3D RECONSTRUCTION AND EVALUATION OF TISSUES BY USING CT, MR SLICES AND DIGITAL IMAGES

S. Dogan

Ondokuz Mayıs University, Engineering Faculty, Dept of Geodesy and Photogrammetry, 55 139 Kurupelit, Samsun, Turkey- sedatdo@omu.edu.tr

Commission V, WG V/3

KEY WORDS: Three-dimensional, Medicine, Modelling, Photogrammetry, Registration, Photo-realism, Volume Rendering, Surface Rendering.

ABSTRACT

In this project, it is provided to reconstruct 3D models of human body by using CT, MR slices and digital images and precisely finding locations of pathological formations such as tumours. For this purpose, within this project we developed a software, which we called as "Medical Image Processing and Analysis System (MIPAS)" and it is still under development for multipurpose medical applications. In this paper, we introduce the abilities of MIPAS briefly and also give a sample application on finding location and visualization of a brain tumour. MIPAS uses volume and surface rendering techniques for 3D modelling of the tissues and provides both volume and surface models at the same time on the screen when required. MIPAS gives many editing and analysis functionalities to medical doctors. For pre-processing of CT and MR images, there are wide range of image processing functionalities. It is possible to register CT and MR images by using both anatomical landmarks and artificial (external) markers. MIPAS also provides surface registration functions with both rigid body and non-rigid body transformation with the variants of ICP algorithm. For photo-realistic visualization of the external human body like face of the patient, it provides a photogrammetric module. This module consists of self calibration with bundle adjustment by using additional lens parameters, automatic image coordinate measurement with ALSM matching technique and texture mapping functions with both colinearity equations and 3D affine transformation. We are still studying to progress the photogrammetric module for plastic surgery. Up to now, we could not still test the MIPAS on the real patients. But we have just started a new project with medical doctors, in order to test the MIPAS on real patients. During this new project, we will see the actual reliability of the system.

1. INTRODUCTION

Medical Imaging techniques are used for diagnosing and treatment of many diseases as well as surgical operations. CT and MR imaging techniques are the mostly used ones. Reconstruction of 3D volume and surface models of the tissues, by using 2D image slices, provides many advantages to medical doctors. For a long time, 3D models have being used in medical applications. During the treatment period, tracing the temporal changes of the abnormalities is a very important task for deciding whether the treatment is positively effective or something going wrong. For detection of changes that appear in tissues, firstly the location and the geometric quantities of the abnormal regions are required. For example, the volume and the surface area of the tumour are to be known for temporal comparisons. Another example may be given for the treatment of Parkinson disease. Furthermore, it is also important to know the location of the abnormalities according to some reference points which were cited on the external surfaces of the body such as human face (Altan and Dogan, 2003).

When someone searches the scientific literature on above tasks, he/she will see that these topics are not directly related to photogrammetry. They are especially related to medical and biomedical imaging techniques that comprise image processing, electronic medicine, radiology and computer graphics. On the other hand, one of the primary aims of photogrammetry is spatial measurement of objects. Near this, in photogrammetry textbooks, some will see the chapters on medical photogrammetry or potential use of photogrammetry on medical applications. But due to the nature of basic data and mathematical basis of photogrammetry, the potential medical applications had been limited by the thoughts restricted with the applications could only be carried out with perspective projection. With this thought in the past, especially in orthopedics, photogrammetric techniques had been used with the roentgen films based on perspective projection, in order to find the 3D location of the pathologies (Elad and Einav, 1996). Almost with the same approaches, photogrammetry had also been used in orthodontics applications (Schewe et. al, 1999). Providing a long bibliography would be easy. However the list of cited studies are limited (Mitchell and Newton, 2002). In photogrammetry, there are some studies on 3D human body measurements. These studies have not been carried out for medical purposes, but for art, forensic sciences or various other applications which are not directly related to medical purposes (Mitchell and Newton, 2002). Up to now, photogrammetric contributions were aiming mainly at the reconstruction of the outer body using optical sensors, the mapping of the internal body presents a much greater research area; both in terms of scientific challenge and in terms of the wider range of applications (Patias, 2002). When looking at the photogrammetry and medical imaging at the first time, someone might think that these are very different topics. Especially, when CT, MR or such other radiological imaging modalities are considered, someone possibly feel that these are not related each other. But when considering the final purposes 3D object reconstruction and determination of the spatial location of object, it would be clear that these two topics are closely related to each other by the means of both mathematical models and

