multimodal images registration
in orthodontic routines

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COMPUTER REGISTRATION SYSTEM AND FUSION OF MULTIMODAL IMAGES FOR ORTHODONTIC PURPOSES

The paper presents aspects connected with development of a computer system for registration and fusion of multimodal images for orthodontic purposes. The idea of the system, of the multimodal image registration, lies in 3D surfaces registering, reconstructed from the sets of MRI or CT planar slices. The system enables the user to perform registration using different approaches based on localised landmarks, based on selected regions of 3D surfaces or based on automatic matching of the whole surfaces. The rigid-body transformation found during the registration is then used to transform the set of slices to generate images that can be fused. The usage of the system was illustrated and the accuracy of the registration was assessed.

1. INTRODUCTION

The main goals of orthodontic treatment include correction of facial aesthetics, improvement of temporo-mandibular joint functions, and reduction of disorders and malformations in the facial and oral area of the skull [4]. The basis of orthodontic diagnosis is still planar X-ray imagery – cephalograms - of the patient's head taken in two projections (lateral and frontal). All measurements and analyses performed are then subject to the errors connected with the projective character of this imaging technique. The advent of 3D imaging provided new possibilities in supporting orthodontic diagnosis and evaluation of the treatment results. The reconstruction of skull surfaces can be done using a data acquired from CT, while images of facial features and other soft tissues, are obtained by MRI [4]. The diagnostic value of these two types of images can be dramatically increased if they are brought into register, i.e. put together in a common coordinate system [7]. The complex software, designed for 3D medical imaging is usually a part of CT or MRI systems, which exist in specialised radiology centres. Moreover, such centres can afford more advanced systems for registering both types of images etc. But those systems are not always available for each orthodontist.

The registration of CT-MRI images could improve diagnosis of temporo-mandibular joint disorder. Registration of two series of images taken in two different moments can help assess the progress of therapy and the results of growth. Therefore, a specialised program designed for the registration and fusion of multimodal images for orthodontic purposes has

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to be still under development. This program should be rather simple (like most programs for cephalometric analysis) and not very expensive.

The current work presents aspects connected with development of the computer system registration and fusion of multimodal images. The system usage was illustrated and the accuracy of registration is assessed.

2. MULTIMODAL IMAGES REGISTRATION

2.1. REGISTRATION TECHNIQUES

The idea of registering two images is to determine which point of either image corresponds to the same point of the real object [7]. Those image points are said to correspond to each other. Another issue is determining the transformation which the object underwent between the points in time when the individual images were taken. This transformation includes any change of shape and size due to growth, disease and medical interventions, as well as of patient positioning, and possibly of coordinate systems between imaging procedures. This problem, also called image matching, determining correspondence, homology searching has been explored in Computer Vision [1,16]. The first practical instances where this problem arose were connected with the analysis of planar images, and various methods were used to determine image locations which were projections of the same object point. The applications ranged from determining optic flow and object tracing, through finding the depth map in stereovision, to analysis of object change, its deformation and growth over a period of time. Many different algorithms were defined to solve this problem, including the gradient method, techniques based on the Fourier domain, logarithm of the Fourier power spectrum (cepstrum), correlation-based algorithms, snakes[13], active shape models, and active appearance models [1, 2, 16,13].

Registering multimodal images is even more difficult, because the differences between images produced by different techniques are significant [7]. Furthermore, apart from the differences in intensity profiles, there exist differences in patient positioning and image resolutions. It is because of those differences that the various images can provide mutually complementary information[10, 7, 8] but in order to perform proper image registration additional assumptions have to be made about correct patient positioning, or artificial geometric markers have to be applied.[6] The correct transformations that bring the images to a common coordinate system can be identified by a simple analytical algorithm, but the method is sensitive to errors in patient positioning and marker localization, and also to errors connected with movements of the patient’s anatomic structures.

