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3D Multicamera Dental Cast Scanning System

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Introduction

The fundamental factors in the diagnosis in the orthodontic treatment are the spacing condition, tooth size, arch form and its dimensions. Plaster model analysis is a time-consuming procedure. Dividers, calipers, and Boley gauges have provided the standart of measurement against which newer methods have been evaluated [1]. Various scanning techniques, including laser scans, structured light, destructive scans, computed tomography scans, magnetic resonance imaging, and ultrasound are now available for 3D reconstruction of anatomy [2]. Replacement of plaster orthodontic models with 3-dimensional (3D) computerized images can benefit orthodontics in the following areas [3]:

- efficiency of having patient records instantly accessible on the computer screen vs retrieving plaster models from a storage area;
- saving money on the monthly cost of storage space needed for the thousands of accumulated traditional plaster models;
- accuracy, efficiency, and ease of measurement of tooth and arch sizes and dental crowding;
- the ability to send virtual images anywhere in the world for instant referral or consultation as needed or for studies purposes.

Studies involving dental casts can be performed with ease because computerized 3D wire-frame diagrams allow models to be cut, superimposed, and measured in the computer [4]. The purpose of this research is to compare the current gold-standard plaster model with the digital counterpart of model for the analysis of dental arch sizes. We present a desktop high accuracy device for measurement of dental arches by scanning dental casts.

Structure of 3D scanning system

System operation is based on the laser triangulation method. Triangulation is a technique that uses the known distance between a structured illumination source and a sensing element, and the angle of reflection pattern to measure depth of a surface [5]. Primarily, it had four components: a rotating platform, a laser light source, a CCD video camera, and a PC computer. The rotating platform, driven by a step motor, had a flat surface over which a dental cast was placed. The laser light source projected a single stripe of light over a dental cast. The digital camera was connected to a computer with a firewire port. The step motor controlled by the computer and the motor driver could be stopped at any angle to allow the camera to capture an image of the object.

Sometimes the laser line on the dental cast is hidden by other parts of the 3D object. This makes it impossible for the camera to get of the part of the dental cast that is obscured. In the resulting 3D image, such areas are represented with missing data. For solving this problem the system is composed by turntable, 4 firewire cameras and 2 laser stripe illuminators, which makes visible a slice of the rotating object being acquired (Fig.1).

A turntable makes rotation 180 degrees. Two high quality uniform non-Gausian laser lines are projected onto the dental cast and its profile is digitized very accurately and at high rate. As laser stripe illuminators Lyte-MV laser modules are used. Laser profilers have to be moved over dental cast to digitize its surface. 3D shape reconstruction is obtained by rectification and collation of the laser profiles from subsequent frames of the sequence. To get the whole 3D shape without missing areas and to get view of small details around undercuts the dental cast has been digitized from different aspects and reunited using the overlap automatic process. The image sensor is a FFMV-03MTM camera connected via Firewire to the processing computer module. All processing of raw scan data and dental cast shape reconstruction routines are performed on the scanner computer module with Hyper-Threading Technology.

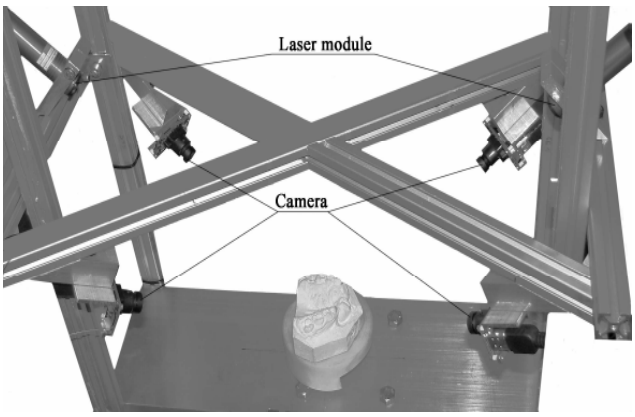

Fig. 1. System setup

Algorithm and Software for 3D model registration

System software (Fig. 2), which was developed by Borland C++ language, can be divided into three logical stages:

1) Create a point cloud of geometric samples on the surface of the dental cast from 4 different views;
2) Registration of pont clouds and meshing;
3) Estimation of geometrical parameters.

