Registration of image medical data

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ABSTRACT

The paper deals with registration algorithms. Suitable procedures for the registration of image medical data are presented. During our work we used manual registration and point-based registration methods to register digitized slices of the temporal bone. To create referential points we included a different type of biological material to the sample of the explored object and the preparation was embedded in paraffin wax. The manual registration was found to be more precise than the point-based registration. Three dimensional reconstructions of the inner ear, ossicles of the middle ear and the facial nerve were made from the set of registered data.

Keywords: registration, medical imaging, reconstruction, temporal bone

1 INTRODUCTION

Recently, new methods based on computer 3D reconstructed objects have entered the field of medical diagnosis and therapy. The value of information that we are able to get from 3D reconstructed objects depends on the quality of source data and on the pre-processing. The source data for reconstructions are frequently in the form of planar cross-sectional images. This kind of data are acquired from various medical scanners as CT, MR, or confocal microscopy. Another possible way to obtain information about the shape of objects and their inner structure is digitization of physical parallel slices of explored objects (e.g. histological samples). Physical slices or their photos are scanned by a digital camera or scanner. It is obvious that digitized images obtained from a scanner are rotated or shifted in respect to their actual position in the object. To enable further processing it is necessary to transform the relevant slices to their correct position. This stage is called registration.

The registration of images in a two-dimensional space can be defined as a method of finding coefficients of geometric transformation (e.g. translation, rotation and scaling) between the reference and the registered images represented by matrices. Derived coefficients are used for transforming of registered image in the way that corresponding objects in both images have the same position, orientation and size. The aim of the paper is to give an account of procedures suitable for reconstruction of anatomical structures from parallel image data.

2 REGISTRATION ALGORITHMS

2.1 Manual Registration

To register image data we can use manual registration. The method is based on interactively setting the parameters of the transformation of the registered picture, e.g. translation, rotation and in special cases scaling. The manual method is very demanding on the training of the staff because it requires knowledge of the structures in the object. Despite the manual registration being very demanding it is the only useful method in many cases. For example, if there are no reference points in the picture, or if only a part of the structure is visible. Interactive work during manual registration consists of simple transformation steps such as translation and rotation around a given point. Particular operations are composed so that the resulting transformation is a combination of one translation t and one rotation R. Let $\{P_j\} = \{[P_{jx}, P_{jy}]^T\}$ be a set of pixels of the original registered image and $\{P'_j\} = \{[P'_{jx}, P'_{jy}]^T\}$ the same set of pixels of the image after transformation, then

$$P'_i = t + RP_i, \tag{1}$$

where

$$\begin{aligned} t &= \begin{bmatrix} t_x \\ t_y, \end{bmatrix} \\ R &= \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix}. \end{aligned}$$

2.2 Point-Based Registration

The manual registration performed only by the interactive transformations of the registered image is very demanding on time and skills. There are several ways to make this process easier. The point-based registration consists in transforming the registered image according to chosen referential points. It is possible to prepare extrinsic points in the explored object so that they are transferred into referential and registered images. The way of creating these points depends on the structure and the material of the object and on the available technology. For example, structures with different colour are placed in paraffin together with explored object and from this sample the set of slices is made. For further processing we have to detect the position of referential points. The detection and marking can be made manually or automatically. For defined given pairs of corresponding points we have found several transformations according to the required characteristics.

2.2.1 Rigid Transformation

The rigid transformation is defined by pairs of corresponding points. Two sets, the referential and the registered points, are given: $\{Z_j\} = \{[Z_{jx}, Z_{jy}]^T\}$ and $\{W_j\} = \{[W_{jx}, W_{jy}]^T\}$; $j = 1, \ldots, n$. The task is to find a transformation $W_j \mapsto t + RW_j$, of the set $\{W_j\}$, composed from a translation t and a rotation R for which the following overall mean square error is minimal,

$$e^2(R,t) = \frac{1}{n}\sum_{j=1}^{n} \|Z_j - (RW_j + t)\|^2. \quad (2)$$

As we are only interested in planar transformation, we can replace the coordinate vectors of points by complex numbers, i.e. $\tilde{z}_j = Z_{jx} + iZ_{jy}$ for the points in the referential image and $\tilde{w}_j = W_{jx} + iW_{jy}$ for the registered image. It is not hard to see that the centres of gravity must be the same, so we should subtract the centre of gravity z_s and w_s from the points. Let us call the new numbers z_j and w_j,

$$\begin{aligned} z_s &= \frac{1}{n}\sum_{j=1}^{n} z_j, \\ z_j &= \tilde{z}_j - z_s, \\ w_s &= \frac{1}{n}\sum_{j=1}^{n} w_j, \\ w_j &= \tilde{w}_j - w_s. \end{aligned}$$

