Classification of Image Registration Techniques and Algorithms in Digital Image Processing – A Research Survey

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Abstract- **Image Registration (IR) occupied a dominant role in the digital Image processing in general and Image analysis in particular. Image registration is a process of transforming different sets of data into one coordinate system, and data may be from - (a) multiple photographs, (b) different sensors and both (a) & (b) vary from different (i) times, (ii) depths, and (iii) viewpoints, and thus aligning to monitor the subtle differences between two or more images. The development of IR techniques and algorithms is highly complex because it is required to find spatial correspondences among images, and have vast applications in - Computer Vision, Medical Imaging, Image Mosaicking, Biological Imaging and Brain Mapping, Remote Sensing, Military, Satellite communication, Criminology, and Optimization, etc. Image registration techniques are not only required but also essentially necessary to compare data & images obtained from different measurements based on their application requirements. Due to its high potential requirement for research, there is a need to carryout a research survey on Image Registration techniques in order to understand the phenomenon of Image Registration and its implementation methodologies. This survey emphasizes Image Registration as the most essential part of panoramic image generation & creation, where applications and uses are unimaginable for researchers longing to invent & implement alternative image registration methods from general to specific to complex applications.**

Keywords- **DIP: Digital Image Processing, IA: Image Analysis, IR: Image Registration, MIA: Medical Image Analysis, CT: Computer Tomography, MRI: Medical Resonance Imaging, PET: Positron Emission Tomography.**

I. INTRODUCTION

In simple terms, image registration is an image processing technique used to align multiple scenes of images into a single integrated image, that enables to overcome the issues such as image rotation, scale, skew, etc., which are common image properties that needs in overlaying images in order to align and connect adjacent images into a single panoramic image.

The research in image registration has long history and is indicated in early 1960's to align 3D images [18]. The research requirement and the potential for image registration techniques are identified in early 1980's [16], [17], and initiated the research based on the application requirement, and are classified based on the algorithms developed for applications. Image registration finds its application, wherever there is a need for visualization of objects inside any body of volume, ex., possibility to visualize objects inside human body (Brain, Heart, Liver, Kidney, Abdomen, Bones & Tissues, etc.,), and advances in computer science have directed to reliable and efficient image processing methods useful in – (i) computer vision (target localization & automatic quality control), (ii) medical imaging (combining data from different modalities like CT & MRI), (iii) remote sensing for geological survey & weather forecasting (multispectral classification), (iv) military (automatic target recognition, satellite data & images for compiling and analysis), (v) criminology (identify & fix the crime), (vi) as a solution to optimization problems (feature & intensity based), and many.

Feature detection, feature matching, transform model estimation, and image resampling & transformation are four essential steps involved in Image Registration process [1]. Feature & intensity based, transformations using Fourier analysis, cross correlation approach using Fourier Transform analysis, sum of squares search technique, Eigen value decomposition, moment matching, techniques, warping techniques, procedural approach, anatomic atlas, internal landmarks, external landmarks, etc., are some of the approaches for image registration in order to find motion vectors and spatial transformation among the images to establish spatial correspondences between them [2].

Image processing methods are able to visualize the objects and techniques developed for various image registration methods that enable to achieve possible solutions through the image registration process. It is pertinent to mention that most of the literature is summarized by keeping image registration in the domain of MIA in the view. Therefore, image registration process is classified based on nine basic criteria which is briefed in chapter 2, and ten image registration models that are explained in chapter 3.

II. IMAGE REGISTRATION CLASSIFICATION

The classification of image registration techniques [3], [4], [5], [6], [7], [8] are summarised and given in the Figure – 1 below:

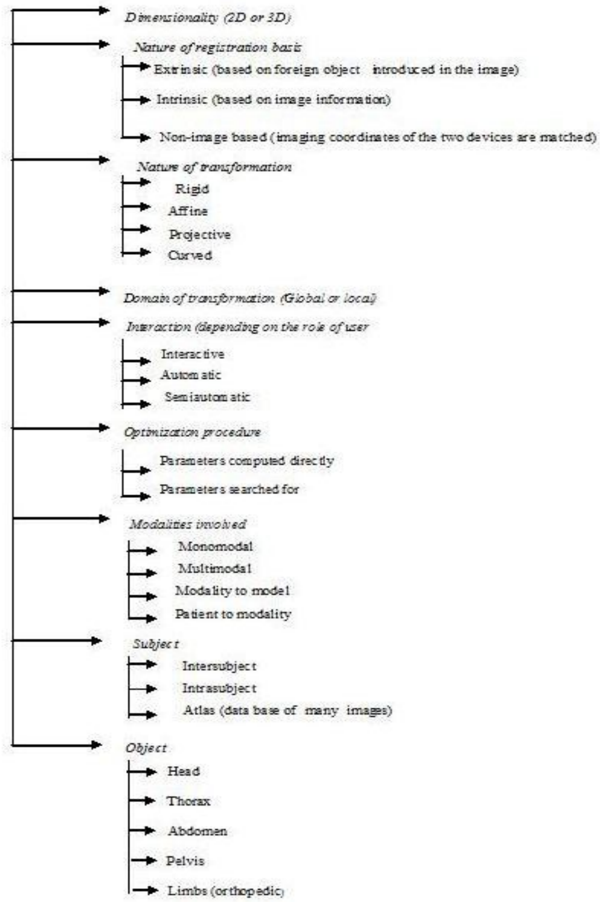

Figure – 1: Image Registration - Classification

The above figure 1 shows the potential and importance of research requirement and necessity of methodologies in the image registration. The image registration models are classified and explained in next chapter.

III. IMAGE REGISTRATION ALGORITHMS – CLASSIFICATION

Many number of algorithms are designed and developed based on the application requirements of image registration techniques which includes mathematical models also. These are all summarised and presented in this chapter.

Image registration algorithms are broadly divided into ten classifications. They are – (i) Intensity-based and feature-based; (ii) Transformation models; (iii) Spatial frequency domain models; (iv) Single-multi-modality modals; (v) Automatic, semi-automatic, manual modals; (vi) Similarity modals; (vii) Uncertainty models; (viii) Optimization models; (ix) Parametric and non-parametric models; (x) Rigid and non-rigid models. These models are briefly described in the following sub chapters.

A. Intensity-based and feature-based models

Image alignment algorithms of image registration process are classified into intensity-based and feature-based. In this process, one of the images is referred to as the reference or source, and the other respective images are referred as the target or sensed or subject images. The image registration is obtained through spatially registering the target images to align with the reference images. In the intensity-based methods, it is compared intensity patterns in images through correlation metrics, and in feature-based methods, finds the correspondence between image features such as points, lines, and contours. Intensity-based methods register entire images or sub-images. If sub-images are registered, centres of corresponding sub images are treated as corresponding feature points. Feature-based methods establish a correspondence between a number of distinct points in images especially. Knowing the correspondence between a number of points in images, a geometrical transformation is then determined to map the target image to the reference images, which indicates point-by-point correspondence is established between the reference and target images [9].

B. Transformation models

The algorithms designed to relate the target image space versus reference image space are classified into transformation models of image registration algorithms. Linear transformation models are the first and broad category of this model where image properties, viz, rotation, scaling, translation, and affine transforms, are specifically observed [10]. Due to the global nature of these linear transformations, it cannot be modelled into local geometric differences between target and reference images. The algorithms developed for 'Elastic' or 'non-rigid transformations are called as second category of transformation models. These transformations are capable of locally warping the target image to align with the reference image. Non-rigid transformations include radial basis functions, ex., thin-plate or surface splines, multi-quadrics, and compactly-supported transformations, physical continuum models like viscous fluids, and large deformation models like medical models, membranes etc.

C. Spatial frequency domain models

Spatial methods operate in the frequency domain for matching intensity features of images patterns. The algorithms developed for feature matching is a superficial to traditional techniques of image registration. When the number of control points exceeds the minimum required to define the appropriate transformation model, iterative Random sample consensus algorithm [19], and be used to robustly estimate the parameters for registration of the images.