sensor geometries. In many respects, current challenges in medical imaging show remarkable similarities to usual photogrammetric problems (Patias, 2002). However, there are great differences between the terminologies of medical imaging and photogrammetry. And this makes very difficult to be motivated on applications that integrate photogrammetry and medical imaging. This last determination is true for this paper's introduction section too. As long as the cooperation between photogrammetry and medical imaging grow up, we believe that these problems would be solved.

With MIPAS, we also aimed to integrate photogrammetry and medical imaging for various medical applications such as radiology, neurosurgery, general surgery , plastic surgery, dental applications etc. But up to now, we considered MIPAS as it has two different modules; photogrammetry and medical imaging and modelling. With the contribution of medical doctors and biomedical engineers, we believe that two modules would be synthesized.

For a system to be used for detection and measurement of the pathological formations; segmentation, detection and registration steps are very important tasks (Betke et.al, 2001). In this paper, we briefly explain the methods which we used in MIPAS for pre-processing, segmentation, detection, registration and photorealistic 3D visualization. We present sample images on finding tumour location. We have produced photo realistic face skin surface model by using texture mapping. And thus, it is possible to see the whole human head on 3D surface models completely with outer face and inner brain tissues. This 3D photo realistic face model may also be used for plastic surgery after some modifications.

2. DATA ACQUSITION AND PREPROCESSING OPERATIONS

For 3D reconstruction from CT and MR slices, spiral scanning technique with parallel slices are preferred. During scanning process, external markers could be used for registration purposes. For CT scans, the best marker shape is sphere and the best marker material is plastic. Radius of the sphere must be at least two times greater than the slice thickness. Thus it would be guaranteed that the same sphere will appear at least on two successive slices (Dogan, 2003; Altan and Doğan, 2003). Before and after scanning, digital images of patient are also taken with digital photograph cameras. During the photograph acquisition, for the precise photogrammetric evaluation, some rules should be obeyed; base and camera-object distance ratios should be selected carefully. Images must be convergent and homologues bundle rays must intersect in the object space in an adequate manner. For the fast and automatic digital image acquisition, we are designing a camera network in our ongoing projects with five digital cameras. But in the sample images presented in this paper, we used only one camera for image acquisition and we have taken images with one camera from pre-planned camera stations. These images are used for photorealistic visualization of the outer body surfaces. These images can also be used for the 3D measurements of the outer body surfaces of the patient. By using digital images, it is also possible to reconstruct 3D point cloud model of the outer faces (D'apuzzo, 2001).

After acquisition of CT and MR images, image data is recorded in DICOM format. In DICOM files, detailed information on scanning parameters is recorded too. For example, slice thickness, pixel size on x and y directions, scanning type,

scanning direction etc. MIPAS can process DICOM files and can convert the image contents of the file to TIFF image file stacks and to individual BMP file sets. MIPAS can also open slices recorded in TIFF, BMP and raw PGM formats.

After CT scanning, on the slice images, scanner table's images are also appeared. And the densities of the table pixels are very close to the densities of the soft tissues. So, during automatic segmentation, table pixels might frequently be classified as soft tissue pixels and this situation is undesired for accurate segmentation and 3D reconstruction. In order to overcome this problem, table images should be extracted and eliminated from the slice images. In other words, only the volume of interest (VOI) should be reside on slices. To select VOI from each slice images, usually a binary VOI mask is designed and used in medical applications. With this VOI mask, by using maximum or minimum filters, only VOI regions of the slices can be selected. To define binary VOI mask, we used logical image operations. By applying union operation with "or", all of the slices are combined on one image. This final image will contain the all of the VOI regions together with undesired table images. In this combined image, the largest VOI boundaries can be seen easily. Some can draw the largest VOI boundary with mouse and thus VOI mask is obtained. If the inner pixels of the bounded VOI region are labelled with a unique density level, binary VOI mask is obtained. Now this mask is compared to all slices and maximum or minimum operation is performed to discard table images.

