Preface

Image registration, as defined by Calvin Maurer in 1993 is “the determination of a one-to-one mapping between the coordinates in one image space and those in another, such that points in the two image spaces that correspond to the same anatomical point are mapped to each other.” Image registration is an inseparable aspect of image processing in the field of computer science. It has applications in many fields, which are further explored in this work; but the one that is most vital to this discussion is medical imaging. This encompasses a wide range of image usage, but the main emphasis is still on radiological imaging.

The past 35 odd years have witnessed remarkable developments in computer vision propelled medical imaging technology. Industries and research institutes have made huge investments in inventing and developing the technology needed to acquire images from multiple imaging modalities. Medical images are being used extensively in computer vision and healthcare research resulting in a very wide range of imaging modalities now available. These different modalities distinctively help in analysing various aspects of the anatomy. For e.g. X-ray computed tomography (CT) images are sensitive to tissue density and atomic composition, and the x-ray attenuation coefficient and magnetic resonance (MR) images are related to proton density, relaxation times, flow, and other parameters etc. Each successive wave of technological improvement in image acquisition systems has helped in faster extraction of higher resolution and improved quality images and together these have been utilized for the greater clinical benefit.

The question that remains however and is crucial to the choice of topic of research in this work is that why medical image registration? Medical imaging is about establishing shape, structure, size, and spatial relationships of anatomical structures within the patient, together with spatial information about function and any pathology or other abnormality. Establishing the correspondence of spatial information in medical images and equivalent structures in the body is fundamental to medical image interpretation and analysis. Image registration aligns the images and so establishes correspondence between different features seen on different imaging modalities, allows monitoring of subtle changes in size or intensity over time or across a population, and establishes correspondence between images and physical space in image guided interventions. Registration of an atlas or computer model aids in the delineation of anatomical and pathological structures in medical images and is an important precursor to detailed analysis. It is now common for patients to be imaged multiple times, either by repeated imaging with a single modality, or by imaging with different modalities. It is also common for patients to be imaged dynamically, that is, to have sequences of images acquired, often at many frames per second. These imaging procedures generally require compensation for any changes in subject position in the course of acquisition process. The ever increasing amount of image data acquired makes it more and more desirable to relate one image to another to assist in extracting relevant clinical information. Image registration can help in this task: inter-modality registration enables the combination of complementary information from different modalities, and intra-modality registration enables accurate comparisons between images from the same modality.

As is a common characteristic with medical images, independent of the used imaging device, images of internal organs more than often suffer from some typical imperfections, as the images are generated in a passive form, pixel intensities of this images derive from volume averaging, resulting in features such as diverse and assorted intensities, low resolution and lower signal to noise ratio (SNR). The direct effect of this acute imaging shortfall is that quite often the boundaries of internal organs are not closed, as some parts are not visible, and therefore look disconnected. Very few works have analyzed the lung movement using CT images. Researchers have tried to quantitatively assess the diaphragmatic motion using radio imaging from displacement area and the total diaphragmatic movement in a respiratory cycle. The movement of the lungs and its variation in time has been of special interest and approaches to obtain this knowledge are a major objective in this work.

It has been proven that breathing process is not a 100% robust process and it is now widely believed and accepted by researchers that it would be beneficial to use prior knowledge of respiratory organ motion and its variability in a subject at different circumstances or between different subjects over time to improve upon existing radiotherapy planning and treatment delivery methods. Respiratory motion modelling has become a dire necessity in various applications of medical imaging (e.g., radiation therapy of lung cancer). The modelling approaches currently in employment are adapted for intra-patient registration of image data representing the individual patient’s anatomy at different breathing phases. Three different approaches have been proposed for thoracic ct image registration and respiration modelling; both intra and inter-subject scenarios have been explored. First two propositions employ a feature point based approach while the third uses strain energy minimization for image pair registration. All three methods are less complex, more time/space efficient and quite accurate than the existing methodologies, which has been the motive of proposing such methods. The proposed approaches have been described in detail in coming sections.