Another approach uses the segmented parts of the objects, which are common to both types of imaging, e.g. the skin. In this case, a three-dimensional surface becomes the basis for the registration process [10]. Surface registration techniques are more recent then image registration, and their development began with the possibilities to acquire 3D surfaces. Nowadays two kind of algorithms can be distinguished, namely ICP (Iterative Closest Point) algorithms [12] and non-ICP algorithms [11]: curve-to-curve matching or point-to-surface matching. But the idea of registration, for all algorithms, is the minimization of some defined criterion in the set of possible rigid body transformations. The choice of this criterion and the choice of the optimisation method are the main factors which distinguish those algorithms. Usually the minimised function is a sum of the smallest point-to-point distances, although other metrics are also used.

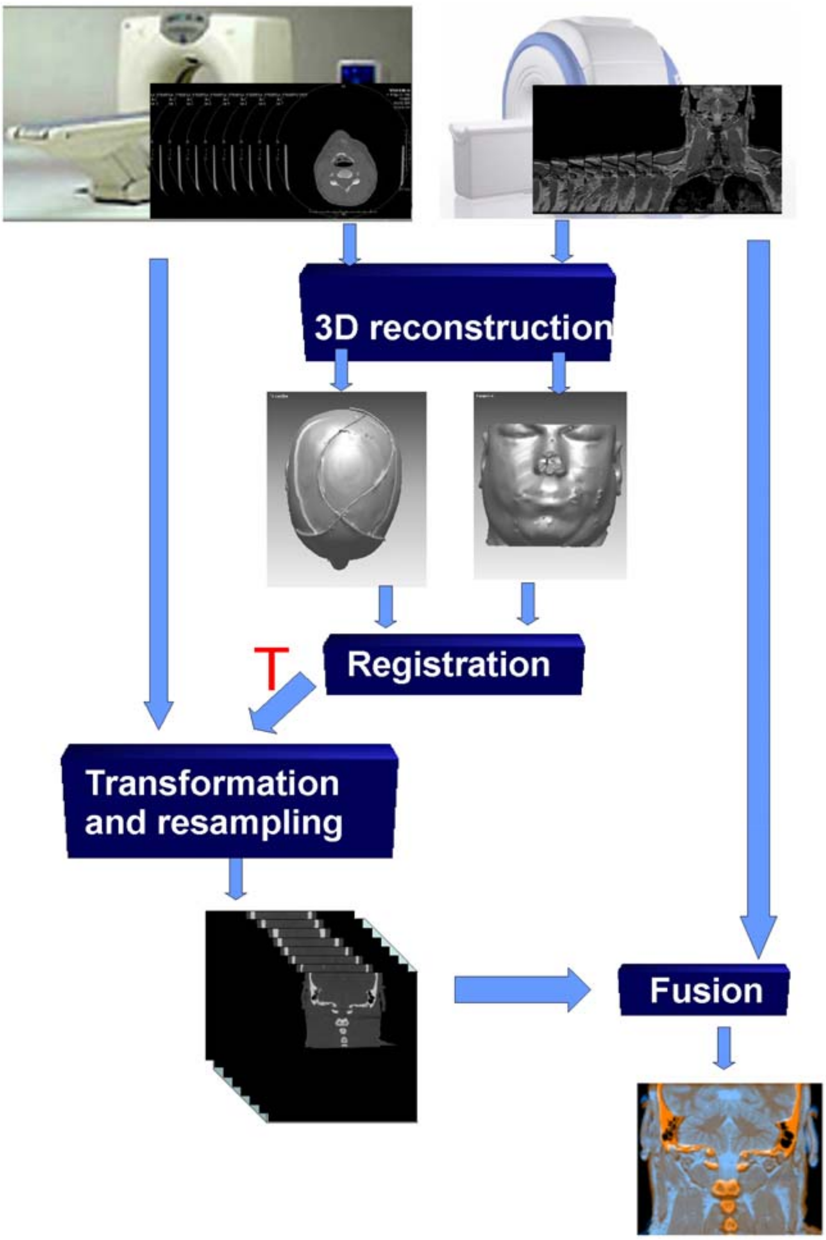

Fig. 1. The idea of the computer system of registration and fusion

2.2. MEDICAL ASSUMPTIONS

When designing a system for orthodontists, one has to consider the customs and expectation of this group of users. The intended use of the system is various comparisons, which usually require different approaches to the registration process.

