Image Registration Techniques: An overview

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Abstract

Image registration is a vital problem in medical imaging. It has many potential applications in clinical diagnosis (Diagnosis of cardiac, retinal, pelvic, renal, abdomen, liver, tissue etc disorders). It is a process of aligning two images into a common coordinate system thus aligning them in order to monitor subtle changes between the two. Registration algorithms compute transformations to set correspondence between the two images the purpose of this paper is to provide a comprehensive review of the existing literature available on Image registration methods. We believe that it will be a useful document for researchers longing to implement alternative Image registration methods for specific applications.

Keywords: *Image registration, co-ordinate system, correspondence.*

1. Introduction

Image processing methods, which are possibly able to visualize objects inside the human body, are of special interest. Advances in computer science have led to reliable and efficient image processing methods useful in medical diagnosis, treatment planning and medical research. In clinical diagnosis using medical images, integration of useful data obtained from separate images is often desired. The images need to be geometrically aligned for better observation. This procedure of mapping points from one image to corresponding points in another image is called Image Registration. It is a spatial transform. The reference and the referred image could be different because were taken

- At different times
- Using different devices like MRI, CT, PET, SPECT etc (multi modal).
- From different angles in order to have 2D or 3D perspective (multi temporal).

Image registration finds its applications in various fields like remote sensing (multispectral classification), environmental monitoring, change detection, image mosaicing, weather forecasting, creating super-resolution images, integrating information into geographic information systems (GIS)), in medicine (combining data from different modalities e.g. computer tomography (CT) and magnetic resonance imaging (MRI), to obtain more complete information about the patient, monitoring tumor growth (Figure 1), treatment verification, comparison of the patient’s data with anatomical atlases ,in cartography (map updating) and in computer vision (target localization, automatic quality control). Figure 1 shows a maximum intensity projection of contrast controlled MR mammography a) without registration b) with registration. It demonstrates superior performance in indentification of cancerous lesions with the use of registration (courtesy Ruckert et al [1]).

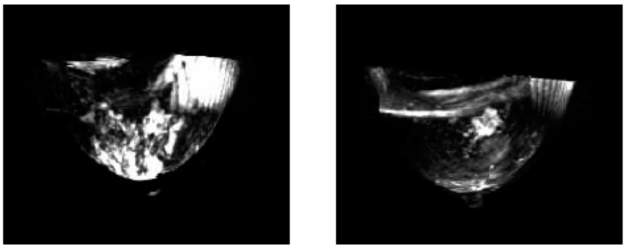

Figure 1. Application of Image registration in MR mammography.

2. Steps involved in Image Registration

Image registration essentially consists of following steps as per Zitova and Flusser [3]. Figure 2 illustrates the process.

- Feature detection: Salient and distinctive objects (closed-boundary regions, edges, contours, line intersections, corners, etc) in both reference and sensed images are detected.
- Feature matching: The correspondence between the features in the reference and sensed image established.
- Transform model estimation: The type and parameters of the so-called mapping functions, aligning the sensed image with the reference image, are estimated.
- Image resampling and transformation: The sensed image is transformed by means of the mapping functions.

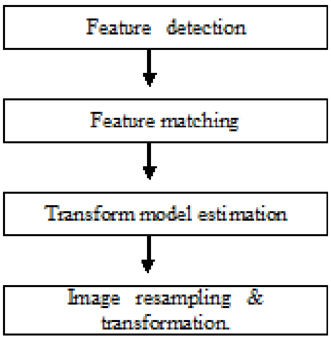

Figure 2. Steps involved in Image Registration

3. Classification

P. A. Van Den Elsen, E. J. D. Pol and M. A. Viergever, had given classification of Image registration way back in 1993 [4]. Maintz later in his survey paper [5] has given a more detailed and augmented version of classification based on nine basic criteria. Figure 3 illustrates the classification.