The algorithms developed to find the spatial transformation parameters between source and target images in the image registration process falls into spatial frequency domain models. These models use frequency transformations such as translation, rotation, and scaling in frequency domain. The phase correlation method is used to a pair of images in order to produce a third image which contains a single peak in the frequency domain. The location of this peak corresponds to the relative translation between source and target images. The phase correlation method is resilient to noise, occlusions, and other defects typical of medical or satellite images, Unlike many spatial-domain algorithms. In addition, the phase correlation uses the fast fourier transform methodology to compute the cross-correlation between the two images that generally results large performance gains. This method is extended to determine rotation and scaling differences between two images by first converting the images into log-polar coordinates [11], [12]. Due to efficient properties of Fourier transform, the rotation and scaling parameters are determined in a manner invariant to translation.

D. Mono-multi-modality models

Another classification is made between mono-modality and multi-modality methods. In single modality model the images are acquired by the same scanner/sensor, while in multi-modality registration methods the images acquired by different scanners/sensors and/or at different times.

Multi-modality registration methods have many applications in medical image analysis. The medical images that are obtained from dissimilar scanners are used for medical diagnosis. The examples include registration of brain CT/MRI images or whole body PET/CT images for a tumour localization or defect in any other human body/part diagnosis purpose. The registration of contrast-enhanced versus non-contrast-enhanced in CT images for segmentation of specific parts of the anatomy, and registration of ultrasound and CT images for prostate localization in radiotherapy is another application.

E. Manual, Semi-Automatic, and Automatic models

The algorithms developed to provide the level of automation are classified into (i) manual, (ii) semi-automatic or interactive and (iii) automatic models of image registration methods. The tools developed for manual alignment of source and target images are called as manual models. Semi-automatic or interactive models needs user to verify the correspondence of registration. Interactive methods reduce user bias by performing certain key operations automatically and help the user to guide for the registration. Semi-automatic methods perform more of the registration steps automatically but depend on the user to verify the correctness of image registration process. Algorithms that are developed for not to allow any user interaction of any sort, and performs all registration steps automatically.

F. Similarity models

Image similarity model is mainly used in medical imaging. In this model, the image similarity measure quantifies the degree of similarity between intensity patterns of two images. The image similarity measure depends on the modality of the images to be registered. The examples of image similarity measures are: cross-correlation, mutual information, sum of squared intensity differences, and ratio image uniformity. The most popular image similarity measure in image registration of multi-modality images are: mutual information and normalized mutual information. The measure like cross-correlation, sum of squared intensity differences and ratio image uniformity are commonly used in image registration methods of images in the same modality.

G. Uncertainty models

There is a level of uncertainty associated with registering images that have any spatial-temporal differences. The challenging and important problem in image registration is to evaluate the performance of registration algorithm in uncertainty models. The direct quantitative approach is to compare the deformation field with ground truth transformation method [22], and with the absence of this transform the uncertainty model uses estimation & training methods for the accuracy to infer image registration error [23]. A confident registration with a measure of uncertainty is critical for many change detection applications such as medical diagnostics. In remote sensing applications used in NASA's LANDSAT imagery where a digital image pixel may represent several kilometres of spatial distance, and an uncertain image registration can mean that a solution could be several kilometres from ground truth. Several notable papers have attempted to quantify uncertainty in image registration in order to compare results [13], [14]. However, many approaches to quantifying uncertainty or estimating deformations are computationally intensive or only applicable to limited sets of spatial transformations.

H. Optimization models

The core idea of image registration is straightforward, but implementation of optimization is complex. Given as input a reference image 'R' and a deformable template image 'T', an image registration algorithm outputs a deformation 'u'. This deformation gives displacements for the vector of locations 'X' and, when these displacements are applied to the template 'T', the modified template should more closely match the reference 'R'. This is an optimization problem, aiming to minimize the difference between the deformed template “T(X-u (X))” and the original reference “R(X)”. Vector 'X' will be used to represent all indices in the image simultaneously. And 'x' will be used for a single location in the image, with “u (x)” being the deformation at that location [20]. Despite the shared model, different methods of image registration will vary in optimization methods and, more importantly, the metric used to determine the difference. Some algorithms will place strict restrictions on the deformation 'u', some will seek to focus on specific aspects of the image, and others will include a regularization term to ensure smoothness of the deformation.

I. Parametric and non-parametric models

Parametric image registration consists of techniques based on finite sets of parameters and/or image features. Foremost among these techniques is landmark - based image registration. A number of markers are specified in both the reference and the template, and a transformation is sought that allows these to align. This transformation could be a linear registration, a quadratic one, or ideally some other type of smooth registration.

