MEDPHOS :
A NEW PHOTOGRAMMETRIC SYSTEM FOR MEDICAL MEASUREMENT

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ABSTRACT:

A multi-camera close range photogrammetric system for robust and precise measurement of human body surface in general and three dimensional evaluation of bedsores in particular has been designed and constructed. MEDPHOS (MEDical PHOtogrammetric System) consists of four digital synchronized cameras the optical axes of which are convergent in a pre-specified point. A light projector is fixed in the center of the cameras-carrying rig. The projector serves as a texture provider that projects a special pattern on the surface to be measured to compensate for the lack of texture in human body surface. Determination of shape, size, and density of the pattern dots was also investigated. The proposed algorithm consists of the following steps: Both cameras and projector were calibrated so that the positional and orientational parameters of the entire system are known. A new method for image segmentation and thresholding using morphologic operators was used for the detection of the projected pattern dots from the uneven background of the images. A watrershed transformation was also applied to tackle the problem of overlapping pattern dots. Then to reduce the effects of specular reflection of light due to the humidity of the object (in the case of wounds), a novel homomorphic transformation was developed and applied to the images. After segmentation of the images, connected component labeling procedure was used to set up the actual matching points. The centroids of these components were precisely calculated. Intensity-based image matching had already been tested that - due to great deviation from the Lambertian assumption necessary for solving the correspondence problem - did not give satisfactory results. So, a new algorithm based on four focal constraint has been developed that makes it possible to carry out the matching procedure without being dependent on intensities of the pixels and without a need for approximate values of the unknowns. This robust and ever valid geometric constraint is found to be very effective with non ambiguous results provided the necessary conditions for the system configuration are met. The fourth camera and the calibrated projector- that is treated like an active camera- serve as additional sources of information for consistency checking of the results. Almost all kind of information in the filed of biometrics can be obtained rapidly, robustly, and easily using MEDPHOS.

1. INTODUCTION

The specific problem treated in this paper is to introduce a new system for the measurement of the location of human body points. Photogrammetry has a distinct value as a medical measurement tool since it uses photography, which offers a quick, convenient, non-contact and safe means of recording a condition at a particular point in time. It is not invasive, and touching the patient, with risk of hurting or infecting, can be usually avoided. Further, photography does not distort the surface being measured. Photogrammetry can be contrasted with other external measurement techniques, such as those involving electrogoniometers and accelerometers attached to the body for movement analysis, which are not only uncomfortable but can interfere with the free movement of the patient (Atkinson, 1996).

2. MEDICAL PHOTOGRAMMETRY

The term photogrammetry covers the whole range of metrology activities that exploit geometric processes based on image acquisition and image processing. As stated by (Mitchell and Newton, 2002): ”The history of attempts to apply photogrammetry to the measurement of the human body is almost as long as the history of photogrammetry itself. Close range photogrammetry can be effectively used for measuring biological forms and functions as well as shapes, locations and three dimensional information of anatomic structures and their deformations and displacements in time. It can record the shape and size in studies relating to a wide range of areas of the human body, such as torsos, heads, faces, limbs, breasts, feet, skin, eyes and teeth. Some of the applications have been for purpose of advancing anatomical studies, while others have related to the detection or treatment of diseases.
Opportunities for such measurement relate primarily to:

- *Detection* of medical conditions.
- *Treatment* of a disease or condition.
- *Study* into the anatomical aspects of human body.
- *Research* into diseases and their treatment.

Although photogrammetric measurement is particularly relevant to orthopaedics and anatomy, it can also contribute to ophthalmology, neurology, dentistry, occupational therapy, ergonomic studies and many other areas related to human health. The users of the results may be involved in health in various ways, as medical researchers, surgeons, clinicians, biomechanical engineers, and so on”. In the past, the disadvantage of sing photogrammetric methods based on analogue photographs and systems was that they required an experienced observer to view and measure the photographs in an expensive stereoplotter. This was clearly unsatisfactory for a clinical situation. The advent of digital photogrammetry has overcome this difficulty, but in the meantime it can be argued that several of other optical methods have been more quickly to an operational stage than the photogrammetric methods (Figure

