A Review on Extrinsic Registration Methods for Medical Images

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Abstract-In medical image analysis, image registration is the process of mapping the features or coordinate space of one image with the features or coordinate space of another image. The main aim of medical image registration is to obtain detail, precise and complementary information from two or more images. Image registration plays an important role in image-guided surgery and radiotherapy. Currently, several types of registration methods are available for the precise registration of medical images. In this paper, the available methods for extrinsic registration are analysed and their pros and cons are discussed in a comprehensive manner. The detail investigation and assessment of each registration method is performed according to various parameters. The aim of this paper is to provide detail knowledge on extrinsic registration methods that has been developed for medical images. This review is a suitable reference for those who are looking for registration methods for a specific application.

Keywords-Medical Image Registration, Extrinsic Registration, Image Guided Surgery, Radiotherapy

I. INTRODUCTION

Image-guided surgery has advanced with the introduction and developments in image processing techniques and imaging modalities. Image registration is one of the important techniques in image guided-surgery and radiotherapy in which one to one geometric correspondence between two or more images are established. In medical image registration, images of the same organ may be taken either from same or different viewpoints, times and scanners. The basic purpose of registration is to properly map the corresponding features and geometric coordinates in each image dimensions[i]. The mapping of two or more images (in which one is called source image and another is called target image) is performed by features or coordinate space comparison, analysis and transformation [ii-vii]. Fig. 1 shows the registration of source image obtained via MRI scanner with target image obtained with PET scanner. In the Fig., the registered image of MRI and PET on the right side is obtained through features comparison, analysis and transformation. The registered image shows more useful information and the differences and visibility of different head organs and tissues can also be observed in the registered image.

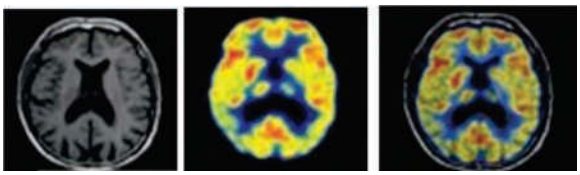

Fig. 1. Multi-modal registration of brain images. Image on the left side is brain MRI while the image in center is PET image of the same patient. Image on the right side is the registered PET image with MRI image

Image-guided surgeries and radiotherapies greatly depend on the accurate registration of medical images. Therefore, medical image registration is widely used in practices and clinics. Image registration also plays a vital role in imaging modalities such as magnetic resonance imaging (MRI), computed tomography (CT), ultrasound (US), Single-photon emission computed tomography (SPECT) and positron emission tomography (PET). Different types of anatomical and functional information in 3D form are precisely obtained with the help of these modalities. [viii]. Therefore, the detection of symptoms and treatment planning is done easily, precisely and with high accuracy.

Extrinsic registration rely on the external objects attached to the patient and these objects are called external markers or frames[ix]. In extrinsic registration methods, external objects are more visible and are therefore, easily distinguished from any other region in the image. Furthermore, the computation speed of extrinsic registration methods is also fast because it does not need complex algorithms for implementation. The registration of complex problems such as the registration of 3D and 4D shapes is easily performed with extrinsic registration methods. Several state-of-the-art survey papers [i], [vii] & [x-xvii] are available which evaluate and discuss the importance of extrinsic registration methods in image-guided surgery and

radiotherapy.

Despite the popularity of extrinsic registration methods, there is lack of comprehensive knowledge on this area of research in the literature. This paper aims to present a review on extrinsic registration methods for medical images. Although, extrinsic registration methods are presented in several state-of-the-art survey papers but the available knowledge is very brief in them. Furthermore, there is also lack of comprehensive evaluation on each method according to different parameters. In this review paper, the available knowledge about extrinsic registration methods is presented in a systematic manner. We have evaluated each registration method based on twelve important parameters that includes accuracy, efficiency, reliability, robustness/ stability, optimization procedure, transformation, error detection, target localization, computation/automation, clinical use/applications, modality and the support/availability of software tools.

The main contributions of this review are as follows.

