DIAGNOSIS
A Global Alignment and Fusion Medical System

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Abstract: In this paper, a global registration-fusion system of medical data is presented in detail. The system is comprised by the following basic subsystems: (1) the multimodal medical image archiving and communication subsystem, (2) the image processing subsystem, and (3) the multimodal registration and fusion subsystem. The system offers various capabilities such as storage, retrieval, distribution and presentation of images from different medical modalities in DICOM format, supports multiple examinations of a patient and uses parallel processing threads to perform the processing of the acquired three-dimensional (3D) data in almost real time. The paper discusses the basic features of the proposed system, analyzes the proposed algorithms for image preprocessing, registration and fusion and presents the results of an experimental study that was carried out for evaluating its performance. The innovation of the proposed work is multilayered. It provides automatic matching based on both segmented surfaces and on different levels of gray and it allows comparison of registration accuracy for the different techniques based on specific criteria to quantify registration. Finally, it improves the registration when there is movement and / or distortion in the data collection of the patient from different imaging systems.

1 INTRODUCTION

Medical imaging is a vital component of diagnostic medicine, and it also has a significant role in the areas of surgical planning and radiotherapy (Maintz, 1998). Often, medical images acquired in the clinical track are using different imaging technologies. Integrating these images, which are often complementary in nature, is a challenging problem. The first step in the integration process is bringing the tomographic images into spatial registration, so that the same anatomical regions coincide, a procedure referred to as registration (Hajnal, 2001). After registration, a fusion step is required in order to combine information from different modalities, or from the same modalities at different examination periods (Hawks, 1992).

A prominent example where the fusion of registered images maximizes the available diagnostic information is tumor diagnosis and radiotherapy treatment. The Magnetic Resonance (MR) imaging system, the SPECT medical imaging and the Positron Emission Tomography (PET) provide functional information even at very early stages of cancerous tumors, but they do not reliably depict the anatomical characteristics of the tested organs. On the other hand, tomographic imaging techniques such as Computer Tomography (CT) and magnetic (MR) scanners, the ultrasound and X-rays provide anatomical information, but usually determine the existence of a cancer tumor only when it is in a later stage compared to the functional techniques. Thus, the combined use of different modalities that offers complementary clinical information is much more effective, allowing early

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diagnosis and accurate identification of a cancer tumor and hence the effective planning of the radiotherapy treatment.

It is often necessary to align medical data to illustrate the changes between the data retrieved at different times so as to assess the progress of a disease, or to assess the effectiveness of the treatment. In this case the fusion of data is implemented to illustrate the changes, as in the measurement of bone support for implants using dental radiographs. Moreover, the data registration applies to cases where data from anatomical atlases in conjunction with real clinical data and studies on patient populations are used.

In this work, a global alignment-fusion system of medical data was developed, which was named «dIaGnosis». Comparable software systems for processing and visualization of medical data are also implemented by Philips Medical Systems Inc., Siemens Medical Systems Inc and others. Medical data in commercial systems are represented in DICOM format, which is the prominent medical data protocol. Most commercial software provide semi-automatic and automatic registration options, as well as possibilities for data fusion after registration alignment, either on sections base (2D problem) or on surfaces base (3D problem). The proposed system overbalances the existing registration techniques. Specifically, it provides automatic matching based on both segmented surfaces and on different levels of gray, while algorithms are applied directly to three-dimensional (3D) data. In addition, it allows the application of different geometric transformations, including an elastic transformation to improve the registration when there is movement and / or distortion in the data collection of the patient from different imaging systems. Finally, it allows comparison of registration accuracy for the different techniques based on specific criteria to quantify registration.

This paper is organized as follows. Section 2 outlines the architecture of the system proposed and presents the algorithms used for image preprocessing, registration and fusion. Section 3 describes the working environment of the implemented system. Section 4 presents the baseline scenario where most of the procedures supported by the system are shown. The efficiency of registration techniques was tested during the pilot study on skull patient data collected from CT and MR scanners.