The first type of registration, typically used in orthodontics diagnosis, is edge superposition [5, 15]. This approach is used when the estimation of movements of landmarks in some strictly defined coordinate system is expected. This coordinate system is created based on some landmarks for each image and next the two coordinate systems are aligned. Such a solution was used in a system designed to support facial features analysis which is being developed in under our research project [14].

The method to estimate of growth, relying, for example, on two sets of CT images, would also require the superposition of some landmarks. A similar problem appears when the results of therapy need to be estimated then registration should be based on local areas defined by the user. The registration process will then require interactive cooperation with the user. The cooperation extension of this, will depend on the particular application and on the quality of reconstructed 3D surfaces. In some cases, fully automatic registration will be expected.

The idea of the multimodal image registration system lies in registering the 3D surfaces reconstructed from the sets of MRI or CT planar slices. The system should enable the user to register those surfaces using different approaches based on localised landmarks, based on selected parts of 3D surfaces or based on automatic matching of whole surfaces. The transformation T found during the registration is then used to transform the set of slices to generate images that can be fused. The idea of the system is presented in Fig1.

3. SPECIFICATION OF THE SYSTEM'S FUNCTIONS

The computer system for multimodal image registration consists of the following functions: visualization, semiautomatic (Procrustes) registration, full-automatic registration, measurements, file read and write functions. These functions are briefly described below.

3.1. VISUALISATION

The registration system has two visualisation modes. The 3D surface mode is used by the registration process. Besides the rendering of 3D surfaces, the application in this mode can perform simple operations like rotation, movement, zooming in and out. There is also the possibility to make the surfaces transparent. The partial surfaces are displayed and their mutual position can be seen. By turning on the "transparent" option, it is easier to see the differences between surfaces.

In tomogram mode, the upper part of the main window of the program shows thumbnails of cross-sections of the patient's body. Clicking one of the thumbnails makes the crossection enlarged; in a lower part of window. One or two images can be displayed at a time (Figure 2). Cross-sections can be superimposed, their brightness and contrast adjusted, distances measured, and it is possible to switch sequentially to the next or to the preceding cross-section.

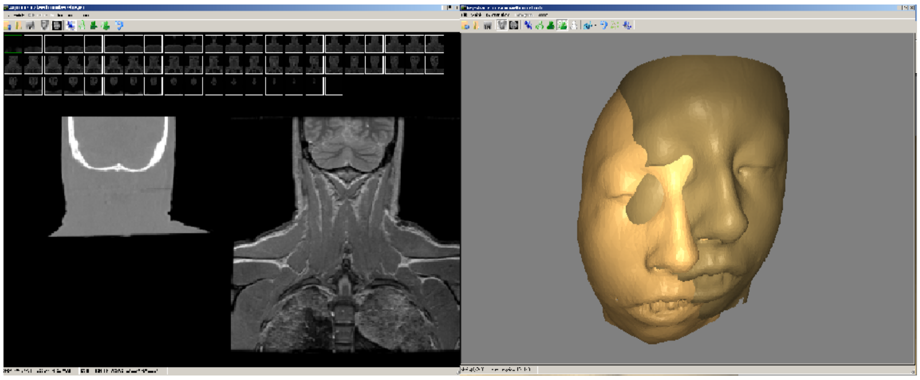

Fig 2. Tomogram view, surface view

3.1. REGISTRATION ALGORITHMS

The semiautomatic registration algorithm used in our program relies on the user to mark (with the mouse) corresponding points on the partial 3D surfaces obtained by imaging procedures. In this technique, the two partial surfaces are displayed separately, and each can be freely rotated and translated. At least four pairs of points must be marked for registration to be possible. All the points are displayed on the 3D surfaces (Fig. 2). The Procrustes method [5, 15] was used to determine the transformation matrix.