- Extrinsic registration methods, which include stereotactic frame, fiducials (screw markers), mould, frame, dental adapter, and skin markers are described concisely.
- The use and performance of each extrinsic registration method on the basis of important parameters are shown.
- Some of the important merits and challenges of each registration method are discussed.
- The paper provides a theoretical foundation for new researchers in the field, which will eventually improve their knowledge on this challenging area of research.

The remainder of this paper is organized as follows: Section II briefly describe the general concept about medical image registration while section III presents detail knowledge on each registration method belongs to extrinsic criteria. Evaluation methodology is discussed in section IV while section V provides analysis and discussion on extrinsic registration methods. Section VI summarizes this paper.

II. Medical Image Registration Methods

Medical image registration is a highly vibrant area due to its broad range applicability and significance in human anatomy. Registration methods relate corresponding significant points in each image, extract similar features, perform optimal transformation and compute similarity measures [xi]. Integrating multiple types of information from more than one modalities such as from MRI and PET into a single one is essential which is only possible by using the appropriate method of medical image registration. The registration of PET and MRI brain images are shown in Fig. 1. In the Fig., the image on the left side is obtained from MRI while the middle one is taken from PET. The differences and visibility of different head organs and tissues are shown in the registered image of PET and MRI on the right side. Therefore, combining information from multiple modalities greatly helps surgeons in the precise identification and separation of tumor from normal tissues during image-guided surgery.

Medical image registration methods are classified on the bases of different criteria by the researchers from time to time and several review articles are available on this challenging area of research. These review articles are listed in Table II, together with the publication years and topics. Most of the classifications briefly cover each method and user cannot get detail knowledge along with their pros and cons. In this review paper, we have narrowed down the classification of medical image registration into extrinsic types. The main aim is to evaluate these methods, cover a comprehensive literature review about them and describe their use and importance in research and clinical practices. Diagrammatic representation of the classification is shown in Fig. 2 and the detail of each method is described in section III.

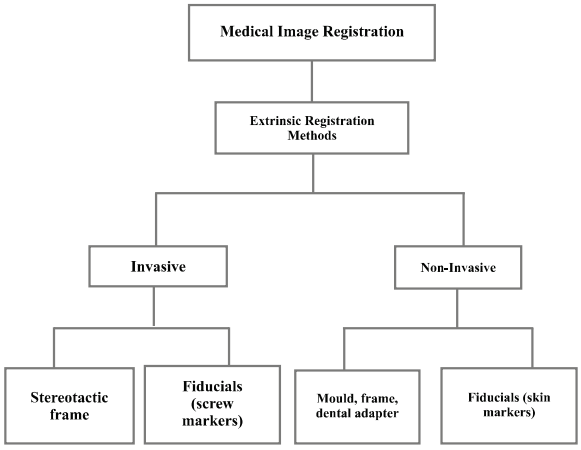

Fig. 2. Extrinsic registration methods for medical images

III. Extrinsic Registration Methods

Extrinsic registration methods are based on external artificial objects attached to patient's body. These registration methods always remain the best option in image-guided surgery. In the last two decades, extrinsic registration methods for medical images have been extensively studied in image-guided surgery and radiotherapy [xi-xii]. The aim is to acquire more efficiency, accuracy and reliability by analysing their corresponding features. Feature detection, feature extraction/ matching [xviii], transformation and optimization are the main steps for mapping source image to target image during registration process. Image features include edges, lines, curves and points

and these features are determined during feature detection step. On the other hand, in feature matching steps, a cost function is used to find the similarity measure in both source and target images. Image translation, rotation and scaling are performed during transformation phase while the optimizer finds the degree of similarity in transformation. Multi-modal images of the same organs containing both anatomical and functional information are effectively integrated using image registration. These different types of information are more reliable and can assist the clinicians and surgeons to take accurate decisions about patient tumor. A number of methods are now available to registered medical images using different types of procedures [xix-xxiii]. Extrinsic registration methods are the popular among them for the successful registration of medical images and are widely used in several clinical applications. Registration methods belong to extrinsic category rely on external objects i.e. artificial markers and frames attached to the patient's body[xxiv-xxv].