5). Whether the photogrammetric systems will replace those methods in the future for clinical measurement of body shape will depend on clear advantages that can be demonstrated by using photogrammetry. It will not be sufficient to argue that rigorous methods of camera calibration and image processing have been used, and therefore the technique is more sound theoretically. In this respect the method will have to be transparent to the operator, be reliable under a variety of conditions, be fast and of sufficient accuracy, and as well, provide the necessary parameters, either those with which surgeons are familiar, or new parameters that can be proved to be more appropriate, to enable them to make an appropriate diagnosis and decisions about treatment.
According to (Heuvel, 2002): "Although medical photogrammetry can look back on a history of almost a century, but photogrammetry never gained solid ground in medicine. This is also reflected on the reports of the chairs of the ISPRS working groups on this topic. In 1976, a working group of Commission V, named "Biostereometrics", was established. In 1988, "Medical Imaging" was added to the name, and the current name of ISPRS working group V/3 is "Medical Image Analysis and Human Motion". Although the term "Medical Imaging" has existed in the Terms of Reference of the Working Group ever since, the contribution of photogrammetrists to this filed has been limited. However, there is definitely a potential for the application of photogrammetric knowledge in the field of medical imaging. In 1990, the editorial of the theme issue of ISPRS Journal of Photogrammetry & Remote Sensing ended with "For those, who are not scared away by the transition form pixels to voxels, medical imaging will represents itself as a truly interesting discipline and a scientifically very rewarding area, which is of great importance to the progress and well-being of man-kind". Maybe photogrammetrists did not find the way to the voxels as they were occupied in other application fields. Nonetheless, the societal relevance of medical applications of photogrammetry is obvious, and therefore, anybody with the knowledge necessary to bring this field forward should not hesitate to do so". The possible advantage of digital photogrammetric methods are the superior accuracies that can be achieved with precise photogrammetric measuring techniques, if such accuracies ! are indeed relevant for medicine, potentially superior speed of processing, more robust algorithms using image matching and therefore greater reliability of the computations, and the relatively simple configuration of the photogrammetric systems, which can lead to cheaper implementation of the technique. It is the method of analyzing and presenting the data that finally determines its value to the clinician, and whether all three stages of measurement, analysis and presentation can be completed in a few minutes. The measurement tasks are the photogrammetrists' business, but of particular importance are the methods of analysis and presentation of data. Appropriate procedures have to developed to ensure that surgeons are able to use the information derived from the measurements. It is therefore a matter of adding value and facility to the data derived by the measurements (Trinder, 1994). Despite its appeal, the implementation of photogrammetry in medicine is not always straightforward. Only a few fully developed systems are available commercially, mainly for dynamics analysis and back shape measurement, and it is often necessary to develop a special system for each application. This a matter of applying photogrammetric techniques to medical situations with some adaptation. It entails making suitable equipment and processing software to suit the special needs of the application. Multiple cameras must be obtained, control and calibration arranged and access to a data reduction system organized. Potential difficulties, such as the requirement to obtain imagery with good contrast and texture, also need to be resolved. Furthermore, the photogrammetrist will need to feel comfortable working with human patients and medical practitioners in unfamiliar surroundings. If these constraints can be overcome, there are few alternatives to photogrammetry in many cases of external measurement in medicine and because of this photogrammetry has been widely investigated as a tool for medical measurement over the past century and a large number of papers have been produced.

However, only a small percentage of the applications have resulted in routine usage and there are very few medical institutions and related health units that use photogrammetry. Thus the real impact of medical photogrammetry on the world seems quite limited. Anyhow, it is obvious that close range photogrammetry is an effective medical measurement tool, which has certain advantages over alternative methods. Some practical examples of the medical usage of photogrammetry are given below:

1. **Face.** Photogrammetric measurement has been used to monitor facial shape as it changes over an extended period of time and also to investigate changes over short periods of time, such as before and after cosmetic surgeries.
2. **Back.** Photogrammetry has been used to detect, measure and monitor the scoliosis and spinal curvature.
3. **Teeth.** Photogrammetry has been used to detect the occurrence of wear, erosion and abrasion in both natural tooth surface and in tooth restoration materials, that requires repetitive measurements for change detection and monitoring.
4. **Interior parts.** Health and medical experts have access to a wide range of internal imaging and measurement systems. Many have little relevance to the photogrammetrist, but a small number of them are of interest because of the growing use of digital image technologies similar to those used in digital photogrammetry. They include X, CT and MRI imageries.
5. **Motion Analysis.** Photogrammetry has been used in the measurement and study of various gait problems, arising primarily from deformities or injuries, and irregularities in walking patterns that can be relevant to other medical conditions, such as diabetes.
6. **Skin.** Photogrammetry has been used to study the changes of sores, ulcers and melanomas and other skin conditions.