On first stage 4 two dimentional images are acquired and stored in computer memory. Customized software based on method of C.Steger for extraction of curvilinear structures from digital images [6], was developed to extract projected laser line data from each image. The approach is based on differential geometric properties of the image function. For each pixel, the second order Taylor polynomial is computed by convolving the image with the derivatives of a Gaussian smoothing kernel. The use of the Taylor polynomial and the Gaussian kernels leads to a single response of the filter to each line. In this case, the line position can be determined with sub-pixel accuracy.

The dental cast surface intersects with the known position of the laser plane, so using standard vector mathematical techniques it is possible to discover 3D locations of individual surface points in camera coordinates. For final geometry reconstruction we need to transform each point into world coordinates using the camera calibration matrix and rotate them into the correct position based on the angular rotation of the frame.

Before registration individual point clouds of different views are filtered using tree different outlier criteria (fit-to-plane, miniball and nearest-neighbor reciprocity criterion [7]) estimators for outlier detection and removing.

For automatic co-registration of 4 point clouds (solving surface matching problem) the modified Iterative Closest Point (ICP) algorithm was used [8]. This algorithm is widely used for geometric alignment of 3D models when initial estimate of the relative pose is know. Due to overlapping areas where points are abundant, point density will be differing to great extent within the dental cast surface after registration. A point thinning software considers an even point distribution with respect to surface and selects those points for deletion.

For surface meshing a special construction named the Power crust is used [9, 10]. It takes a sample of points from the surface of a three-dimensional object and produces a surface mesh. The approach is to first approximate the medial axis transform (MAT) of the object. Then an inverse transform to produce the surface representation from the MAT is used.

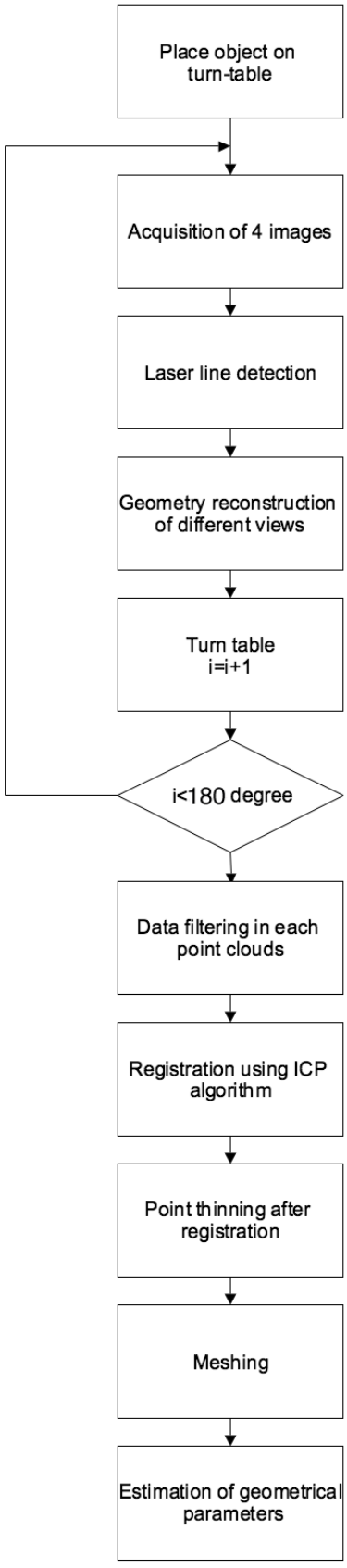

Fig. 2. Algorithm of dental cast scanning system software

3D model of denral cast can be stored in 3D databases, model data can be used for design of appliances. 3D model can be viewed on the screen of user monitor (Fig. 3), imported to a reverse modelling software package Rapidform™ 2006 for additional analysis and estimation of dental arches.

