SOFT TISSUE ANALYSIS AND CAST MEASUREMENT IN ORTHODONTICS USING DIGITAL PHOTOGRAMMETRY

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ABSTRACT

In orthodontics the lateral X-ray and its analysis is an important part of the diagnostic procedures since the discovery of X-ray and the introduction of cephalic measuring with almost parallel X-rays. Making lateral and frontal photographs of the patient represents another common diagnostic method in this particular medical subject area. But both methods only allow a two dimensional inspection of cephalic or facial structures. While making a lateral X-ray the patient is exposed to radiation. Furthermore, the bony structures of the cephalic skeleton are pictured as a summation, which increases the probability of misinterpretation of the measured values.

With the three dimensional photogrammetric measurement of the facial skull using 5 standard views a new diagnostic resource is available to the orthodontist, which allows the non-tactile, radiation free acquisition of the measure points of the viscerocranium with an accuracy in the range of 0.1 mm. Particularly the spatial acquisition of soft tissue points is possible for the first time without considerable instrumental expenditure and radiation for the patient.

Also digitizing of teeth and jaws from a plaster cast may be performed and the data transformed to the skull data using a special transformation bar which is photographed while the patient holds it with his teeth and also while attached to the plaster casts.

Off the shelf digital cameras are used (Fuji DS-300 (1280x1000 pixels) and a Kodak DC260 (1536x1024 pixels)). The obtained results are very well in the range of the point definition accuracy of soft tissue points.

1 INTRODUCTION, MOTIVATION

The three dimensional acquisition of structures opens new perspectives for medical research and surgery. The rapid development in information processing technology allows a quick and more and more accurate determination of spatial points.

In orthodontics the lateral X-ray (cf. Figure 1) and its analysis is an important part of the diagnostic procedures since the discovery of X-ray and the introduction of cephalic measuring with almost parallel X-rays. Making lateral and frontal photographs of the patient represents another common diagnostic method in this particular medical subject area. But both methods only allow a two dimensional inspection of cephalic or facial structures. While making a lateral X-ray the patient is exposed to radiation. Furthermore, the bony structures of the cephalic skeleton are pictured as a summation, which increases the probability of misinterpretation of the measured values.

With the three dimensional photogrammetric measurement of the facial skull using 5 standard views a new diagnostic resource is available to the orthodontist, which allows the non-tactile, radiation free acquisition of the measure points of the viscerocranium with an accuracy in the range of 0.1 mm. Particularly the spatial acquisition of soft tissue points is possible for the first time without considerable instrumental expenditure and radiation for the patient.
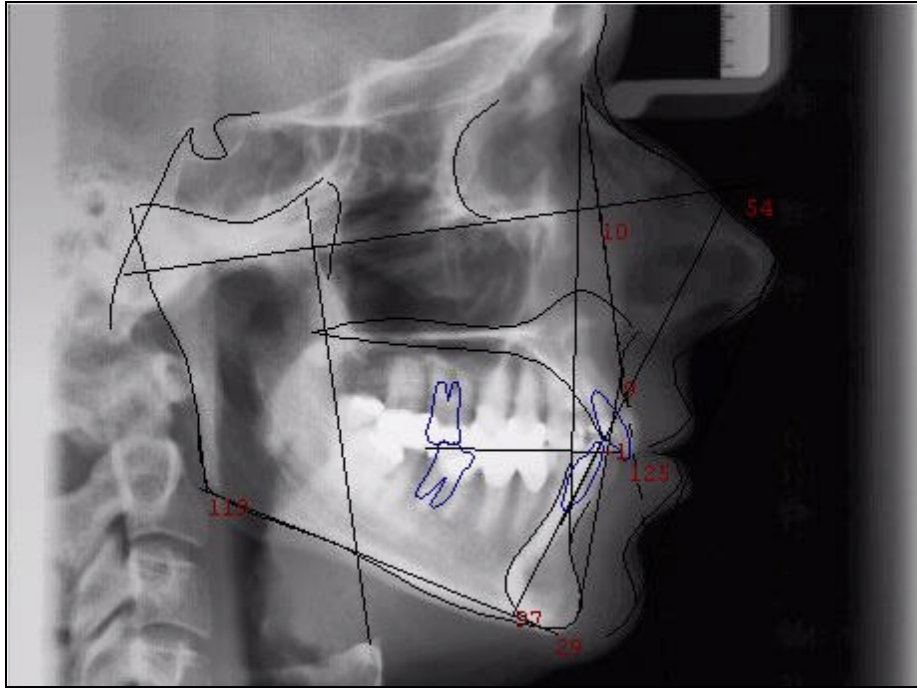
Figure 1 : Lateral X-ray

2 EQUIPMENT

2.1 Camera

Camera Selection. A prerequisite for a day by day usage of a system is that the handling is easy and no special hardware is used. A moderate price is also very important. In order to have a quick response time a digital camera is used. The photographs can be checked and repeated if necessary and the measurements can start immediately without any photographic processing.

