PHOTOGRAMMETRIC QUANTIFICATION OF CHANGES OF SOFT TISSUE AFTER SKELETAL TREATMENT OF THE FACIAL PART OF THE SKULL

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ABSTRACT

In Germany, threedimensional non-invasive measurement techniques for medical purposes are not in routine use. Completely integrated applications of photogrammetric technology are still missing. In daily routine the possibilities of clinical findings, therapeutical and operative plannings are only subjective. The results of clinical examination, X-rays and prae- and postoperative photographs from different planes have been used for medical analysis. In an interdisciplinary research project we tested the general applicability of photogrammetric measurement systems. We examined patients with malformations of the mandible-maxilla complex by taking pictures from the face. In order to achieve a surface structure we projected regular patterns onto the surface. The first investigations were made in-vitro with an analog camera and the manual measurement of an analytical evaluation system. In this case we calculated about 800 points on the surface of a plaster cast with an accuracy higher than 0.4 mm. Furthermore we made comparative studies of living persons with a widely automated procedure using a digital photogrammetric recording and evaluation system. The measurement of digital image coordinates with the program PHAUST is supported by elliptical and center-of-gravity operators and shows a significant improvement of accuracy and time involved. Finally graphical analyses of measurement results are presented in a clinically relevant shape. We produce representations of the plaster casts and the faces in AutoCAD by means of regular meshes which allow any perspective view, longitudinal and lateral sections. In addition to calculating angles, distances, surfaces and volumes, the visualisation of the shape is a good help for documentation and quantification of changes of soft tissue of the human face under surgery treatment.

KURZFASSUNG

Hochpräzise dreidimensionale nicht-invasive Meßechnik ist derzeit in Deutschland in der medizinischen Routine nicht verbreitet. Es gibt auch keine in den klinischen Alltag integrierten photogrammetrischen Technologien. Die Möglichkeiten der Befunddokumentation, Operationsplanung und Quantifizierung von Weichteilveränderungen infolge therapeutischer und / oder operativer Maßnahmen sind derzeit rein subjektiv. Dem behandelnden Arzt stehen neben Röntgenaufnahmen und den Ergebnissen seiner klinischen Untersuchungen u.a. auch Photographien frontal und seitlich, prae- und postoperativ, zur Verfügung. Im Rahmen eines interdisziplinären Forschungsprojekts wird die anwendungsorientierte Entwicklung photogrammetrischer Meßtechnik zur Beantwortung medizinische Fragestellungen gefördert. Zur Festlegung der spezifischen Meßbedingungen in der Gesichts- und Kieferchirurgie wurden zunächst prae- und postoperative aufwendige Gipsmasken angefertigt und mit Hilfe analoger Aufnahmetechnik (Teilmeßkammer ROLLEI Metric 6006), unter Aufprojektion eines regelmäßigen Rasters, erfaßt. Die manuellen Bildmessungen wurden an einem analytischen Auswertesystem (Zeiss Planicomp C100) im Komparatormodus ausgeführt. Ca. 800 Punkte auf der Maskenoberfläche konnten mit Punktgenauigkeiten im quadratischen Mittel besser als 0,4 mm bestimmt werden. Weiterhin führten wir vergleichende in-vivo-Untersuchungen an Patienten mit Fehlstellungen des mandibulo-maxillären Komplexes durch. Hierbei wurden 4 CCD-Kameras eingesetzt und die Auswertung an einer digitalen photogrammetrischen Auswertestation durchgeführt. Die Bildkoordinatenmessungen unter Verwendung von Schwerpunkt- und Ellipsenoperatoren zeigen deutliche Genauigkeitssteigerungen und einen erheblich reduzierten Zeitaufwand. Die abschließende graphische Bearbeitung, die Darstellung über Gittermaschen und Shadings, erlaubt die Herleitung beliebiger perspektivischer Ansichten, Longitudinal- und Lateralschnitte sowie Flächen- und Volumenvergleiche. Neben den angulären und linearen Messungen stellt bereits die dreidimensionale Visualisierung ein gutes dokumentarisches Hilfsmittel für die klinische Diagnostik dar.