Extrinsic methods are categorized into invasive and non-invasive registration, which are further divided into stereotactic frame, fiducials (screw markers), mould, frame, dental adapter and skin markers. Invasive registration methods integrate and transform information obtained from multiple sources into a single image containing more information. Functional and anatomical information from human organs are obtained with minimum incisions, low pain and rapid recovery using the methods of invasive registration. On the other hand, non-invasive registration methods obtain the same types of information from internal organs without any incisions. In these methods, instruments are passed into internal organs and their images are shown on monitors during image-guided surgery with fast operating mechanism and without any collateral damage to the skin and normal tissues. The two categories of extrinsic registration methods i.e. invasive and non-invasive are discussed in the sub-sections below.

A. Invasive Registration Methods

Invasive image registration methods have been widely accepted as a treatment options because of the availability of realistic information related to patient's anatomy. In image-guided surgery, minimal invasive methods play a vital role by providing significant information about the organs under observation [xxvi]. Minimal invasive surgery provides several types of benefits to both surgeons and patients i.e. for surgeons the manipulation of surgical devices is performed in a best possible way and for patients, small incisions are made in the skin leading to less pain and fast recovery.

The development and availability of different types of imaging modalities result their wide spread use in the medical field. It is because of these developments that clinicians now uses minimal invasive techniques to get functional and structural information from human body. Furthermore, it is also now necessary for clinicians to learn increased amount of skill for the proper operation of the available techniques. Clinicians usually face some problems during image-guided surgery such as poor tactile feedback, eye-hand coordination and low visual feedback as compared to physical surgery [xxvi]. The solution for such problems is to take 3-D images of the organ using different modalities such as CT, MRI, PET and SPECT, integrate common features in them and presenting more informative image to the surgeons. Such type of integration and transformation of multi-modality images into single more informative image is performed with the help of invasive image registration methods. The importance of invasive methods of medical image registration is obvious due to the availability of specific information i.e. functional or structural. Stereotactic frame and fiducials markers are the two types of invasive techniques, discussed in the sub-sections below.

1) Stereotactic Frame Registration

Stereotactic frame is one of the earliest invasive registration techniques for multimodality images in the field of image-guided surgery. Stereotactic frame is directly fixed on the patient's head and the images of human organs are displayed on computer monitor. This process is performed simultaneously with the help of different imaging modalities in different orientations. Images obtained from multiple modalities are aligned in order to share and transform similar information [xxvii]. Stereotactic frame registration is also called image-to-physical coordinate space registration. In Stereotactic frame registration, image space is related to physical space occupied by the patient i.e. the mapping of MRI or CT coordinate system with the stereotactic frame coordinate system [xxviii]. Clinicians uses stereotactic frame devices for the proper navigation of mechanical apparatus such as probes, electrodes and biopsy cannulas with the help of image guidance in three dimensional spaces. They can perform effective surgery with freedom and flexibility by linking invasive frames to the patient's skulls through screws before pre-operative scan of CT and MRI. Stereotactic systems consist of stereotactic reference frames, a technique for stereotactic image acquisition and a mechanism for the proper direction of surgical devices. It is due to these features that target points are defined and the fixation of rigid body skull becomes possible using pins or screws which create a stereotactic coordinate system in physical space as shown in Fig. 3. Stereotactic frame registration is used for the proper management of general surgery as well as specific surgical problems such as orthopedic, neurosurgical, craniofacial and otolaryngology. These surgical procedures are performed with highest accuracy, safety, efficiency, highest probability of tumor removal and less surgical exposure. Applications

of stereotactic frame registration in image-guided surgery include biopsies, catheter insertions, gamma knife surgery, injections and aspirations. Despite several advantages of stereotactic frame registration it is invasive and uncomfortable.

