

# FaceSCAN<sup>3D</sup> – Photorealistic 3D Images for Medical Applications

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## Abstract

We present a technology for the creation of 3d-surface data of human faces. The radiation free technique enables the data acquisition in approx. 400 msec. The robust measurement principle uses the projection of sinusoidal fringe patterns to create three point clouds. The patented mirror setup allows to scan the patient easily from ear to ear. The data processing starts with the fully-automatic and accurate alignment of the three point clouds. Sophisticated pre- and post-processing algorithms enable then the creation of a curvature dependent thinned triangular mesh. Finally, a high-resolution 2d image is mapped to the mesh with sub-pixel accuracy to create a photo-realistic representation of the patient's face.

Especially in a clinical environment the acceptance of new equipment depends strongly on the convenience of the handling of the device. The FaceSCAN<sup>3D</sup>'s simple user interface makes this as easy as using a digital camera. Operating the scanner can be learned in less than 20 minutes. The data can be exported in a variety of formats suitable for importing into analysis software. The applications range from radiation-free cephalometrics to overlay with CBCT data. The FaceSCAN<sup>3D</sup> data is an additional channel for the surgeon not only to do state-of-the art patient education but also gives him the possibility to plan his operations based on what we call a virtual patient model. An accurate before-after comparison enables quality control of the outcome of the surgery.

In this paper the basics of our measurement principle are explained. After a short course about 3d data processing we focus on two interesting applications.

**Keywords:** 3d face scanning, fringe projection, point cloud calculation, registration, mesh reconstruction, texture generation, 3d data processing, medical applications

## 1. Introduction

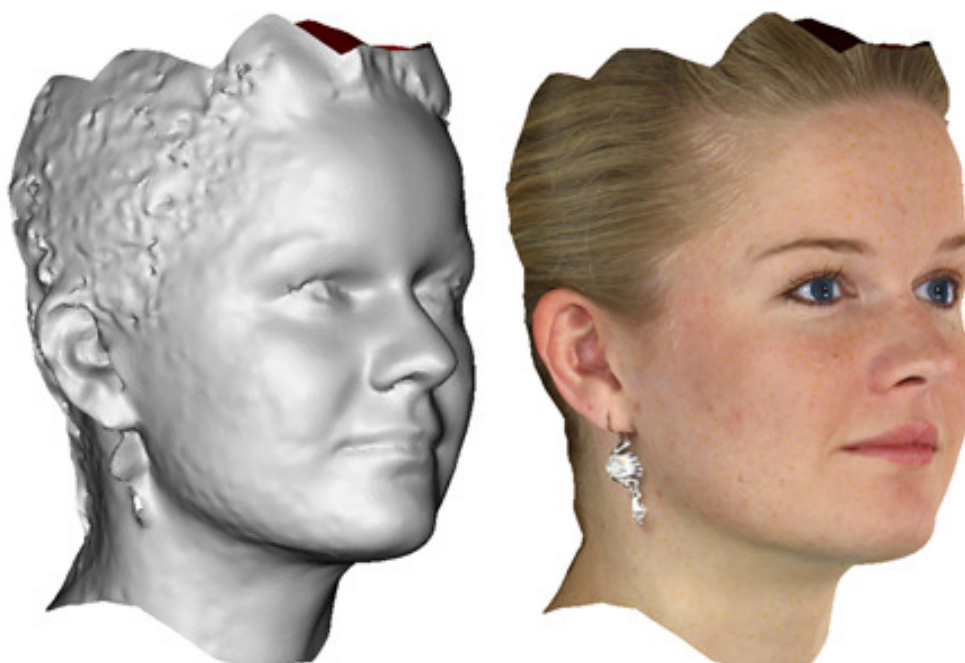
A considerable challenge in generating 3d-surface datasets of people is motion blurring. In the past patients had to sit absolutely quiet during the measuring process. Even the blinking of the eyes could destroy the results. To avoid this problem, 3D-Shape developed a so called mirror-unit with two or three mirrors (Fig. 1). With the help of this mirror-unit we can measure a face from ear to ear (in case of a two-mirror setup) or the complete head (three mirrors) with a single shot. Furthermore, high-speed cameras acquire the necessary images in less than half a second, so that motion blurring can be avoided in most instances. The same results could be achieved by using three separate scanner units, however, our concept helps to reduce hardware costs and the mirror-unit can be utilized as a tool to ensure that the patient is positioned completely within the measuring volume.

With the help of the two-mirror-unit we can measure three views at once: front, left and right, resulting in a set of three 3d-point-cloud datasets. To assemble these datasets the scanning-software can match them without any markers or other auxiliaries and automatically generates a single triangle mesh with a high resolution texture mapped onto it (Fig. 2). The total scanning process (from data acquisition until the final textured mesh is saved to disc) is finished in less than one minute.