We want to minimize

$$A(\alpha) = \sum_{j=1}^{n} |z_j - \alpha w_j|^2 \quad (3)$$

where $|\alpha|^2 = 1$, i.e. α denotes a rotation R. Now

$$\begin{aligned} A(\alpha) &= \sum_{j=1}^{n} (z_j - \alpha w_j)(\overline{z_j} - \overline{\alpha w_j}) \\ &= C - 2\,\mathrm{Re}(\alpha B) \end{aligned}$$

where

$$B = \sum_{j=1}^{n} w_j \overline{z_j}$$

and

$$C = \sum_{j=1}^{n} |z_j|^2 + \sum_{j=1}^{n} |w_j|^2.$$

The terms B and C do not depend on α. To minimize $A(\alpha)$ we want to maximize $\mathrm{Re}(\alpha B)$. This is obtained as $|\alpha|^2 = 1$, by choosing $\arg\alpha = -\arg B$, i.e.

$$\alpha = \frac{\bar{\alpha}}{|\alpha|} = e^{i\phi}.$$

Coefficients of the transformation can be expressed by the following equations,

$$\begin{aligned} t &= z_s - \alpha w_s, \\ t_x &= \mathrm{Re}\, z_s - \cos\phi\,\mathrm{Re}\, w_s + \sin\phi\,\mathrm{Im}\, w_s, \\ t_y &= \mathrm{Im}\, z_s - \sin\phi\,\mathrm{Re}\, w_s - \cos\phi\,\mathrm{Im}\, w_s, \\ \phi &= \arctan\frac{\mathrm{Im}\,\alpha}{\mathrm{Re}\,\alpha}. \end{aligned}$$

2.2.2 Rigid-Body Transformation

Another way of determining the parameters of the transformation matrix between corresponding points, the rigid-body transformation, applies translation, rotation and scaling. The following procedure of deriving coefficients of this transformation is general. It can be used in n dimensions and also for the rigid transformation without scaling.

Let us have two sets of corresponding points, referential $\{Z_j\}$ and registered images $\{W_j\}$. The task is to find a transformation $W_j \mapsto t + sRW_j, j = 1, \ldots, n$, of the set $\{W_j\}$ composed of a matrix of rotation R, a vector of translation t and a scaling parameter s so that the squares error

$$e^2(R,t,s) = \frac{1}{n}\sum_{j=1}^{n} \|Z_j - (sRW_j + t)\|^2, \quad (4)$$

is minimized.

According to a theorem due to Umeyama [Umeya91] the optimal Euclidean transformation minimizing the mean squared error (4) is given by $R = USV^T$, $t = Z_s - sRW_s$, where Z_s and W_s are the centres of gravity of the data sets $\{Z_i\}$ and $\{W_i\}$ respectively, and UDV^T is the singular value decomposition of the matrix,

$$\sum_{zw} = \frac{1}{2}\sum_{j=1}^{n}(Z_j - Z_s)(W_j - W_s)^T. \quad (5)$$

The matrix S is given by

$$S = \begin{cases} I & \text{if}\det(UV) = 1, \\ \mathrm{diag}(1,1,\ldots,-1) & \text{if}\det(UV) = -1. \end{cases}$$

Coefficients of the transformation can be expressed by the following equations,

$$\begin{aligned} R &= USV^T, \\ t &= Z_s - sRW_s, \\ s &= \frac{1}{\frac{1}{n}\sum_{j=1}^{n}\|W_j - W_s\|^2}\,\mathrm{tr}(DS). \end{aligned}$$

3 DATA

The data set consisted of 60 slices of the histological preparation of the human temporal bone. The temporal bone was removed within 24h after abortion. After fixation in 10% formaldehyde solution, specimen was decalcified in 10% formic acid, embedded in paraffin wax (celoidin) and sectioned horizontally (midmodiolar plane) at a thickness of $10\mu m$. Every fifth section was stained with hematoxylin-eosin. Particular slices were scanned and digitized into the true colour raster format RGB. The size of one image was 800x500 pixels [Fig.1].

During the process of cutting and scanning, the corresponding images were shifted and rotated so that direct visualization was not possible.

Extrinsic points that had been created by added tissue with different colour characteristic were supposed to be used. But while the physical slices were being made, the position of the referential points was changed and we had to use intrinsic points derived from anatomic landmark points in the structure. We choose three pairs of referential points.

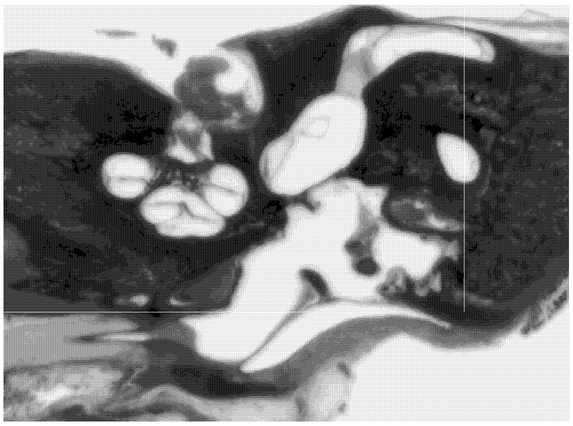

Figure 1: Image data (cochlea, inner meatus, semicircular canal, vestibulum stapes, external meatus)

To measure errors of registration it was necessary to create a referential object. A part of suitable tissue from two randomly chosen consecutive slices was segmented and as a result we obtained a raster image that was comprised only from pixels of two levels. The white level was used for the referential object and the black level for the background.

