PRECISE BIOLOGICAL SURFACE MEASUREMENTS IN SOME MEDICAL AND DENTAL STUDIES

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ISPRS Commission 5

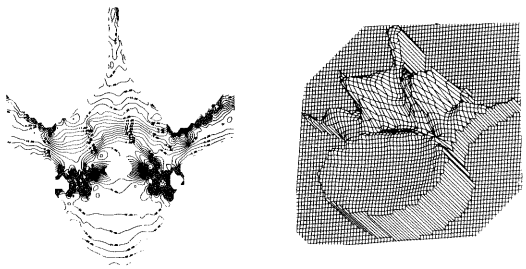
ABSTRACT

Non contact, precise measurements of the topography of irregular biological structures are important needs of medical and dental investigators.This work presents novel non-contact procedures and techniques for the measurement and mapping of a variety of biological organisms and features.After an introduction on the scope of biostereometrics in South Africa,the paper discusses such diverse topics as the upper cervical spine, the "screw" in the rat portal vein, the attrition of denture teeth,regional body surface motion, human head movements and the precise measurements of bone growth in a rat model using stereo xrays.

Key words:Biostereometrics; Biological form; Measurements.

1.INTRODUCTION

Biostereometrics (medical stereo-photogrammetry) has been defined as the spatial and spatio-temporal analysis of biological form and function based on the principles of analytical geometry (Karara, 1989).



Computer generated contour plot and perspective view of L4 (inferior) lumbar vertebra.

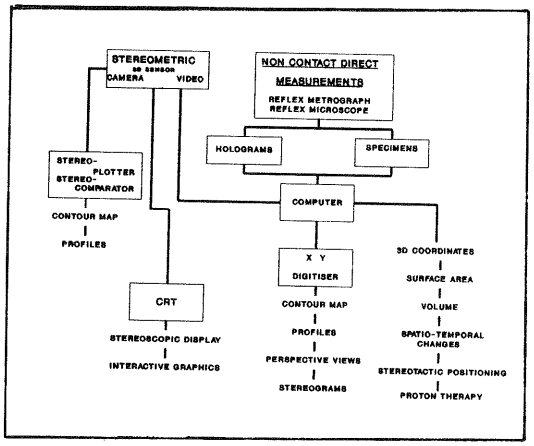
For many years , topographic maps of the earths surface have been compiled by the method of stereo-photogrammetry, using a variety of sensors to capture the necessary images for measurement purposes. The main sensor has been the traditional air camera but, with the advent of new technologies,use is also been made of satellite imagery obtained through multi-spectral scanners, video solid state cameras, radar imaging and so on. Biostereometrics contemplates the "mapping" of biological form, using similar techniques and algorithms utilised in topographic mapping, but adapted for close range imaging.

In the past , lack of convenient sensors inhibited the growth of biostereometrics but today there is a growing variety of sensors to choose from, which will provide stereo images of one sort or another and which can be measured to yield precise spatial data of biological form.These sensors include stereometric cameras,stereometric (CCD) video cameras, stereometric x-rays, computed axial tomography(CAT), magnetic resonance imaging (MRI), hologrammetry, ultra sonic imaging and direct reflex measurements.

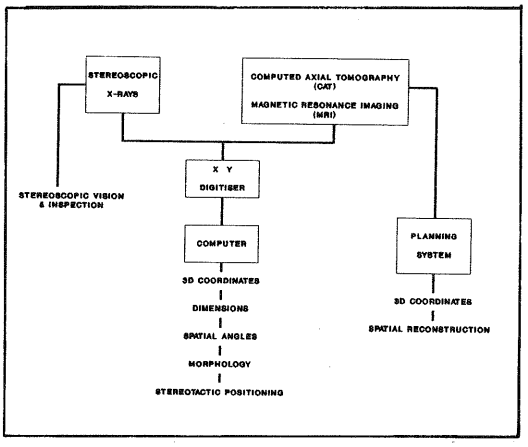
The biostereometrics section in the department of Biomedical Engineering at the University of Cape Town has been set up to undertake research projects, in conjunction with medical and dental researchers, to provide precise measurements of biological form.The UCT/MRC biostereometric group is engaged in numerous research projects using most of the sensors listed .

