International Journal of Computer Applications (0975 – 8887)
Volume 178 – No. 12, May 2019

A Review of Image Registration Methods in Medical Imaging

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ABSTRACT
Image registration is the series of methods which superimposes or aligns two or more images of the same picture taken at different instance of time or moment, from different perspective or angle, and/or by different sensors or any external device. Registration makes the pixels in two images precisely coincide to the same points in the scene. After registration of the images, it can be combined or fused in a way that improves information extraction. Image registration combines two images, i.e., reference image and sensed image, geometrically. There are different approaches of image registration and these approaches are categorized according to their nature that is area based and feature based. Essential steps in Image Registration are feature detection, feature matching, transform model estimation, and image resampling and transformation. This paper focuses on an analysis on Image Registration methods. A literature survey of different research of Medical Image Registration is also presented here. Medical Imaging plays a significant role in medical diagnosis and treatment. It provides a clear view for medical experts in taking the correct decisions on patient's condition. By combining more than one image obtained from different medical imaging modalities, experts can achieve better image visualization for different human anatomy. The aim of this paper is to provide a source for the researchers involved in Image Registration as well as Medical Image Fusion used in diverse applications.

Keywords
Image Registration; Feature Detection; Feature Matching; Transform Model Estimation; Resampling; Transformation; Medical Imaging; Medical Image Modalities.

1. INTRODUCTION
Image Registration is an image processing technique in which images can be combined or fused in a way that improves information extraction. It makes the pixels in two images specifically relate to the same points in the scene. Therefore it also helps to align multiple scenes into a single integrated homogeneous image. It is also thought of as a process of superimposing or aligning of more than two images of the same picture taken at different instance of time or moment, from different perspective or angle, and/or by different sensors or any external device. It overcomes issues such as image rotation, scaling, and skewing which are common when superimposing images. The goal of image registration is to align images spatially to minimize a desired error with respect to each other. The input for this process is two images: the original image is known as the reference image while the image that will be aligned with the reference image is known as the sensed image. It produces more useful and better vivid images based on the input ones as shown in Fig 1. Essential steps in Image Registration are feature detection, feature matching, transform model estimation, and image resampling and transformation.

(a) Image 1 (Focus on left) **(b)** Image 2 (Focus on right) **(c)** Fused Image (All focus)

Fig 1: Fusion result for multi-focus images

The Application of Image Registration can be arranged into the following categories as discussed below:

i. **Various Perspective/Angle (Multi-view Scene Analysis):** From multiple perspectives, the images captured of the same object or views are taken into consideration for better representation of the scanned object.

Examples: Image Mosaicing (Panorama view), gesture analysis, face detection etc.

ii. **Various Time/Moment (Multi-temporal Sequential Analysis):** At various instance of time / period, images taken of the same object or scene under different circumstances to monitor changes are taken into consideration.

Examples: climate change, biodiversity, agriculture, forestry, monitoring of tumor evolution.

iii. **Various Sensor/Spectral (Multi-modal Spectral Analysis):** Acquiring the images captured from various sensors of the same object or scene is considered to obtain the minutiae of the scanned object.

Examples: In the field of Medical Imaging the capturing of anatomical information with the combination of sensors like magnetic resonance image (MRI), Ultrasound or CT, positron emission tomography (PET), single photon emission computed tomography (SPECT) analyzes seizure disorders, Alzheimer's disease and other diseases [1 - 6].

As shown in Fig. 2, Image A and Image B are combined to produce a fused image of higher resolution with a better vision.

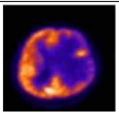
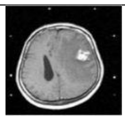
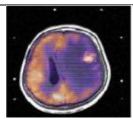
Category	Image A	Image B	Fused Image
Multi View Scene Analysis			
Multi Temporal Sequential Analysis			
Multi Modal Spectral Analysis			