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1. INTRODUCTION

The assessment of therapies or operative interventions should be made by objective means and include threedimensional aspects. At the moment the possibilities for documenting clinical results, follow-ups, surgery plannings and the quantification of changes of soft tissue after skeletal treatment e.g. are only subjective.

In addition to X-rays, photographs were taken in frontal and in lateral planes, prae- and post-operative. In the course of clinical examinations, distances and angles of arbitrarily fixed anatomical landmarks were measured by means of compasses and ruler. The complicate manufacture of plaster casts is another device for documentation. Apart from the considerable stress for the patient (time for taking a plaster cast is about 20 minutes) an inaccuracy of some millimeters, inherent in the system, affects the quality. Therefore this method is not taken into account as a routine method for the quantification of clinical results. In principle X-rays faciliate the measurement of distances, but they ignore the third dimension of the contour of the body shape as well as cosmetic apects of therapeutical interventions.

Photogrammetric techniques aim at the geometric description of objects, conditions or movements in one or more photographs. In the past the original fields of applications were essentially the production of topographic maps from aerial photographs. The latest developments of computer-aided processing and the research of digital image-systems offer new possible uses for the close-range photogrammetry in architecture, industry and medicine.

Considering the evident need of objective methods for clinical judgement, non-invasive optical measurements were employed for the quantification of changes of the soft tissue of the human face. This work is supported by the Dept. of Science and Research of the German state of Nordrhein Westfalen. It is an interdisciplinary project of the University of Essen, between the Clinic of Maxilla Facial Surgery (Prof.Dr.Dr. D. Schettler) and the Faculty of Surveying (Prof.Dr.H.-J. Przybilla) to investigate photogrammetric applications for specific surgical purposes.

2. PRESENTATION OF THE PROBLEM AND PRELIMINARY EXAMINATIONS

Computer-aided measuring methods are rarely in use for the registration of anthropometric facts as well as a device for documentation and follow-up of the results of both conventional therapy and surgery. Examplary photogrammetric investigations have taken place only within the frame of scientific academic studies (Gäbel, 1995).

A highly precise reproduction of threedimensional measuring points make great demands on recording and evaluation techniques. Beyond that extensive specialized knowledge is necessary, so that a routine application by a physician seemed to be impossible up to now. The general applicability of photogrammetric techniques for answering medical questions was basically proved in orthopaedic examinations.

At the present patients with a malfunctioning of the mandible-maxilla complex were measured during therapy to specify the conditions for facial surgery. In this context the effect of the skeletal modification of the upper and the lower jaw on changes of the soft tissue should be registered. Accuracy of some 1/10 millimeters is indispensable to compare prae- and post-operative symmetry, surfaces and volumes of the face.

Our preliminary studies were made in-vitro, we took analog images from plaster casts. In this case we only needed one camera. We used the ROLLEI Metric 6006 and the projection of a regular cross-line grid of about 3 mm^2 size (fig.1). The images were measured manually with an analytic evaluation system, ZEISS Planicomp C100. It took about 8 hours to measure one plaster cast with more than 4000 image points. Checking and transforming of image coordinates and the multi-image-orientation for calculating 3D object coordinates took about 4 hours. We measured 100 calibration points in the reference frame and about 800 points on the surface of the plaster cast with an accuracy of $\sigma_{x,y,z} = \pm 0,37$ mm (Rehling, 1995).
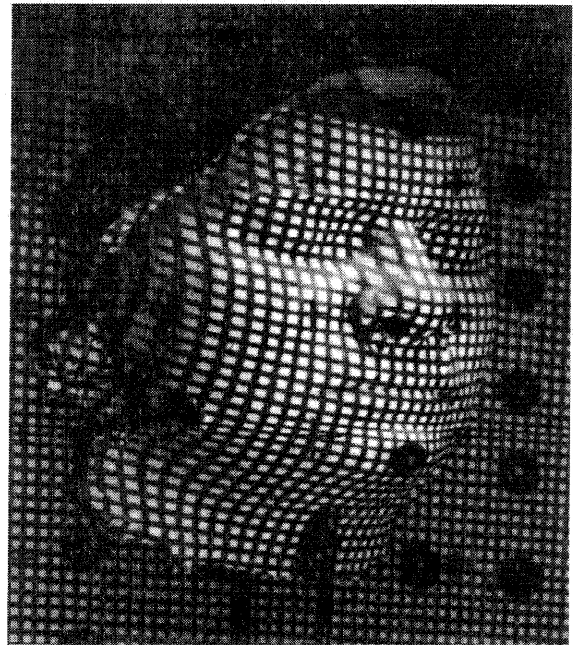