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*Fig. 1. FaceSCAN<sup>3D</sup> with two-mirror setup.*



*Fig. 2. Final triangle mesh (left: surface rendering only, right: with texture mapping).*

## 2. Data Acquisition

### 2.1. 3D Data Acquisition Using Fringe Projection

Two different measurement principles are commonly used: active projection of light patterns and passive stereo photogrammetry. While the latter has the advantage that no artificial illumination is required, the active approach usually achieves more accurate results. Furthermore, this method is quite robust. For that reason we decided to use fringe projection [1, 2].

A digital video projector projects a sequence of sinusoidal fringes onto a surface under test, a human face in our case (Fig. 3, left, Fig. 4, center). One or two cameras observe the light pattern from another direction. The projected light stripes are modulated by the topography of the surface (Fig. 4, center) and are reflected on the camera chip(s) (Fig. 3, right). This technique is a variant of the so-called triangulation methods. If the triangulation angle and the distance between camera and projector are known, each point of the surface in space can be computed by trigonometry. Since the addressing of the surface points with a periodical pattern is not unique, a sequence of 8 fringes with varying phase and frequency is used to generate a unique mapping from camera pixels to surface points. This process is called “phase unwrapping”. With a frame rate of 60 Hz, the recording of the 8 frames takes 133 msec, the complete scan of 3 views 400 msec.

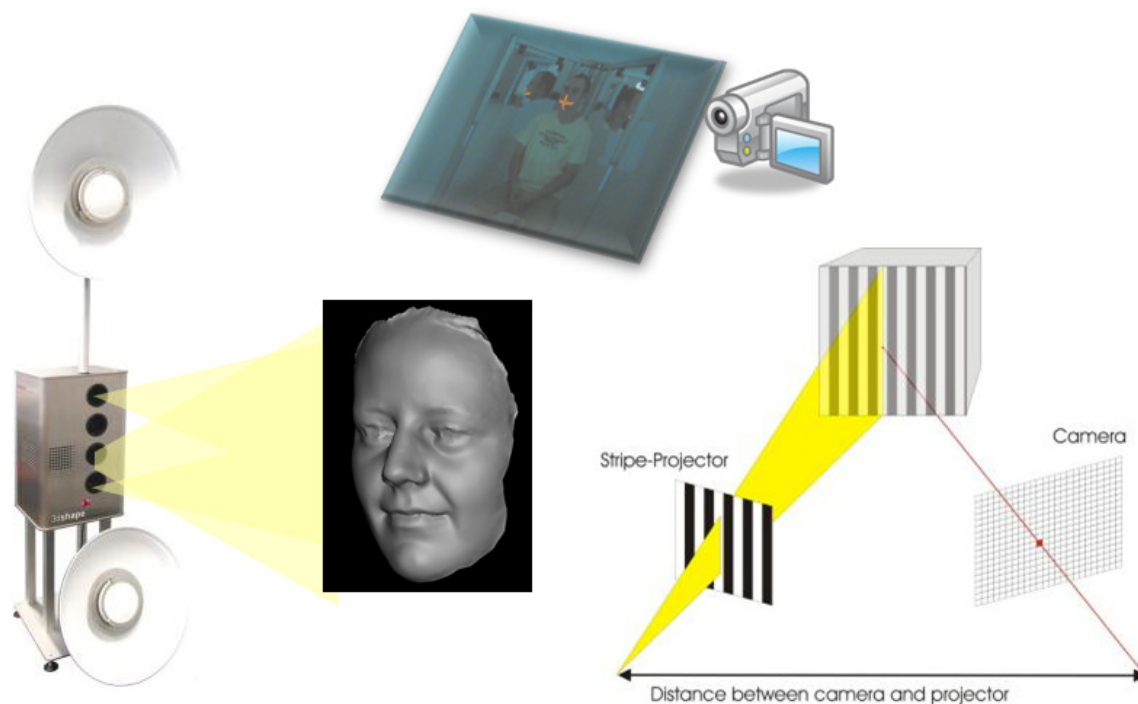


Fig. 3. Data acquisition using fringe pattern projection and a digital still camera for recording the texture.



Fig. 4. Acquisition of a single 3d view.

## 2.2. 2D Texture Acquisition

For acquiring the 2d texture of the surface, a digital still camera takes a high resolution photo that is illuminated almost uniformly by a twin flash with large reflectors (Figs. 3 and 5). Because of the flash, here the exposure time is approx. 1 msec. only.