2 SYSTEM ARCHITECTURE

In Figure 1 the overall system architecture is depicted. The system consists of five complementary layers-subsystems, managing the registration and fusion of the medical data, as well as the interaction with the final user.

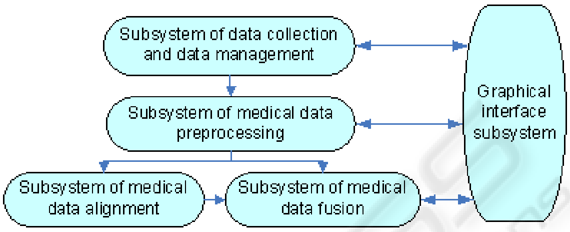


Figure 1: The system architecture.

According to the proposed architecture, the system consists of the following five subsystems.

2.1 Data Collection and Data Management Subsystem

The subsystem of data collection and management allows the storage, retrieval, distribution and presentation of medical images:

- Using Magneto-optical instrument, and
- Data transfer via network from the diagnostic consoles of the CT and MR scanners, or a workstation where digital medical data are acquired.

The medical data collected are a series of sections from the same patient from different imaging modalities (CT and MR scanners) and correspond to a specific region of the human body. In the pilot version of the system the data correspond to the region of the skull as acquired from both CT and MR scanners.

As mentioned earlier, DICOM format is the prominent international protocol for medical data. Thus, the medical data acquired by the scanners are compatible with this format. The entry, management and export data are in DICOM format too. (NEMA, 2006)

In this subsystem we implemented a function that reads the header of the DICOM file (DICOM header) and includes automatically the following technical characteristics of the system: the number of sections, the number of pixels per section, a data analysis per section (mm/pixel), the interval sections (mm), the number of bits/pixel and the patient data (patient code, DATE examination, etc.), if available.

The basic technical capabilities of the subsystem include:

- Patient (code) correspondence with the initial data of his/her examination.
- Multiple examinations per patient (through appropriate code).
- Data display with multiple horizontal sections in icon size.
- Data storage after their process (in DICOM or other format) in the hard disk of the computer system.
- Determination of reference data from the user.
- Ability to support multiple data to align common reference data.

2.2 Medical Data Preprocessing Subsystem

The data preprocessing is an optional step. It applies to data which are characterized by high levels of noise and the containment is achieved by using the appropriate filters. So, it is usual that before the registration a re-sampling of one or both data sets that have the same discretionary analysis is needed. Thus in the subsystem an appropriate technique for re-sampling is incorporated (Unser, 1993). The data pre-processing subsystem includes the segmentation technique as developed. In this case, anatomical information is extracted from the two data sets (for example the external surfaces of the skull from both CT and MR scanners), which is then used to perform the registration.

2.2.1 Pre-processing Techniques

The acquired 3D data may include noise and/or characterized by heterogeneous background. This noise is undesirable and should be removed, without the loss of significant anatomical information contained in images. For noise reduction, suitable filters are implemented to improve the quality of images, which are applied on section based (two-dimensional problem - 2D) (Gonzalez, 1993).

Specifically, within the subsystem the following filters have been implemented to improve image quality:

- Mean filter: It is a low-pass filter which reduces high-frequency noise in an image.
- Median filter: it is another filter for noise containment.
- Gamma correction: The factor γ determines the function which distributes the values of pixels, according to the intensity of brightness of the screen. The factor γ is equal to one when there is a linear relationship between pixel values and intensity of brightness. Images that appear darker usually require the factor γ have values larger than one, while those which appear bright usually require the factor γ have values smaller than one.
- Histogram Equalization filter: it is a commonly used technique for better visualization of the diagnostic information of an image. In cases where the biological tissue of interest shows rates (different levels of gray), which vary between certain limits in the digital image, the visualization of the tissue is significantly enhanced if the function which corresponds the values of pixels in the image with brightness in screen changes.
- Adjust brightness and contrast: It is one of the most basic functions for image editing. The implementation of this subsystem provides the opportunity to change the brightness and contrast of images by the simple linear transformation:

$$I'(x,y) = aI(x,y) + b \qquad (1)$$

Where I(x,y) is the pixel of the initial image with coordinates (x,y) and I'(x,y) is the pixel of the adjusted image.