Fig 2: Examples of different Image Registration Categories

2. CLASSIFICATION OF IMAGE REGISTRATION METHODOLOGY

Image Registration is a highly vibrant area due to its broad range applicability in remote sensing for weather forecasting, fusion of medical images which are taken from different medical imaging modalities like CT-MRI, PET-MRI etc. Image Registration Methodology and steps are discussed here. According to Barbara Zitova and Jan Flusser [7] the field of Image Registration can be categorized into two groups: area based methods and feature based methods. Area based methods are used for comparing a pixel in the sensed image to that of the referenced image. It basically uses gray value of the pixels to describe matching entities. On the other side Feature based methods does not uses gray value to describe matching entities, instead it uses image features derived by feature extraction algorithm to find the corresponding pairs. Features such as edges, surfaces, corners, point of intersection, contours etc, which carries relevant information about images used for matching. Majority of the registration methods consist of following four basic steps [8]:

i. **Feature Detection:** In this step, the significant and appropriate features like Regions, Edges, Corners, etc are identified in both reference image and sensed image automatically or manually by various domain professionals. The above detected features are also known as Control Points Set.

ii. **Feature Matching:** The mapping of features in the reference and sensed image are considered. Matching method is selected on the basis of image content **or the Control Points Set.**

iii. **Transform Model Estimation:** It is one of the crucial steps where once the selected features are extracted with reference to the position of the sensed image and reference image, the parameters and the type of the transformation is estimated. Some of the transformation functions which can be applied are linear, affine, projective etc.

iv. **Image Resampling and Transformation:** Once the transformation is estimated, the sensed image is transformed and then is resampled using interpolation techniques.

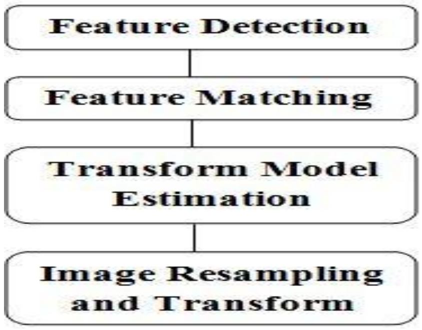


Fig 3: Steps in Image Registration Process

3. VARIOUS IMAGE REGISTRATION METHODS

3.1.Extrinsic Methods

In this method external objects or markers are used in the patient body [9-12] to be registered. The goal of this method is to obtain more effectiveness, correctness, consistency, high computational speed by evaluating their matching features as it does not need complex algorithm for implementation. It is used in brain image registration skin markers or stereo-tactic frames are used.

3.2.Moments and Principle Axes Methods

Principal Axes Registration (PAR) is used for global matching of binary volumes from CT, MR or PET images. The inertia is diagonal when computed with respect to principal axes. The centroid and principal axes can describe the orientation of a volume. The principal axes registration can resolve six degrees of freedom of an object (three rotations and three translations). It can compare the orientations of two binary volumes through rotation, translation and scaling [13]. In moment based methods pre – segmentation is done to obtain satisfactory results.

3.3.Mutual Information Based Methods

Mutual Information is applied to measure the statistic dependence between the image intensities of corresponding voxels in both images, which is assumed to be maximal if the images are geometrically aligned [14]. It is a measure of how much information one random variable tells about another. For two images, the mutual information is computed from the joint probability distribution of images intensity and gray value. In medical image processing, an application where the alignment is based on images of the same individual is known as intrapatient registration. Matching datasets of different individuals is known as interpatient registration. One of the main advantages of using mutual information is than it can be used to align images of different modalities (e.g. CT to MR-T1, MR-T1 to PET etc).

3.4.Surface Methods

It is used for extracting corresponding surfaces in different images and computes the transformation by minimizing some measure of distance between the two surfaces. The surface representation can be simply a point set (i.e., a collection of points on the surface), a faceted surface (e.g., triangle set), an implicit surface, or a parametric surface (e.g., B-spline surface). Surfaces can provide basic features for both rigid body and non rigid registration. Most of the surface based registration algorithms that have been reported are concerned with rigid body transformation [15 – 16].

3.5.Wavelet Based Methods

The wavelet transform (WT) has gained widespread acceptance in the field of signal processing. The wavelet transform is calculated for each segment according to time at different frequencies. They are particularly suitable for applications where scalability and tolerable degradation are relevant as it is multi-resolution in nature. In Discrete wavelet transform, wavelets are discretely sampled. At each level of decomposition, the signal is split into high frequency and low frequency components. The low frequency can further be decomposed until the desired resolution is achieved. Different types of wavelets like the Haar, Symlet, Daubechies [17] and Coiflets are applied for finding the correspondence with different sets of wavelet coefficients.

