Fig. 2). The calculation of these points is done through a simple photogrammetric process since the position, rotation and internal geometry (ie. both exterior and interior orientation) of the camera are already known.

By repeating the above steps the whole object is scanned and a dense point cloud is created. The size of the rotation angle is defining the spatial analysis along the vertical axis of the object hence the radial analysis of the 3D model and varies from $0,6^o$ to $2,3^o$, on a user defined basis. This means that 150-600 incremental rotations are needed to cover the whole object in a whole revolution.


(a)

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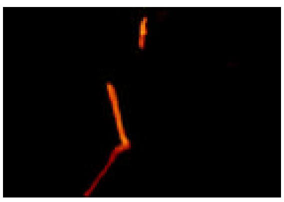
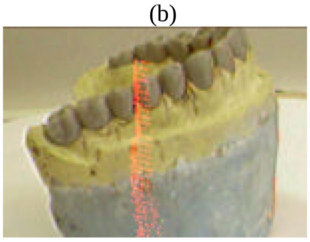
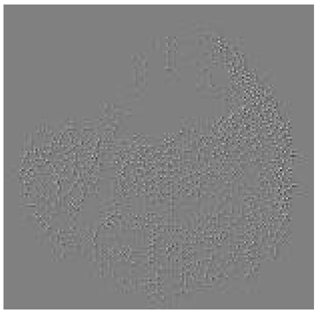
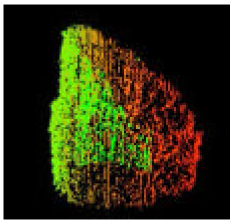
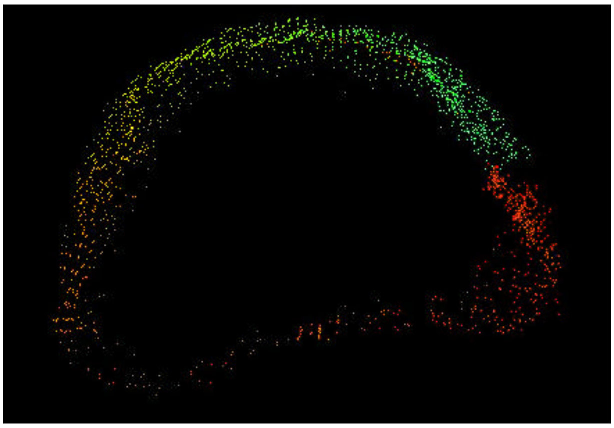

(c)

(d)


(d)

Figure 2: System's operation. (a) Image capture with laser off, (b) Image capture with laser on, (c) Difference image, (d) Back-projection of a sample of the determined points on the 3D model, (d) the determined points.

In order to produce a uniform coverage of the object the horizontal and vertical spacing of the points is suggested to be equal, although this is not mandatory.

3. CASE STUDY

In our initial case study, the creation of a 3D model from a patient's initial diagnostic cast of maxilla was created. For the same patient, the cast of the proposed treatment modality was formed, following diagnostic wax up, whose 3D model was also created using the 3D scanner (Fig. 3).



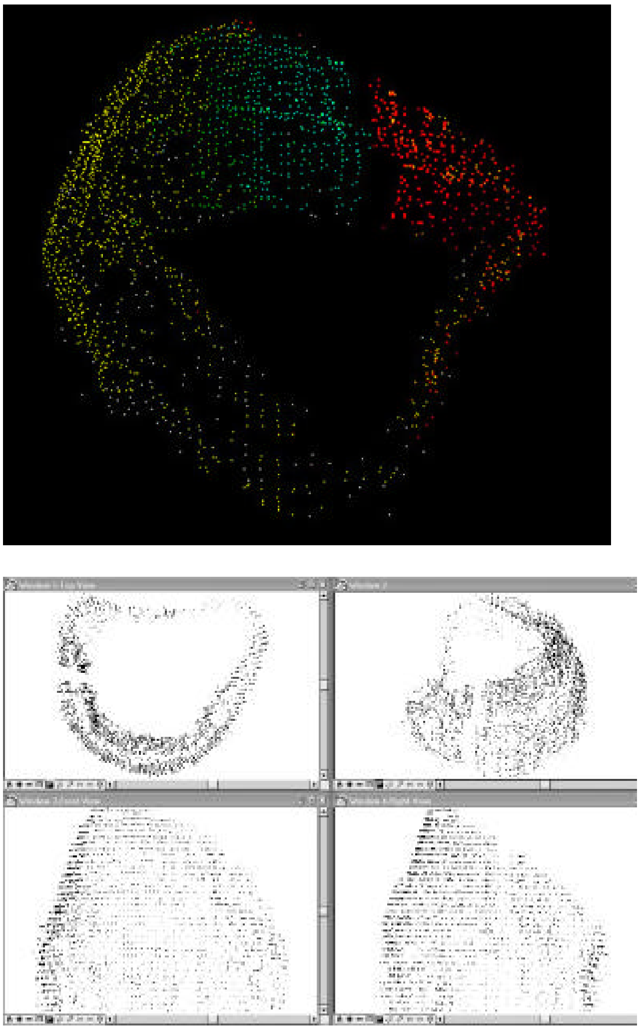


Figure 3: Views of the dense point cloud

Both the vertical and horizontal spacing of the points have been selected as 0,5mm, which resulted to a dense 3D cloud of nearly 11.000 points, that describe an object of nearly cylindrical shape with a base radius of 6cm and a height of 6cm. The 3D coordinate accuracy of the points is better that 5μm, giving a relative accuracy of the order of 10^{-4}, or 1/10.000 or 100ppm.