We chose a Fuji DS-300 (1280x1000 pixels) and a Kodak DC260 (1536x1024 pixels). The cameras both are color cameras with auto focus, which can be switched off, and zoom lenses. The images are stored on SmartMedia-Cards (Fuji), or CompactFlash memory cards (Kodak), respectively. These cards can be used with a PC-Card adapter that allows access to the image files as on a virtual hard disk.

Figure 2: Kodak DC260

Figure 3: Fuji DS 300

Camera Calibration. In general photogrammetric cameras require calibrated lenses with a fixed or fixable lens system. The first step was to investigate how precise the lens systems of these off the shelf cameras can be calibrated and how stable these calibrations can be reproduced.

In order to check the repeatability of subsequent camera calibrations 12 images of a flat point field (>1000 points) were used for one calibration setup (cf. Krzystek 1995). The focal length was set to one end of the zooming range in order to be able to set it to the same position each time.

The calibration results differed by ca. 0.02 mm in focal length (25.33 mm) and 0.05 mm in principal point co-ordinates (-0.2 mm; +0.4 mm). The radial distortion parameters were varying by about 1 % of their values. Taking into account the mechanical construction of the camera these results were surprisingly good.

2.2 Coded Point Targets

Coded Point Targets are used in order to be able to use the system without having to deal manually with the measurement of control points (cf. 4.2).

2.3 Helmet

In order to provide more comfort for the patient the head is not fixed in some rigid support. A special helmet that can be fixed tightly to the head carries 22 points which are co-ordinated in advance. So the patient is free to move his head slightly between the single photographs. This is much more convenient than fixing the head during exposure time or even during measurement time as done with other systems.

Figure 4: Helmet

2.4 PictranMed

PictranMed is an add-on to the Pictran system for digital photogrammetry (Technet Berlin/Stuttgart). It takes care of the special requirements and project organization within an orthodontical surgery, such as different patients and different dates for the same patient. Also the photogrammetric pre-processing (image selection and import, interior orientation, automatic measurement of control and tie points, bundle adjustment) is done in this step. It is also necessary to select the used camera for each of the images, or the corresponding set of calibration parameters, respectively.

The user only needs to measure the 3d-points he wants to determine manually, in 2 or more images.

Also, a post-processing step is added to transform the measured 3d points to a co-ordinate system which is defined by certain points at the patients head, and to export the data to various formats.

3 WORK FLOW

This chapter describes the standard workflow for a typical 3d point measurement with PictranMed.

3.1 Preparations

First of all the patient has to be prepared: the soft tissue points which are to be measured later on must be marked on the skin with a special pencil. For many of the points the surgeon has to touch and feel the skin to be able to mark the point correctly. Therefore this is the task where the expertise of the orthodontist plays a very important role; here the points are selected and identified at the patients head.

The helmet must be fixed tightly to the head of the patient using the suspension system straps, so that it cannot move when the patient moves his head.

3.2 Photographing

The camera parameters (distance, zoom, iris, ...) must be set to the calibrated position. With the DC260 this can be done using a script which can be executed from a menu on the camera or automatically after switching on the camera. With the DS-300 the user must take care of these settings manually.

Five images are taken from different directions (left, left_45, front, right_45, right). The camera is used vertically to utilize the image format to a better extent. This setup is used as a compromise between good image overlap and a small number of images and could be varied.

3.3 Orientation

The Orientation is done fully automatically within the pre-processing of PictranMed (cf. 2.4). The images are prepared for the usage with Pictran (cf. 4.1), the control points are measured automatically (cf. 4.2) and the bundle adjustment is started. The result is checked, and if it is correct the orientation are transferred to the corresponding images. If an error

is detected, the user is informed. Users of such a system are generally not very familiar with photogrammetry and are not willing or not able to deal with details of a bundle adjustment. Therefore care must be taken to give reasonable advice how to overcome the problems. A very simple approach could be to take new photographs.

Figure 5: Set of five standard images during pre-processing

3.4   Digitizing

The main task for the user is measuring corresponding soft tissue points which may or may not be marked on the skin in 2 or more images. This is done monoscopically and is supported by epipolar lines and optionally semi-automatic point transfer or target matching (cf. 4.3). As soon as a point is measured at least in 2 images the 3d co-ordinates are displayed as well as sigma for the ray intersection (which corresponds to the parallax in the images).