3.6.Correlation Based Methods

The maximum is searched from the matching or corresponding points obtained from window pairs of sensed and reference images. This is eventually used in multi-modal images and for comparison of various images of similar object or scene [18]. There are two techniques namely Cross – correlation and Phase – correlation based on Fourier transformations are used for image registration. Fourier-based techniques along with search algorithms have been used to estimate the transformation among the two input images [19].

3.7.Soft Computing Based Methods

It includes Artificial Neural Networks, Fuzzy Sets and several Optimization Heuristics.

3.7.1. Artificial Neural Networks

Artificial Neural Networks are used to process the information the way biological systems process analog signals like image and sound. There are three layers namely Input Layer, Hidden Layer, Output Layer. In Back propagation algorithm, information about errors is filtered back through the system and is used to adjust the connections between the layers, thus improving performance. The algorithm is used to update weights and bias of the neural networks. Weight and bias decides the functionality of the network. Value of the weight and bias elements are calculated during training phase. Neural Networks are used in the medical field for solving mono-modal and multi-modal image registration problems [20].

3.7.2. Optimization Heuristics

Optimization Problems may be unconstrained or constrained having both continuous as well as discrete variables. With many limitations being present at the points of global optima the task of finding the optimal solutions is hard. Meta-heuristics include Genetic Algorithm (GA) [21], Gravitational Search Algorithm (GSA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) [22], Stimulated Annealing (SA), and Plant Propagation Algorithm (PPA) and so on. These heuristic methods are being used by image registration problems for finding out the best possible parameters necessary for designing a transformation problem [23].

3.7.3. Fuzzy Sets

Fuzzy Sets are the extension of conventional (crisp) set theory. It handles the concept of partial truth using a membership function or degrees. It extends conventional Boolean logic to find out partial truths and uncertainties. It is a dominant means to represent and process human understanding in form of fuzzy if-then rules. It is a group of all approaches that understand and process the images, their sections and features are fuzzy sets. This permits Fuzzy sets to deal with vagueness and incorrectness. Fuzzy Sets have been applied in the field of Medical Image registration also [24].

Summary of Various Image Registration Methods are listed below in Table 1.

Table 1: Presents a summarized view of various Image Registration Methods.

Methods	Key Points	Application
Extrinsic Methods	External objects or markers are used in the patient body to be registered.	Brain image registration skin markers or stereo-tactic frames.
Moments and Principle Axes Methods	It requires the computation of the centroid and the three principal axes for each of the two scans.	This method is applied in radiation treatment planning based on combined CT/MR images, in study of orientation of the scaphoid bone in the wrist and in analyzing PET images of schizophrenics.
Mutual Information Based Methods	Measures the statistic dependence between the image intensities of corresponding voxels in both images, which is assumed to be maximal if the images are geometrically aligned.	It is highly reliable and effective method of the multimodal images registration.
Surface Methods	Surface-based image registration methods involve determining corresponding surfaces in various images (and/or physical space) and computing the Transformation that best aligns these surfaces.	Used in Multimodality Brain image.
Wavelet Based Methods	It usually extracts a large number of control points. The candidate control points are extracted using the local maxima of the wavelet coefficients.	It has been used for Electrocardiography, functional neuro-imaging including positron emission tomography and functional MRI.
Correlation Based Methods	Eventually used in multi-modal images and for comparison of various images of similar object or scene. Extracted features from the images are used to obtain the cross – correlation coefficients for image registration.	It has been used to register tomographic brain and abdominal images.
Artificial Neural Net-	It is formulated based on biological neural	It has been used in solving mono-modal

works	networks.	and multi-modal medical image registration problems.
Optimization Heuristics	Genetic Algorithm (GA) is used to determine which such features are the most predictive.	It showed good results in diagnosing patient of liver, thyroid disorder, and cancer.
Fuzzy Sets	It is a dominant means to represent and process human understanding in form of fuzzy if-then rules. This permits Fuzzy sets to deal with vagueness and incorrectness.	It showed good results on retinal images. Bio-medical images made use of Neuro fuzzy approach.

4. MEDICAL IMAGING APPLICATIONS

For acquiring high resolution and more edifying analysis of human anatomies and its functions becomes possible due to the rapid advances in medical imaging technology. Such development motivates the researchers in the medical image analysis field. Medical Image registration methods can be grouped based on some criterion [25] listed below in Table 2.