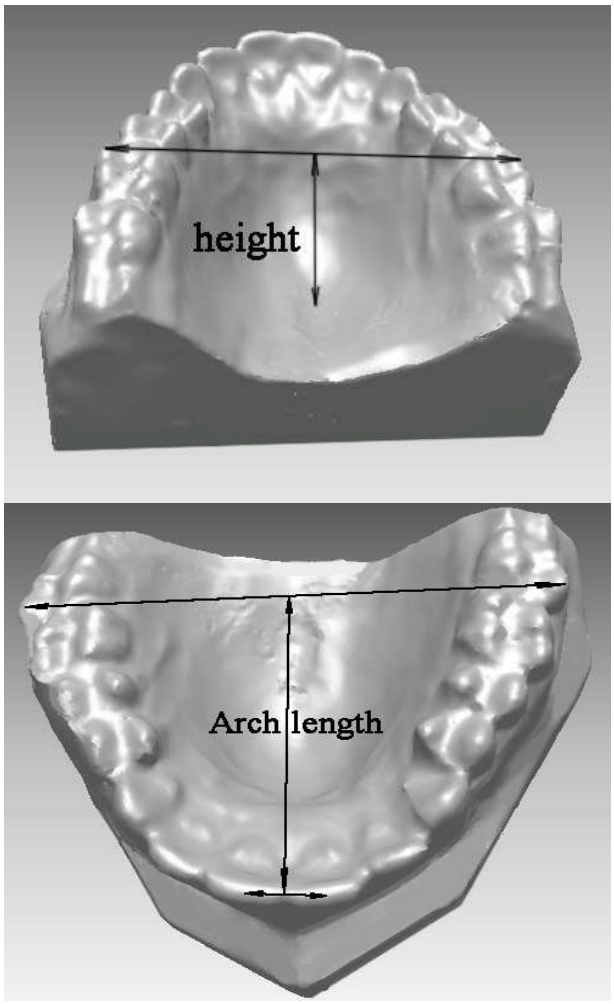

Fig. 3. View of 3D Dental Cast model and estimated parameters

Results

3D multicamera scanning system is designed to achieve a total measuring depth of 45 mm and depth and lateral resolution of 50 μm. Accuracy of system was tested on a geometrical calibrated cylinder. It was found that spatial distance measurement was accurate to 0.1mm (±0.05mm) in the vertical and horizontal dimensions. The 16 dental casts were also scanned and measured to test the reliability of multicamera system, contrasting with manual measurement.

Arch length, breadth and height were measured 7 times for every dental cast and repeatability of conventional and multicamera measurement methods was compared. The average values of arch parameters using different methods were compared. Due repeatability of conventional method is low (up to 0.5 mm), for comparison mean values were ranged by size and approximated to third degree curve (Fig. 4).

