

Hybrid Feature Point Based Registration of 2D Abdominal CT Images

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Abstract

Liver lesions like abscess, cirrhosis, metastases etc usually appear globular with gray levels differing remarkably from that of the surrounding liver region but the boundaries of these lesions are poorly defined and give an approximate picture of the extent of invasion of the lesion into surrounding regions. Choice of feature points and their matching in the images under consideration is crucial and image dependent. This leads to variations in registration methods. The objective of the proposed technique is to enhance registration for such abdominal CT images with the use of invariant points lying on the boundaries of lesions and the lesion centroids as the feature points. This paper uses a combination of hull points and centroids as feature points to register the images and compares results with those obtained by registration using only centroids as feature points. The outer margins of lesions become more sharply defined which helps in improving diagnostic accuracy.

Keywords: *image registration, elastic registration, feature point, wavelet decomposition*

1. Introduction

Image registration or image matching is applied to medical images to obtain more or precise information from two images which are images of the same scene but differing from each other with respect to time of acquisition, angle from which they are taken, type of modality for image acquisition etc. When these images are compared or matched for detailed analysis and diagnosis, they need to be brought in the same spatial coordinates. This process of mapping spatial coordinates of one image to those of the other image is called image registration [1]. Type of registration depends on type of deformation in the image. When image as a whole undergoes translation or rotation or scaling, rigid registration corrects these deformations but when objects within the image are deformed such that deformation is at the local level then elastic or non rigid registration is carried out. This happens due to regression of disease or some growth in the anatomical region etc. However rigid registration precedes non rigid registration. Abdominal CT images typically require non rigid registration as they involve involuntary organs and it is difficult to establish precise boundaries as reference. To access specific features within the image means those features invariant to translation and rotation should be used. These feature points can then register the images using a method called landmark based registration method.

Hybrid registration techniques using intensity based rigid registration and landmark based registration method incorporate the benefits of both these methods. However due to variation in image modality, the organ of which image is considered, type of disease being considered, the type of deformation in the image, lead to variations in the method to be adopted for registration. Intensity based registration is employed to correct any global deformations before correcting local deformations. To correct local deformation, use of landmark based method uses specific landmarks also called feature points. In landmark based method, selection of landmarks or feature points and their matching plays a crucial role in correctly registering the images.

Most of the hybrid registration techniques were initially deployed for images of the brain where its precise boundaries with reference to the skull can be easily obtained. Brain images were first affine registered using hierarchical methods then elastically interpolated using a local similarity measure [2][3][4]. Hierarchical B splines have been used to correct local deformations in the brain images [5]. Hybrid registration methods were also applied to human skeletal muscle fibre where images were hierarchically initially registered and then elastically interpolated. Use of prior and floating information of joint probability speeds up registration process and local consistency checks improve overall registration accuracy [6]. Choice of landmarks varies with analysis required and the anatomy. To detect lung nodules precisely in chest CT images, anatomical landmarks like trachea and the sternum have been used [7]. Geometrical landmarks like barycentre of the skeleton is used to register inter frame abdominal kidney CT images because barycentre varies very little between two frames [8]. Centroids of canny edges and points with maximum and minimum distances to centroids were used to register images taken over a time interval. This helped in 3D reconstruction of 2D images [9]. The technique used in this paper for landmark based registration uses hybrid of convex hull points and centroids of lesions within the image when registration is done at the local level. Use of these hybrid feature points will take care of the information of points on lesion boundaries accounting for variations in its shape and also variation in orientation of the lesion by use of centroids. This is done after initial registration of the reference and study images which removes global deformities like those of translation and rotation. Maximization of mutual information has been used as the similarity measure for initial registration as it is a powerful statistical measure [9][10]. Wavelet decomposition is used to register the images at lower resolution layers to improve computational complexity [11]. Rigid registration using maximization is explained in section 2. Image segmentation for selection of region of interest and selection of feature points is covered in section 3. Use of these sets of feature points for elastic registration is explained in section 4. Results and conclusion are given in section 5 and 6 respectively.