3. WOUND MEASUREMENT

When a patient is supported in such a manner that a pressure sufficient to obstruct blood flow in capillaries results, bedsores or pressure ulcers occur. This condition arises at bony prominences; by far the most common location is the sacrum. An ulcer is a chronic wound of the skin that, at best, takes many months to fully heal and causes great distress to the patient. As an example, treating ulcers places a large financial burden upon the National Health Service in the United Kingdom, estimated to be in excess of £300M annually and is predicted to rise to £500 million per annum. (Plassmann, 1998). Measurement of the size of ulcers is a guide to assessing the progress of wound healing, and the use of non-invasive measurement techniques avoids damaging or infecting the wound or causing pain for the patient. With so many treatments to choose from, doctors need a precise and objective means of deciding whether a particular treatment is effective.

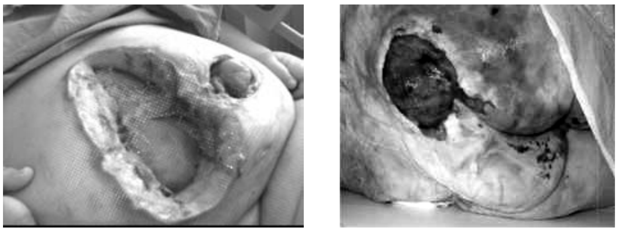


Figure 1. Typical Bedsores

3.1 Existing Methods for Wound Measurement

1. **Structured Light.** An instrument named MAVIS (Figure 2) has been made in the department of computer studies, University of Glamorgan, Britain to measure area and volume of wounds based on the principal of color coded structured light. This system has good performance but is rather too big and expensive.

Figure 2. MAVIS (Plassmann, 1998)

2. **Acetate Sheet.** The current method of measuring area is to place a transparent acetate sheet onto the wound and to trace its perimeter. The tracing is then placed onto graph paper and the number of squares counted. This method is inaccurate and unreliable (Figure 3).

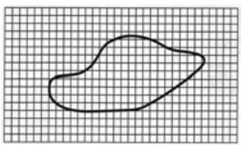


Figure 3. Acetate Sheet

3. **Saline Injection.** The wound is filled with saline (Figure 4). The volume dispensed from the syringe equals the wound volume. The main source of error is that the wound absorbs the saline and it is difficult to ensure that the plastic cover takes up the shape of the original healthy skin. It is also a contact method so it is problematic to the patient.

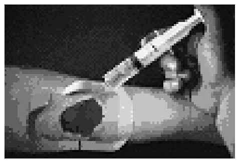


Figure 4. Saline Injection

4. **Mould Making.** A mould of the wound is made using special powders. This is also a painful and infecting method.
5. **Laser Scanning.** Laser scanning can be used to measure the wounds provided the patient remains still during the scan period, which cannot be guaranteed for a dynamic object like human body.
6. **Image Processing.** The area of an ulcer is currently measured by presenting a human observer with a captured video image of a wound, who then uses a mouse or pointing device to delineate the wounded region. This method is inaccurate and gives only two dimensional information.
7. **MEDPHOS.** This system has been designed and made in the department of surveying engineering, University of Tehran, Iran. It is based on the ideas of multi camera photogrammetry and projective geometry using off-the-shelf components. It can effectively provide the physicians and clinicians with three dimensional information, measurement and reconstruction of the wound surface. Major problems related to wound measurement has been considered and resolved in the design and production of this system. MEDPHOS is an integrated close range photogrammetric system for surface reconstruction capable of performing almost all kinds of external medical measurements specially wound analysis.

The sections that follow give a brief review of the basic components of MEDPHOS.