One of the problems that may rise during the comparison process of the two models is the registration of the two models. For this reason a manual matching of at least 3 points coming from conjugate positions of the two models should be performed in advance. The matching is done in the 3D space model. The operator of the system needs to define the location of the conjugate points in three different images (Fig. 4).

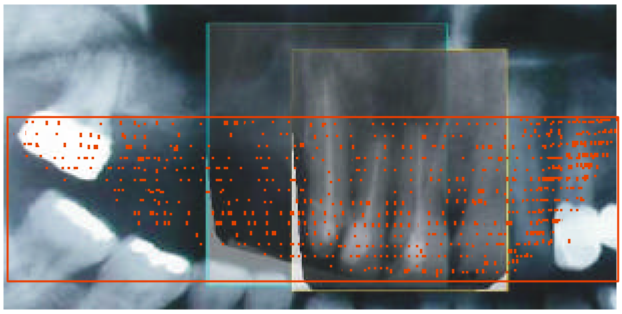


Figure 4: Fusion of multi-source data.
Panoramic x-ray (background), 2 periapical x-rays (in yellow and blue frame), and a subset of the recorded 3D points (in red)

4. 3D-STEREO VISUALIZATION AND DATABASE CONNECTION

The stereo 3D visualization is achieved through the OpenView © system (Sechidis, et. al., 2004). The hardware of the system consists of two Compaq projectors with polarized filters and two Notebook-type CPUs, with appropriate high-end graphic cards. Moving and rotating the 3D model is achieved using the keyboard and the mouse or a joystick (URL2). Moving forward and backward, turning and strafing left and right, going up and down (using mouse wheel) has been already implemented, while different motion behaviours (e.g. head up/down) are under construction. Rotation is achieved interactively using mouse. Motion and rotation speeds are not fixed and can be changed in real-time.

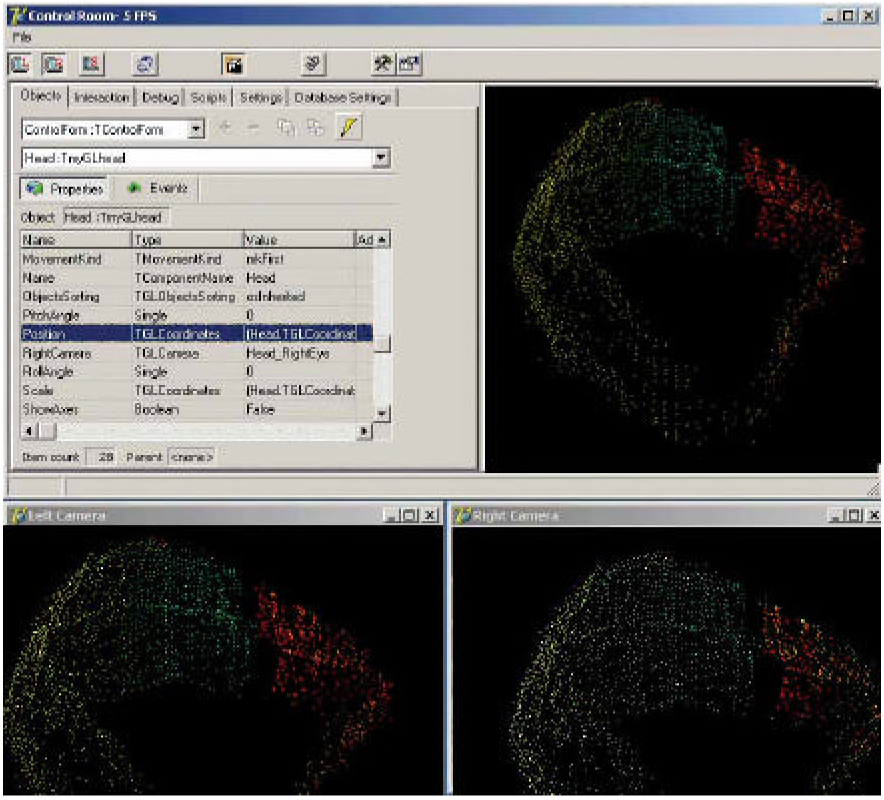


Figure 5: Stereo 3D Visualization and Database connection through OpenView

Another important functionality is the connection of the 3D model to database information. Technically speaking, OpenView © "talks" to database using SQL queries, making it "neutral" to database format (eg. It can use Oracle, Access or any other database server). Different types of data (databases, tables, fields, pictures, video or sound) can be associated with the 3D model, through the OpenView's © smart interface, while for convenience reasons, all database settings can be stored into files and can be loaded when needed. Database information is been retrieved, through an on-line creation of an SQL query. This task is done in the background, so it is invisible to viewer. The results are displayed to both left and right windows in order to be seen stereoscopically (Fig. 5).

These two features, namely the stereo 3D visualization and the database connectivity are extremely important for both (a) effective testing of alternative strategies in treatment planning, in full stereo-3D mode and (b) for enhancing the 3D with any kind of necessary external information (eg. panoramic or periapical x-rays, x-rays, intra-oral photographs, periodontal and dental measurements, medical records, etc.).

5. CONCLUSIONS

A method is proposed for the creation and visual interpretation of 3D models of human dental and periodontal tissues, originating data from casts, x-rays, photos etc. The technique can be used for several applications, such as education, documentation of patient information, treatment predictability games, and archiving and statistics purposes of a dental clinic..

The comparative procedure of initial and proposed state as well as even the pre-treatment and post-treatment alternative situation can lead to virtual and predictably successful techniques of dental rehabilitation.

Future research and development aspects of the device deal with the use of fully automatically procedures for the comparisons of soft 3D models and more realistic visualization processes.

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