2. Rigid Registration using maximization of Mutual Information

Images have rigid deformation like translation and rotation during acquisition due to movement of gantry, patient movement etc. This requires initial rigid registration to be performed. To correct these global deformations, wavelet decomposition [9] is used. It helps to access images at lower resolution at each level of hierarchy. Thus size of image also reduces at each level which in turn reduces the computational time as search space is reduced. dB8 wavelets have been used for this. Rigid registration is then carried out for a certain angle of rotation and translation maximising the mutual information.

Mutual information I (A, B) is a statistical similarity measure [10] that uses joint entropy of two images A and B. Joint entropy H (A,B) measures the amount of information that we have in the two images combined. It reduces the redundancy between the two images. Entropies of the individual images H (A) and H (B) are obtained from the marginal probability density functions $p_A(a)$ and $p_B(b)$ of the respective reference and study images and joint probability density function $p_{A,B}(a,b)$ where a and b are the pixel intensities in the images A and B. Mutual information I(A,B) between the images A and B is expressed in Eq. (1) and Eq. (2).

$$I(\mathrm{A,B}) = -\sum_{a,b} p_{A,B}(a,b).\log\frac{p_{A,B}(a,b)}{p_{A,}(a)\,p_B(b)} - \qquad (1)$$

$$\mathrm{I(A,B)} = \mathrm{H(A)} + \mathrm{H(B)} - \mathrm{H(A,B)} \qquad (2)$$

The normalised mutual information $I_N(A,B)$ is given as in Eq. (3)

$$I_N(A,B) = \frac{H(A)+H(B)}{H(A,B)} \qquad (3)$$

When mutual information is maximised, image is said to be registered. Translation and rotation obtained at one level of hierarchy when mutual information is maximised is used as an estimate for registering the images at next higher level. This is continued till the base level of hierarchy with highest resolution. The registered image so obtained at this level is used to further correct local deformations using elastic registration.

3. Segmentation and Feature Identification

Once global deformations have been corrected, region of interest are required to be separated to correct local deformations. To access regions of interest within the image ie. lesions in the image, segmentation is carried out. Lesions present in the liver have been observed to have intensity levels different from the surrounding liver regions. From a general observation of intensity levels, two intensity thresholds T_1 and T_2 are used to carry out multi level intensity thresholding. Now to isolate the regions of interest ie. lesions, a constraint over their boundary length is used. This process of segmentation is applied separately to both reference and study images. The correspondence between the segmented lesions in the two images is determined by region labelling coupled with boundary length.

Centroid of any arbitrary lesion is chosen as the reference centroid in the reference image. Euclidean distances (D) as expressed in Eq. (4) are calculated for all hull points from this reference centroid i.

$$D_j = \sum_{i=1}^{M} \sum_{j=1}^{N} [\, \| c_i(x,y) - h_j(u,v) \|^2 \,] \qquad (4)$$

In equation (4) $c_i(x,y)$ are the coordinates of reference centroid of segmented lesions and $h_j(u,v)$ are the coordinates of hull points of lesions, M is the number of centroids of lesions in the images and N are the number of hull points of these lesions. Euclidean distances of these hull points are normalized as in Eq. (5).

$$\text{Normalized distance } (ND_j) = D_j / D_{max} \quad (5)$$

D_{max} in Eq. (5) is the distance of farthest hull point from the reference centroid. All hull points $h_j(u,v)$ with Normalized distances, ND_j greater than threshold T are chosen as feature points in the reference image. The threshold T is taken as mean of Normalized distances of all these hull points as given in Eq. (6)

$$T = \frac{\sum_{j=1}^{N} ND_j}{N} \quad (6)$$

Similarly feature points of hull points and centroids are also obtained in the study image by the same method. To establish point correspondence in the reference and study image, Normalized distances of hull points in reference image and Normalized distances of hull points in study image are compared. Hull points in the reference image which give minimum difference of these distances are considered as the corresponding matched points in study image. These matched point pairs are elastically registered using Thin Plate Splines. However to obtain more accurate registration with precise feature points, those point pairs that contribute to reducing the correlation coefficient below that of the correlation coefficient of the reference and study images are rejected. The remaining valid hull point pairs in concatenation with the centroids of the lesions found earlier serve as the corresponding feature points in reference and study image. These two sets of feature points are then are used to elastically register the images.