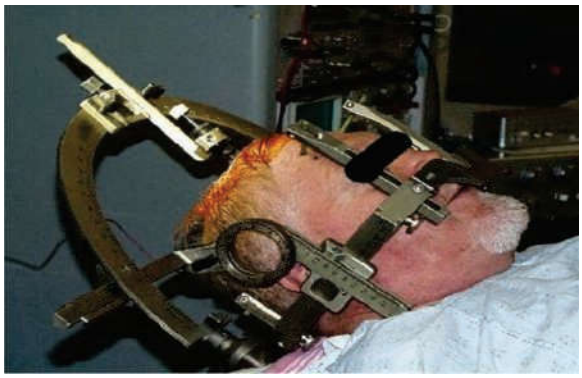

Fig. 3. Stereotactic frame is rigidly attached to the patient skull during image-guided surgery

2) Fiducials (Screw Markers) Image Registration

Fiducial markers are artificial objects attached to human organs, which provide transformation between image space and physical space. These objects are composed of different shapes and material such as plastics, ceramics, passive reflective, liquid-filled and steel [xxx]. The registration of medical images using fiducial screw markers is commonly used methods in invasive image-guided surgery where predefined fiducials i.e. screw markers are specifically applied on the preoperative images of different modalities such as X-rays, CT, SPECT and MRI. Furthermore, correlation is established between the preoperative images obtained from different modalities and intra-operative physical anatomy of patients. In other words, objects are positioned in the visible field of different imaging system for measurement and as a reference point in fiducial based image-guided surgery. In this invasive image guided surgery, surgeon put screw markers on patient's skin without rupturing under local anesthesia. Surgeon uses fiducial screw markers is an easy tracking tool for treatment of several image-guided surgeries such as bone treatments, prostate, orthopedic and brain surgeries. Fiducial screw markers are flexible objects and used with different types of imaging modalities and are easily used with X-ray, CT and MRI due to the availability of multimodal screw markers. These markers can also check errors for co-registration. Fig. 4 [xxxi] shows invasive screw markers over the anterior facial skeleton in which the green markers were used for registration while the blue markers are used for finding the target registration error.

Image registration with extrinsic fiducials screw markers is simple and automatic. Due to which it is used for the registration of both mono-modal and multi-modal images [xxxii]. In fiducial screw marker based registration, there is no need to apply complex computation parameters and algorithms. However, un-comparability, patient movement and invasiveness are the major limitations of it. Furthermore, high skill and planning is required for the clinicians to place screw

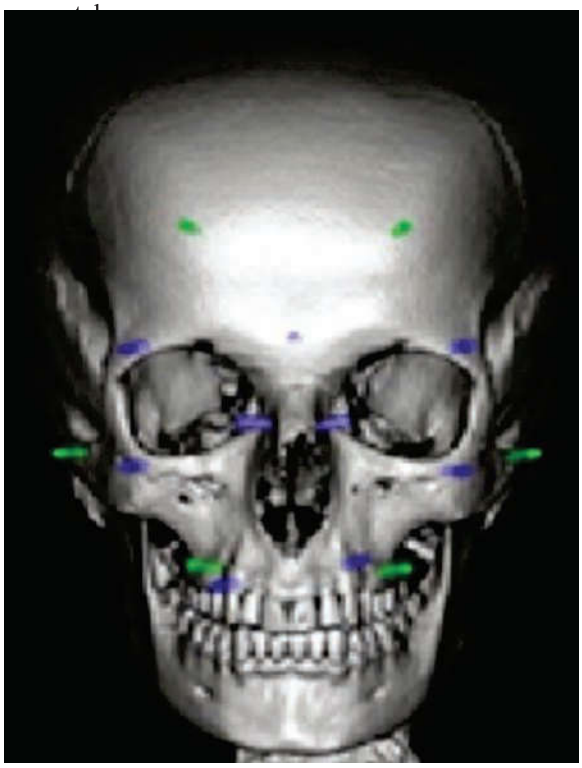

Fig. 4. Invasive fiducial markers placed in each skull

B. Non-Invasive Registration Methods

The techniques of minimally invasive image-guided surgery dramatically changed the way operation is performed and the patient's recovery in a minimum possible time. However, minimal invasive surgery still requires incisions and penetration into the body. On the other hand, in non-invasive image guided surgery, the concept of cutting the skin or tissue has been entirely eliminated. This type of surgery is done through endoscopy, in which an instrument is penetrated through natural human orifices such as mouth, the vagina, and the anus[xxxiii].