4. METHODOLOGY

Surface reconstruction technology has evolved considerably in the last few years. A common characterization subdivides different surface reconstruction methods into *contact* and *non-contact* techniques (Figure 5). An important subclass of the latter is *optical* technology.

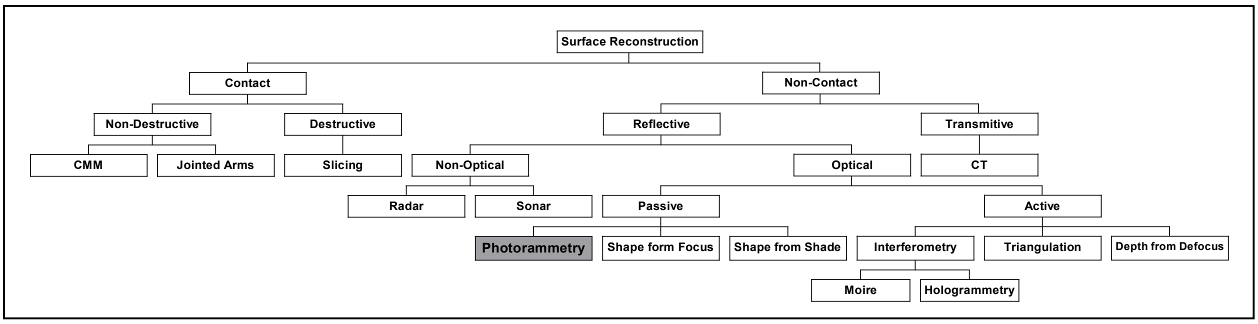


Figure 5. Three Dimensional Surface Reconstruction Methods

Active optical devices are based on an emitter, which produces some sort of structured illumination on the object to be measured, and a sensor, which is typically a CCD camera and acquires images of the projected pattern reflected by the object surface (Rochini, et.al., 2001). In most cases the depth information is found by triangulation, given the relative positions of the emitter and the sensor. The passive measuring methods function like human vision system. In MEDPHOS, a combination of active and passive methods has been used.

5. SYSTEM CONFIGURATION

Considering the error propagation from the imaging component only, the positioning accuracy of object point coordinates is mainly determined by four factors: the object distance, the base line, the focal length, and the mean square error of image coordinate measurements.

The selection of the CCD cameras is critical in terms of pixel spacing and sensing area specifications. Pixel spacing affects the accuracy of image coordinate measurements, while sensing area of the camera eventually influences the parameter setting related to base line and focal length since the positioning accuracy is dependent on base line and focal length of the cameras. The larger the focal length, the larger the image scale. On the other hand, the use of a shorter focal length will increase the lens distortion errors. In addition, using a larger focal length instead of a larger base line will reduce the ambiguities of image point matching and improve the point measurement accuracy. However, a tradeoff should be made in order to maintain a certain field of view (Tao, 1999). If a large sensing area is used, either the focal length can be increased or the field of view can be extended. Thus, the base line can also be extended, provided the same image overlap is maintained. It is obvious that the large sensor cameras offer better performance in terms of sensing area, pixel spacing and number of pixels. Consequently, if large sensor cameras are employed, the settings of imaging parameters will be more flexible and the total performance of the system can be improved. However, the problematic aspects of the low image capture rate and high storage requirements have to be taken into account. In addition, the geometric performance of different types of CCD cameras may vary in terms of electronic noise.

An analysis for optimal configuration shows that the maximum length of the base line is restricted by the desired overlap percentage, the overlap percentage is affected by the filed of view angle, and the filed of view angle is determined by the focal length and the sensing area of the camera. Regarding the above considerations and the average size of medical objects to be measured, an overall compromise was achieved to reach an optimal configuration.

5.1 Multi Camera Concept

Multi image geometrical configurations have been recently proposed to overcome the limitations of binocular vision (Faugeras, 2001). The limitations including mainly relatively poor reliability and low accuracy of reconstruction process. If third and fourth cameras are added, the geometry becomes much more richer than that of two camera system. By applying the trifocal and four-focal constraints, point correspondence can be found robustly. If the cameras geometries are known, transfer is done in a straightforward fashion by three dimensional reconstruction and reprojection (malian, et. al., 2002).