2.3 Medical Data Alignment Subsystem

In many cases in the current clinical practice it is desirable to combine information provided by two or more imaging modalities or to monitor the development of a treatment based on data collected at different times by the same modality. In particular, when monitoring the development of a treatment, it is very often the imaging anatomical structures displayed in two sets of data that have been collected at different times to be characterized by geometrical movements, revolutions, etc. It is necessary to find an appropriate geometric transformation, which achieves the spatial coincidence of anatomical structures of the two images. This process of finding the transformation is called registration.

The medical data alignment subsystem consists of a set of techniques for 3D registration of brain data on surface based or using the levels of gray (gray-based). Particular attention has been given to the design of the automatic registration techniques. Alternatively, there is the option of manual registration using appropriate surface driving points as selected by the expert.

Within the design of this subsystem three registration techniques were implemented:

- Automatic registration based on surfaces,
- Automatic registration based on gray levels and

- Manual registration.

2.3.1 Surface-based Registration Technique

This technique is automatic and based on the spatial matching of segmented anatomical structures of data from different imaging modalities (Matsopoulos, 2003).

The basic stages of the automatic method for surfaces registration include:

- Surface Pre-alignment. The stage of pre-alignment includes the spatial displacement of two triangulated surfaces, so that the centres of mass coincide. Also, a transformation of scale in each axis is done separately, based on the voxel sizes of the two images (Matsopoulos, 2000).
- Geometric transformation application. The second phase implements an overall geometric transformation. Its parameters are calculated by optimizing a function that quantifies the spatial matching of a triangulated surface of the reference image (computer tomography - CT) and the modified image (MRI - MRI). Four models of geometric transformation in three dimensions, are explored and evaluated based on the final results of the registration (Van den Elsen, 1993).
- Matching function definition. The registration can be seen as the optimization of a Measure of Match - MOM according to the variables of the selected transformation. At the case of surfaces matching an appropriate matching function is the average of the geometric distance between the transformed points of the magnetic scanner data and the corresponding closest points of computer scanner data.

2.3.2 Registration Based on Gray Levels

This data registration technique is based on the automatic spatial identification of data from different imaging systems and is applied on image values directly, without the prior requirement for segmenting common anatomical structures (Kagadis, 2002).

2.3.3 Manual Registration

In the case of the manual registration method, the expert selects points in the respective sections of the two imaging modalities and the registration of the data is based on the selection of a particular geometric transformation (Maurer, 1997). This method has been developed so that its performance can be compared to the performance of the proposed automatic registration methods.

2.4 Medical Data Fusion Subsystem

Medical data fusions scope is to combine information from different modalities, after the application of the medical image registration process. The fusion subsystem is designed appropriately to allow the composition of anatomical information from the aligned medical data using techniques such as the pseudo-colour scale, logic functions for the diverse overlay of image parts on another image and change the degree of transparency in the overlay of anatomical structures (Matsopoulos, 2008).

2.4.1 Fusion Techniques

Within the proposed system, the following techniques for medical data fusion, were developed and applied after registration:

- Implementation of logical functions for the diverse parts overlay of one image on the other. Specifically, after the data registration, the anatomical information derived from data of the CT Scanner overlays on the respective aligned sections of the MR scanner in order to fuse the information from the two imaging systems. This process is mathematically standardized with the logical operator Exclusive Or (XOR), which is implemented as follows:

$$I(x,y) = I_A(x,y)(1 - M(x,y)) + I_B(x,y)M(x,y) \quad (2)$$

where I_A and I_B the reference image and the image to align respectively and M is the mask that has value 1 at the pixels that overlay from both the I_B to the I_A. The mask M may be the segmented structure of interest of the I_B image that has to be visualized from the reference system of I_A, or repeated normalized geometric shapes, where the aim is to visually confirm the accuracy of the registration of I_B relatively to I_A.