Simply matching the markers and nothing else, however, can result in ill - formed solutions, as explained later. Evaluating the smoothness of the transformation could be more useful, and a modified landmark - based registration is presented later in this paper. Landmarks, however, are difficult to automatically locate. While some automation of marker finding is possible, human intervention may still be needed, reducing the autonomy of this method drastically.

Principal axes are put forward as an alternative; the centre of an image, along with the vectors along which its main axes lie, are easily found through basic numerical analysis. Finding a transformation between the axes of the reference and the template is easy, but has its weaknesses. In particular, the principal axes method holds too much ambiguity. With even different rectangles sharing the same features by this measure, the ability of the principal axes method to match images is limited at best.

Alternatively, the image features could be expanded to include the whole image, and the parameters to optimize could be restrained. Several methods restrict themselves to affine linear transformations, aiming to optimize only a few terms. Among these are some intensity - base schemes using Gauss - Newton methods, and a few schemes using new distance measures. While intriguing, these go beyond the scope of this paper.

In non - parametric image registration, by contrast, it is neither focus on specific points nor demand an affine linear transformation [20]. While such a transformation may be preferred, non - linear deformations are possible. As such, we aim to minimize the metric $J[R,T; u] := D[R,T; u] + \alpha S[u]$ where D is a metric for the difference between the reference and the deformed template, and S is a measure of the deformation’s smoothness. For the difference, the sum of squared differences is a popular metric which can be quickly computed over Ω.

$$D[R, T; u] := 1/2 \; \| R - T u \| 2 = 1/2 \int \Omega \, (T(x - u(x)) - R(x)) \, 2 \, dx$$

The smoothness measure, on the other hand, varies widely with the specific non-parametric method used. Finally, depending on the problem to be resolved, appending a penalty term is possible if particular solutions are to be avoided.

J. Rigid and non-rigid models

Historically, rigid and non-rigid model classification is existing in image registration. In the rigid models, the images are assumed to be of objects that simply need to be rotated and translated w.r.to one another to achieve the required correspondence. Non-rigid models are extension to rigid models by allowing deformations in order to achieve good matching. Non-rigid image registration models are more general approach than the widely used affine and rigid models, but require more complex methodology and computational effort to implement for its requirement. The purpose of non-rigid registration is to correct the comply with the image transformation model [21]. The performance evaluation of non-rigid image registration algorithms is a difficult task since point-wise correspondence from one image to another is not unique. That is there is rarely if over a ground truth correspondence map to judge the performance of a registration algorithm, hence a complex task, and the complexity is understood, while, rigid and affine registrations can typically be determined in seconds or minutes but most non-rigid registration algorithms require minutes or hours with that time being spent either identifying a geometric set of corresponding features to match directly or automatically determining a large number of parameters by matching voxel intensities directly. Nevertheless, there is a growing body of published work that focuses on real-world applications of non-rigid registration rather than technical refinements, and non-rigid registration method is a key requirement for the application of biomechanical models of human body. Creation of creation of a generic cardiac model that is instantiated by linear elastic registration with cardiac images of a subject acquired with more than one imaging modality [15].

IV. CONCLUSIONS

Image registration is an active field of research in image processing. Many methods can still be considered for image processing in general and image analysis in particular. The need and requirements in medical research is unimaginable provided that the designed algorithms & methods are validated properly. Although the proper verification methods are known in most cases, and coarsely laid for most applications the painstaking work of conducting the many experiments involved is only now starting due to its computational complexity. Image registration process is the most essential part of panoramic image generation and creation, where application and uses are unimaginable for researchers longing to invent the image registration methods from general to specific to complex applications in the field of digital image processing.

ACKNOWLEDGEMENTS

The author submit sincere thanks to the Hon'ble Vice-Chancellor, Registrar, DEAN and all the staff members of all the departments of the Mother Teresa Women's University for their high level motivation and encouragement in all respects for my research work. Also, I sincerely thank HOD and all the staff members, and Dr. S.Vimala, Associate Professor, of Computer Science Department for their continuous support and encouragement for this research work. Finally, I thank all the students and all the guest faculty of my University for their support in all respects.

REFERENCES

[1] Barbara Zitova, Jan Flusser, "Image registration methods: a survey", Image and Vision Computing 21 (2003), 977–1000.