4. Elastic Registration using Thin Plate Splines

Thin Plate Splines [12] is a scattered data interpolation technique and has the capability to model biological deformations very well. The advantage of using TPS is that it requires lesser feature points for accurate matching as compared to other splines used for interpolation. In the abdominal CT images the number lesions as well as the deformations, are limited hence TPS is most suitable for interpolating the points in the study image to reference image of abdominal CT images. The hybrid feature points identified in reference and study images are elastically registered using Thin Plate Spline. The Thin plate spline interpolating function is given as in Eq. (7)

$$f(x,y) = a_1 + a_x x + a_y y + \sum_{i=1}^{n} w_i U(|P_i - (x,y)|) \quad (7)$$

In Eq. (7) coefficients a_1, a_x, a_y represent the affine parameters and coefficients w_i represent the warped parameters and P_i are feature points in reference image. Eq. (7) is derived from solution of biharmonic Eq. (8)

$$\Delta^2 U = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) U \; \alpha \; \partial_{(0,0)} \; ------- \; (8)$$

If (x_l, y_l) represents a set of feature points in reference image and (x_l', y_l') represents a set of points in study image and the function f(x,y) represents a thin steel plate which is to have a height z_l at (x_l, y_l) as given by z(x,y) in Eq. (9)

$$z(x,y) = -U(r) = r^2 \log r^2, \quad r = \sqrt{x^2 + y^2} \quad (9)$$

and minimum bending energy, then the function f(x,y) minimizes the integral I_f as in Eq. (10).

$$I_f = \iint_{R^2} ((\partial^2 f / \partial x^2))^2 + 2(\partial^2 f / \partial xy)^2 + ((\partial^2 f / \partial^2 y)) dxdy \quad (10)$$

By letting $z_l = x_l'$ and $z_l = y_l'$ respectively we obtain f_x (x, y) and f_y (x,y)which give the coordinate correspondence between the images. This requires determining coefficients a_1, a_x, a_y and weights w_i in Eq. (7) which can be computed from matrices obtained from the coordinates of corresponding points in reference and study image and forming various matrices [12] and use of Eq. (10). This helps in smoothly transforming coordinates in the study image to corresponding coordinates in the reference image.

5. Case Study

2D abdominal CT scan 512x512 JPG images of a patient having liver abscess are used as case study. The study image was obtained from the reference image by deforming it to test the performance of proposed technique. From the set of 40 slices, slice 14 was used for the case study as it contained the maximum portion of abscess regions. The reference and study images are initially decomposed using dB8 wavelet and registered using maximization of mutual information. Results of one registration hierarchy layer are used to estimate the input to the next registration hierarchy by varying the rotation angle and assuming that translation to be negligible as patient is stationary and only minor variations are due to movement of gantry or growth of lesion may occur. Slice 14 reference and study images are as shown in figure 1(a) (Fig. 1) and figure 1(b) (Fig. 1) respectively. Figure 1(c) (Fig. 1) shows the difference image.

Initial registration is done using wavelet decomposition to remove global deformations. To identify the lesions, segmentation in the initially registered study image and the reference image is done by simple thresholding technique to simplify the computational complexity because lesions are having distinct intensity characteristics as compared to their surrounding region. It is observed that in the abdominal CT images, for intensity thresholds T_1 and T_2 lying between 110 -122.5, the abscess regions become predominant in the segmented image. These regions are then labeled and regions whose lengths of boundaries are greater than 200 pixels are chosen to eliminate the non-abscess regions for correspondence in the two images. In each of the segmented regions so found in the reference and study image, their respective centroids and hull points are determined as feature points. In order to obtain feature point matching in the reference and study image, for a particular lesion, normalized distances of hull points of that lesion from its centroid point are calculated as in Eq. (4) and Eq. (5). Corresponding hull points in study image are obtained from hull points in reference image having minimum difference in normalised distance ND. The corresponding hull points so obtained in both images are used as landmarks for elastic registration using Thin Plate Splines. The performance of proposed technique of elastically registering the images using hybrid feature points is analysed by comparing the registered images using only centroids of lesions for elastic registration. The performance of proposed technique achieved considerable improvement in registration accuracy as compared to the latter in terms of Correlation Coefficient (CC), Signal to Noise ratio (SNR) and Mean Square Error (MSE). This has been observed for a single slice and for different lesions in the slice independently. Proposed technique has been applied for different slices in [13].