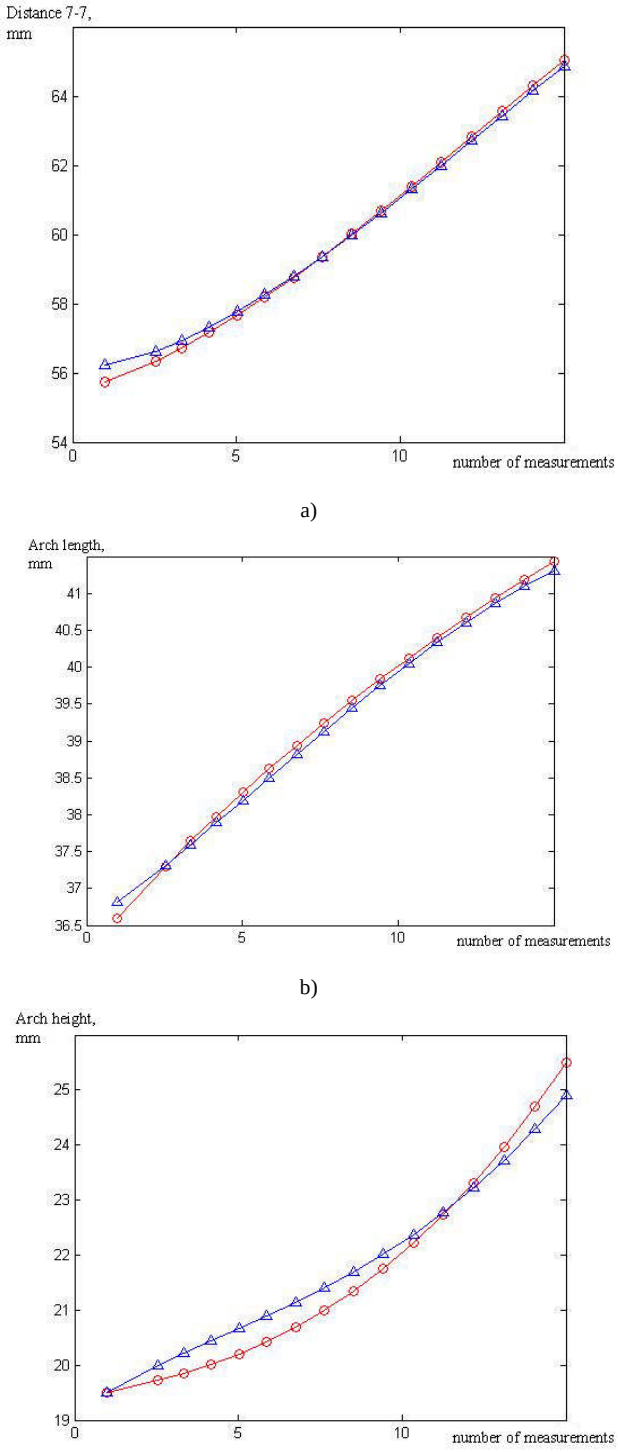

Fig. 4. Comparison of measurement results using different technique. “o” – presents measurement results of conventional equipment, “^” presents multicamera system measurement results: a - measurement results of arch width (distance 7-7), b – measurement results of arch length, c – measurement results of arch height

Within a confidence interval of 95%, we could say that measurement results of arch width (distance 7-7) and arch length using two different methods don't differ more than 0.1 mm. The heigh measurement results for few casts differs more than 0.4 mm. This is caused by low resolution of conventional equipment (0.5 mm).

Conclusions

1. Digital models are acceptable alternative to dental casts for routine measurements used in orthodontic practice.
2. This system is useful objective tool for medical tasks solution and further investigations are required in order to confirm effectiveness in orthodontic patients care.

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R. Adaškevičius, A. Vasiliauskas. 3D Multicamera Dental Cast Scanning System // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 2(82). – P. 49–52.

A possibility of creating a high accuracy device that could automatically measure dental arches by scanning dental casts is presented. The original multicamera system using four firewire cameras and two laser modules is designed. System software uses acquired data for measurement of dental arches, to store dental cast models in 3D databases, to use model data for design of appliances. The 15 dental casts were scanned and measured to test the reliability of multicamera system, contrasting with manual measurement. This system is useful objective tool for medical tasks solution and further investigations are required in order to confirm effectiveness in orthodontic patients care. Ill. 4, bibl. 10 (in English; summaries in English, Russian and Lithuanian).

Р. Адашкявичюс, А. Василяускас. Трёхмерная многокамерная система для сканирования зубных отпечатков // Каунас: Технология, 2008. – № 2(82). – С. 49–52.

Представлен анализ создания высокоточной системы, предназначенной для измерения параметров зубных отпечатков. Создана оригиналъная система состоящая из 4 видеокамер и 2 лазерных модулей. Программное обеспечение позволяет фиксируемые трёхмерные данные использоватъ для измерения геометрических параметров зубных отпечатков, хранения в базе данных, использования для дальнейшего проектирования. Для оценки надёжности метода были проведены измерения 15 зубных отпечатков и резулътаты сравнены с полученными при помощи ручного метода измерения. Система подтвердила себя как объективное оборудование, предназначенное для зубной медицины и может в дальнейшем совершенствоватъся для расширения её возможностей. Ил. 4, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Adaškevičius, A. Vasiliauskas. Erdvinė daugiakamerinė dantų atspaudų skenavimo sistema // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 2(82). – P. 49–52.

Atlikta labai tikslaus prietaiso, skirto automatiniam dantų atspaudų parametrų matavimui, galimybių analizė. Sukurta originali sistema, kurią sudaro keturios vaizdo kameros ir du lazerio šviesos moduliai. Programinė įranga fiksuojamus erdvinius duomenis panaudoja dantų lankų parametrams matuoti, erdviniams modeliams saugoti duomenų bazėje arba toliau projektuoti. Metodo patikimumas buve vertinamas lyginant 15 dantų atspaudų tyrimo skirtingais matavimo prietaisais rezultatus. Nustatyta, kad ši sistema tinkama taikyti medicinoje ir gali būti toliau tobulinama, kad tiktų plačiau taikyti odontologijoje. Il. 4, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).