Table 2: Classification of Medical Registration Methods

Criteria	Methodologies	Examples
Dimensionality	2D - 2D, 2D - 3D, 3D - 3D	2D – 2D: registration of temporal mammograms. 3D – 2D: 3D computed tomography images and 2D portal images. 3D – 3D: registration of two tomographic datasets, monitoring of tumor growth.
Domain of Transformation	Global	Image of the entire head based on computation done in the area of facial surface only.
	Local	Individual vertebrae in an image of a spinal column.
Type of Transformation	Rigid	Head of the same patient, the skull, falx, tentorium, cardiac images and postoperative images etc.
	Affine	
	Projective	
	Non Linear	
Parameters of Registration	Parameters computed directly	-
	Parameters searched for	
Subject of Registration	Intra subject	3D / 3D MR or CT brain image application.
	Inter subject	
	Atlas	
Object of Registration	Head	Brain or Skull, Eye, Dental.
	Abdomen	General, Kidney, Liver.
	Thorax	Entire, Cardiac, Breast.
	Limbs	General, Femur, Hemurus, Hand.
Nature of Registration	Extrinsic	Stereotactic frame, Fiducials (screw markers), Dental adapter etc.
	Intrinsic	Image Formation
	Non Image Based	Position of surgical tools mounted on robot arm to images.
Interaction	Interactive	-
	Semi automatic	
	Automatic	
Modalities involved	Mono Modal	Two myocardial SPECT images are acquired of the patient under rest and stress conditions.
	Multi Modal	PET images are registered to an MR image.
	Patient to Modality	In radiotherapy treatment, patient can be positioned with the aid of registration of in – position X-ray simulator images to a pre-treatment anatomical image.

Image Registration Techniques are discussed in the fields of Diabetic Retinopathy and Lesion Detection in Cervix. Other diseases along with its diagnostic modalities used and registration / fusion classes are listed out in Table 3.

5. DIABETIC RETINOPATHY

Diabetic Retinopathy is a microvasculature complication of diabetes in retina, causing damage to the blood vessels of the light sensitive tissue at retina, which may also lead to blindness [26]. Eventually due to the increased permeability of the capillary walls, mircroaneurysms along with haemorrhages are formed in retina [27]. As there is an increase of sugar in the blood, it can lead to blockage of the blood vessels which causes microinfarcts called soft exudates in the retina. Clinical signs observed by color fundus photographs include mircroaneurysms, haemorrhages, exudates and intra-retinal micro-vascular abnormalities [26].

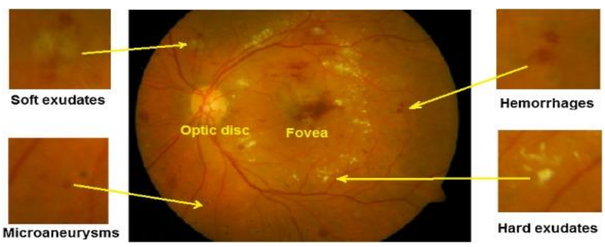


Fig 4: Typical diabetic retinopathy features on a color fundus image.

Longitudinal Registration method is used to detect and monitor retinal change in Diabetic Retinopathy development and progression. It makes use of Feature based registration methods to extract a set of feature points from each of the reference and floating images, which are then matched to find the transformation. The features are normally vessel structures, branching, bifurcation points, cross-over points etc. which are extracted manually or automatically.

Other Retinal Image Registration methods that are considered are cross-modality registration, spatial registration and temporal registration. When the ophthalmologists wants to use two various imaging modalities to get complementary information about retinal vessel disorder cross-modality registration is considered and when the ophthalmologist's wishes to merge narrow-field images together to produce a wider field view of the retina, spatial registration is considered. The need for temporal registration occurs when it is required to track the changes of retina eventually.

6. LESIONS DETECTION IN CERVIX

The abnormality found in cervical cells may develop into Cervical Cancer if left untreated. Temporal image registration method is used to detect precancerous lesions of the cervix. The images are obtained from colposcopy examinations. The proposed approach yielded the time series for all pixels in the initial image of the sequence because such values form the basis to establish the similarity. The Temporal method provided the best tradeoff between low error values and time required to carry out the registration process. In addition to it, the temporal method is the most robust among other methods.