During the pre-processing step, MIPAS provides manual image coordinate measurement possibility. Thus it is possible to find the 3D model coordinates of the each marker's center points.

3. SEGMENTATION OF SLICE IMAGES

Segmentation is the process of classifying pixels in an image or volume. It is one of the most difficult task in the visualization processes. For reconstruction of medical 3D surface and volume, interest tissue boundaries should be distinguished from others on all the image slices. After the boundaries have been found, the pixels, which constitute the tissue, can be assigned to a constant grey level value. This constant value represents only this tissue.

Label values can be used as isocontour value for surface rendering. For volumetric rendering, in spite of the surface properties of the tissues, their inner properties are also important. Because of this reason, we should find the opacity values for the individual voxels. And near this, wee need different colours to separate the volume the elements which belong to different tissues. For these purposes, segmentation results are used too. In MIPAS, we have used three different segmentation approaches. These are; interactive histogram thresholding, contour segmentation and manual segmentation.

3.1. Interactive Histogram Thresholding

The simplest way of image segmentation is thresholding. By this technique, according to image histogram, possible threshold values are found. The pixels, that have values above or below this threshold is assigned to constant values. Thus a binary-segmented image is obtained. One can choose more than one thresholds. In this case, between values of these thresholds are replaced with constant label values. In our software, in spite of histogram analysis, we have also presented an interactive

thresholding option. By this option, when one changes the threshold by using a track bar, its effect is seen on the screen synchronously. By the time user decide that the optimal segmentation has obtained, he/she can change the threshold. After thresholding, on the images, there would be many holes and also many small areas. To delete, unwanted small areas, we make a connectivity analysis, (Gonzalez, 1987, Teuber, 1993). By this analysis, the areas that are smaller than the area threshold are deleted. After connectivity analysis, still there might be some unwanted pixels on the image. We have written functions to delete these areas manually. After thresholded-segmented regions have been obtained by using morphological operators such as erode/dilade, we fill or delete the remaining holes. The final segmentation is recorded as a file.

3.2. Contour Segmentation

By this method, possible boundary value of a tissue is selected with histogram analysis. This value is assumed to be the contour value and the interested image is contoured by tracking this value. After contouring, small areas can be detected automatically by connectivity analysis or manually with hand. After refinement of contours, we assign labels to pixels which are bounded by the counter lines. If user doesn't like the contouring result, he/she can ignore it and make a new segmentation easily.

3.3. Manual Segmentation

With the automatic segmentation procedures, it is inevitable to make some incorrect label assignment. So in the literature, manual segmentation is said to be still the best method. For precise medical applications, manual segmentation will give the best results. In this case, user draws the boundaries of the interested region by using mouse pointer. User can make editing during manual segmentation. However, manual segmentation is too time consuming. It can take hours or sometimes days to segment complex MR images by manual segmentation.

4. REGISTRATION OF 2D SLICE IMAGES AND 3D SURFACE MODELS

Registration is the determination of a one to one mapping or transformation between the coordinates in one space and those in another, such that points in the two spaces that correspond to the same anatomical point are mapped to each other. Registration of multimodal images makes it possible to combine different types of structural information (for example CT and MR) (West et al, 1997).

In this paper, basically two types of registration are mentioned: 1) Registration of 2D (slice images) point sets and 2) Registration of 3D (surface models) point sets. Let us assume that, a patient had been scanned with CT and MR scanners. As known, CT images are geometrically more correct than MR images. But on the other hand, radiometric information of MR images are richer than CT images. By keeping this in mind, we cam easily say that, on CT images bone structures are well defined when compared soft tissues. But on the other hand, MR images represent soft tissues with greater radiometry information. Advantages of these two imaging modalities can be brought together. For this purpose, 2D image registration and fusion techniques are used. I.e., if we assume CT images of the same patient as a base, if we can find the corresponding anatomical points or details on MR images then we can map the

MR image pixels onto CT image with a mapping function (generally a transformation function). After this mapping, CT and MR image information is brought together. New density values of combined (or registered) image pixels could be showed by using r, g, b bands. For example, CT densities are in red band and MR densities are in blue band etc. This visualization is known as image fusion. With this technique, new 2D slices may give more detailed 2D information to medical doctors.