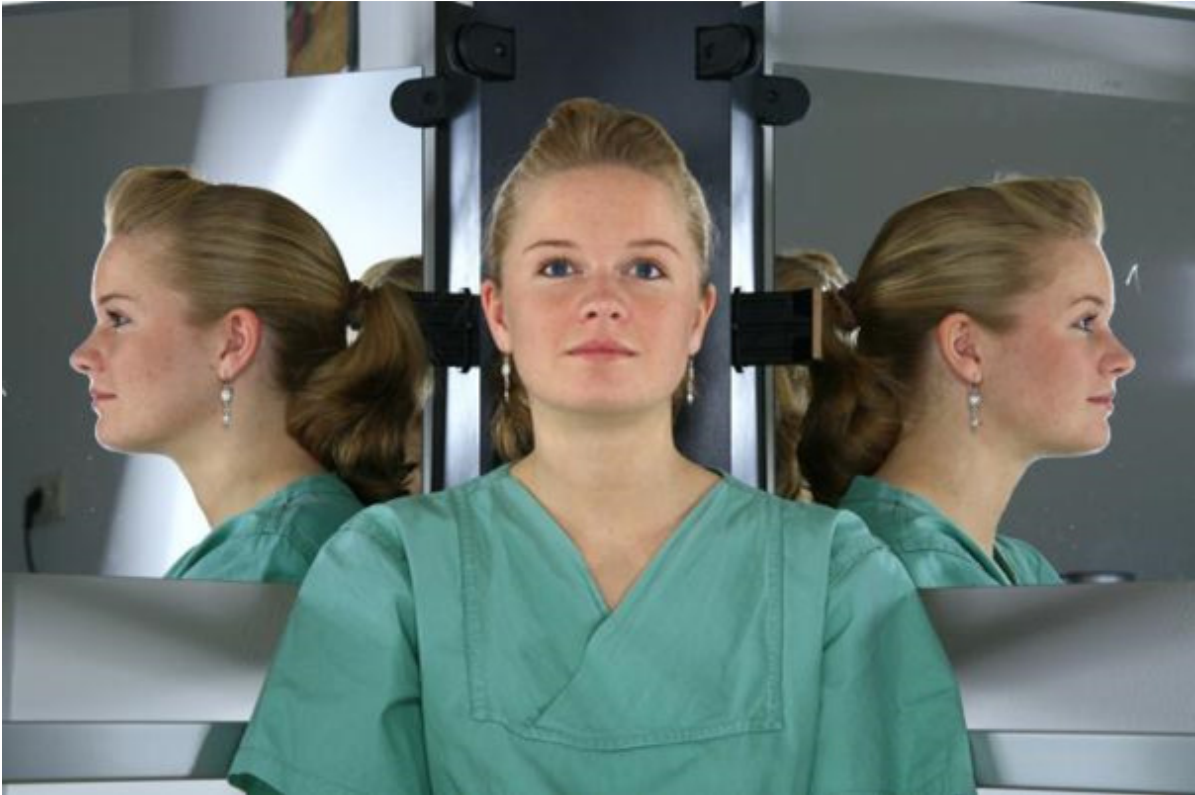


Fig. 5. High resolution texture image.

## 3. Camera Calibration

In order to generate range images containing  $(x,y,z)$ -coordinates from the measured fringe images, a transformation is computed that maps the camera pixels into world coordinates [2, 3]. For that purpose a special calibration plate is shot in various orientations and bundle adjustment software is used to calculate the intrinsic (e.g. focal length and optical distortion) and extrinsic (distance, orientation) camera parameters (Fig. 6). This process usually is performed only once when the *FaceSCAN<sup>3D</sup>* system is installed.

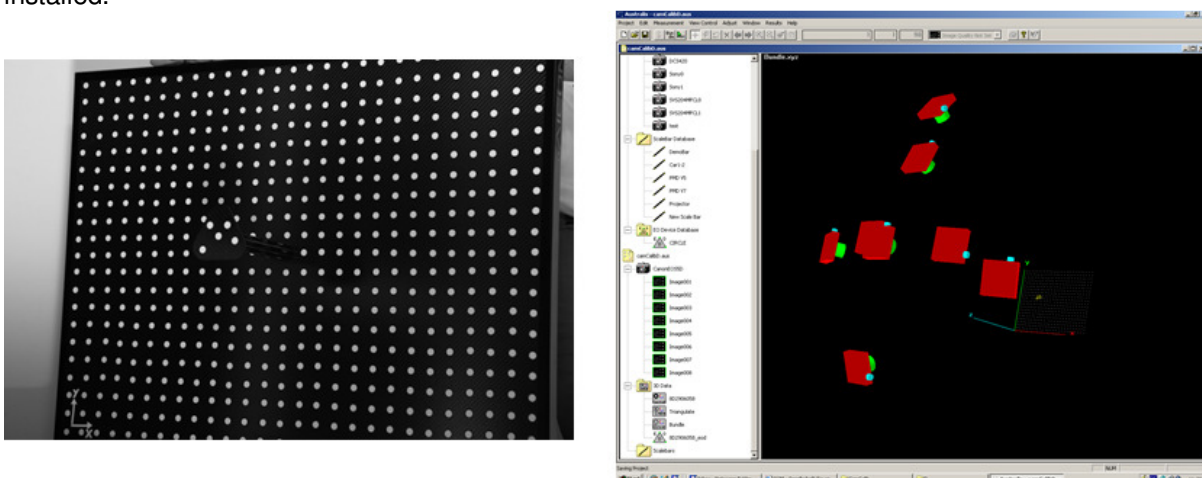


Fig. 6. Calibration plate used for camera calibration (left) and bundle adjustment software (right).