The user may digitize standard points as well as freely chosen points, provided that there is sufficient surface texture available to identify the same point in different images. It is also possible to digitize objects (connections between points), or to measure points or objects in a certain plane (cf. Figure 7).
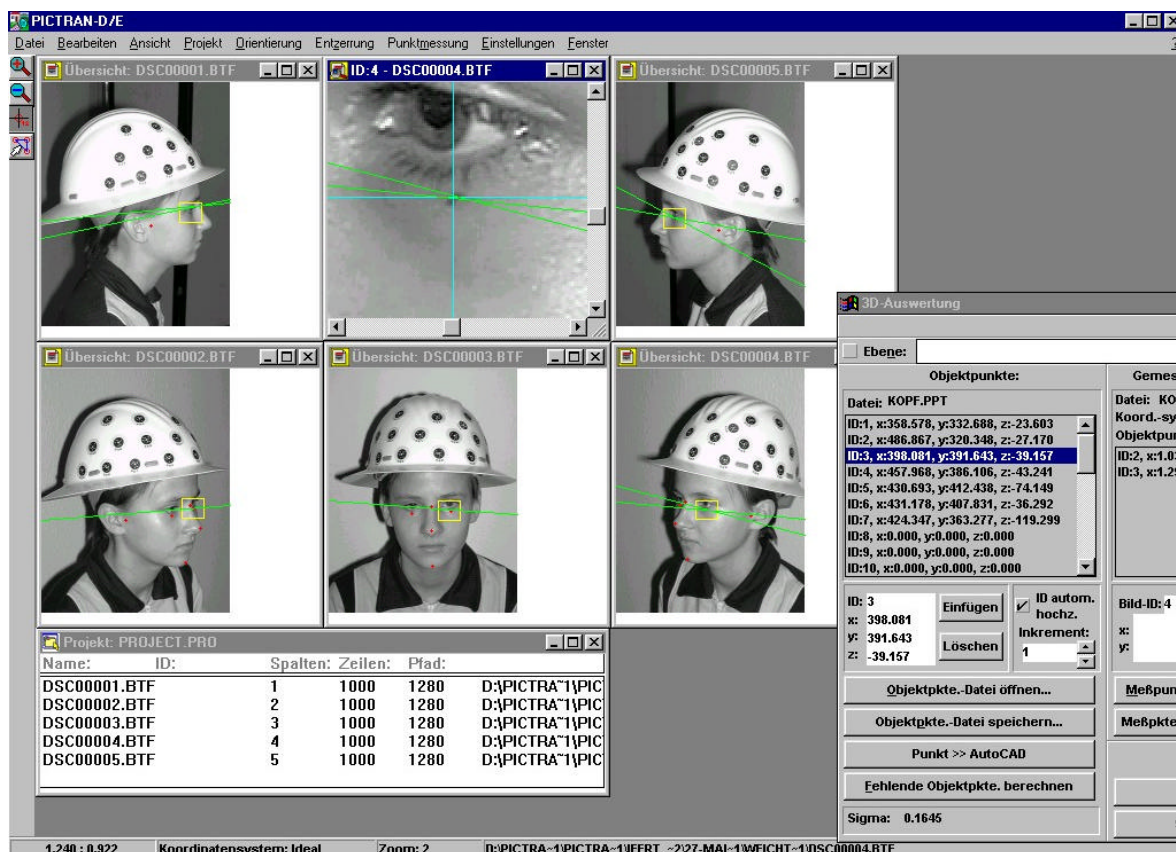
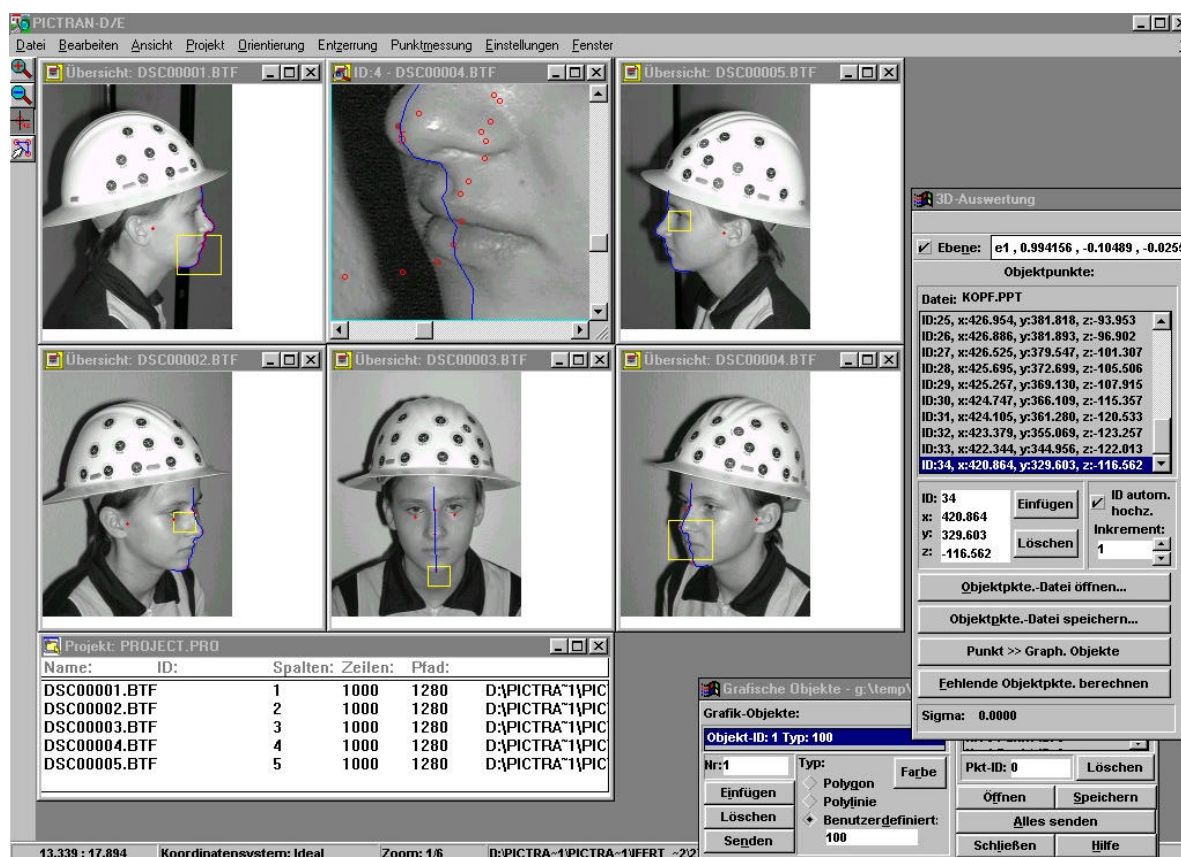Figure 6: Digitizing of 3D points within Pictran