Non-invasive surgery requires image registration methods which combines and translates the images obtained from internal organs through penetrated instruments and displays them on the monitors for guidance. Non-invasive image registration methods are used in several image-guided procedures such as laser treatment, dermatological procedures and skin treatment surgery, in gastrointestinal issues and vision problems. These types of image registration methods have changed the way operation is performed. Their main features include fast operating mechanism, complete resection of infected tissues and no cut and

However, despite major improvements and success in these methods, non-invasive surgery is limited in scope and several challenges are still faced by the clinicians. One of the major challenges is the provision of proper interactive image guidance during surgery. Because high utilization of related information in the real time images obtained from different modalities is only possible due to interactive image guidance paradigm [xxxiv]. Using interactive image guidance paradigm during surgery, surgeon can utilized both 2D and 3D patient data properly i.e. 3D MR data for therapy arrangement and target demarcation while 2D real-time ultrasound for visualization of the eliminated region. Therefore, the proper registration of medical images obtained from multiple modalities with changing nature due to tissue motion and deformation is vital for the successes of non-invasive image guided-surgery in the future. Non-invasive medical image registration techniques are further categorized into Mould, Frame, Dental Adapter and Fiducials (Skin Markers), discussed in the sub-sections below.

1) Mould, Frame and Dental Adapter Registration

Despite its accuracy and usefulness, invasive registration methods such as stereotactic frame and fiducials screw markers are not suitable for the registration of non-malignant cases. In non-malignant surgery such as otologic the scale of accuracy is very high using fiducial systems [xxxv]. Non-invasive markers or landmarks such as moulds, frames and dental adapters are appropriate for these types of surgical cases. Moulds, head holder frames and dental adapters are tightly attached to the patient skin during otologic image guided surgery. During image-guided surgery, the frame encloses the subject area with non-invasive fiducial markers. Moreover, fiducial markers when localized in the physical and image space, provides transformation of interested image data between physical space and image space as shown in the Fig. 5.

Registration based on extrinsic non-invasive frame and dental adapter is applicable for both mono and multimodal image registration. Detection of the subject markers in multimodal images is easy due to which it can register two images automatically [xxxii]. Non-invasive image registration methods based on these landmarks is suitable choice for efficient image-guided surgery with accuracy because it can perform registration without any need for complex optimization and computation of image registration parameters. On the other hand, patient movement and dislocation of markers glued to the patient skin greatly affect the accuracy of registration.

Fig. 5. Image registration using non-invasive dental adapter

2) Fiducials (Skin Markers) Registration

Image registration based on skin markers is non-invasive method used in image-guided surgery. In this method, artificial external markers are placed on the patient's skin before MR or CT imaging which uniquely identify and show particular reference points [xxxvi]. It is widely used in image-guided surgery because surgeon can clearly see the reference points on both the surface of the patient's body and on the image under observation. The proper attachment of the markers is essential until the completion of operation [xxxvii]. Fig. 6 [xxxviii] shows image-to-patient registration based on fiducial skin markers. It is shown in the Fig. that the registration is performed between image space i.e. left side and physical space i.e. right side using set of corresponding points.

The placing and removal of fiducial skin markers are easy as compare to invasive screw markers and frames during image-guided surgery. Although the accuracy of fiducial skin markers is good and range up-to 2 mm but sometimes unpredictable errors are generated at the time of data acquisition and during surgery due to natural skin movement. Registration based on skin markers is suitable for nasal sinus surgery and neuro-navigation. However, this registration method is not suitable for the revision and operations of recurrent disease due to the unavailability, inaccessibility and displacement of reference structure. Furthermore, consistency in the size and shape of the skin markers is also an important factor to be considered during image- guided surgery.