## 4. Data Processing

### 4.1. 3D Point Cloud Calculation

The sequence of 8 fringe images is unwrapped into one single phase image for each camera [2]. This image encodes for each pixel the phase of a virtual fringe on the observed surface with a period that is large enough to cover the whole object uniquely. In these unwrapped phase images, pixels corresponding to the same point of the object surface can be identified by having equal phase values. From that information a disparity map is computed, which encodes the distance between corresponding pixels in the two phase images of the stereo camera pair. Finally, the disparity map can be transformed into a range image containing the  $(x,y,z)$ -coordinates of the observed surface points. This is done using the transformation from camera pixels into world coordinates that was computed during the calibration process of the cameras.

Currently, the calculation of a single range image of size  $1024 \times 768$  requires approx. 10 sec. However, we have recently implemented a new algorithm which can do this for a  $1280 \times 1024$  range image in approx. 0.1 sec, so that our future products will have higher lateral resolution and will be able to display the 3d point cloud almost instantly after pressing the exposure button. Figure 7 shows how the current *FaceSCAN<sup>3D</sup>* user interface displays the three point clouds after data acquisition.

Our actual *FaceSCAN<sup>3D</sup>* product has a  $300 \times 300 \times 300$  mm<sup>3</sup> measuring volume. The 3d camera resolution is  $1024 \times 768$  pixels, which covers all three views and therefore results in a lateral resolution of 1 mm. The longitudinal measurement uncertainty is  $200 \mu\text{m}$  ( $\pm 2\sigma$ ).

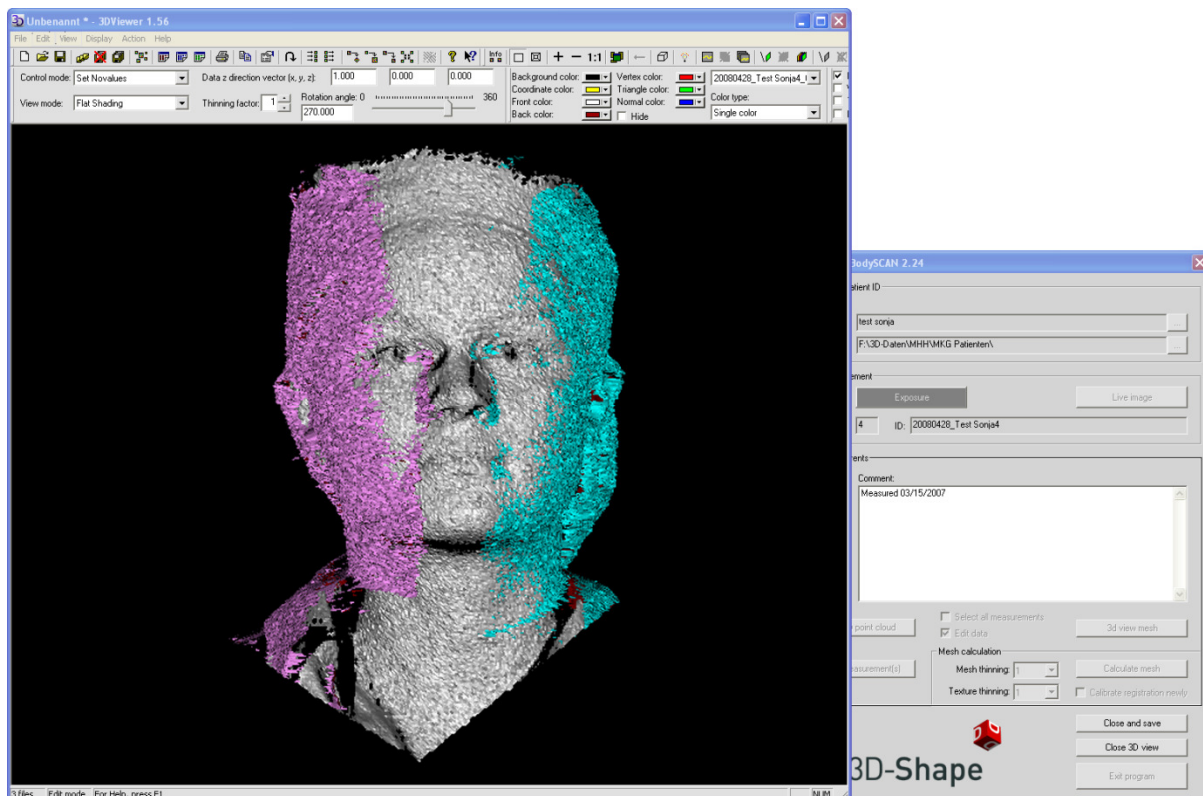


Fig. 7. The *FaceSCAN<sup>3D</sup>* user interface displaying the three point clouds (magenta, white and cyan) after data acquisition.