5.2 Structured Light

Surface measurement of skin involves some problems regarding targeting especially if the object is dynamic or alive. Structured light means the projection of patterns onto an object surface. It provides in some cases the only reasonable approach for surface reconstruction. Different technologies can be used to produce structured light pattern: laser emitters, light projectors, slide projectors, and video projectors. In particular, target projection is used for any object surface that does not lend itself for target placement or does not have rich texture. This also avoids the time consuming placement of retro reflective targets and the placement and alignment of the corresponding light source required for retro targets. These targets are detected and localized by specific image processing techniques. The pattern used should satisfy some characteristics: it should not be drastically altered by small variations in photometric and geometric conditions, the detection, localization and discrimination of its constituent features from the reflected image should be easy and accurate and so on. The size of the object is limited by the possibilities of the projector and the environment, that is, by the strength of the projector illumination and environmental light. Project planning must therefore take into consideration not only the characteristics of the camera such as depth of field and filed of view, but also those of the projector. This idea is used in MEDPHOS as dot target projection using a slide projector that serves also as an active camera with known calibration parameters.

5.3 Prediction

By going beyond the classical binocular vision, the problem we now address is to predict how the scene would look like from a third and a forth camera. In other words, given the calibration information of third and fourth cameras and image coordinates of an object point in one image, predict the locations of corresponding image points on other images. The ***transfer*** concept is used in MEDPHOS; The homologous point of a selected image point lies on the epipolar bands of the other images. In other words, for one or more image points in a given image set, the corresponding points in other image sets can be predicted using *Essential* and *Fundamental* matrices. Width and length of the epipolar band can be restricted with information on the error budget and approximate depth, the latter is estimated by applying the MEDPHOS algorithm on a few non-ambiguous dots distributed within the projected pattern.

6. PROCEDURES

MEDPHOS consists of four digital and calibrated cameras mounted on a rig that allows required rotations. The cameras are activated in a synchronized manner. The base lines of the cameras can be set in different lengths. The pattern projector is fixed at the center of the system (Figure 6). It can accept various pattern types. A total calibration of the system by series of convergent photography and self-calibration bundle adjustment (malian, 2000) provides the relative position and attitude of the cameras and the projector as well as the epipolar geometry for any image point in any camera. The captured images are directly fed to the computer where the related software processes the data in real time. The designed dot pattern is projected onto the object and recorded by the four camera system. To reduce the effects of specular reflectance, homomorphic filtering is applied to the images (malian et.al, 2002). The observed light pattern is then used to detect the image coordinates of the dots using an optimal thresholding technique. Then, a connected component labeling procedure is applied to identify the points. Watershed transformation is also performed to isolate the overlapping dots and find the center of the gravity of each dot.

Establishing correspondences is the key problem in 3D reconstruction from multiple images. The goal of correspondence is to assign matches to each point in the reference image. The essential problem in geometric image matching lies in establishing a correspondence among the projections of the same physical location in each of the four cameras. Conceptually, the correspondence process in image matching consists of two stages *: local matching* and *global matching*. In the local matching stage, for every feature point in the base image, an attempt is made to find a set of candidate match points in other images which have similar local properties and which satisfy the *four focal* constraint. In the global matching stage, a scheme for imposing the global *consistency* among the local matches is used to disambiguate multiple local match point candidates through the solving of a *consistent labeling problem*.

In general, image matching algorithms can be divided into intensity-based and feature-based. Intensity-based algorithms can produce dense depth information but are very sensitive to degradation in illumination and contrast and hence are not stable. Their distinguishability is poor especially in textureless conditions. Furthermore, most intensity-based techniques have a low-pass filer effect on the derived object surface as a result of the large matrix sizes. On the other hand, smaller matrices lead to a rapid reduction of accuracy and reliability. Moreover, These techniques require good approximations for the unknown parameters. That is, the solution of the problem should be known a priori. Regarding the typical situations of medical measurements, it is obvious that intensity-based approaches are not reliable enough for users in medical and health sectors. Feature-based algorithms first select some salient points of the object and perform the matching process on these points based on some similarity measures in particular the correlation windows centered around the selected features. These methods are of course more robust but still rely on the Lamebertian assumption that states image intensity is independent of the viewing direction. This is not usually the case in close range photogrammetry especially in for medical objects. So, applying intensity-based techniques for an object without Lambertian assumption being met, can produce a lot of points that are related to homologous elements.