[2] J.V.Chapnick, M.E.Noz, G.Q. Maguire, E.L.Kramer, J.J.Sanger, B.A.Birnbaum, A.J.Megibow, "Techniques of Multimodality Image Registration" Proceedings of the IEEE nineteenth Annual North East Bioengineeering conference, 18-19 March 1993, 221-222.

[3] P. A. Van Den Elsen, E. J. D. Pol and M. A. Viergever, "Medical image matching: a review with classification", IEEE Engineering in medicine and biology, 12(1):1993,26-39

[4] J. B. Antoine Maintz and Max A. Viergever, "A Survey of Medical Image Registration", Medical Image Analysis (1998) Volume2, number 1, pp 1-36, Oxford University Press

[5] Brown Gottesfeld L, "A survey of image Registration Techniques", ACM Computing surveys 24, 1992, 325-376

[6] Mauer C.R., Fitzpatrick J.M., "A review of medical image registration, in: Interactive Image Guided Neurosurgery", Maciunas R.J. (ed), American association of Neurological Surgeons, 1993, 17-44

[7] Letser.H, Arrige S.R., "A survey of hierarchical nonlinear medical image registration" Pattern Recognition, 1999, 129-149

[8] Wan Rui, Prof.Li Minglu, "An Overview of Medical Image Registration", Proceedings of the Fifth International Conference on Computational Intelligence and Multimedia Applications (ICCIMA'03), 2003, 385-390

[9] A. Ardeshir Goshtasby: 2-D and 3-D Image Registration for Medical, Remote Sensing, and Industrial Applications, Wiley Press, 2005.

[10] L. Shapiro and Stockman, Computer Vision.
Prentice-Hall, 2001.

[11] B. Srinivasa Reddy, B. N. Chatterji: An FFT-Based Technique for Translation, Rotation and Scale-Invariant Image Registration. IEEE Transactions on Image Processing, 5, no. 8.

[12] G. Wohlberg, S. Zokai: ROBUST IMAGE REGISTRATION USING LOG-POLAR TRANSFORM • A paper on using the log polar transform for registration

[13] Simonson, K., Drescher, S., Tanner, F., A Statistics Based Approach to Binary Image Registration with Uncertainty Analysis. IEEE Pattern Analysis and Machine Intelligence, Vol. 29, No. 1, January 2007

[14] Domokos, C., Kato, Z., Francos, J., Parametric estimation of affine deformations of binary images. Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing, 2008

[15] Sermesant M, Forest C, Pennec X, Delingette H, Ayache N. Deformable biomechanical models: Application to 4D cardiac image analysis. Med Image Anal 2003;7:475–88

[16] Pelizzari CA, Chen GTY, Spelbring DR, Weichselbaum RR, Chen CT. Accurate 3-dimensional registration of CT, PET, and/or MR images of the brain. J Comput Assist Tomogr 1989;13:20–6

[17] Hill DLG, Hawkes DJ, Crossman JE, Gleeson MJ, Cox TCS, Bracey EECML, et al. Registration of MR and CT images for skull base surgery using point-like anatomical features. Br J Radiol 1991;64:1030–5.

[18] L.G. Robers, Machine Perception of 3-D Solids, Ph.D. Thesis, MIT, 1963.

[19] M.A. Fischler and R.C. Bolles. Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography. Communications of the ACM, 24(6):381–395, 1981.

[20] Stuart Alexander MacGillivray, Cuvature based image registration: Review and extentions, An essay presented to the University of Waterloo in fulfillment of the essay requirement for the degree of Master of Mathematics in Combinatorics and Optimization Waterloo, Ontario, Canada, 2009.

[21] Peter Rogelj and Stanislav Kovaˇciˇc, Similarity Measures for Non-Rigid Registration, Ministry of Science and Technology of the Republic of Slovenia, Research program.

[22] M. Hub, M.L. Kessler, and C.P. Karger. A stochastic approach to estimate the uncertainty involved in B-spline image registration. MedImg, 28:1708–1716, 2009.

[23] Uncertainty in Probabilistic Image Registration by Tayebeh Lotfi Mahyari, Tayebeh Lotfi Mahyari 2013, Simon Fraser University, Canada, Summer 2013.