### 4.2. Registration

After point cloud calculation the three range images are defined in their local camera coordinate systems and therefore have to be transformed into a common world coordinate system before they can be merged into one final dataset [4, 5]. This so-called “registration” process is performed in two steps (Fig. 8). First the views are coarsely aligned by a progressive 6 dimensional cross correlation function. All combinations of the 6 degrees of freedom within a certain range are examined, starting with a coarse quantization of the 6 dimensional parameter space, which is iteratively refined. This step needs only to be applied once after the scanner has been installed. The resulting transformation is then stored and reloaded by all subsequent measurements as long as the mirror-unit is not moved.

The result of the coarse registration step is still a rather rough alignment (Fig. 8, center), which is further improved by an ICP (Iterative Closest Point) algorithm [6], that iteratively minimizes the distances between the corresponding points in overlapping parts of the surfaces (Fig. 8, right). For distance minimization the Levenberg-Marquardt method is used.

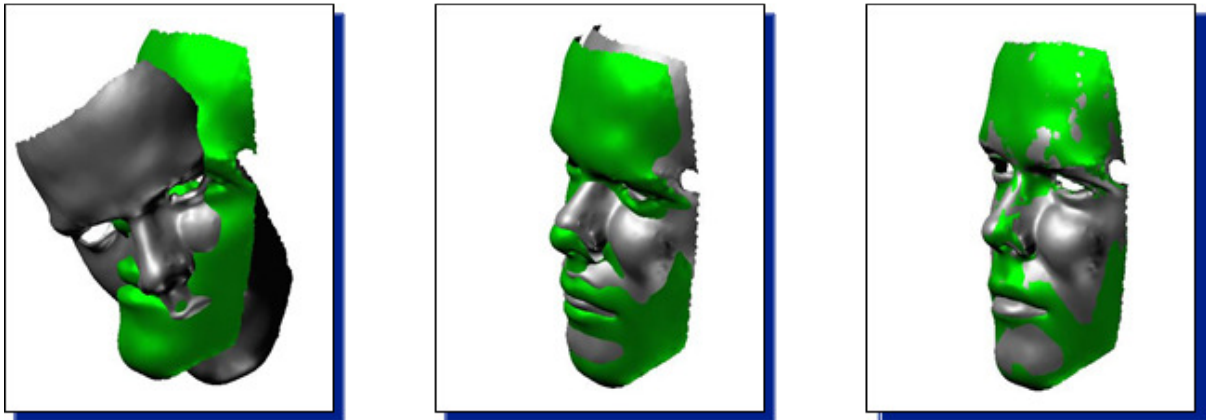


Fig. 8. Two point clouds before registration (left), after coarse alignment (center) and after fine registration (right).

### 4.3. Mesh Reconstruction and Texture Mapping

The three range images are converted into triangle meshes. The meshes are smoothed then, holes are closed, measurement artifacts like outliers are removed and they are curvature dependently thinned in order to save memory and processing time. Then they are merged into one single mesh [5]. Finally, a special texture image that contains only relevant texture data and compensates the brightness differences in the transition regions between the different views is generated and mapped onto it [7] (Figs. 9 and 10). For calculating the texture mapping transformation, the same calibration method as for the 3d cameras is used (see Sec. 3).



Fig. 9. Final mesh with curvature dependent density (left) and with texture (right).



Fig. 10. The texture map that is stored within the final mesh, containing relevant information only.

The final mesh can now be edited manually and be exported in a variety of mesh formats like OBJ, STL, VRML or DXF for evaluation with external applications.

The whole process from data acquisition until the final textured mesh is saved to disc is finished in less than one minute.

## 5. Medical Applications

Our *FaceSCAN<sup>3D</sup>* is applied in the following medical branches:

- Orthodontics
- Oral- and maxillofacial surgery
- Stomatology
- Reconstructive surgery
- Plastic surgery
- Breast augmentation and recovery
- Paediatrics
- Orthopaedics
- Prosthetics
- Accident surgery and orthopaedics
- Dermatology
- Forensics

Dentists, orthodontists and oral-maxillofacial surgeons for example use *FaceSCAN<sup>3D</sup>* to compare the patient's situation before and after a surgery, to document the healing process, for medical evidence, treatment planning and even for marketing purposes.

From the variety of applications we will focus on two examples here.