In the pilot study, information from the CT scanner was isolated and was inserted in the aligned data of the magnetic scanner using logic functions (XOR). This fusion method allows the expert – a doctor to assess the accuracy of the registration method, while it gives information on the position of the bones from the computer tomography in comparison with other soft tissues or tumors, as shown in MR.

- Ability to change the degree of transparency 'a' during the overlay of anatomical structures in order to achieve a combination of information and assess the quality of the registration result. This technique was implemented on the basis of the relationship:

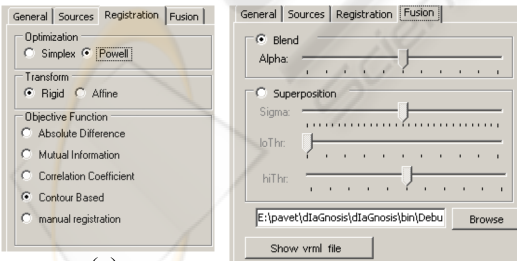
$$I(x,y) = I_A(x,y)(1-a) + aI_B(x,y) \qquad (3)$$

- Fusion of data in 3D is a particularly difficult problem because the extra dimension makes the data display difficult even without the extra complexity of the data fusion. In this work, a simultaneous demonstration of common anatomical structures - surfaces before and after the registration is achieved using the proposed representation techniques in the form of VRML.
- The results are visualized using pseudo-coloring according to the medical system used (e.g. red for the visualization of the anatomical structure of the axial scanner and blue for the magnet scanner), to make clear to the expert the relative position of the two surfaces and the change before and after the registration (Gomes, 1998).

2.5 Graphical Interface Subsystem

The graphical interface subsystem is an important part of the developed system, as it allows the final user use the necessary functions of the registration software. The subsystem was developed having in mind the following requirements:

- Ease of use and user friendliness,
- Speed enforcement functions and
- Reliable performance of the software's individual applications



(a) (b)

Figure 2: (a) Selection of registration parameters (b) Selection of the fusion parameters and implementation of the fusion settings.

The key features of the graphical interface subsystem include:

- Creation of an appropriate graphical environment: This feature concerns the design and development of an appropriate interface that offers: a) easy navigation to the software's menus, b) easy access to medical data and c) a clear definition of the integrated techniques – algorithms.
- Visualization of the medical information: An important feature of the software is the ability to visualize data and present the results of the applications and techniques applied in an comprehensible manner. It provides: a) visualization of the original medical data, b) visualization of the data processing results, particularly the results of automatic registration methods and c) visualization of the fusion of information from the registration. In particular it allows simultaneous display of relevant medical data (e.g. CT and MR sections) before and after the registration and presentation of the fusion results. Quantification of the registration results: Beyond the visualization of the registration and fusion results another important feature is the presentation of quantitative data. The data are related to registration results based on a)specific success criteria and b) on geometrical differences (displacements and rotations) of the data to align from the reference data.

3 WORKING ENVIRONMENT

The user can use the basic components and navigate to the input and output data using a tree structure (Figure 3). The tree structure starts from the node of the project. The project is the main component of the system. A project consists of source images, processing settings and output images and can be saved and retrieved at will without losing the settings of the user. It is the root of the tree that represents, while the intermediate nodes and leaves of the tree represent individual project data or processing information.

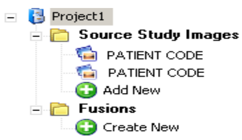


Figure 3: System information data.