In MEDPHOS, a new strategy for image matching has been employed that needs a minimum amount of information about the intensities of the pixels and object space conditions. Robust geometric constraints that exist in a multiple view system are used to establish robust correspondences among different images of the object.

A number of difficulties arise in the establishment of correspondences that must be taken into account:

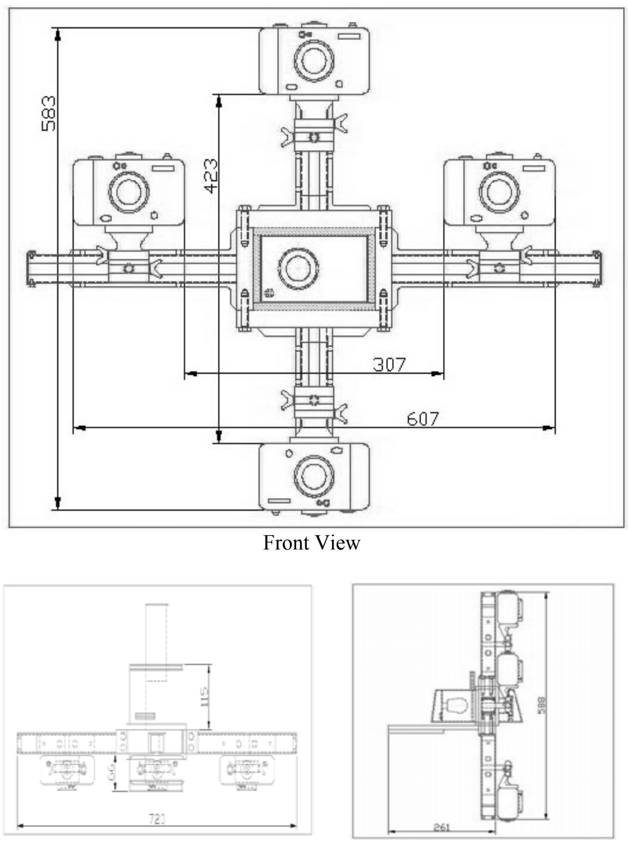
1. False matches can occur due to
    - Photometric differences and specular reflectance
    - Lack of texture
    - Incorrect camera calibration
    - Discrete nature of a digital image
    - Noise
2. Missing matches can occur due to
    - A point becomes invisible when the line of sight is interfered with by another object
    - Part of the scene not being in the field of view of the other cameras
    - A matching element is too weak in one of the images and, therefore, is discarded as noise in the feature extraction process

In MEDPHOS software, the image point correspondence problem is solved using maximum weighted bipartite technique (malian, et.al., 2002).

After the establishment of all correspondences, three dimensional object points are computed and the quality control criteria is done. Beside the determination of three dimensional surface points, a blunder detection and correction strategy is used to resolve the following problems:

- Gross errors due to image point detection and localization
- Gross errors due to the ambiguity in point correspondences
- Gross errors due to incorrect three dimensional reconstruction.

An integrated multiple image forward intersection is carried out to monitor the quality of the results. The resulted point cloud is classified into different reliability levels based on the information stored in the cost functions used during the reconstruction procedure and the distance to next best answer for each matching candidate. Finally, the desired quantitative medical parameters are computed and a global surface fitting technique is used for three dimensional surface reconstruction.



Front View

Top View

Side View

Figure 6. MEDPHOS: Hardware Plan

7. CONCLUSIONS

Close Range Photogrammetry is an effective medical measurement tool which has a number of advantages over alternative methods. These include the following:

- The method is non-contact and hence it avoids distorting, hurting or infecting the patient.
- Results are precise and reliable.
- Data collection is quick, and movement of the patient is overcome even in dynamic situations.
- A permanent image record is provided which may be consulted and remeasured at any time in future.
- Recording in wavelength outside the normal visible range can reveal conditions not apparent otherwise.

In particular, combining the ideas of multi camera photogrammetry and projective geometry, not only produce theoretical solutions to the problem of wound measurement but also lead to robust algorithms that has been practically used in MEDPHOS.

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