Measurement of Medical Parameters Based on 3D Surface Models

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ABSTRACT

In medical diagnostics one need to perform quantitative analysis and measurements of 2D or 3D data. The length, angle, area of region, 3D surface area, volume are measure to determine medical parameters. This paper presents uncertainty estimation of 3D surface model created from object boundaries using CT, MRI series of images. Error propagation from CT images acquisition to the anatomical structure pointed (measured) by operator using 3D model cross-sections is introduced.

Keywords

3D surface model, uncertainty estimation.

1 INTRODUCTION

In medical diagnostics, mainly in surgery, orthopaedic surgery, neurosurgery, it is necessary to estimate many geometrical parameters: length in 2D and 3D space, angle, object volume and surface area. Values of these parameters are helpful while distinguishing between the pathological and normal condition of the human body, and estimating the degree of pathology. Monitoring values of different parameters during the treatment allows for a quantitative analysis of the improvement or deterioration of diseases. The measurements can be done on the base of 2D radiological images, CT or MRI slices and 3D surface or volume models. 3D surface and volume models are also used for pre-operative planning and intra-operative navigation. There is a lot of computer software that can create 3D surface and volume models based on 2D cross-section images and measure different parameters. However, none of them enables the metrological analysis of the obtained results of measurements. The validation study of the accuracy of medical modelling based on a semi-anthropomorphic phantom of human head was carried out within the scope of PHIDIAS project. The measurements of the phantom and its model (built using RPT (Rapid Prototyping Technology) of a geometrical surface model created of 2D cross-section CT images of the phantom) were carried out using a coordinate measuring machine. The measured characteristics of the phantom and the model were compared.

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2 MOTIVATION

The analysis of measurement error in diagnostic imaging is a key problem to ensure the reliable results of measurements. It contributes to convince physicians to apply modern hardware and software tools in diagnostics. The quantitative error estimation of 3D model is also very important in pre-operative planning and intra-operative navigation, where the accuracy of the model and measurements is critical.

3 ACCURACY ANALYSIS FOR 3D SURFACE MODELS CREATION

The accuracy of the model is dependent on a lot of factors: resolution and processing of 3D image data, thickness and distance between slices, the method of reconstruction (control parameters of decimation algorithm and smoothing filter), factors connected with marking measurement points by the operator. To determine the accuracy of 3D surface model, the following procedure was developed. The CAD model had a geometrical structure similar to the human costal geometrical structure (curves with various radii, openings of various diameters, sharp edges) and the internal density similar to the internal density of bones. The CAD model was scanned with a CT scanner with a spiral scan and slice thickness equal to 1mm. The image data was processed (threshholding, filtering). A 3D surface model was created using the marching cube algorithm.

3.1 Analysis of image data

The first step of the error analysis was the comparison of image data with cross-sections of the CAD model (contour images). Image data were contoured and the longest contour was determined (the following contours were skipped). The same longest contour was determined on cross-sections of the CAD model. Both contours were scaled to the same scale and placed in two raster images, filling the interior of each contour. The XOR Boolean operation was performed to yield the third image, which contained the shape disparity of both contours. The comparison method of two images is called Disparity Surface Method (DSM).

The error of single contour comparison e_{pk} is:

$$e_{pk} = \frac{P_r * O_p}{O_k * P_p} 100\% \qquad (1)$$

where:

P_r - surface area of disparity image

P_p - surface area of the rectangle circumscribed on the contour

O_p - periphery of the rectangle

O_k - length of contour

The fraction O_p/O_k in formula 1 allows to correct the estimated percentage error in the situation where the surface area of the filled contour is small in relation to the length of the contour. The comparison was carried out with the distance between images 1mm, equal to CT slice thickness.

3.2 Analysis of the 3D surface model

The error estimation of the 3D surface model was performed by means of comparing the CAD model with the reconstructed model. The longest contours of the cross-sections of both models were compared using the DSM method with the distance between 0.5mm slice (CT slice thickness was 1.0mm). The orientation of the cutting plane was perpendicular and parallel to the scanning direction. The error of the whole model e_m is the mean error of all cross-sections. The maximum percentage error of the model is the maximum percentage error of the cross-section.

3.3 Measurement verification

The measurement verification of medical parameters using the reconstructed 3D model is impossible because there is no access to actual anatomical structures in the patient. Therefore, the experiment was performed that consisted in the measurement of the same geometric values on the CAD model and on the reconstructed CAD model. The measuring procedure was similar to the measuring procedure of measurement performed for the dysplastic pelvis in order to establish orthopaedic parameters, and it was performed in the following way: within the openings of the tested model, spheres were placed in such a way that the sphere surface closely adheres to the inner surface of the opening, a line was drawn through the centres of the spheres, the angles were established, whose apices were situated in the centres of the spheres, one of arms was the line, while the other arm crosses the specific points of the model.

4 RESULTS AND CONCLUSIONS

The comparison results of CT slices and CAD model, within the range of the mean percentage error and the maximum percentage error, are as follows:

$$e_m = 0.22\% \qquad e_{max} = 0.28\%$$

The mean percentage errors and maximum errors in the direction of each axis for reconstructed 3D surface model present as follows:

	Mean error [%]	Max. error [%]
Z axis	2.54	7.4
Y axis	4.08	15.2
X axis	2.90	20.7
Entire model	3.17	20.7

The slightest reconstruction errors occur always in the direction of CT slice image registering. The error analyse suggest that the model error is not constant and it depends on the surface shape and scanning direction. It may easily be seen that the most serious errors of the reconstructed model occur always in places where a sudden change of surface shape appears, and the normal for the surface is directed at a large angle in relation to the scanning direction.

The results of measuring verification according to the procedure mentioned above are in the range of 0.4-0.8%. Moreover, the standard deviation is rather small, which suggests considerable repeatability of measurement.

Analysing the procedure of processing CT image data and CT images for the 3D surface model and the measurements performed on this model, it may be stated that the largest error occurs in the process of the 3D surface model formation (see below). Strangely enough, the error of measurements performed on this model is considerably smaller than the error of the model itself. The explanation is as follows: measurement points, used for the calculation of angle values, and the distance, were reconstructed accurately, while the error of the model is the most strongly influenced by the inaccuracy of surface reconstruction in places where a sudden distance change occurs and the slope angle of the normal towards the surface in relation to the scanning direction is large.

CT Slice error - 0.22%
3D surface model error - 3.17%
Measurements of 3D model error - 0.69%