2D registration can be performed after segmentation of CT and MR images too. In this case there is no need for fusion. Segmented 2D CT and MR images are combined and by using this new registered (combined) segmented slices 3D models of the tissues can be constructed.

A medical imaging system should also provide 3D registration functionalities. This 3D registration functionality might be used for various purposes. For example, for temporal comparison of two surfaces generated from the same or different scanner type images such as CT and MR. On the other hand, one can reconstruct models individually from CT and MR slices without register them in 2D. But finally, he/she might want to visualize these individual surface models at the same time. For example, the same patient's inner brain tissues surface models could be obtained from MR slices, and skull and outer skin models could be obtained from CT slices as in the example given in this paper. This case is equivalent to the registration of the two different surface models problem.

In MIPAS, we provide both 2D and 3D registration functionalities. For registration, we used iterative closest point transform (Rusinkievicz and Levoy, 2001; Betke et al, 2001; Kaneko et al, 2003; Fitzgibbon, 2001). For two dimensional registration, we provide both rigid body (2D similarity transformation) and non-rigid body (2D affine transformation) transformations as being mapping functions. If 2D images which are to be registered, had been obtained by the same scanner with the same pixel aspect ratios, these images could be matched with one transformation, two translations and one scale factor. If two image sets to be registered, are scanned with different pixel aspect ratios, then a non-rigid transformation is required. In this case, we use 2D affine transformation as being mapping function. We estimate the transformation parameters with least squares adjustment and to do this we use external markers or anatomical landmarks as being common points.

For 3D registration, above assumptions are valid in analogy. We use 3D similarity mapping function for rigid body and 3D affine for non-rigid body transformation in ICP algorithm. In MIPAS, common points are selected manually. We are still studying on automatic point selection. Our ICP implementation works with global mapping functions. We are still studying for local non rigid registration with spline curves (Xie and Farin, 2000; Ruckert et al., 1999).

5. PHOTOREALISTIC TEXTURE MAPPING

After the outer face (skin) surface model had been created from CT or MR slices, digital photographs of the patient's face can be texture mapped on to 3D surface model for photorealistic visualization. Some examples have been shown in the next chapter. For texture mapping, we should know the corresponding picture (texture) coordinates of the vertex points of the triangles that cited on the 3D model. Later, the colors of

the inner pixels of the triangles should be mapped on to surface, (Watt and Watt, 1992). Since the scale differences between 3D model and pictures, it is obvious to see that there is no one to one correspondence between the pixels of the picture and the model. For this reason, to find the colors of triangle pixels, a color resampling is required. For the color resampling we used linear interpolation.

While visualizing the texture mapped model, it is possible to integrate texture colors with illumination and shading equations. This integration process is done by OpenGL. Texture mapping is performed in two steps: (Watt and Watt, 1992).

- Referencing the vertex coordinates of the polygonal model with (u,v) texture coordinates,
- Filling the inner region of the polygons (triangles) by interpolating (u,v) coordinates (indirectly corresponding colors), on the pictures.

In this study, we obtained (u,v) texture coordinates by using backward mapping of the vertex coordinates on to texture maps (images) by using 3D Affine transformation and photogrammetric bundle resection techniques separately. With both techniques, 3D model coordinates of the vertex points are projected on to 2D images. During the projection (transformation), z coordinates are being lost. For 3D Affine transformation, common points are selected from model and image by hand with our program. Then our program computes transformation unknowns with least squares adjustment. Z coordinates of the image points are all assumed zero.