Table 3: The current diseases based fusion works

Disease / Disorder/ Surgery	Fusion Classes	Diagnostic Modality
Head		
Arterial steno-occlusive disease of the head to study head motion scanning errors [28]	Rigid	PET
	Monomodal	
Pituitary adenoma [29]	Rigid	MR
	Monomodal	
Brain		
Huntington's disease [30]	Nonrigid	MR
	Monomodal	
Parkinson's Disease [31]	Nonrigid + Rigid	MR
	Multimodal	SPECT
Eye		
Eye fundus (ocular pathologic conditions) [32]	Rigid	Ophthalmological images
	Multimodal	
Retinal diseases [33]	Rigid	Ophthalmological images
	Multimodal	
Oral		
Tongue disorders [34]	Nonrigid	hMR
	Multimodal	Cine MR
Lung		
Assist in detecting and diagnosing lung cancer [35]	Nonrigid	Chest Radiographs
	Monomodal	
Cardiac		
Coronary artery diseases [36]	Rigid	X-ray
	Multimodal	CT
	Nonrigid	MR
	Monomodal	
Ischemic heart disease [37]	Rigid + Nonrigid	CT
	Monomodal	
Liver		
Hepatocellular carcinoma [38]	Nonrigid	CT
	Monomodal	

Some of the contributions done in this field along with its best registration / fusion technique are listed out in Table 4.

Table 4: Presents some recent work in medical image fusion for diverse applications

Work	Fusion Technique	Level of Fusion	Modality	Organ	Contribution
"Extraction of brain regions affected by Alzheimer disease via fusion of brain multispectral MR images" [39].	Dual tree wavelet transform (DTWT)	Pixel based	MRI	Brain	Proposed a new technique for extraction of affected regions by Alzheimer disease from multispectral medical images by means of fusion and segmentation methods.
"Multimodal medical image fusion using modified fusion rules and guided filter" [40].	Gaussian decomposition, guided filters, modified saliency and weight maps	Window based	MRI	Brain	Proposed a modified fusion algorithm to reduce the contrast reduction and halo artifacts.
"Multimodal medical image sensor fusion framework using cascade of wavelet and contourlet transform domains" [41]	PCA	Pixel based	MRI, CT	Brain	Proposed a multimodal fusion algorithm that consists of two stages: stationary wavelet transform (SWT) and non sub-sampled contourlet transform (NCST) to enhance the shift variance, directionality and phase information.
"Medical image fusion by combining SVD and shearlet transform" [42].	Maximum fusion rule	Pixel based	MRI, PET	Brain	Proposed a two stage fusion technique using shearlet transform and then applying SVD on low pass subbands before fusion to provide higher image quality.
"Free-breathing diffusion tensor imaging and tractography of the human heart in healthy volunteers using wavelet based image fusion" [43].	Wavelet based image fusion algorithm	Window based	Diffusion Tensor Imaging(DTI)	Heart	Proposed a technique to provide 3D fiber architecture properties of the human heart.
"Spine medical image fusion using wiener filters in shearlet domain" [44].	Maximum fusion rule	Pixel based	MRI, CT	Spine	Proposed an algorithm that provides both functional and anatomical structure for spine by applying three steps: Shearlet transform, Wiener filter, Fusion of low and high pass sub bands.
"Multi focus and multi modal image fusion using wavelet transform" [45].	Dual tree discrete wavelet transform(DT-DWT)	Pixel based	MRI, CT	Brain	Proposed a multifocus and multimodal image fusion techniques using DT-DWT then applying fuzzy logic clustering for segmentation that helps in tumor identification.

7. CONCLUSION

To extract information from different images which comes from different sources, Image Registration plays a crucial role. This paper presented a survey on various Image Registration methods as well as Medical Image Registration and/or fusion. Fundamentals of Image Registration methods and techniques were discussed followed by the application areas where it is used. Objective of Image Registration is to combine two or more images and extract information from them. Then a discussion for Medical Imaging Modalities and the Medical Image Registration was been done. In today's context, Medical Image Registration is considered relevant for the medical experts to make decisions regarding the patient's condition. This paper also covers some recent contribution of Medical Image fusion for diverse applications.

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