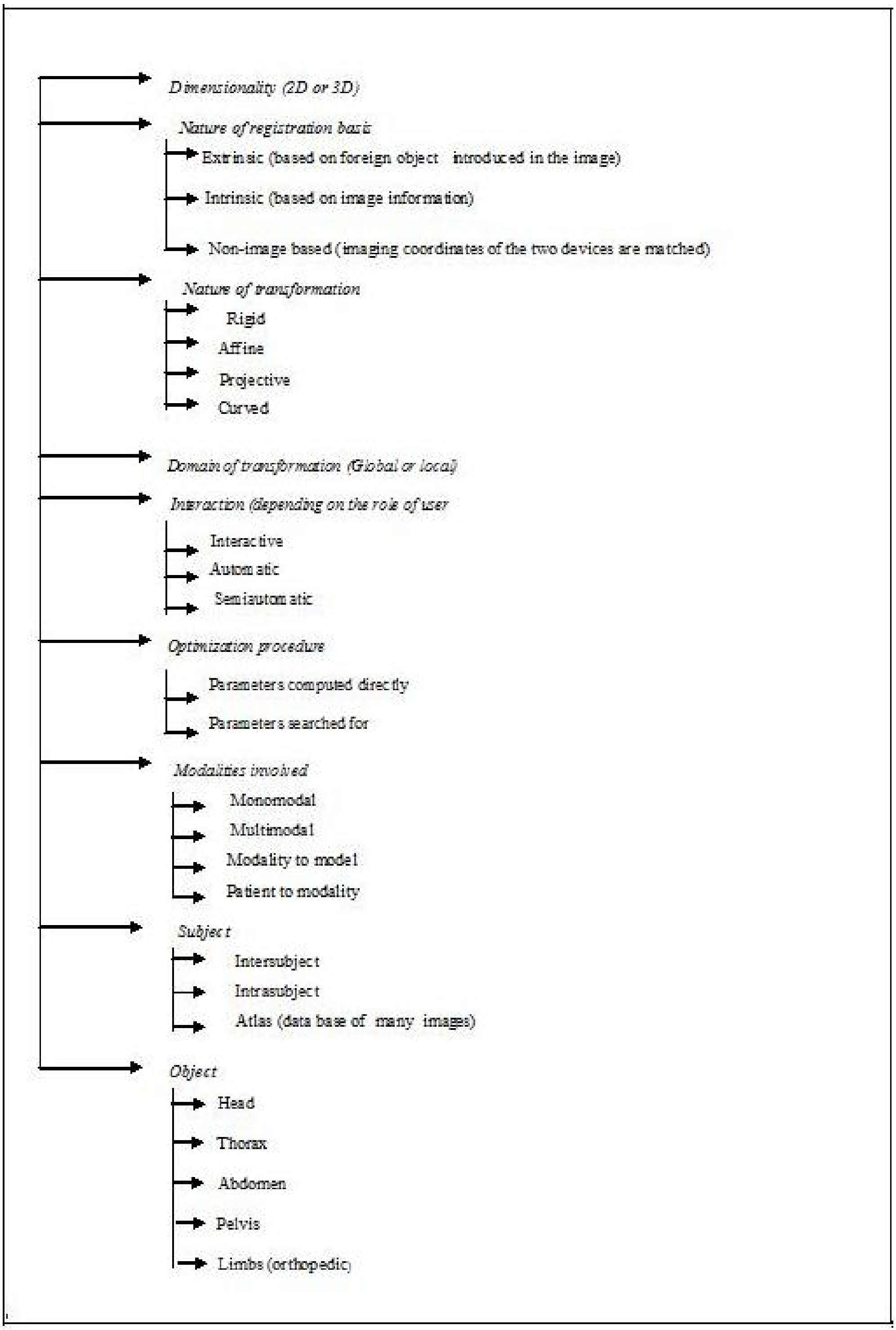

Figure 3. Classification of Image Registration

Leszek Chmielewski, Dorota Kozinska [9] have summarized classifications given by earlier papers [4],[6],[7],[8] . The classification is based on following features. Wan Rui, Prof.Li Minglu [9] have also has mentioned similar classification.

Dimensionality: 2D/2D, 2D/3D, 3D/3D Image registrations are possible. Sometimes time could be the fourth dimension.

Domain of transformation*: It could be global or local depending on whether the whole image or its part is to be registered.*

Type of transformation*: The transformation could be rigid, affine, projective or nonlinear.*

Tightness of feature coupling: The transformation can be interpolating (features of the objects in one image are exactly transferred into features in the other image) or approximating.