### 5.1 Registration of Soft Tissue with Dental Casts Using a Bite Fork

For medical studies and the postsurgical quality control it's sometimes desired to measure the position of the teeth in relation to the soft tissue of the face without exposing the patient to any harmful radiation like X-rays. We have therefore developed a method to integrate dental scans into face scans [8].

For this purpose the 3d-mesh of the dental cast model that was measured with a Smart Optics Activity scanner [9] has to be registered with the face scan. This cannot be done using an ICP method, since there is no overlap between the two meshes. To solve this problem, we use a special bite fork with three pellets attached to it (Fig. 11).

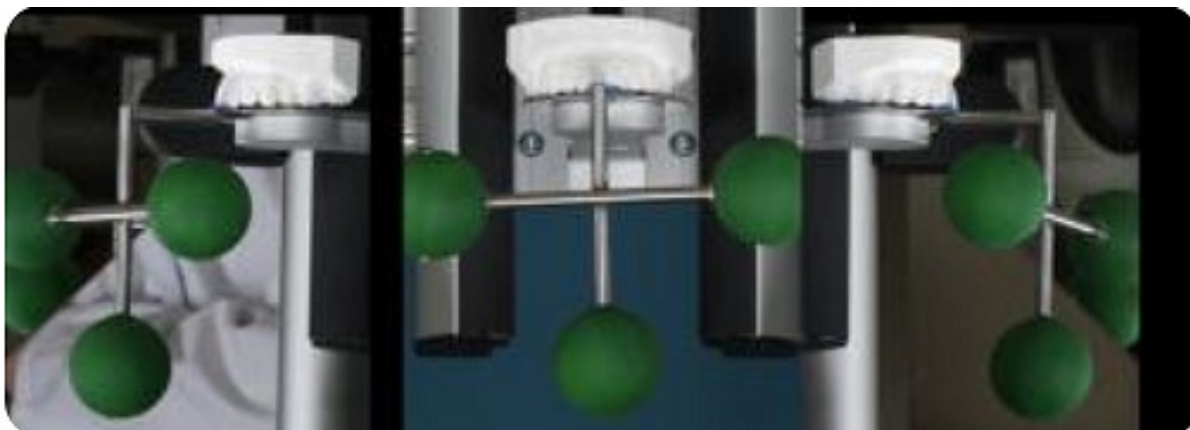


Fig. 11. Photos of the plaster cast of the upper jaw with the special bite fork for registration attached to it.

The patient takes the bite fork into his mouth letting the pellets stick out of it. Then a face scan of this situation is made. The bite fork is attached to the plaster cast in exactly the same position as the patient bit on it. After scanning this construct, the pellets now can be used to register the cast and the face data (Figs. 12 and 13).

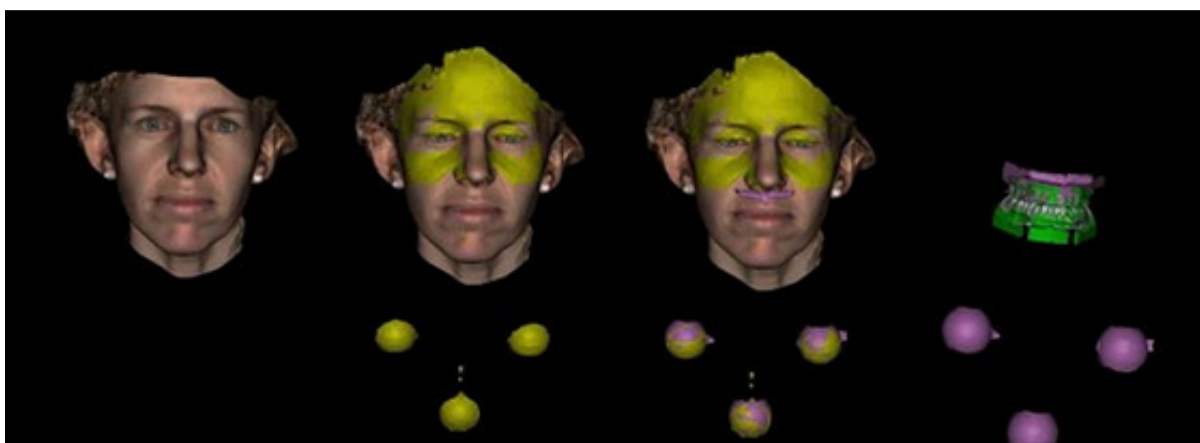


Fig. 12. Registration chain for placing the dental cast model correctly within the face scan (from left to right: face scan, scan of face with bite fork added, scan of cast with bite fork added, scan of cast added and face scans removed for visibility).