For the bundle resection, we use the control points. We know the model coordinates of the control points and also we measure the image coordinates of these points from image pairs by using ALSM matching. Then we compute exterior and interior orientation parameters with additional lens distortion parameters by using bundle adjustment. After the orientation parameters have been computed, model coordinates are mapped to image space by using spatial bundle rays resection equalities. Thus (u,v) texture coordinates are obtained. Then the mapping procedure begins. Before texture mapping we did not rectified the images according to the model. So there are many deformations on texture mapped model because of the height and perspective differences. We are still studying on rectifying images.

6. SAMPLE IMAGES PRODUCED WITH MIPAS

In Figure 1, digital images of the patient are seen with control points. These images were taken as soon as the scanning operation has finished. These images were used for texture mapping and photogrammetric evaluations.

Figure 1. Control points and patient's face images

In Figure 2, some volume models of the skin of the patient head which was created by our program have been shown. On the upper left in the figure, opaque skin volume model, on the upper right MIP volume with skin and bone structures and on the bottom, bone and skin volume models are seen.
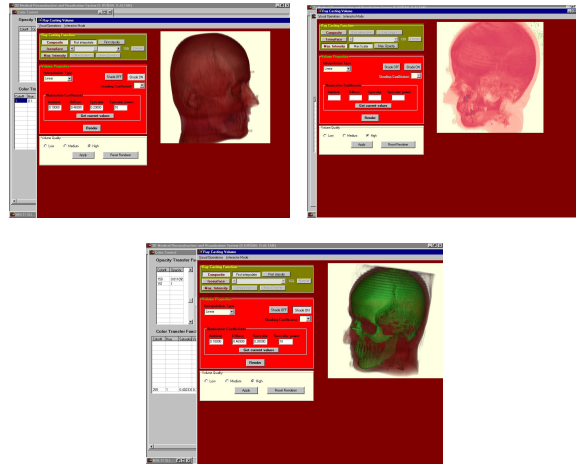

Figure 2. Volume model examples generated from CT slices

With the volume models, by changing opacity, color and gradient values, it is possible to see the 3D medical data under desired illumination and shading conditions. When these values are changed, corresponding volume segmentation effect is seen synchronously on the screen. Thus it is possible to see the intended parts of the tissues. On the volume models, it is possible to learn the coordinates of picked points.

In Figure 3, segmentation of tumor on MR image slices is seen. By using segmented images, individual tissues' surface models are obtained.
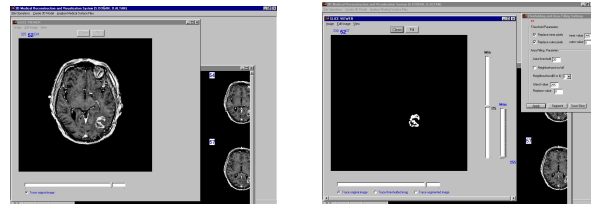

Figure 3. Segmentation of tumor on MR slices

In Figure 4, on the left, tumor surface model and information about its coordinates, area, volume etc. are shown. On the right, tumor with brain cortex and on the right with skin and brain model is shown.
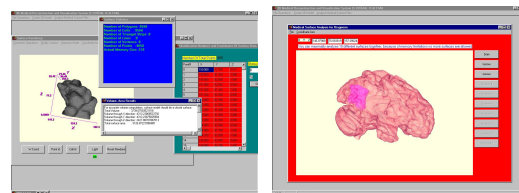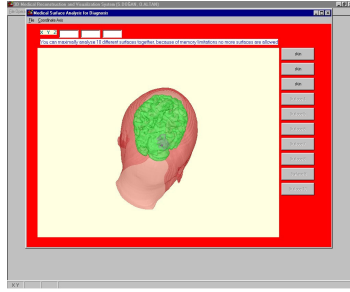

Figure 4. Tumour and brain

Figure 5. Tumour, brain and skin

In the Figure 5, brain surface has been defined as translucent and the tumour surface is opaque. Thus, it is possible to see brain and tumour together. Here skin model had been obtained from CT slices and the others from MR slices. Brain and tumour surface models have been registered with 3D affine mapping.