fig.1: plaster cast

3. METHOD

3.1 Digital Recording System

Pictures were taken synchronously from at least 4 CCD-Cameras (Charge Coupled Device) in defined spacial positions (fig.2).

The right choise of details and lenses facilitates a complete recording from one angle of the jaw to the other.

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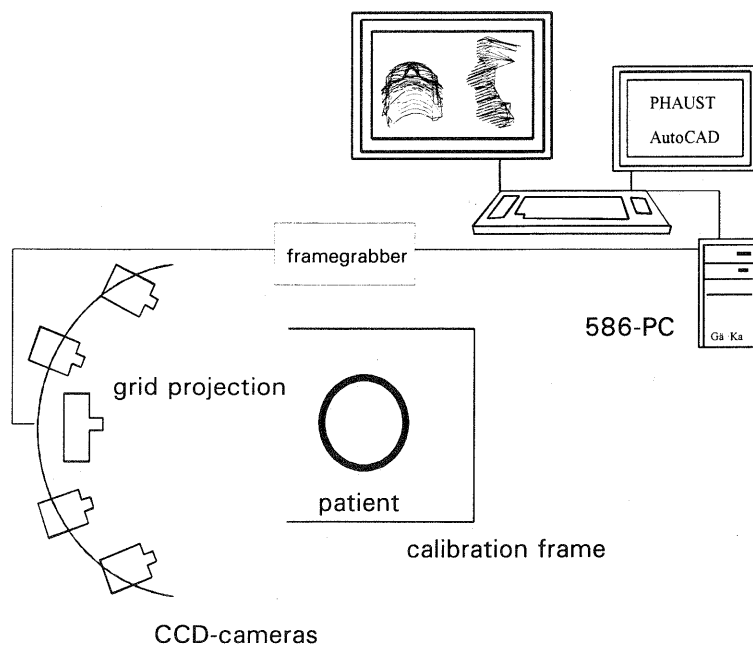
fig.2: recording configuration

In order to assign the bipupil-line, the patients were requested to focus on a distant point during recording. Emphasizing anatomical landmarks, such as infraorbital borders or median line, makes it easier to compare prae- and post-therapeutical conditions (fig.3).

We used 4 CCD-Cameras with a 2/3" sensor (768*484 pixel = 8.91*6.58 mm^2) and 16 mm lenses (fig.4). The images can be controlled immediately on the screen (on-line) and can be repeated right away if necessary. Amongst other things the quality of the digital image (sufficient contrast and brightness) has to be taken into account. One has to ensure that the surface is measured comprehensively without covering up important details, excluding shadows and overlapping (fig.5). The pictures can be stored on harddisk in conventional image formates (e.g. TIFF, BMP). A capacity of about 1,8 MByte for 4 images is needed. In pictures with various points of view the natural structure of the human skin is insufficient to identify obvious points on the surface. That´s why a projection of regular patterns is needed. We tested different numbers, forms and sizes of lines, cross-lines and point patterns. It is also necessary to illuminate the whole face in consistent distribution avoidung extended shadowy areas.

3.2 Digital Evaluation System

Depending on the recording configuration the following procedures take place:
The relative positions of the cameras to one another and their absolute position are unknown. Therefore the external orientation must be determined by means of a bundle adjustement, such as CAP (Combined Adjustement Program), with the help of a calibration field (Hinsken, 1989). The internal orientation can be determined within a simultanous calibration.