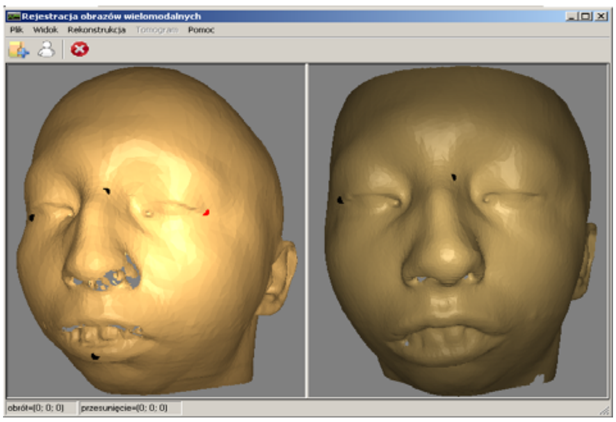

Fig 3. Semiautomatic registration – marking the points

The procedure used for automatic registration of 3D surfaces relies on a genetic algorithm to minimise a criterion defined as the sum of smallest point-to-point distances. The task of the genetic algorithm is to avoid being trapped in a local minimum of the goal function, which might lead to erroneous registration. It uses notions borrowed from natural evolution such as selection, survival of the fittest, reproduction, crossover and genetic mutation. The algorithm is fully automatic and does not require any input from a human operator. Its speed and precision can, however, be enhanced if the most similar parts of the two partial 3D images are initially marked by hand. The algorithm terminates when one of two conditions is met: the mean-square error is reduced to less than 1, or the number of generations has reached 25.

In order to speed up automatic registration, the user can select the points that will be taken into consideration. It is possible to select at random 1%, 10% or 50% of the points of each surface. Another option is to select the points manually using the mouse.

3.2. FUSION

The result of the registration is a set of parameters defining the rotations and translations needed to fit two surfaces together. These parameters can be applied to transform a set of cross-sectional data. It then is possible, for a given cross-section of one examination, to generate the corresponding cross-section of the other. Interpolation is used to obtain as correct values as possible for the pixels of the cross-section being generated. The particular interpolation technique used in our program relies on seven voxels. Intensity of a pixel is primarily generated based on the voxel in which its centerpoint is located. The six adjacent voxels are also taken into consideration. The final value of the pixel is a weighted average of the seven voxels, with the weights inversely proportional to the distance from the pixel's centerpoint to the centerpoint of each voxel. This algorithm is fast and ensures good quality results.

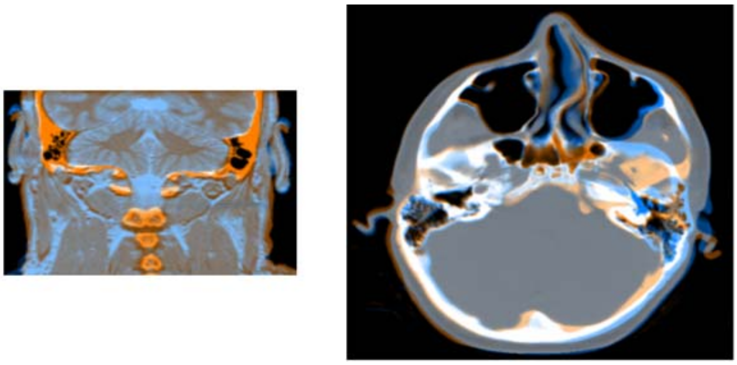

Fig. 4. Superimposing registered data (NMR/CT, CT/CT)

The final result can be displayed as two images in neighbouring parts of a window or as one superimposed image, with each image in different colour.

3.3. DATA READ/WRITE

The program can read medical imaging data from DICOM files. Under this standard, one file can store the patient's personal data and the results of one or more imaging examinations (such as X-ray or CT), including such technical parameters as brightness, contrast, magnification, pixel spacing and slice spacing.

Before proceeding to registration, it is assumed that image data have been segmented to reconstruct object surfaces. The program can read OBJ files, which store surfaces represented as triangular meshes.

After reading in the individual files, the entire project can be stored in an XML file. It stores the pathnames to files representing individual examinations and reconstructed surfaces, brightness and contrast settings, registration results and the associated transformations.