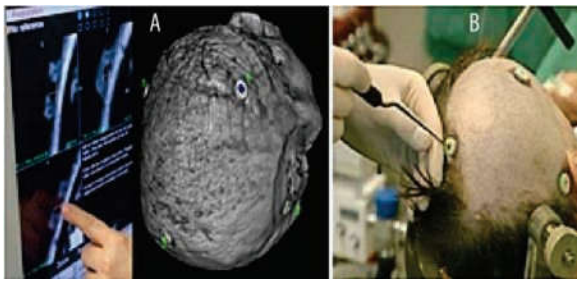

Fig. 6. Image registration using fiducial skin markers

IV. Evaluation Methodology

This paper evaluate extrinsic registration methods on the bases of twelve parameters which includes accuracy, efficiency, reliability, robustness/stability, optimization procedure, transformation, error detection and calculation, target localization, computation/automation, clinical use/applications, modalities involved and software tools availability. The purpose is to give insight knowledge and understanding of the available extrinsic registration methods. In order to evaluate the different registration methods according to the above mentioned parameters, they are presented in Table I. The Table provides state-of-the-art information to the users and researchers in the image registration field. The categorization of extrinsic registration methods is also shown graphically in Fig. 2 and the important parameters for evaluation are as follows.

- Accuracy: Accurate image registration is essential for useful clinical applications and in improved health care [xxxix-xl]. The registration method is called inaccurate if errors either actual or timely occurred at any time during registration. Therefore, it is necessary to modify and replace weak and inaccurate registration methods with more advanced and sophisticated methods [xli]. Two types of accuracy is achieved with medical image registration i.e. quantitative and qualitative. The former requires a ground truth that is consistent in clinical applications while the later type of accuracy is obtained using simple visualization tools and spectrum. Accuracy of registration methods is improved with several types of techniques such as non-rigid deformation and composite warping.
- Efficiency: Speed and computational efficiency are very important for the registration of medical images during image-guided surgery and radiotherapy. Efficiency is now become more important with the development of complex algorithms, which always reduce the speed and efficiency of registration process. Moreover, efficiency with reliability is required for successful registration. Therefore, several types of registration methods with high efficiency and reliability are developed which play an important role in image guided surgery and radiotherapy [xlii]. High efficiency is achieved with the optimization of interpolation and transformation parameters, reduction in number of similarity measures and with the development of fast template based tracking approaches.
- Reliability: Reliability is one of the important parameters in medical image registration because expected results are always required in the range of possible clinical input. The testing of registration method on several combinations of input images providing the same results as expected shows high reliability of that registration method.
- Robustness: The natural behavior of continuous organ movements and instability in human anatomy greatly affect the robustness and consistency of registration. Registration method is more robust if a small amount of change in the source image results the same amount of change in the target image [xliii]. On the other hand, registration method is less robust if a small amount of change in the source image results more change in the target image.
- Optimization Procedure: Some of the important parameters for registration methods such as accuracy, preciseness and robustness are measured with optimization procedures [xliv]. These procedures are applied iteratively until the merger of similarity measures obtained from the source and target images during registration. Several types of optimization techniques are available for the enhancement of registration process such as gradient decent, nonlinear conjugate gradient, multi resolution techniques, evolution strategy and simultaneous perturbation.
- Transformation: The mapping of points in one image space with another image space during registration is called transformation. Proper transformation of points in target image space to the points in the source image space is essential for successful registration[xxxi].
- Error Detection: Errors in image registration mostly occur due to the variations and movements in medical images which also effect accuracy [xlv]. Although error detection was a major problem in the early registration methods but it is now an easy job with the introduction of advanced methods. Several types of testing techniques have been developed which can easily and automatically detect errors in image registration.
- Target Localization: The division of tumor from normal tissues is called target localization. Target localization allows more local control of tumor volume in image guided surgery and radiotherapy. In modern radiotherapy, target localization is performed by the use of advanced registration methods and image fusion [xxx]. The registration and fusion of different modalities such as CT-MRI now clearly separate tumor from normal tissues and provide better target localization.
- Computation/Automation: Several types of automatic and semi-automatic registration methods are available which need less or no interaction from the users. These methods increase the speed and accuracy of registration process when there is high number of images to be registered. Automatic registration methods have also the capability to integrate both functional and

anatomical features from images belong to different modalities. Therefore, such types of automatic techniques are now a suitable choice for researchers and clinician due to their precise and fast mapping mechanism.