If the internal and external orientations are already known by advanced calibration, the object coordinates can be assigned with a spatial forward intersection. Measurement of image coordinates (fig.6) is carried out with a specific module of the image processing program PHAUST (Photogrammetrische Auswerte Station, Woytowicz, 1993).

First the measurement images are correlated. The semi-automatic point measurement is performed by elliptical and center-of-gravity operators to determine the image coordinates. The next step is the calculation of object coordinates either by bundle adjustment or spatial intersection.
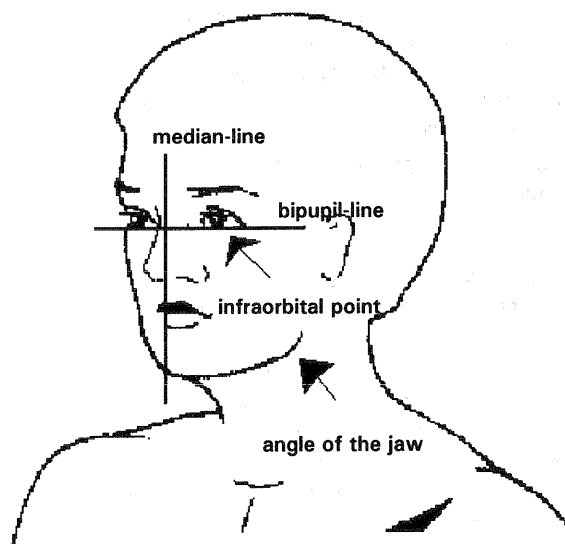

fig.3: anatomical reference points

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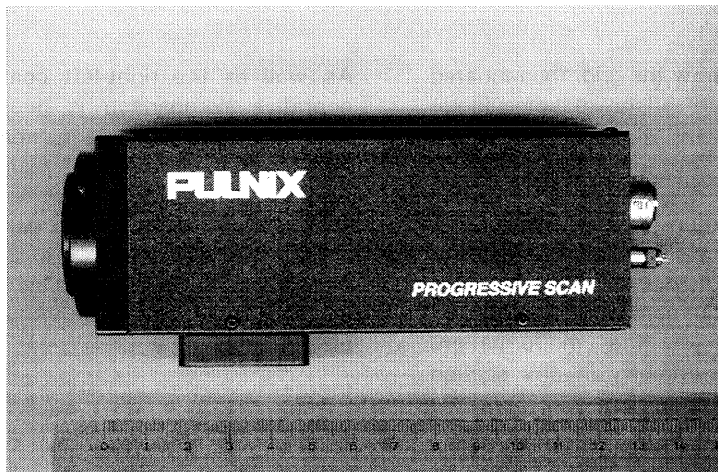
fig.4: CCD-camera

As a result we receive spatial (X,Y,Z-) coordinates of the measured shape of the face and the plaster cast. For further analysis the data files are transferred to CAD-programs (Computer-Aided-Design).

After running the PHAUST module some hundred points are available to be linked up within regular surface meshes in AutoCAD or Microstation. With that any interpolation of points is possible depending on the demanded accuracy. For example a cubic B-spline is used in AutoCAD to interpolate 3D polylines and meshes. Special applications allow the assessment of post-therapeutical changes of all points on the measured faces.

Lists of coordinates or graphic analyses are available. In other words: photogrammetric measurement of patients at two or more points in time allow a numerical and / or graphic overlay and comparison of the shapes. The derivation of views from any possible perspective, transversal and lateral sections as well as the calculation of angles, distances, shapes or volumes now allow the objective evidence of the consequences for soft tissue after skeletal surgery treatment. The following figures 5a and 5b show details of the frontal measurement image with a projected point grid and the appropiate image points. In the background of the picture some retroreflecting targets of the calibration frame are visible.
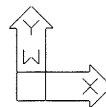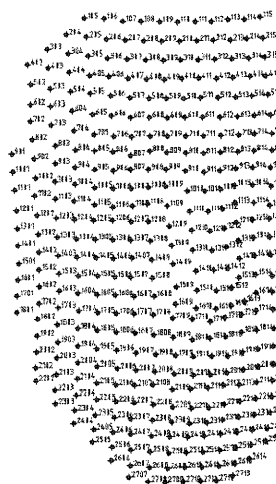