2. SCOPE OF BIOSTEREOMETRICS IN SOUTH AFRICA

The scope of biostereometrics in South Africa, using various sensor devices, is outlined schematically in the following two diagrams:



Visible Spectrum Imaging



Non Visible Spectrum Imaging

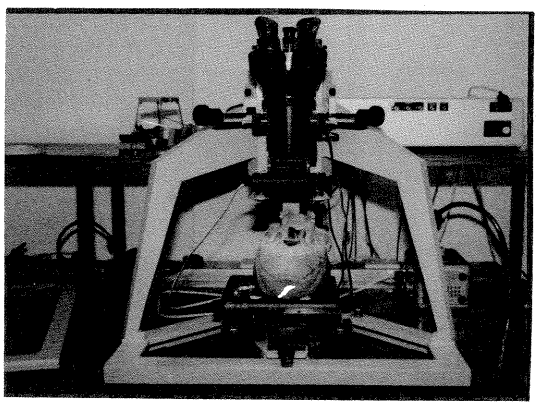
3. MEDICAL AND DENTAL RESEARCH PROJECTS MAKING USE OF BIOSTEREOMETRICS AS A PRECISE MEASURING TOOL

To illustrate some of the research work concerned with the measure of biological form which has been developed by the UCT/MRC biostereometrics group, a few examples are presented here:

3.1 VISIBLE SPECTRUM

3.1.1 NON-CONTACT PRECISE MEASUREMENTS.

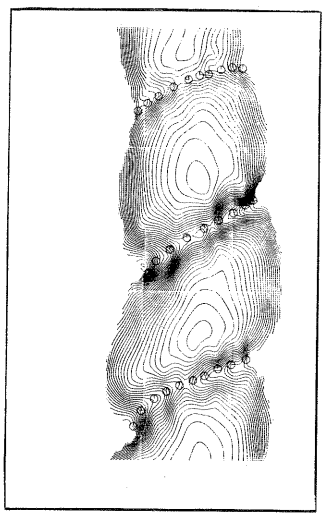
The main measuring tool in these studies has been the Reflex Microscope (Scott,1981).



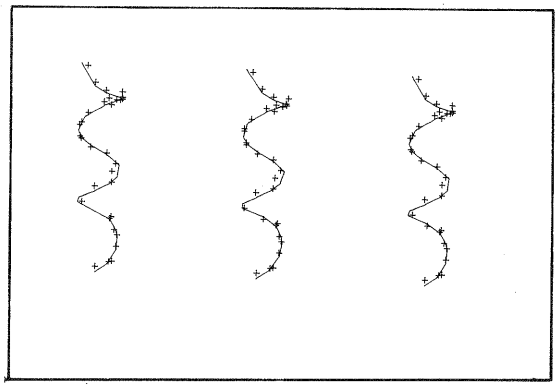
The Reflex Microscope

3.1.1.1 The rat portal vein screw.

Although the helix (screw like structure) in the portal vein of the rat, pig and baboon was described over 20 years ago, the function remains poorly understood. This has been largely due to the lack of a technique for measuring changes in the screw under different conditions. In conjunction with the Department of Surgery and the Liver Research Unit at the University of Cape Town, the biostereometric researchers are using the reflex microscope to measure the size and characteristics of the helix on resin casts of the rat portal vein.
Although the project is in its initial stages, interesting results are already being obtained as illustrated in the graphical plots included here:



The screw of the rat portal vein

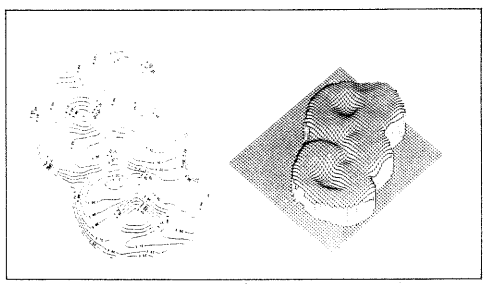


A stereo-triplet of a rat portal vein helical "screw" which demonstrates how closely it conforms to a "best fit" mathematical helix. ***Note: Stereopsis of any two adjecent members yields two spatial images with reversed depth. The stereoscopic effect can easily be achieved either by viewing the triplet with the naked eye using the parallel eye method or by the cross-eye method, in which case the "depth" will be reversed. For the stereoscopically "uninformed" a simple hand stereoscope should be used to achieve stereoscopy.***