We applied referred registration methods on slices modified (segmented) as shown above. Three pairs of corresponding points were chosen as referential intrinsic points. Besides methods of automatic registration, the data were also registered manually according to visual information. To determine the error we used the following methods.

The first method measured the surface which had not been correctly registered.

Let A be a set of all white pixels of the referential image and let B be a set of all white pixels of the registered image. Then the result of the binary operation XOR with the sets A and B gives the number of pixels that were not correctly registered [Fig.2]. Better registration methods are characterized by smaller values of the XOR operation.

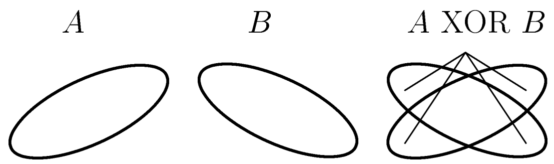

Figure 2: XOR operation on the referential and the registered image

The second method was based on the measurement of distances between boundary points of the registered referential object. Let A be the set of all boundary pixels of the referential object in the referential image and B be the set of all boundary pixels of the referential object in registered image.

For each pixel from the set A consider the distance to the closest boundary pixel in the set B. Then Σ_{AB} is the sum of squares of these distances. Similarly, Σ_{BA} is the sum of squares of the distances between pixels from B and the corresponding closest pixels from A. We look for the smallest values of Σ_{AB}, Σ_{BA} to determine the most suitable registration method.

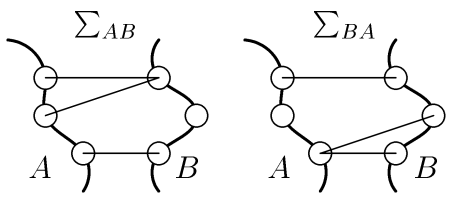

Figure 3: Measurement of distances between border points

Measured values for rigid body registration, rigid transformation and manual registration are shown in the Table 1.

4 RESULTS

We can see in the Table 1, that the least errors were obtained from the manual registration. The reason is that the operator uses more information than several pairs of referential points.

	Rigid	R-Body	Manual
t	[3.3;4.0]	[4.5;5.3]	[1.9;2.8]
$\phi[^\circ]$	4.42	4.10	4.18
s	1	0.98	1
A XOR B	296	306	275
$\sum_{AB}$	639	589	467
$\sum_{BA}$	569	491	389

Table 1: Measured value of Rigid, Rigid-Body and Manual Transformations.

In case we need to register image data from scanners with different scales it is necessary to use the Rigid-Body transformation.

5 CONCLUSION

Three methods suitable for registration of medical images were presented. Point based methods, Rigid transformation and Rigid Body transformation, were compared with manual registration. The methods were tested on a data set that consisted of parallel raster images of the temporal bone. The quality of registration was evaluated by two methods. The first one was based on counting of correctly registered pixels in the referential object. The second method was based on assessing of the sum of squares of distances between the closest boundary pixels. According to the measurement, the manual method has shown better results than the point-based methods. The supposed reason is that the operator uses more information for registration than several pairs of referential points used in a point-based methods.

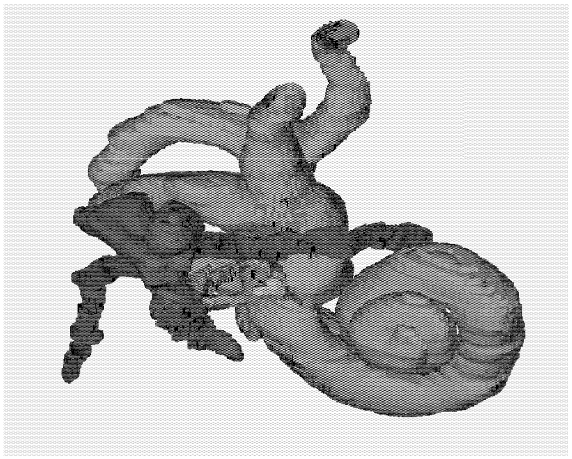

Figure 4: 3D reconstruction of temporal bone (semicircular canals, facial nerve, cochlea)

To test the algorithms of registration the program *Pix* for *Silicon Graphics* computers was created. The program deals with two chosen image data sets. Images are read from input files in raster format which enables one to work in true colour resolution. Referential and registered images are simultaneously projected and it is possible to chose the level of transparency. The user can make registration manually, by interactive setting or automatically after inserting referential points. Registered images were used as a source for the visualization software *Medicus*, which was created in our computer lab. For segmentation of the registered images the software *Analyze*^{TM} was used. Results are shown in the Figure 4.

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