The Bausch & Lomb Photogrammetric Award

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Photogrammetry in Medicine

Undergraduate Award

ABSTRACT: *Medical photogrammetry is the term used to cover all applications of photogrammetry in the broad field of medicine. The applications are wide in range; however, the majority relate to the measurement of the shape and size of body parts and to changes in the form of these parts with time. The primary tool of medical photogrammetry is stereophotogrammetry but other forms of imagery, such as moiré fringe interferometry and holography, are also used. The applications are classified according to the imaging system employed, and, for each system, a number of applications are discussed in detail in the body of this paper. Finally, the value of photogrammetry in medicine is felt to be a very important asset in the research of form, shape, and size of the human body and body parts.*

INTRODUCTION

ALL THROUGH HISTORY, measurements have been made by eye estimate, tape, and calipers to describe the form of the human body. A system of proportions was set up by Egyptian artists over 4000 years ago based on the width of a human hand as a unit of measurement. However, these methods were found to be very frustrating and difficult due to the lack of obtaining direct measurements and the lack of a convenient three-dimensional measuring system.

As a result of continued research in this area, photogrammetry was developed in the middle nineteenth century. Holmes, an American physician, is credited with the first application of photogrammetry in medicine. In 1863 Holmes studied gait by using stereopairs of photographs taken of humans. These techniques enabled Holmes to design artificial limbs for men who lost arms or legs in the American Civil War. Applications began to gradually increase and diversify into several areas of medicine. However, development was slowed drastically by the research done for aerial surveys during the First World War. By the 1930's interest in the medical aspect of photogrammetry began to rise again. At this point aerial surveying was well established, which brought about better and more sophisticated equipment to be used for medical research. Research in this field was brought to a halt once again by the Second World War; however, progress began to pick up again in the early 1950's. Since the 1950's, development and diversification of new methods has rapidly continued. Due to the increasing availability of computers and the introduction of nonconventional imaging systems such as moiré fringe interferometry and holography in the last 15 years, progress in medical photogrammetry has advanced significantly. The largest number of investigations made in medical photogrammetry has dealt primarily with the measurement of size and shape of all body parts in conjunction with body geometry and form and cranio-facial morphology studies.

APPLICATIONS

Movement is normally involved in medical applications of photogrammetry, due to what is being studied or due to the subject being alive. Because of these situations, it becomes necessary to obtain a synchronized pair of cameras for photogrammetry to be used. Normally the distance between the camera and observation specimen is between 0.25 metres and 5 metres. The stereometric cameras have the shutters synchronized to about 20 milliseconds to halt any motion caused by the object being photographed. Control is also required, as in all other

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types of photogrammetry, to enable scaling and orientation of the model for future calculations and analysis. By finding two points a known distance apart within the overlap of the two photos, scaling can be acquired rather simply. Additional control points may be needed if it is decided to orient the specimen model to a datum plane. The amount and type of data to be taken from the photograph, the accuracy of measurement required, and the photographic system used are determining factors a person must consider when choosing a method of analysis for any one application in determining body forms and measurements.

There have been a large number of applications developed in the field of anthropometrics (measurement of body form), and the largest concentration is in the determination of the volume and surface areas of the whole body or of different types of body parts. Applications and procedures differ according to the body part being investigated, and will be discussed in the following paragraphs to show the different methods used for each body part.

WHOLE BODY MEASUREMENT

Methods used for measuring the whole body were developed in the early stages of medical photogrammetry. The single greatest difference between the various types of investigations made were the ways that the photographs of the specimens were obtained and in the type of pose used. In 1954, Berner used stereophotogrammetry to measure the body's surface area by applying horizontal profiles drawn at regular intervals from head to foot; however, there was no detail as to the equipment used or the conditions under which the photos were obtained. In 1975, it was reported in Sweden, by Torlegard, that progress was taking place in the development of a photogrammetric method for measuring the body. Torlegard reported that the subject is placed in front of a pair of non-metric cameras separated by a vertical base. Mirrors are then placed a short distance behind the subject and on both sides of the subject being photographed. This type of procedure enables the photographer to obtain the direct photo image, the left mirror image, and the right mirror image all on the same photograph so that, by using the stereopairs, measurement of the body is possible.