3.4. ADDITIONAL FUNCTIONS OF THE PROGRAM

In tomogram mode, simple measurements can be carried out on the cross-section images. The results are given in millimetres. Therefore there exists a possibility to measure different distances on fused images that is to measure displacement between homologues regions of two images.

4. RESULTS OF REGISTRATION

The registration system was tested on two sets of data. The first one contained NMR and CT scans of the same person, obtained within a short timeframe. The other set contained two CT scans of the same person, taken at an interval of 3 years.

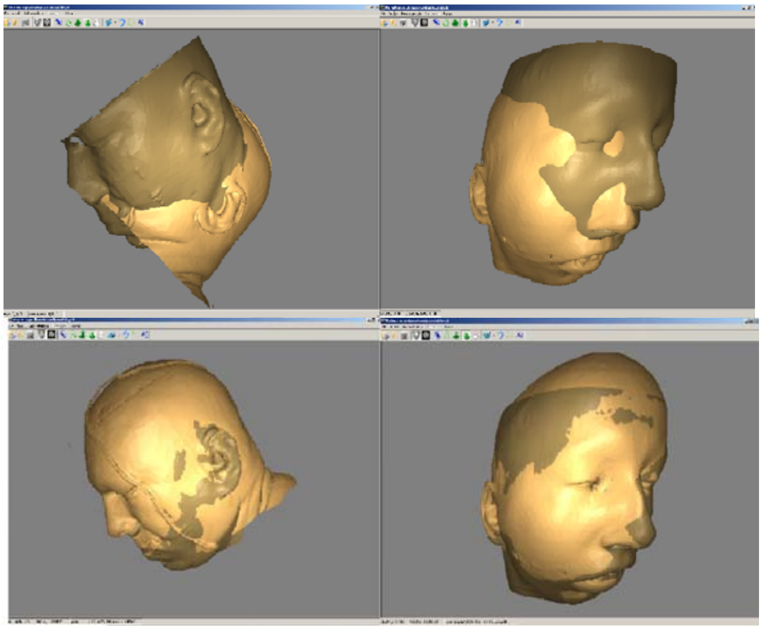

Fig. 5. Set of test images after automatic registration.

During semiautomatic registration, for either set of data, four pairs of matching points were marked manually. In either case, the Procrustes algorithm used for this registration found the correct transformation at the first time.

When testing the automatic algorithm, similar feature areas were marked on either surface and then automatic registration was started. The results are more precise than those obtained with semiautomatic registration. However, the algorithm could not always find the correct solution if feature areas were not initially marked by hand.

To use full results of registration, corresponding cross-sections are usually superimposed (Figure 4). The final result is a single image showing the structures obtained in both examinations.

The RapidForm software was used to determine the accuracy of the proposed algorithms. RapidForm has its own functions for surface registration. It can also compute the average deviation between two surfaces. The set of data used for the measurements was the two CT scans of the same person, taken at an interval of three years. Registration in RapidForm showed an average deviation of approximately 1.1mm. Using semiautomatic registration, we obtained an average deviation between 1.5 and 2.5mm, depending on how precisely the feature points were marked. Automatic registration with randomly selected points yielded an average deviation of 2mm. If manually marked feature regions were supplied, the standard deviation of automatic registration was reduced to 1.5mm. The accuracy of our registration techniques is therefore comparable to that of the solution used in RapidForm.

5. CONCLUSIONS

The presented paper describes the computer system functions of registration and fusion of multimodal images, for the purposes of orthodontics. The advantage of the program concerns possibility of selection between semiautomatic and fully automatic registration, depending on the purpose of registration. As far as the searched transformation is assumed to be rigid body transformation, this approach requests the user to realise the most correct result of registration that is the region (possibly small), which was chosen as the basis for the registration; especially in the cases when deformation or growth can be observed.

The development of the system will include a possibility to perform 3D surface reconstruction form slices (up till now it is done by extern application) [9], a possibility to localise and visualise landmarks also in particular slices, a possibility to generate any cross-sections of fused data.

Some works towards automatic selection of local most matching regions, some optimisation of the time performance and the accuracy are also planned.

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