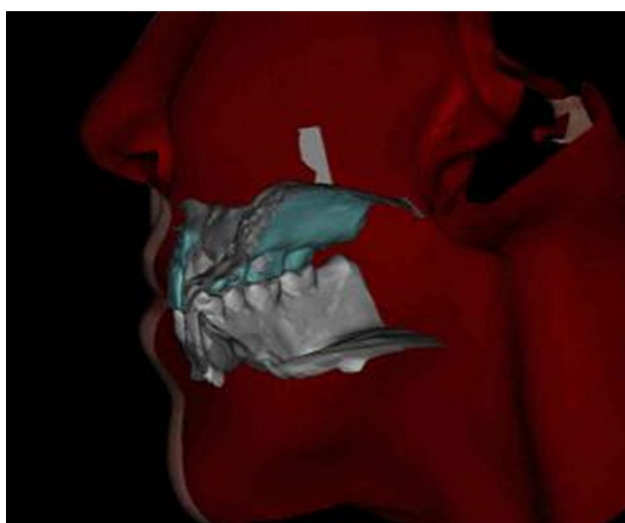


Fig. 13. Result of registration of face and dental cast scans.

Figure 14 shows how the registration result can be analyzed using cephalometric software like Onyx Ceph 3.

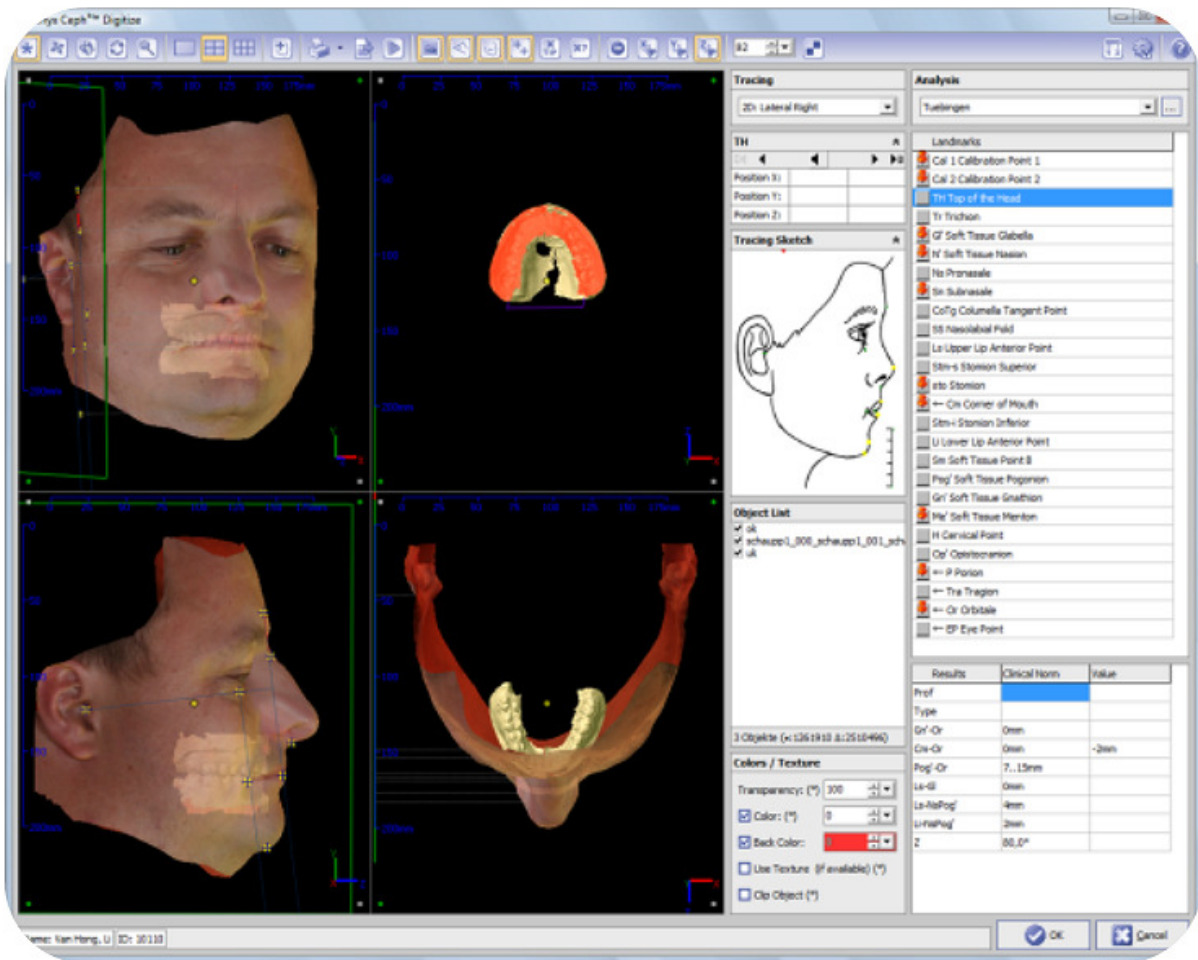


Fig. 14. Analyzing the registration result in Onyx Ceph 3.