In chapter 1, a brief introduction of the topic starting with background information has been presented where a basic definition of image registration is discussed along with its four basic applications depending on the circumstances of image acquisition; also, in this heading the concept of source and target images, forward transforms and transformation in physical coordinates and their image space mappings are discussed, these are followed by the motivation and objectives of the thesis. As a part of the motivation problems generally faced by researchers, scholars and clinicians while working on deformable image registrations have been detailed, the kind of problem would depend on their profession, but problems nonetheless. Results and conclusions from recently reported and published works in the area were used along with authors' own experiences while starting to work on the said topic. Objectives set to be achieved through this work have been listed and explained in detail. A detailed list of contributions this thesis provides in the field of deformable image registration has been presented. The proposed methodologies with their pros and cons along with small details of respective literature surveys have been explained. Finally, this chapter concludes with a brief summary of chapter wise thesis organization.

Chapter 2 brings rudimentary concepts and theoretical background behind the topic of image registration in the start and later on deformable image registration specifically. Starting with a basic introduction, it explains morphological classification of images based on subject of which the images are and the relevance of this information in forthcoming proposed works. Inspired by the morphological properties of images, a survey of deformable image registration methods based on geometric image deformation models has been presented. Small preludes of registration methodologies proposed in the thesis have been furnished.

Feature detectors/description methods used in the thesis are explained with proper justification for their use. Then the image database used in the proposed methods is described, database dimensions, its acquisition details, ethical issues that come along with medical image acquisition etc. Lastly, accuracy/similarity metrics employed to assess the proposed registration methodologies are defined and explained using existing formulas.

Chapter 3 presents a 'moving least squares' based approach for deformable image registration of thoracic ct images using common landmark point sets. The common landmark point cloud between a pair of images is determined using a feature detector/descriptor which returns the common feature keypoint sets between images along with their attributes. In the respective images, these keypoints are distinct and have only a double in the paired image. A point-surface generation method is used which transforms one image using its key-points such that it gets aligned with the other image; and that's how registration between this image pair is achieved. It starts with a small introduction to the topic, followed by a background study, preparation for and description of the implementation of the methodology. This is followed by results and discussion and finally conclusion.

Chapter 4 brings forth a point correspondence path tracing and deformity estimation methodology for registration of thoracic ct image sequences from full inhale to full exhale positions. In this method, a common landmark point set between the frames of an image sequence is obtained using a feature detector/descriptor procedure. One of the frames of the sequence is predetermined as the reference frame. Remaining frames are transformed and registered with respect to the reference frame using the common feature keypoint obtained earlier.

The changing physical locations of the common keypoints make an impression as if that same point cloud is travelling through the image frames leaving behind a trail. These trails have been assessed to estimated the total displacement of the common point set and hence the effective displacement in the image deformation. It starts with a small introduction to the topic, followed by a background study, preparation for and description of the implementation of the methodology. This is followed by results and discussion and finally conclusion.

In chapter 5 an automatic deformable thoracic ct image sequence registration using strain energy minimization has been coined. Images being worked upon in this work belong to the family of elastic images. A parallel has been drawn between the image morphology and mechanics of elastic objects. Transformations in elastic images have been modelled after an elastic object under strain. An image pair has been considered as an isolated system on its own. The strain energy of this system is considered to be zero that is the system is considered to be at a stable configuration only if the image pair is registered with respect to each other. The strain energy of the system is minimized in an iterative procedure until their intensity difference comes down to zero (or a difference of third decimal place). It starts with a small introduction to the topic, followed by a background study, preparation for and description of the implementation of the methodology. This is followed by results and discussion and finally conclusion.

Chapter 6 is about conclusions of the thesis and summaries of the main findings of this work. This chapter also proposes some possible future perspectives of the research work conducted so far.

Novel approaches for thoracic ct image registration and determination of respiratory motion models in inter and intra-patient scenarios have been proposed.

These methods will help in an image registration procedure for not just thoracic ct images but all varieties of medical images in multiple modalities, in the establishment of a mean respiration motion model upon which the respiration motion variability of different subjects would come to a common platform for comparative research and medical analysis. The proposed methods would enrich the field of computer vision and would help in modifying existing methods to gain better results with advancing techniques.