fig.5a: measurement image

fig.5b: image points

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4. RESULTS

The following illustrations show the grid, the rendered surface and a left right comparison of some longitudinal sections of the lateral view of a measured plaster cast (fig. 6a,b,c). The number of points to calculate the meshes is 1.5 times as high as the orginal number of measured image points. The interpolation method is a cubic B-spline. The point of view is the same as in the X-rays and well-known to the physician. It allows judgement of the profile and thereby the dimensions of the malformation. Comparisons of right-left-symmetry in any section quantify conspicious areas and allow more specific analyses.

As well as the right-left comparison a prae-post-operative comparison is possible, shown in fig. 7a,b,c. In this case, only minimal changes are visible, functional aspects more than cosmetical aspects were the general reason for the surgical intervention. The problem area in these cases is the mouth, the representation of the lips is not satisfying, as mentioned above a possible reason may be the inaccuracy of the manufacturing process of the plaster casts.
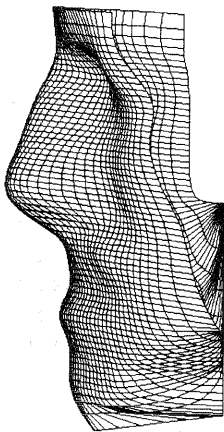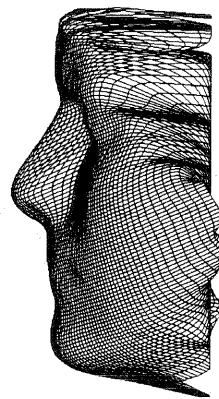

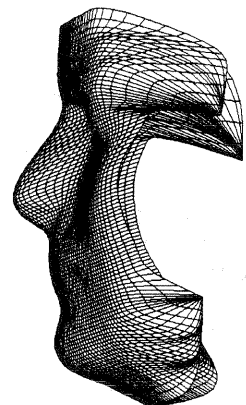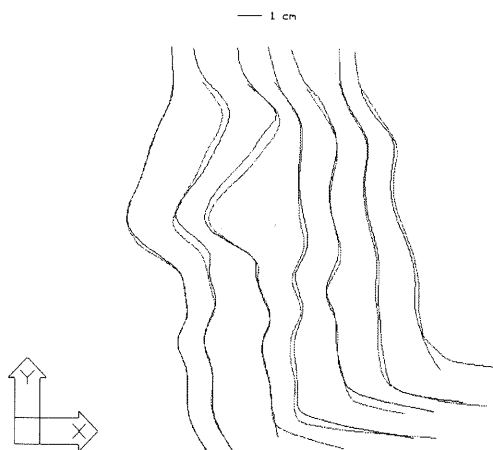fig.6a: meshes

fig.6b: rendering

fig.7a: praeop
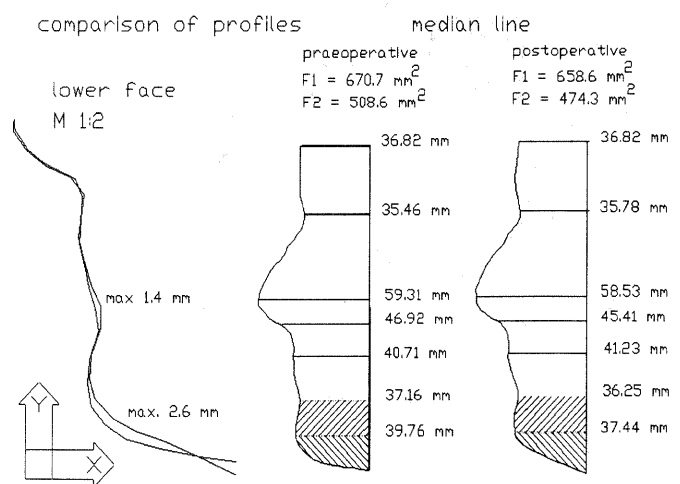

fig.7b: postop

fig.6c: longitudinal sections

fig.7c: prae-post comparison

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5. DISCUSSION AND OUTLOOK

Applications of photogrammetric measurement techniques referring to clinical diagnosis assistance were presented.