Measure of registration Quality: Various measures are applied depending on the data features or data itself.

Method of parameter determination: The parameters of the transformation can be found out using direct or search oriented methods.

Subject of registration: If the two images contain the same subject it is intra subject registration. If the subject in the two images differs it is intersubject registration.

Type of data: It can be raw data, features extracted from data or introduced markers in data.

Source of features: Features explicitly present in the data are called intrinsic features where as those introduced from outside are called as extrinsic features.

Automization level: This can be automatic or semiautomatic depending on user intervention level.

3. Approaches to Image Registration

J.V.Chapnick, M.E.Noz, G.Q. Maguire, E.L.Kramer, J.J.Sanger, B.A.Birnbaum, A.J.Megibow [10] have mentioned the following approaches of image registration way back in 1993.

- Transformations using Fourier Analysis
- Cross correlation approach using Fourier Analysis
- Sum of squares search technique
- Eigen Value Decomposition
- Moment matching techniques
- Warping Techniques
- Procedural approach
- Anatomic Atlas
- Internal landmarks

- External Landmarks

4. Methods of Registration

4.1. Extrinsic registration methods

In Extrinsic registration methods, artificial objects, which necessarily should be detectable, are attached to the patient's body. This method doesn't require complicated algorithms and is hence good computation speed can be achieved. The marker objects, which are used in this method, are

- Stereo tactic frame screwed rigidly to the patient's outer skull table[11-14]
- Screw-mounted markers [15-18]
- Markers glued to the skin [19-22]

4.2. Curve methods

Batler et al. [23] registered 2-D projection images. using a curve matching method. He sampled to generate sequences of corresponding points to be registered.He searched for corresponding "open" curves manually, and then registered two-dimensional projection radiographies. Corresponding open curves were matched by searching for the optimal fit of the local curvatures in the two curves. Nicholas Ayache and Andre P. Gueziec [24] have presented a method of matching of 3D objects extracted from medical images. Crest lines computed on the object surfaces correspond to meaningful anatomical features, and that they are stable with respect to rigid transformations. The extraction of the crest lines is done by computing up to third order derivatives of the image intensity function with appropriate 3D filtering of the volumetric images, and by the 'marching lines' algorithm. The recovered lines are then approximated by spline curves, to compute at each point a number of differential invariants. Matching is finally performed by a new geometric hashing method. The whole chain is now completely automatic, and provides extremely robust and accurate results, even in the presence of severe occlusions. Peng Wen , in his paper [25] , has suggested a medical image registration method using points, contour and curves is proposed, which has the accuracy of registration based-on points and the robust of registration based-on lines (including contour and curves). The operator can exactly extract the features from the images with semi-automatic extraction method.

4.3. Surface methods

Boundaries or surfaces, in medical images are many times more distinct than landmarks and hence can be used for segmentation by locating high contrast surfaces. Surface matching algorithms are normally used for rigid body registration. The representation of surface methods is a surface-based approach for registering multimodality brain image. They fit a set of points extracted from contours in one image to a surface model and extracted from contours in the other image. The image that covers the larger volume of the patient, or the image that has a higher resolution if volume coverage is comparable, is used to generate the surface model. Another version of surface matching is to provide user with an interactive transformation package that allows the user to translate and rotate one image with respect to the other. Audette and Ferrie [26] have reviewed the surface based registration methods in medical imaging. Pelizarri had proposed a surface fitting technique for registration of images of the head which became known as 'Head and Hat Algorithm' [2]. The registration algorithms have been developed in recent years are Iterative Closest Point algorithm [27-31] and Correspondence matching [32-36]. Jack and Roux [36] have proposed to formulate the surface registration problem as a high dimensional optimization problem, which can be solved by a genetic algorithm.

4.4. Moment and Principal Axes methods

Moments are used in classical mechanics to characterize rigid bodies by the spatial distribution of their mass. The principal axes are those orthogonal axes about which the moments of inertia are minimized. If two objects are identical except for a translation and a rotation, then they can be registered exactly by bringing their principal axes into coincidence. If two objects are shaped similarly, they may be registered approximately by this process [9]. J.Flusser and T. Suk derived affine transform invariants [37] and subsequently used it for registration of SPOT and Landsat images [38]. Moment based methods also appear as hybridly classified registration methods that use segmented or binarized image data for input. In many applications, pre-segmentation is mandatory in order for moment based methods to produce acceptable results [5].