LIMB AND TRUNK MEASUREMENT

By using mirrors to produce all-round photography of limbs and limb remnants, Kratky in 1975 utilized the multiple points so that a digital model of the limb can be acquired. With the aid of computer processing, numerically controlled machines are then used to produce an exact replica of the limb, which aids in the fitting of artificial limbs. In 1974, Atkinson used repeated stereometric photography to enable himself to examine the relationship between prosthesis content and volume in the case of breast reconstructive surgery. One serious problem faced with this procedure was the issue of constant reference points on the patients skin during the investigation period. Small tatoo marks were made in the patients skin, to be used as reference points, until surgery has been accomplished.

HEAD, TEETH, AND JAW MEASUREMENT

Photogrammetry has also been used in the study of the head, teeth, and jaw. This is mainly due to the importance placed on personal appearance and the ability to eat efficiently. This area of the human body has been addressed by photogrammetry more than any other area of the body due mainly to the pre-described reasons. Orthodontists and dentists have become very interested in photogrammetry due to procedures and results enabling them to obtain measurements of shape and changes in shape resulting from growth, surgery, and dental treatment. Applications of photogrammetry, dealing with the head, teeth and jaw, are divided into the following three categories: facial studies, palatal analysis, and tooth measurement.

Facial Studies. In Sweden, in 1954, Bjorn reported on measurements concerning the measurement of post-operative facial swelling. A Wild 400-mm stereometric camera was used, but he reduced the camera to the object distance of 800 mm by attaching close-up lenses. Wictorin of Sweden, in 1971, has had some of the more recent studies dealing with the change of soft tissue contours of the face following surgical treatment of mandibular protrusion. Photographs of the patients were taken before and after surgery with a Nikkor stereometric camera. A Wild A7 stereoplotter enabled the plotting of the facial contours. Natural detail points on the face were used as control points, to allow comparison of facial plots made from the two sets of photographs. With this procedure used, fixation of the head was not required. In 1977, analysis of surgically corrected abnormal faces was undertaken in the United States by using stereopairs taken before and after the facial operation. In this work the subject was prepositioned in a reference frame and three stereometric cameras, each equipped with an electronic strobe projector to enhance skin contrast, were used to obtain complete coverage. Studies of these types have involved the use of conventional stereometric cameras and stereoplotters to enable the user to produce life-size contour plots of the face and to analyze information concerning facial changes.

Palatal Analysis. As a result of growth, orthodontic treatment, and surgical repair, stereophotogrammetry has been explored by several researchers as a means of measuring the forms of palates, of both normal and cleft palate subjects. Impressions of the palate are made available from plaster casts and are then used to acquire information concerning the shape and size of the palate. By

moving the plaster cast sideways between exposures, stereo-photography of the palate was achieved by Berkowitz in 1971 by using a single metric camera. Stereophotogrammetry has been making it possible to analyze the shape and size of palates with far greater detail and accuracy than any other methods previously used. If a great deal of care is taken, however, good results may be obtained with a good quality non-metric camera.

Tooth Measurement. Investigations dealing with teeth configuration and tooth morphology have also been included in stereophotogrammetry. Methods for measuring the occlusal surface of teeth and then obtaining contour plots is accomplished in the same manner as for the measurement of palates. In 1967, Gruner developed a close-range camera system to obtain measurements of the mouth in order to control and determine changes in teeth configuration, gum, and bone tissue before and after surgery. A large number of points are measured on the tooth surface, which allows the surface to be described mathematically by a surface fitting technique. For this type of application stereophotogrammetry is considered to be superior to any conventional technique.

The Moiré Fringe Technique

The moiré fringe technique was developed in Japan in the middle 1960's. With this technique, contours are produced on the experimental subject as interference fringes while the subject is illuminated by a point source of light through a plane grating of equally spaced lines. The pattern is produced by the interference of the grating and its shadow on the object, and this pattern can then be recorded by replacing the observer's eye with a single or stereoscopic camera. The moiré fringe technique is very convenient to use, and the interpretation of the photographs is fairly simple and, best of all, does not require the use of sophisticated measuring devices and computer systems. Furthermore, posing proves to be no problem because the contour fringes can be observed by the naked eye. In simpler terms, the subject can be rotated with respect to the grating until satisfactory orientation and contour pattern is achieved. One problem with this technique is that the contour interval is not constant when using simple radiating light. However, by using parallel light, this problem can be easily overcome. This technique is being increasingly used in the medical field, especially in the area of spinal analysis and in the early diagnosis of scoliosis.