6. Results

Proposed technique is tested on reference and study images as shown in figure 1(a) (Fig. 1) and figure 1(b) (Fig. 1). Figure 1(c) gives their corresponding difference image. These are images of slice 14, 2D abdominal CT image of a patient with liver abscess.

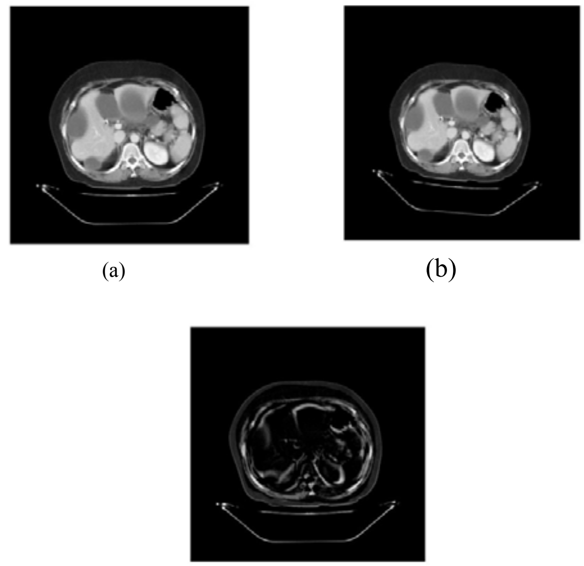

Fig. 1 (a) Reference image (b) Study image (c) Difference image

The abscess regions are labeled as 1, 2 and 3 in Figure (Fig.2).

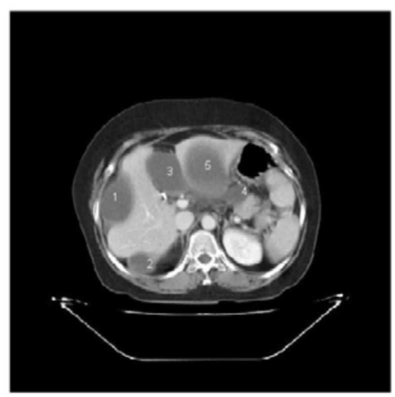

Fig. 2 Reference image with lesions

Reference and study images as shown in figure 1(a) (Fig. 1) and figure 1(b) (Fig. 1) are thus elastically registered using the proposed technique. The coordinates of corresponding matched feature points and their Normalized Distances from reference centroids are shown in Table 1 for each of the three chosen lesions.

Table 1: Coordinates and Normalized distances of lesions1-3 using proposed method

	Reference Image			**Study Image**		
Lesion	**Matched Hull Points**		**Normalized Distance**	**Matched Hull Points**		**Normalized Distance**
	x	y	ND	x	y	ND
1	134	234.	0.95917	170	254.	0.96724
	124.	244	0.95917	158	265.	0.92058
	145	225.	1	177	248.	1
2	229.	211	0.88154	253.	237	0.88064
	223.	193	0.97752	248.	221	0.9739
	223	192.	0.97963	248.	221	0.9739
3	164	331.	0.93215	195	346.	0.91465
	162.	334	0.96746	192	355.	0.96912
	161.	337	1	191.	355	1
	161.	338	0.99844	191.	353	0.99995

Statistical performance of the proposed technique using hybrid feature points is evaluated by CC, SNR and MSE as shown in Table 2. Choosing different feature points of these lesions the correlation coefficient and SNR is seen to improve and the mean square error reduces as expected.