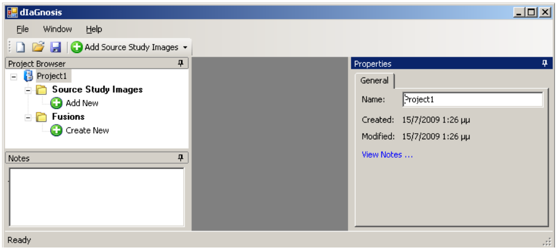


Figure 4: Starting the application.

There are also collection nodes, which group different snapshots of similar information existing in each project. Each node, depending on the information that represents may correspond to a dynamic description, have associated notes, contain interfaces presenting information and have properties that are processed by the user and others. New nodes can be created by the user and added to the project while some existing may be removed.

In Figure 4 the general working environment of the application is shown. The working environment is dynamic. The user interfaces can be aggregated into tabs, to activate the automatic concealment within the window, to match them all together and more. The user options are saved by closing the application, and retrieved the next time booted. Also some templates of the user interface are created and the user can easily select the one he likes.

The images can be loaded either from an existing list or with the process of surveying examination (Figure 5).

As the recovery process of the examining image from DICOM files may be slow, the system makes the process to use parallel processing threads. During the information retrieval the system notifies the user about the status of recovery and does not allow access to the node's data.

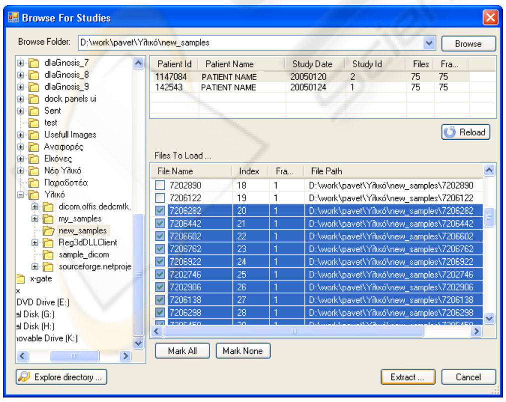


Figure 5: Image loading with the process of surveying examination.

4 PILOT SCENARIO

In order to have an exhaustive testing of the system a testing scenario was defined. This scenario uses all the processes supported.

Specifically, the system was installed and evaluated by an expert-radiologist on the credibility of the operation and performance of the registration techniques.

Data sets from axial (CT) and magnetic tomography (MRI) from 5 patients from Strahlenklinik of the Stadtische Kliniken Offenbach of Germany were used. The axial tomography data were the «Reference data», while the magnetic tomography data were the «Data to align».

After any registration technique an overlay - fusion of the CT data on the corresponding sections of the MRI data took place. In this way, the expert assessed optically the performance of the registration techniques.

Figure 6 shows characteristic results of the registration-fusion techniques using real medical data. Based on an analysis of these results we came to the following conclusions:

- The performance of the automatic registration techniques is much better compared to the semi-automatic alignment technique.
- Among the automatic registration techniques based on gray levels, the technique of mutual information has better performance compared to the technique using the correlation coefficient.
- The technique of surface registration is worse compared to the technique using mutual information and is almost equivalent to the technique using the correlation coefficient.

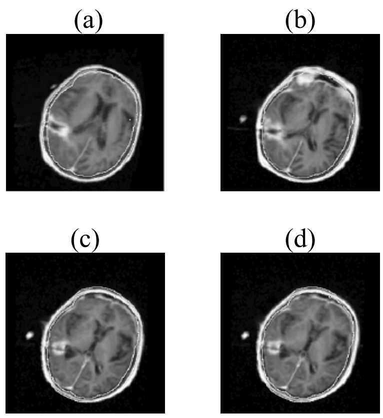


Figure 6: Registration results using (a) Automatic registration using correlation coefficient. (b) Automatic surfaces registration (c) Automatic registration using mutual data coefficient. (d) Semi-automatic registration technique.