In Figure 6, photo realistic skin surface model after texture mapping is shown from different angles.
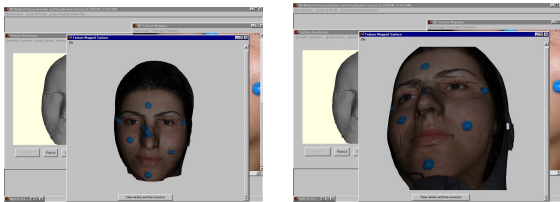

Figure 6. Photo realistic skin surface model after texture mapping

7. CONCLUSION

By using 3D models, it is easy to diagnose pathological formations and preparing the treatment plans. With 3D models, it will be possible to trace the progress of the diseases. Thus, for many diseases such as Parkinson, new treatment methods may be developed. On the other hand, a such system may be used in plastic surgery or in dental diagnosis and treatments.

When the medical imaging and photogrammetry get closer, it would be possible to produce new approaches and techniques for medical purposes. By considering the photogrammetric methods in medical imaging, some progressed changes would be obtained on designing medical image acquisition and evaluation systems.

8. REFERENCES

Altan, O., and Dogan, S., 2003. 3D modelling of human face and brain by using CT, MR and digital images for finding abnormalities. *Optical 3D MeasurementTtechniques VI,* Zurich, Switzerland, Vol. I, pp. 148-155.

Betke, M., et al., 2001. "Automatic 3D registration of Lung Surfaces in computed tomography scans", http:// citeseer.nj.nec.com / betke01automatic.html, (accessed March 2001).

D'apuzzo, N., 2001. Human face modeling from multi images. *Proc. Of Third International Image Sensing Seminar on New Development in Digital Photogrammetry,* Gifu, Japan, pp. 28-29.

Dogan, S., 2003. 3D Reconstruction and evaluation of tissues by using CT, MR slices and digital images, PH. D. Thesis, İTÜ, FBE, Istanbul, Turkey.

Elad, D., and Einav, S., 1996. 3D measurements of biological surfaces, *Photogrammetric Record,* 45, pp. 248-265.

Fitzgibbon, A.W., 2001. Robust registration of 2D and 3D point sets, http://citeseer.nj.nec.com/fitzgibbon01robust.html, (accessed March 2001).

Gonzales, R., C., 1987. Digital Image Processing. Addison Wesley Publ.Comp, USA.

Kaneko, S., et., al., 2003. Robust matching of 3D contours using iterative closest point algorithm improved by M-estimation, September 2003, pp. 2041-2047. http: //iris.usc.edu /Vision-Notes/bibliography/match-pl521.html (accessed Oct. 2003).

Mitchell, H., L., Newton, I., 2002. Medical photogrammetric measurement: overview and prospects, *ISPRS Journal of Photogrammetry and Remote Sensing,* 56, pp. 286-294.

Patias, P., 2002. Medical imaging challenges photogrammetry, *ISPRS Journal of Photogrammetry and Remote Sensing,* 56, pp. 295-310.

Ruckert et., al., 1999. Nonrigid registration using free form deformations: application to breast MR images, *IEEE Transactions on Medical Imaging,* 18, pp. 712-721.

Rusinkievicz, S., 2001. Efficient variants of the ICP algorithm, www.cs.princeton.edu/ ~smr/ papers/ fasticp/ fasticp_paper.pdf (accesed March 2001).

Schewe, H., et al., 1999. PictranMed- an orthodontic application of digital photogrammetry, *Third Turkish German Joint Geodetic Days,* Istanbul, Turkey, pp. 257-261.

Teuber, J., 1993. Digital Image Processing, Prentice Hall, UK.

Watt, A., and Watt, M., 1992. Advanced Animation and Rendering Techniques. Addison Wesley, USA.

West, J., et. al., 1997. Comparision and evaluation of retrospective intermodality brain image registration techniques, *Journal of Computer Assisted Tomography,* 21(4), pp. 554-566.

Xie, Z., and Farin, G., E., 2000. Deformation with hierarchical B- splines, *Mathematical Methods in CAGD,* Oslo, Norway, pp. 1-8.