- Clinical use/Applications: Excessive adaptation of image registration methods in clinical practices shows their strength and usefulness. In this regard, the use of rigid registration in clinics is more than non-rigid registration methods. However, accuracy validation is essential for any registration methods to be useful in clinical practices.
- Modality: CT, PET, MRI and SPECT are the popular imaging modalities used by the registration methods to integrate different types of information. The accuracy and quality of registration depends on these modalities. Registration of multimodal images such as CT-MRI and PET-CT are widely used in medical diagnoses such as tumor localization, segmentation of organs and prostate localization.
- Software Tools support/availability: Clinicians and other technical users always demand the availability and support of software tools for a registration method. Because a software tool provides an environment for users to create, store, edit, maintain, and visualize image information in registration process. Therefore, the popularity and widespread use of a registration method require the availability of popular and easy to use software.

V. Analysis and Discussion

Researchers contributed high efforts in developing powerful methods for extrinsic registration. These methods are applicable for several types of registration problems. In this review article, the available extrinsic registration methods are highlighted in extreme. To further refine the subject and enhance the strength of understanding, the available methods are evaluated using a criteria described in section II. A detail analysis of the main features of the extrinsic registration methods are presented in Table I. It is found out that both invasive and non-invasive registration methods provide their own facilities and potentials to registered medical images in different formats effectively. However, non-invasive registration methods are more appropriate to represent medical images. The superiority of non-invasive registration methods including moulds, frames, dental adapters and fiducial skin markers over its companions is attributed due to some of its prominent features including: (1) their high efficiency compared to invasive techniques (2) simple optimization procedure (3) easy errors detection (4) easy target localization (5) manual and automatic mechanism to detect coordinates (6) widely used clinical applications and software tool availability.

After thorough analysis, it is found that both types of methods can be used to successfully register medical images. Although the two sets of registration methods have some degree of differences but have majority ratio of similarities. Therefore, can be used for any type of medical registration problems subject to the introduction of sophisticated technology and algorithms in the field. The list of similarities among the methods includes efficiency, reliability, robustness, simple optimization procedures, wide spread clinical applications, applicability to mono and multi-modalities, open source software tool availability and easy and quick transformation mechanism. The restriction of extrinsic registration to only rigid transformation greatly affects its flexibility. However, more transformations such as shearing and scaling are possible with the introduction and implementation of more sophisticated frames and fiducial markers. Low accuracy of extrinsic registration methods is also a big problem which need the development of more advanced tools and algorithms.

The current registration methods are mostly developed for specific problems and situation. The available methods are based on either single or multi-modality, based on either point based or surface based, rigid based or non-rigid based, subject based or object based and or dependent on image dimensions. Therefore, we came up with a conclusion that due to the diverse scenes, applications and several kinds of objects with different behaviors, generic and powerful registration methods are need to be developed. These generic and powerful methods should have the capability to precisely and efficiently register medical images of any kind and in any situation.

VI. Conclusion

The importance and need of image registration in the medical field is obvious because obtaining accurate information from sets of images is always required for successful image guided surgery. Therefore, researchers developed a number of registration methods in the past several years due to which clinician and patient now takes lot of benefits in medical diagnoses and surgeries. In this review article, we have presented a detail overview of the extrinsic registration methods for medical images and described their use and importance in image-guided surgery. These registration methods provide efficiency, accuracy and automation by integrating information from multiple sources in image-guided surgeries and radiotherapies. The leading factors affecting the efficiency, reliability and accuracy of medical image registration are complex physical associations between source and target images, complex optimization procedures, intensive computation, transformation mechanisms, invasiveness, compatibility issues, missing or partial

data and difficult target localization. Therefore, for the reliable, efficient and precise registration of medical images, more advanced and sophisticated methods are needed to be developed in near future. Nevertheless, the introduction of such advanced technologies and their use in clinics is difficult and still needs a massive amount of research contributions from the research communities.