4.1 Quantitative Analysis of Registration Results

The four registration techniques implemented within the proposed system were further quantitatively evaluated in terms of accuracy. Towards this direction, five patients were used forming five pairs of sets, each set consisting of CT and MRI head data of the same patient. The accuracy of each registration technique was measured as the mean distance of the centers of all the external markers for each data set before and after registration (in pixels). The centers of the external markers were obtained manually by an experienced radiotherapist. Comparisons on the performance of these registration techniques based on this criterion are shown in Table 1.
From the quantitative result in Table 1 it is shown that all automatic techniques were performed better than the semi-automatic technique. Furthermore, the mutual information registration technique was outperformed from the other two automatic registration techniques. Finally, the surface and the correlation coefficient registration techniques were performed equivalently.

4.2 Three-dimensional Display of Anatomic Structures

An important factor in the process of medical data fusion is the ability of the system to visualize the results of the registration. Specifically, the system supports the display of the exported external.

Table 1: Registration Techniques comparison.

Data Sets	***Registration Techniques***	
	Automatic Mutual Information	*Automatic Correlation Coefficient*
Set 1	*0.27 ± 0.01*	*0.59 ± 0.02*
Set 2	*0.28 ± 0.02*	*0.67 ± 0.03*
Set 3	*0.32 ± 0.01*	*0.80 ± 0.02*
Set 4	*0.31 ± 0.01*	*0.61 ± 0.05*
Set 5	*0.29 ± 0.01*	*0.46 ± 0.02*
Data Sets	***Registration Techniques***	
	Automatic – Surface Registration	*Semi-automatic Registration*
Set 1	*0.60 ± 0.03*	*1.89 ± 0.37*
Set 2	*0.63 ± 0.01*	*1.87 ± 1.21*
Set 3	*0.49 ± 0.07*	*1.33 ± 0.07*
Set 4	*0.50 ± 0.01*	*0.47 ± 0.00*
Set 5	*0.43 ± 0.00*	*0.53 ± 0.04*

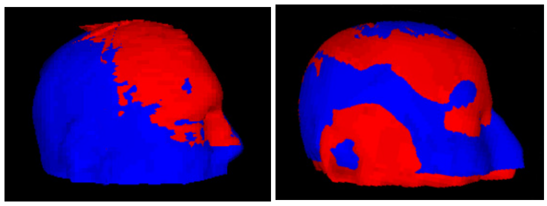


Figure 7: (a) Before registration (b) Registration using the surface registration method.

anatomical structures - three-dimensional surfaces - before and after the registration

Furthermore, an indicative visual result of the overlay of the axial and magnetic scanner surfaces is presented using VRML and a surface representation algorithm.

It may be noted that the pre-aligned skin surfaces are different and the area of the axial tomography is external and above the area of the MRI. With the method of surfaces registration the registration between two surfaces is enhanced, as shown by the alternation of the two colours of the surfaces.

In Figure 7 we can see the overlay of the skin surface of the axial tomography (red colour) on the corresponding surface of the magnetic tomography (blue colour) for a specific couple using the algorithm for surface representation in VRML format.

5 CONCLUSIONS

In this paper we have illustrated our registration-fusion system in detail, described the algorithms used and shown the basic scenario of the application's usage. Diagnosis is an integrated environment that facilitates the automatic matching based on both segmented surfaces and on different levels of gray and it allows comparison of registration accuracy for the different techniques based on specific criteria to quantify registration. It also improves the registration in case of movement and / or distortion in the data collection of the patient from different imaging systems.

After the implementation of the system, a number of tests were performed for evaluating the developed registration techniques both qualitatively and quantitatively in order to test the stability and accuracy of the techniques. As for future work, we plan to extend our system by developing further fusion and registration techniques. Additionally, more tests will be conducted to support the efficiency of the implemented system.

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