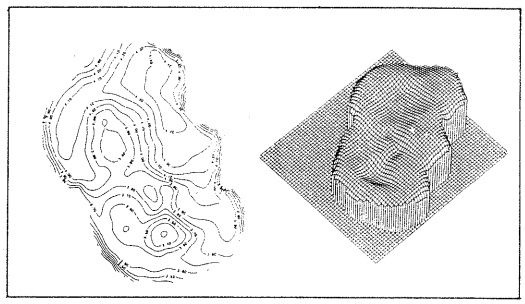
3.1.1.2 The quantification of wear of denture teeth.

The attrition of denture teeth has been a concern to prosthetists for a long time. With the advent of acrylic resin however, the problem has become more acute, although in recent times, acrylic resin technology has progressed significantly in producing harder resins which are more suited to withstanding occlusal wear. To quantify comprehensively the extent of wear and to display the volumetric loss of material under clinical conditions, has proved difficult in the past. A method using a reflex microscope to undertake direct and highly precise three-dimensional measurement of denture casts, for the purpose of mapping and determining the volumetric loss of material over a period of time, has been developed jointly by University of Cape town biostereometric researchers and dental researchers from the University of Stellenbosch (Adams et al, 1989).

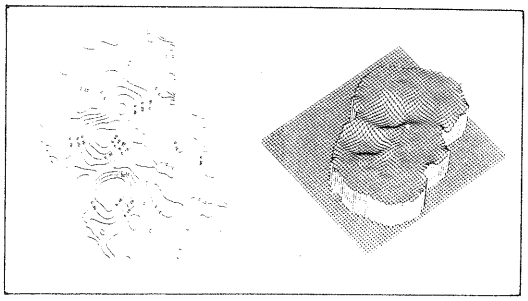
Examples of graphical computer outputs, demonstrating the loss of material, are shown here:



Tooth 46 before wear



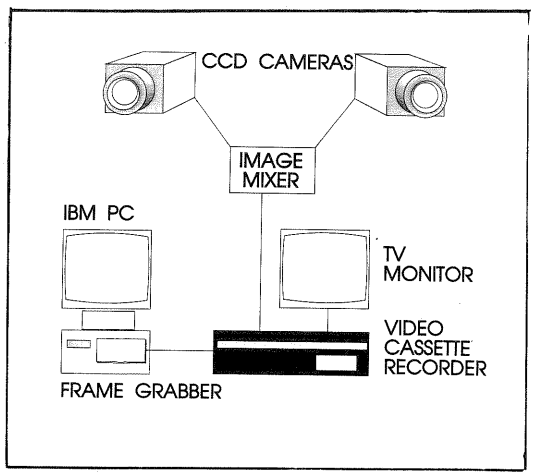
Tooth 46 after one year of wear



Difference plot demonstrates loss of material.

3.1.2. STEREO VIDEO TECHNOLOGY.

A stereometric video camera system has been established and numerous motion study projects have been undertaken using the system, or modifications of the system.



A near real-time stereometric system

Two of the studies are described briefly here:

3.1.2.1. Regional body surface motion in respiration.

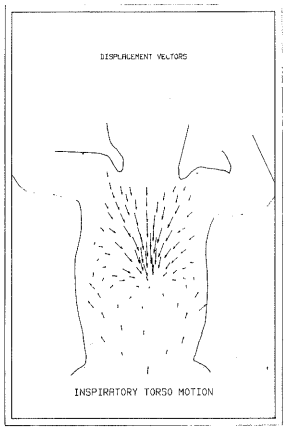
The process of breathing is remarkably complex and our understanding of it is incomplete even at the qualitative level.

Interest in the study of respiratory motion stems from the insight this gives into the function of the respiratory muscles; the only skeletal muscles in the body essential to life.
Since respiratory muscle weakness is an important factor in the genesis of acute respiratory failure, it has become important to gain a better understanding of their function.