Figure 7: Digitizing an object in a vertical plane

3.5 Results

The resulting point co-ordinates may be exported to various file formats. During export the points can be transformed to a standard co-ordinate system which is defined by 4 prominent points at the ears and below the eyes ("orbitale", "porion"). Therefore the 3d data can be compared to standard values and between different epochs in order to monitor and document the orthodontic treatment.

4 AUTOMATION

For the application of a photogrammetric system in a non-specialist environment is important to do as much as possible of the photogrammetric work automatically and possibly hidden from the user, so that he can concentrate on his main work and expertise.

4.1 Image Preparation (Acquisition, Import, Interior Orientation)

The images are stored on the memory cards generally as JPEG-Files which can be accessed as if residing on a hard disk. They have to be converted to grayscale images for the automatic image processing and imported to an appropriate image format. The interior orientation is constant for all images of the same camera and is represented by an affine transformation from the pixel co-ordinate system to the camera co-ordinate system. These things are done automatically for all images of a project in a pre-processing step, where the user can input and change some parameters as the used camera (for calibration parameters) or rotate the images for an upright portrait, etc.

4.2 Automatic Point Detection, Identification and Measurement

The automation of the measurement process is also very important. The point correspondence plays a prominent role in the process of image orientation and/or 3D measurement. In this case we use the coded target CIRCO (Inpho, Stuttgart) for automatic point detection, point identification and determination of image co-ordinates (cf. Ahn, Schultes, 1997).