## 5.2. Helmet Therapy for Babies

The helmet therapy enables the treatment of deformational plagiocephaly and other head shape deformities in early infancy without surgical intervention [10].

“The heads of infants can show deformations or asymmetries after the birth process. There are many factors that may influence the development of deformational plagiocephaly, such as premature births, restrictive intrauterine positioning, multiple births and/or birth trauma. The majority of deformations can be treated with physiotherapie – however a small proportion of deformations persists. To bring the heads to shape a lightweight plastic-helmet can be used. The Helmet is a customized orthosis to treat head shape deformities. At correctly grown areas the helmet is in contact to the skull, whereas it leaves a void over the flattened areas so constituted that normal growth is possible. Due to that, the best age for treatment is between 3 and 9 months. In this time the skull is growing at the fastest rate.” [11]

We have designed a setup with four mirrors that acquires 5 views of a baby’s head and allows to generate a full 360° model of the head (Fig. 15). From this data the helmet to treat the deformation can be manufactured by rapid prototyping (Fig. 16)

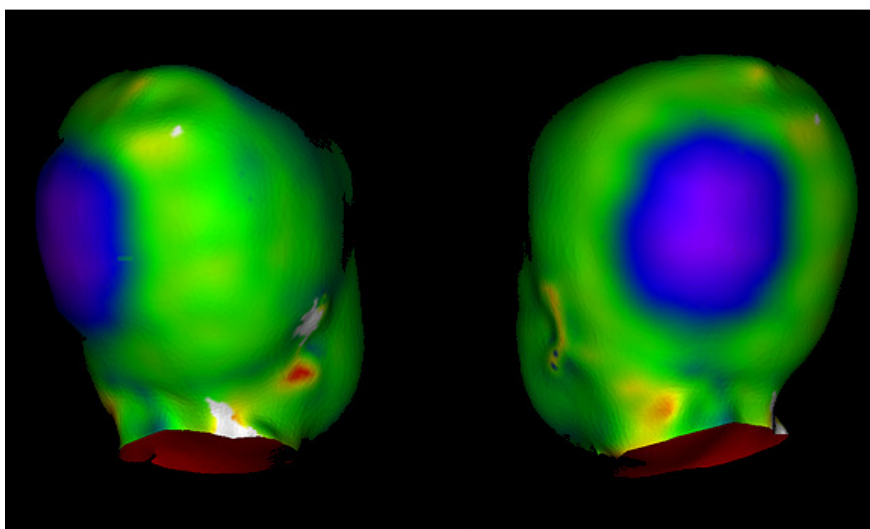


*Fig. 15. Four-mirror setup to get 5 views with one shot.*



*Fig. 16. Manufacturing the helmet by rapid prototyping.*

For analyzing the effect of the helmet therapy on the head shape, our comparison software enables the attending doctor to visualize and measure the volumetric changes that have been achieved (Figs. 17 and 18).



*Fig. 17. Visualizing the effect of the helmet therapy on the head shape.*

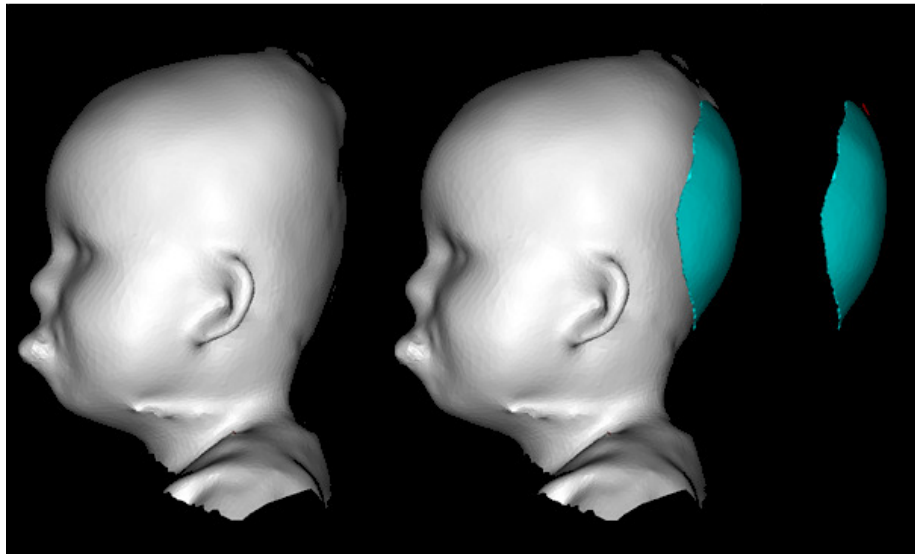


Fig. 18. Evaluating the change in volume.

## 6. Outlook

We are currently working on faster data processing by optimizing the algorithms and by utilizing the parallel processing capabilities of modern CPU's. As mentioned already, point cloud calculation already is possible in less than 1 sec.

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