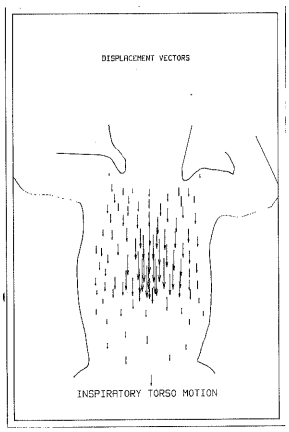
A near real-time biostereometric method using stereometric CCD cameras is presently in use at the Department of Paediatrics and Child Health for clinical research studies at the Red Cross War Memorial Children's Hospital in Cape Town. The system allows for the precise spatial determination of targetted points on the chest at any given time (Adams et al, 1990).

A part pictorial demonstration of a "funnel" chest is shown here:

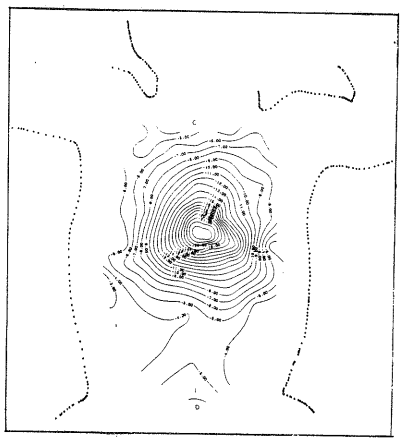
Plots of Epoch Difference
Breath-in minus Breath-out



X Y Displacement Vectors



Z Displacement Vectors



Contour plot

3.1.2.2. Human head movements.

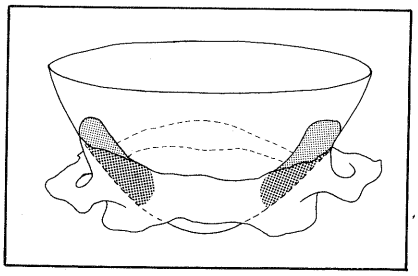
Using a pair of synchronised CCD cameras in stereometric mode, the movement, in three dimensions, of a reference point attached to the face of a number of normal subjects, were determined stereo-photogrammetrically as the subjects moved their heads in flexion, extension, laterally and right and left axial rotation. From these measurements , the surfaces, described by the reference point in the various movements, could be mathematically ascertained. In the event, the surface described proved to be a very close approximation to an elliptical paraboloid with a tendency towards a sphere. An interesting result since this would imply that there is a single point of rotation; the centre of the "sphere".

A normal Subject being recorded during axial rotation. ***Note: The targetted harness allows for shoulder movements to be mathematically isolated from head movements.***

Interpretation of this unexpected finding is not straightforward since cervical movements result from 23 individual synovial joints in the neck which, together, permit different planar movements, rotations and shear motion.
Panjabi et al (1988) showed that the greatest intervertebral motion in the cervical spine was axial rotation, at the C1-C2 joint, and flexion/extension at the occiput-C1 joint.Having established stereophoto-grammetrically that the combined motion of a point on the face described the surface of an elliptical paraboloid, with a tendency towards a sphere, it was considered interesting to attempt to explain the findings by studying the geometry of the surfaces of the articulating facets of the occiput-C1 and C1-C2 joints, since the greatest movements took place at these junctions.Six macerated, human adult, whole cervical spine specimens (base of skull to C7) were obtained. Using the reflex microscope, measurements were concentrated on the articulating bony joints of the skull with C1 superior and C1 inferior with C2 superior. In the event, it has been established that the bony surfaces of the occiputal condyles, C1 superior and C2 superior pairs of articulating facets all form part of the surface of individually common elliptic

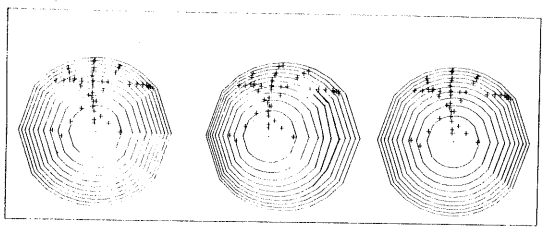
paraboloids to a very high degree of agreement.These findings would seem to support the postulate that a point on the moving head of normal subjects moves with a locus on the surface of an elliptic paraboloid.