The targets consist of a central circle which represents the point location itself, and coding dots which surround the central circle (cf. Figure 8) and provide for robust identification of the target. Checks can be applied for completeness, coding sequence, and geometry of the coding dots.
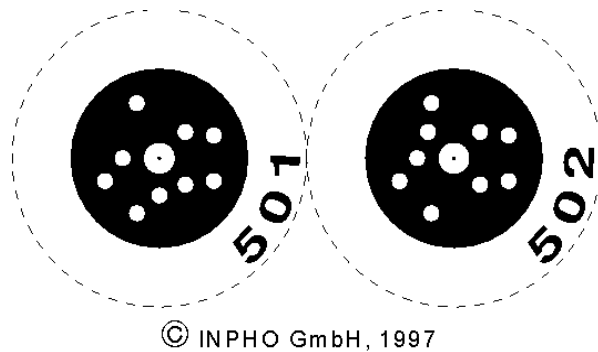

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Figure 8: Coded Targets

Some major requirements of a coded target are fulfilled with this target design:
- Independence of location, rotation and scale
- Robustness of defective decoding
- Accurate center point determination
- Detection and localization in any image without initial values
- Short processing time
- Compact target size
- Provision of a sufficient number of identification points
- Low manufacturing costs

The image processing strategy used here is an efficient recursive application of binary and gray image processing in consideration of the unique characteristics of the coded target (cf. Ahn, 1997).

The coded targets are detected, identified and measured automatically in the images and the resulting pixel co-ordinates are transformed to the image co-ordinate system and used for the bundle adjustment. This process is fully automatic and results in readily oriented images for the user to digitize 3D points.

4.3 Semi-Automatic Point Transfer

The point transfer from one image to another is supported by least squares matching. The user can save a certain image area in one image which will be used as a template for a Least Squares Template Matching in the other images. The

approximate position of the corresponding point is given by the user clicking in the image. Also artificial templates can be used, e.g. to measure points marked with circular dots.

This leads to a higher accuracy of the image point measurement compared to the manual measurements.

5   TRANSFORMING PLASTER CAST MEASUREMENTS TO THE SKULL SYSTEM

It was investigated, how accurate the data from measurements on a plaster cast of the teeth can be transformed to the skull co-ordinate system. Therefore image blocks have been taken of the plaster casts of upper and lower jaw separately, both of the casts holding the transformation bar between them, and the patient holding the transformation bar between the teeth. During taking these photographs of the patient the transformation bar was mounted with cast compound so that the re-positioning between the casts can be guaranteed. The cast mounts and the transformation bar hold several signalized points so that the measurement can be done automatically. The cast images were taken on a background with marked points in order to get stable geometry within the sub-blocks.
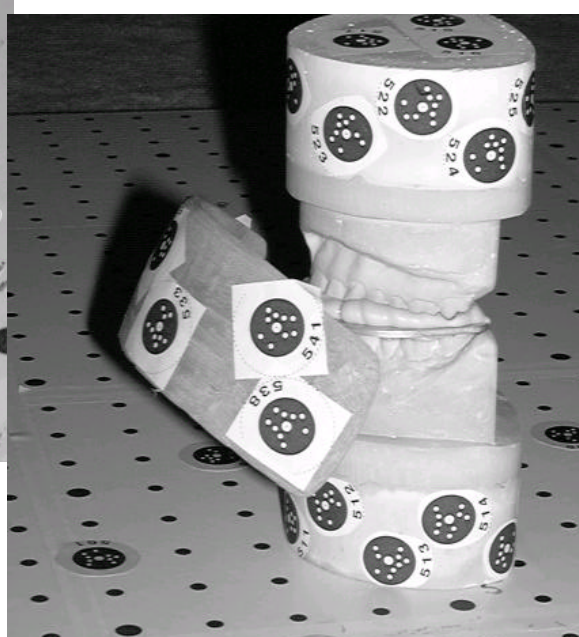

Figure 8: Plaster cast,

plaster casts with transformation bar,

transformation bar used by patient

Since the casts are much smaller than the head with helmet a different image scale was used by a smaller object distance. The camera had to be refocused and a second calibration set was determined. The focal length differed by about 1 mm.

The sub-blocks (patient with transformation bar, casts with transformation bar, upper cast, lower cast) were adjusted separately in a first step. A final bundle block adjustment with the points on the helmet used as control points with an accuracy of 0.1 mm leads to an accuracy at the transformed points on the jaws of 0.2 mm.

6   CONCLUSIONS

PictranMed is a prototype system that shows the suitability of photogrammetry for applications in orthodontic surgeries. The orthodontic diagnostics and the documentation of the progress of orthodontic treatments can be performed without using X-ray.

The basic system for measuring the topography of the human face is going to be used as a standard equipment in school surveys in order to detect needs for orthodontic surgery sooner than today.

The transformation of points measured on a plaster cast into the skull co-ordinate system is possible. Many images and additional equipment are needed, however, what makes this method rather costly.

In this field of orthodontics it is possible to do 3d-measurements with satisfactory results by using off the shelf digital cameras.

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