4.5. Correlation methods

Correlation methods are useful for registration of monomodal images, for comparison of several images of the same object, e.g. to analyze development of the disease. The early survey paper by K. Ghaffary, A.A. Sawchuk [39] covers mainly the methods based on image correlation. The most exhaustive review of the general-purpose image registration methods has been given by Gotsfeld [6]. Literature on Cross-correlation of original images or extracted feature images is found in [40-63]. Literature on Fourier domain based cross-correlation, and phase-only correlation is reported in [65-69]. Recently Min Xu and Varshney P.K. [64] have specified the application of a subspace-based frequency estimation approach for the Fourier-based image registration problem. They have used multiple signal classifier algorithm for more robust and accurate results resulting into moderate increase in computational complexity. Correlation Technique was used to refine the user-defined landmark positions to register tomographic brain [70, 71] and abdominal images [71]. A. Collignon [72 and 73] has suggested the use of the Entropy Correlation Coefficient (ECC), for image registration using normalized mutual information. S. Sanjay-Gopal, H. P. Chan, T. Wilson, M. Helvie, N.Petrick and B. Sahiner [74] have compared mutual information and the correlation coefficient for registration of intrasubject mammograms. Samritjiarapon O. and Chitsobhuk O.[75] have used fourier-based technique along with best-first search algorithm to find the translation between two input images. The Fourier-based technique is used to estimate the candidate translations to decrease searching space while best-first search algorithm is used to further search for the correct translation. This technique can estimate large translations, scalings, and rotations in images by an extension of phase correlation technique. They focus on increased accuracy of this technique to detect large translations compared to the other techniques in frequency domain.

4.6. Atlas methods

If one image is acquired from a single patient, and the other image is taken from an image information database, we call it atlas registration. In the literature, registration of a patient image to an image of a normal subject is termed atlas registration. This also may be useful from the point of view of research studies viz. study of images obtained from separate individuals. Wan Rui and Li Minglu [9] have stated that standardized brain coordinate system has been used in automatically segmenting individual cerebral structures in brain image volumes and stereotactic neurosurgical planning. Numbers of researchers [76-86] have discussed various aspects of atlas registration. These techniques have been proved to be useful in medical diagnosis. K.K. Bhatia, J.V. Hajnal, B.K. Puri, A.D. Edwards and D. Rueckert [87] have described group wise registration algorithm that simultaneously registers all images to a common reference space. Gradient projection method has been applied constrained optimization is applied to maximize the similarity between the images. Daniel J. Blezek and James V. Miller [88] have explored question, whether a single atlas is appropriate for a given sample or whether there is an image based evidence from which we can infer multiple atlases, each constructed from a subset of the data, referring this process as atlas stratification.

4.7. Mutual information-based methods

Mutual information-based registration begins with the estimation of the joint probability of the intensities of corresponding voxels in the two images. The use of information-theoretic measures such as mutual information has obviously benefited voxel-based registration. The present papers have demonstrated that mutual information can be used to parameterize and solve the correspondence problem in feature-based registration.

They have appeared recently and represent the leading technique in multimodal registration. Registration of multimodal images is the difficult task, but often necessary to solve, especially in medical imaging. The comparison of anatomical and functional images of the patient's body can lead to a diagnosis, which would be impossible to gain otherwise. Remote sensing often makes use of the exploitation of more sensor types, too.

P. Viola and W.M. Wells [89] have maximized Mutual Information using gradient descent optimization method. Researchers [90-92] have used various methods like Parzen window; spline pyramids to achieve mutual information based image registration. Other methods used are hierarchical search strategy together with simulated annealing [93], the Brent's method and the Powell's multi- dimensional direction set method [94]. Frederik Maes, Dirk Vandermeulen and Paul Suetens [95] have investigated the performance of various optimization methods and multiresolution strategies for maximization of mutual information. Josien P. W. Pluim, J. B. Antoine Maintz and Max A. Viergever [96] have given a review of mutual information based image registration methods.