Table 2: Performance evaluation of elastically registered images with centroids of lesion 2 as reference and hull points of lesion 1-3

No. of feature points	**Correlation Coefficient(CC)**	**SNR**	**MSE**
3	0.9225	18.250	19.430
4	0.9288	18.096	20.292
5	0.9294	18.378	19.743
6	0.9208	20.608	15.804
7	0.9203	20.381	16.566

Table 3 shows a comparison of these statistical parameters for the unregistered images and images registered using only centroids as feature points and images registered using proposed technique i.e. using hybrid of centroid and convex hull points as feature points. The proposed technique shows considerable reduction in mean square error and improvement in SNR and Correlation coefficient.

Table 3: Comparison of proposed method with original images and rigid registered images

Method	**CC**	**SNR**	**MSE**
Unregistered images	0.8346	11.3482	38.1
Elastic registration using centroids	0.9116	16.7973	22.3981
Elastic registration(Proposed Method of hybrid feature points)	0.9294	19.4745	17.3878

Pictorial analysis of the proposed algorithm can be seen in figure 3 (Fig. 3). Figure 3 (a) shows registered image with only centroids as feature points, figure 3 (b) shows the registered image so obtained with hybrid feature points of centroids and hull points of lesion 2, figure 3(c) shows the registered image so obtained with hybrid feature points of centroids and hull points of lesion 3. Figures 3 (d), 3 (e) and 3 (f) show corresponding difference images with only centroids as feature points, with centroids and hull points of lesion 2 and with centroids and hull points of lesion 3 respectively. It is seen from the difference images that differences are reduced in figure 3(e) and Figure 3(f) compared to those of figure 3 (d).

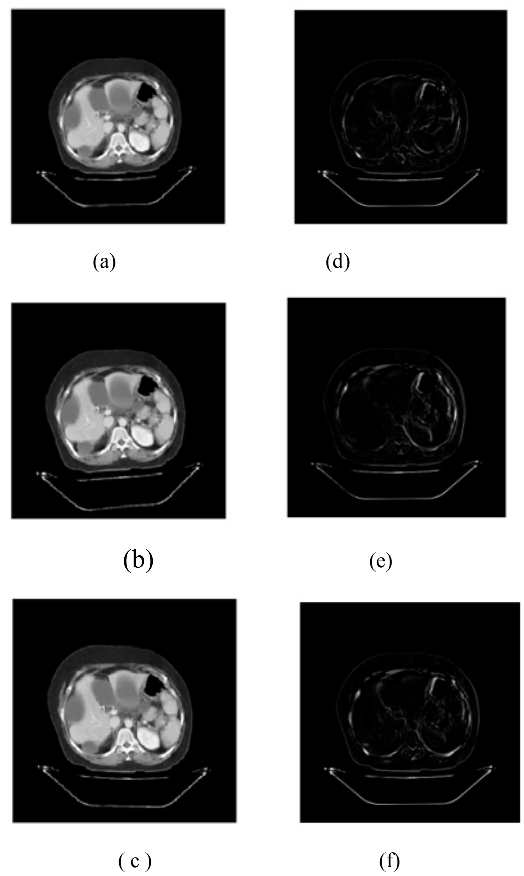

Fig. 3 (a) registered image using centroids (b) registered image with lesion2 (c) registered image with lesion3 (d) difference image using centroids (e) difference image with lesion2 (f) difference image with lesion 3

7. Conclusions

Registration of abdominal CT images is complex due to involuntary nature of organs and absence of defined boundaries for reference. To use features within the image for registration, access to region of interest within the image and selection of specific features invariant to translation and rotation is of utmost importance. The proposed technique for registration of abdominal CT images with liver lesion like liver abscess uses hybrid feature points like centroids and convex hull points. The proposed technique improves correlation between the registered image and the reference image, increases signal to noise ratio and reduces mean square error. Registered image appears sharper than the reference image with lesion boundaries being more defined. This is useful in improving diagnostic accuracy.

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