Holography

Holograms rather than photographs are utilized in Holography, and the use of these for measurement purposes is called hologrammetry. Coherent monochromatic light must be used during the recording of holograms to illuminate both the object and the photographic plate. This light is most commonly produced by lasers. Several different types of holograms may be formed by varying the geometry of the optical arrangement used to record them. There are practically no optical limitations on focusing and the depth of field, because no lenses are involved in this type of research. With this advantage, it makes it particularly suitable for very close range work. One problem with holography is that the object size is restricted to the size of the photographic plate. Exposure times are very long and during exposure relative motion between object and recording beam must be avoided, which can cause problems when studying live subjects. Holographic systems are also limited to use in areas such as laboratories where coherent light is available. Holography may be used in such areas as the study of bone structure and the study of tooth displacement and the stress-strain distributions in the peridontal ligament caused by point loading applied to teeth. However, the future of this procedure in medicine is uncertain and will need much more research and development before it becomes as convenient, versatile, and accurate as stereophotogrammetric methods.

Advantages

When applied to measurement in medicine, important advantages of photogrammetry over conventional methods have been indicated by applications under review by researchers.

- Photogrammetry is a non-disruptive technique in that it totally avoids all risks involved in hurting, infecting, or distorting the human subject being studied. The main advantage is that of the object not being distorted by contact, which proves to be very important because the human body can be easily distorted by applied pressure on the soft tissues.
- Photogrammetry can make it very easy to measure objects which in the past have been very difficult to measure by conventional methods. By using a synchronized pair of cameras in photography, object movement at the instant of exposure is frozen which in turn enables the range of applications to be broadened to non-rigid and moving object situations.
- With the use of photogrammetry, permanent records in the form of photographic images are always provided and available on file. Storage space for these photographs is relatively small, and the photographs may be pulled at any time for remeasurement, if the need ever arises.
- Body structures, which could not be seen or illustrated before, can often be studied by photogrammetry. This is mainly due to the ability to select and compare models of the same subject photographed in monochrome or color using visible or non-visible light.
- Versatility is another advantage in using photogrammetry for medical purposes. Any desired degree of accuracy can be achieved by making a suit-

able choice of equipment and technique. Also, simple and complicated shapes of a wide range of sizes may be measured with equal facility.

- Finally, data obtained from photogrammetric measurements, especially if put in coordinate form, can be easily utilized by computer systems. Applications in this form can be easily used by professionals to calculate body surface areas and volumes.

Disadvantages

With the use of photogrammetry in medicine, a few problems are found to be significant, such as

- The acquisition of photography such that all parts of the subject are covered;
- The need for control points to allow for scaling and the orientation of successive sets of photography to a common reference system;
- The need for the subject to maintain a constant pose; and
- The need to improve features such as skin contrast.

Conclusions

At the present time, the field of medical photogrammetry seems to be somewhat contradictory. Techniques in this field have remained, for the most part, largely experimental and are still far from being introduced into routine medical procedures, although almost every researcher in this field has recognized the immense capabilities and usefulness of photogrammetry. However, there are some factors which have held back the advancement of photogrammetry in medicine. Some factors involved are the limited availability and high cost of the necessary equipment and the lack of communication between the medical specialist and the photogrammetrist.

One solution to the problem would be to develop measuring centers around the country and equip each individual hospital with a simple photogrammetric system for use in routine clinical work. The most ideal system to have for this type of work would appear to be one containing a simple, portable camera-plotter system, capable of being operated by the medical photographers in each hospital. In order for a system such as this to work, both the photogrammetrist and the medical personnel must be precisely trained, because they definitely come from two completely different backgrounds and disciplines.

New imaging systems, on the technical side, such as holography and moiré fringe interferometry, have been introduced and tested in recent years. Because of these two techniques, the range of applications in medical photogrammetry has been greatly extended. The promise of medical photogrammetry is great, but there remains an urgent requirement for more time and energy to be spent on further research, development, and education before it reaches its rightful place as a method of measurement in medicine.

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