4.8. Wavelet-based methods

The multi-resolution wavelet decomposition transform is an intermediate representation between Fourier and spatial representations; it can provide good localization properties in both spatial and Fourier domains. The wavelet-based approaches preserve the spectral characteristics of the multi-spectral images better than the standard PCA and HIS methods. The wavelet-based image registration can be performed in two ways:

(1) Selecting wavelet coefficients by selection rules such as the maximum absolute wavelet coefficient in the multi-spectral image and the high-resolution image for each band;

(2) Replacing partial wavelet coefficients of the high-resolution image with these of the multi-spectral low-resolution image.

Recently, wavelet decomposition of the images was recommended for the pyramidal approach due to its inherent multiresolution character. Methods can differ in the type of the applied wavelet and the set of wavelet coefficients used for finding the correspondence. Most frequently used methods decompose the image recursively into four sets of coefficients (LL, HL, LH, HH) by filtering the image successively with two filters, a low-pass filter L and a high pass filter H, both working along the image rows and columns. Use of various orthogonal and biorthogonal wavelets [97], Daubechies wavelet [98], Gabor feature-based methods [99] has been reported. Gang Hong and Yun Zhang [123] have proposed a new image registration method based on combination of feature based and area based matching. A wavelet-based feature extraction technique, normalized cross-correlation matching and relaxation-based image matching techniques are used. This algorithm can select enough control points to reduce the local distortions.

4.9. Soft Computing based methods

Methods based on soft computing techniques such as neural network, Genetic Algorithm, Fuzzy logic etc are recently being used. L. Ramirez, N. G. Durdle and V. J. Raso [100] have described these various methods.

4.9.1. Artificial Neural Networks

An artificial neural network (ANN), often just called a "neural network" (NN), is a mathematical model or computational model based on biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. In more practical terms neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data.An artificial neural network (ANN) is a computational structure that is composed of a number of single processors connected through a set of links, which have some weight associated with them. There are two types of network architectures: 1) feed-forward networks, in which the links have no loops (e.g., multilayer perceptron (MLP) and radial basis function neural networks (RBF) and 2) recurrent networks, in which loops occur (e.g., self-organizing maps (SOM) and Hopfield networks). To train feed forward networks, knowledge of the desired output is normally required. Recurrent neural networks normally do not require previous knowledge about the expected output. The training process in an ANN involves modification of the network architecture and the connection weights to learn complex non-linear input-output relationships.

Radial basis functions [101] & [102], self organizing maps [103], Hopfield networks [104] can be used for different computational aspects in Image registration. Heng Liua, Jingqi Yan,, David

Zhang [105] have proposed a three-layer neural network to determine the registration matrix for 3D surface Image registration. Min Li, Wei Cai, Zheng Tan [106] describe an application of pulse-coupled neural network to multi-sensor image fusion problem based on the use of image regions. Lifeng Shang, Jian Cheng Lv, Zhang Yi [107] have used principal component analysis (PCA) neural network for CT-MR and MR-MR registration. J. Zhang , Y. Ge , S.H. Ong , C.K. Chui b, S.H. Teoh , C.H. Yan [108] have described a 3D surface-based rigid registration system for image-guided surgery on bone structures.

4.9.2. Genetic Algorithm

A genetic algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics. Genetic algorithms are a particular class of evolutionary algorithms (also known as evolutionary computation) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover (also called recombination).Genetic algorithms are implemented as a computer simulation in which a population of abstract representations (called chromosomes or the genotype or the genome) of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem evolves toward better solutions. Traditionally, solutions are represented in binary as strings of 0s and 1s, but other encodings are also possible. The evolution usually starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and possibly randomly mutated) to form a new population. The new population is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population. If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached.

Jean-Jose Jack, Christian Roux [109] have presented a method based on a canonical genetic algorithm to achieve volume-to-volume and the surface-to-volume registration problem in 3-D medical imaging. Kin Chow, Hung Tat Tsui, Tong Lee Surface [110] and Zsolt Janko, Dmitry Chetverikov, Aniko Ekart [111] have used Genetic algorithm based optimization to solve the problem of surface registration. L. Ramirez, N. G. Durdle, V. J. Raso [100] have reported use of to find the parameters of different transformations in Image registration e.g. rigid [112] and [113], affine [114], projective [115] and curved [116].