TABLE I
ANALYSIS OF EXTRINSIC REGISTRATION METHODS USING A SET OF EVALUATION PARAMETERS

Parameters	Extrinsic Registration Methods			
	Invasive Registration		Non-Invasive Registration	
	Stereotactic Frames	Fiducials (Screw Markers)	Mould, Frame, Dental Adapter	Fiducials (Skin Markers)
Accuracy	Very High, because registration cues can be taken from a device that is built expressively to provide such cue	Perform accurate registration, but requires high skill from surgeons	Less accurate then invasive registration	Less accurate due to motion of the skin during surgery
Efficiency	Less efficient in head frame placement	Efficient, because there is no need for complex optimization algorithms	Quick and fast then invasive	Quick and fast then invasive
Reliability	More reliable because neither the anatomy nor the pathology are involved in registration	Reliable but small surgical risk associated with their use	Reliable	Not reliable due to elasticity in human skin
Robustness/ Stability	Provide robust basis for registration	Mechanically stable	More stable and robust	Less robust due to the independent motion of the markers on the skin
Optimization Procedure	Not complex but inconvenient	Simple and no need for complex optimization procedures, since the registration parameters can often be computed explicitly	Simple, because registration parameters are mostly computed explicitly	Simple, because registration parameters are mostly computed explicitly
Transformation	Relationship between skull and brain remain rigid during surgery	Often restricted to rigid (Translation and Rotation)	Often restricted to rigid (Translation and Rotation)	Often restricted to rigid (Translation and Rotation)
Error Detection	Can easily detect errors introduced as a result of the mathematical operations	Can check and detect errors for co-registration	Can detect target registration errors and fiducial localization errors	Easily detect fiducial localization errors
Target Localization	Requires high spatial Accuracy	Sophisticated markers and algorithms are available which can quickly and accurately localize targets	Provide precise target localization and patient setup	subject to localization errors
Computation/Automation	Automatic and explicit	Automatic and explicit	Automatic and explicit	Automatic and explicit
Clinical use/Applications	General surgery, orthopedic, neurosurgical, craniofacial and otolaryngology	Biopsies , Catheter Insertions, Gamma Knife Surgery, Injections and Aspirations, Orthopedic and facial surgery	Biopsy, thermal ablation, endoscopy, and laparoscopy	Orthopedic and facial surgery nasal sinus surgery and neuronavigation
Modality	Well visible and accurately detectable in all of the modalities	Visible and can be detected in both mono and multimodal	Visible and can be detected in both mono and multimodal	Well visible and accurately detectable in all of the modalities
Software Tools Availability	Nero surgical planning software tools are available	Available	Available	Available

TABLE II
REVIEW ARTICLES ON MEDICAL IMAGE REGISTRATION METHODS

Year	Reference	Topic
1992	[xi]	A Survey of Image Registration Techniques
1998	[x]	A Survey of Medical Image Registration,
2010	[xx]	Non rigid Registration of Medical Images: Theory, Methods, and Applications
2012	[xiii]	A review of 3D/2D registration methods for image-guided interventions
2013	[xiv]	Survey of Medical Image Registration
2003	[xv]	Image registration methods: a survey
2013	[xvii]	Medical image registration: a review
2014	[xii]	Image Registration Concept and Techniques: A Review
2015	[1]	Current trends in medical image registration and fusion
2016	[ii]	Evaluation of Medical Image Registration Techniques Based on Nature and Domain of the Transformation
2016	[xlvi]	INTRINSIC REGISTRATION TECHNIQUES FOR MEDICAL IMAGES
2016	[xlvii]	Deformable Registration Methods for Medical Images: A Review Based on Performance Comparison

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