Some illustrations, of the findings of this continuing research project, are shown here:

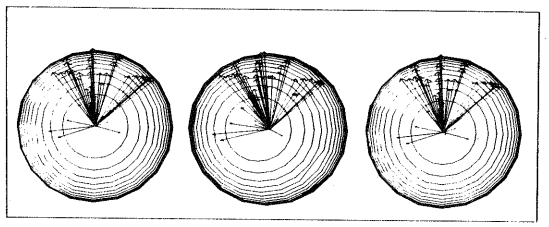


An elliptical paraboloid "sitting" on the facets of C1 superior.

STEREO -TRIPLETS: FEMALE SUBJECT



Elliptical Paraboloid



Sphere

Note:The closed lines represent the best fit elliptic paraboloid or sphere. The crosses and arrow heads show the actual positions of the moving target.

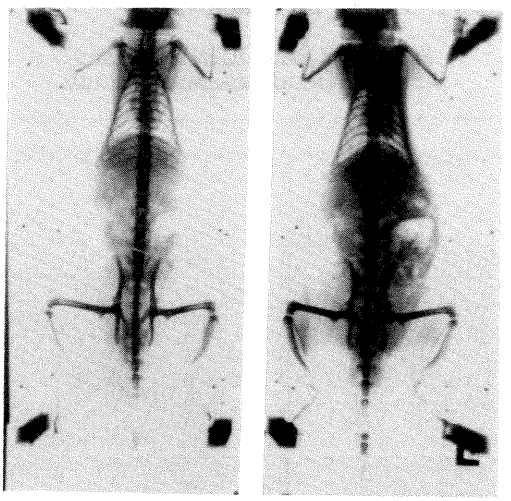
3.2. NON VISIBLE SPECTRUM.

This includes CAT and MRI images and stereo x-rays. A brief description of a research project using stereo x-rays to determine limb lengths follows.

3.2.1. Stereo x-rays in the study of bone growth in a rat model.

The management of peripheral vascular injuries in children has been the subject of much concern. A central issue in this regard is whether or not compromised arterial flow which does not threaten viability of the limb might nevertheless produce ischemic changes in the cartilagenous growth plate of young bones, resulting in long term growth disturbances.

In this study (Bass et al,1992), x-ray stereophotogrammetry was used as an accurate means of in-vivo measurement to asses the effects of temporary arterial interruption on longitudinal limb growth in growing experimental animals.



Positive prints of a stereoscopic x-ray pair of a rat model.

4. FUTURE DEVELOPMENTS

Very interesting and important work in the development of a stereotactic positioning device, using near real-time stereo video technology, for use in orthopaedics and neurosurgery is in progress and a prototype devise is presently being constructed.

The use of stereo x-ray photogrammetry as a precise measurement device in the study of the human anatomy is hamperered by the requirement that usually simultaneous stereo x-ray imagery is required. This is a costly procedure since it normally implies the use of "two focus" x-ray instrumentation (Turner-Smith, 1991).

Using simultaneous x-ray exposure and stereo video image capture, the movement of the patient between stereo pair x-ray exposures allows the use of a single x-ray focus apparatus to produce a pair of "controlled" x-ray films.

Much is expected of this study.

5. CONCLUSIONS

Biostereometrics is beginning to be recognised by the medical research community and the clinician as a very important and precise spatial measuring tool. For many years the authors had undertaken biostereometric research work in a department of surveying, an enviroment remote from the medical world. Although much useful work was done, the medical researchers found it difficult to accept that topographical measurement was very closely allied to biological measurement. The relocation of the main biostereometric researchers at the University of Cape Town into the Faculty of Medicine has undoubtably made stereophotogrammetry medically "respectable" in South Africa, albeit under the guise of "biostereometrics".

6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the generous financial support received from the S.A. Medical Research Council, the University of Cape Town Staff Research Committee and the Faculty of Medicine Ethics and Research Committee.

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