4.9.3. Fuzzy sets

Fuzzy sets are sets whose elements have degrees of membership. Fuzzy sets (FS) have been introduced by Lotfi A. Zadeh (1965) as an extension of the classical notion of set. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition - an element either belongs or does not belong to the set. By contrast, fuzzy set theory permits the gradual assessment of the membership of elements in a set; this is described with the aid of a membership function valued in the real unit interval [0, 1]. Fuzzy sets generalize classical sets, since the indicator functions of classical sets are special cases of the membership functions of fuzzy sets, if the latter only take values 0 or 1.Fuzzy sets technology depend on linguistic terms (e.g.: small, large, tall, short, etc.) to summarize the domain knowledge explicitly. Consequently, the results are clearly interpretable. FS are able to express the notion of partial membership (expressed by a real number in the unit interval [0, 1] of an element to a particular information granule. This property allows Fuzzy sets to handle uncertainty and imprecision. L. Ramirez, N. G. Durdle, V. J. Raso [100] have mentioned use of fuzzy sets in image registration. G. Berks, A. Ghassemi, and D. G. von Keyserlingk [117] and Y. Hata, S. Kobashi, S. Hirano, and M. Ishikawa [118] have used fuzzy sets to determine the transformation. B.P.F. Lelieveldt, R.J. van der Geest, M.R. Rezaee, J.G. Bosch, and J.H.C. Reiber [119] has used fuzzy sets to select and pre-process the features to be registered. Jean-Philippe Tarel [120] has proposed a method using Fuzzy Clustering to solve 3D registration problem. Ramirez L., Durdle N.G. and Raso V.J. [121] have divided the image registration process in two phases. Phase 1 is used to obtain an accurate estimate of the rotations and a rough estimate of the translations. Phase 2 is used to achieve precision in the translation estimates. In each phase, a fuzzy logic controller is used to adjust the registration parameters to obtain accurate transformation estimates.

4.9.4. Rough Sets

Rough set is a formal approximation of a crisp set (i.e., conventional set) in terms of a pair of sets which give the lower and the upper approximation of the original set. The lower and upper approximation sets themselves are crisp sets in the standard version of rough set theory, but in other variations, the approximating sets may be fuzzy sets as well. Rough sets (RS) use lower and upper approximation bounds of a concept to manage uncertainty. These bounds are defined with respect to some indiscernibility function. RS can be seen as a special type of FS in which membership values attain a value of zero for elements outside the upper approximation bound, a value of one for elements inside of the lower approximation bound, and a value in the unit interval [0,1] for elements located between the upper and lower approximation bounds. RS have been used to find corresponding points in medical time series [122].

5. Discussion

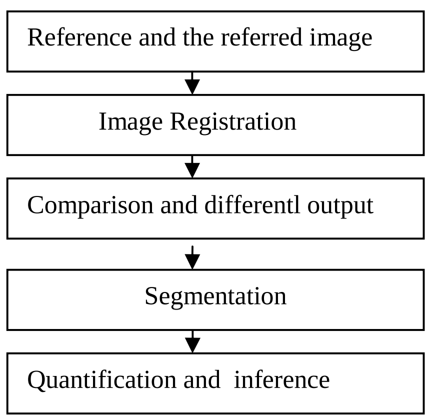

Figure 4. Computer aided diagnostic system

Over the last two decades image registration has been a very successful topic with variety of applications. Fat and convenient access of data is now possible due to development in digital data archiving and communication. This provides platform for registration of multimodal images in various disciplines. But registration is often a component of an image processing analysis package. Methodologies like segmentation and quantification may be required to form a computer aided diagnostic system as a whole.

Followed by image registration in the medical applications, segmentation is needed to determine areas of interest in the image and in many cases accurate demarcation of objects yields valuable information. Quantification is often the ultimate goal especially in medical applications. Once the diagnosis has been made the physician needs a quantified data to determine the extent of progression of a disease. Thus progress in image registration has to go hand in hand with other areas as well.

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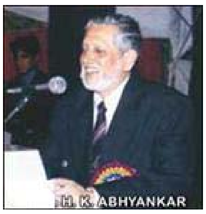

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