This technology implies high-precision, non-contact documentation of clinical findings. On account of the short time for recording (some 1/10 seconds) conditioned reflex changes of posture can be ignored. By synchronously releasing at least 4 cameras it is possible to determine complex body surfaces, for instance back and chest shape and faces.

Advantages of the presented method are the quick measurement process (minimal stress for the patient), the non-invasiveness (no exposure to radiation) and little physical contact. In addition to that, photogrammetric data offer high accuracy and extensive information of the images. The digital gray value image can be controlled immediately on a large format screen and the quality of measurement material can be checked at once.

The presentation of longitudinal and lateral sections in anatomical and / or therapeutical relevant areas facilitate

- the quantification of go down measure
- the documentation of lymph drain
- the consequences for soft tissue volume after implantation of foreign material.

For the planning of reconstructive interventions it is useful to look at the surface from different points of view. The assessment of the physian is supported by a threedimensional visuell impression of the momentary status and allows a picture of the planned result.

Apart from long term studies and follow-ups, screenings can prove any changes of soft tissue and the shape. The prae- and post-operative conditions can be quantified. Posture, muscle tonus and surface structure are documented. Additional anthropological investigations can easily be realized, for example the assessment of growth, consecutive interindividual comparisons as well as advanced planning.

As a result of that kind of screenings, the development of predicting software is conceivable for the future. In context of computer-aided therapy-planning it should be possible to predict changes of soft tissue after skeletal treatment of the facial part of the skull. Another goal is the technically supported diagnosis of dentoalveolus malformations.

The research of measurement systems for intraoral examination with derivative recording sensors should be supported.

Photogrammetric measurement is useful for diagnoses and helps to increase objectivization. Disadvantages are mainly the amount of time involved for the complete process, the expenses for hard- and software and the required expert knowledge.

Future developments aim at the simplification and wide automation of the recording and evaluation systems. On the one hand hardware configuration with 4 fixed CCD-cameras within a calibrated frame is useful to minimize the time for taking pictures. On the other hand the conditions for evaluation are optimal, the calculation of object coordinates results from spatial intersection. Provided the parameters for the interior and exterior orientation are known, the complex calibration process can be reduced to rare checks.

The results must be presented in clinically relevant time and shape and should be comprehensible for non-photogrammetric users.

In addition to that the following advantages can be recapitulated:

- non-invasive, non-contact
- the real measurement time is short
- high accuracy, extensive data memory
- availability for further check-up
- results are 3D objevt coordinates ☞ open architecture
- calculation of angles, distances, surfaces, volumes
- presentation of longitudinal and lateral sections, meshes, shadings.

6. REFERENCES

Gäbel,H.,et al.;1995: Photogrammetrische Verfahren zur Erfassung von menschlichen Körperoberflächen, VDV-Tagung, Essen

Hinsken,L.;1989: CAP: Ein Programm zur kombinierten Bündelausgleichung auf Personal-Computern, Bildmessung und Luftbildwesen, S. 92-95

Kakoschke,D.,Gäbel,H.;1996: Dreidimensionale photogrammetrische Erfassung von Gesichtsoberflächen, 46. Tagung der Deutschen Gesellschaft für Mund-Kiefer-,Gesichtschirurgie, Regensburg

Rehling,J.;1995: Photogrammetrische Messungen am menschlichen Gesichtsschädel unter Anwendung digitaler Aufnahme- und Auswertetechniken, Diplomarbeit, Labor für Photogrammetrie FB 11, Vermessungswesen, Universität GH Essen

Woytowicz,D.;1993: PHAUST - A photogrammetric evaluation system for digital images, Optical 3D Measurement Techniques II, A.Gruen and H.Kahmen (Eds.)

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