UNIVERSITI PUTRA MALAYSIA

COMPUTED TOMOGRAPHY AND ECHOCARDIOGRAPHY IMAGE FUSION TECHNIQUE FOR CARDIAC IMAGES

SAMANEH MAZAHERI KALAHROODI

FSKTM 2016 45

COMPUTED TOMOGRAPHY AND ECHOCARDIOGRAPHY IMAGE FUSION TECHNIQUE FOR CARDIAC IMAGES

By

SAMANEH MAZAHERI KALAHROODI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

September 2016

DEDICATIONS

To my lovely husband, Rohollah, who has been proud and supportive of my work and who has shared the many uncertainties, challenges and sacrifices for completing this dissertation.

To my father, Reza, who has been my role-model for hard work, persistence and personal sacrifices, and who instilled in me the inspiration to set high goals and the confidence to achieve them;

To my mother, Zahra, for her endless love, sacrifices, prayers, supports and advices;

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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September 2016

Chairperson : Puteri Suhaiza Binti Sulaiman, PhD
Faculty : Computer Science and Information Technology

Ultrasound is used in minimally invasive cardiac procedures widely, because of its convenience and noninvasive nature. However, the low quality of ultrasound images usually limits their usefulness as a tool to guide cardiac procedures; it is often complicated to relate images to their anatomical context in the heart.

For improving the interpretability of ultrasound images, where keeping ultrasound as a flexible real time imaging and functional modality, there is a need for some registration techniques that integrate them with their correspond context in high quality pre-operative models, such as Computed Tomography images or Magnetic Resonance Imaging.

In this study, a fusion system which integrates the knowledge of segmentation and intensity into registration is presented in Computed Tomography and Echocardiography images of heart. The goal of this thesis is integrating detected features, segmentation result information, and intensity information from two mentioned images, into a non-rigid registration framework, and achieve a high quality spatial mapping.

The fusion system is developed as following:

First, multiple Echocardiography images are compounded to get a better quality image with wider field of view. A fusion method is presented which particularly intends to increase the segment-ability of echocardiography features such as ventricle contours and improving their contrast. The presented method is also capable of enhancing the contrast, decreasing the impact of echo artifacts, expanding the field of view and improving the signal to noise ratio.

Then, a segmentation approach based on a constrained Level set method is developed to identify the feature from Echocardiography images. It is a new geometrically level Set algorithm for the segmentation of the endocardial contours in echocardiographic images in presence of intensity non-uniformity. It will present an accurate and robust segmentation technique, which its results are going to use as input for fusion system in the following.

In last stage, non-rigid registration is applied using segmentation result information plus intensity information from two images and a consistent transformation to match these features together is calculated.

The proposed fusion system can use for medical interventions, for better physiological understanding, effective image guidance surgery, treatment, monitoring and diagnostic purposes, through finding spatial mapping between two images, to observe the changes of anatomical structure and to merge the information from multiple modalities.

As it will be discussed in detail in the thesis, for input image, the proposed technique is unable in accurate segmentation in many instances at end diastole (87.3%) and over half the time at end-systole (61.7%). However, for fused images, it is unable to detect accurate segmentation 24.6% of times at end diastole, whilst there was just one failing at end systole (3.1%). It means fusion results in enhanced image quality consequently leads to effective ventricles segmentation.

For evaluation, beside uncertainty estimation and visually evaluation by experts, quantitative and qualitative evaluations are conducted. For measuring the accuracy quantitatively, target registration error (TRE) is calculated before and after the registration, then a comparison is made. Also, different performance metrics are implemented to examine the performance of the proposed fusion system.

For further studies, the combined navigation system can be designed for real-time surgery guidance. Furthermore, integrating virtual models and echocardiographic images will provide a potential means for giving image-guidance for processes which include both functional and anatomical imaging.

Another direction for further study will be doing the registration for whole cardiac cycle: applying temporal synchronization between CT and echocardiography which is achieved by using ECG signals. Visualization of the result can be investigated further, as well.

Abstract tesis yang dikemukakan oleh Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KEFUNGSIAN HIBRID DAN SISTEM GABUNGAN IMEJ MORFOLOGI UNTUK IMEJ JANTUNG

Oleh

SAMANEH MAZAHERI KALAHROODI

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Ultrabunyi digunakan dalam prosedur jantung invasif minimal secara meluas kerana cirinya yang mudah dan tidak invasif. Walau bagaimanapun, kualiti rendah imej ultrabunyi biasanya menghadkan penggunaan mereka sebagai alat panduan untuk prosedur jantung; kebiasaannya proses untuk mengaitkan imej dengan konteks anatomi jantung juga adalah rumit.

Untuk meningkatkan kebolehtafsiran imej ultrabunyi, mengekalkan ultrabunyi sebagai pengimejan masa nyata yang fleksibel dan kefungsian modaliti, beberapa teknik pendaftaran diperlukan. Teknik ini mengintegrasikan konteks sepadan dalam model pra pembedahan berkualiti tinggi seperti imej tomografi berkomputer atau pengimejan reasonans magnetik

Dalam kajian ini, sistem gabungan yang mengintegrasikan pengetahuan segmentasi dan intensiti ke dalam pendaftaran dibentangkan dalam imej tomografi berkomputer dan imej ekokardiografi jantung. Matlamat tesis ini adalah untuk mengintegrasikan ciri yang dikesan, maklumat keputusan segmentasi, dan maklumat intensiti daripada dua imej tersebut kedalam rangka kerja pendaftaran yang tidak tegar dan mencapai pemetaan ruang yang berkualiti tinggi.

Sistem gabungan telah dibangunkan seperti berikut:

Pertama, beberapa imej ekokardiografi dikompaun untuk mendapatkan kualiti imej yang lebih baik dengan pandangan medan yang lebih luas. Satu kaedah gabungan telah dicadangkan dengan menambah segmen-keupayaan ciri ekokardiografi seperti kontur ventrikel dan meningkatkan kontras imej tersebut. Kaedah ini juga mampu meningkatkan kontras, mengurangkan kesan artifak gema, memperluaskan medan pandangan dan meningkatkan isyarat kepada nisbah bunyi.

Kemudian, pendekatan segmentasi berdasarkan kaedah Level Set dibangunkan untuk mengenal pasti ciri dari imej ekokardiografi. Ia adalah set algoritma tahap geometri yang baru untuk segmentasi kontur endokardial didalam imej ekokardiografi dengan kehadiran intensiti ketidak- keseragaman. Ia akan membentangkan teknik segmentasi yang tepat dan teguh, dimana keputusannya akan digunakan sebagai input untuk sistem gabungan yang berikut.

Pada fasa yang terakhir, pendaftaran tidak tegar telah diaplikasikan dengan menggunakan maklumat keputusan segmentasi serta maklumat intensiti daripada dua imej dan transformasi konsisten untuk memadankan ciri-ciri ini juga dikira.

Sistem gabungan yang dicadangkan boleh digunakan untuk intervensi perubatan, untuk pemahaman fisiologi yang lebih berkesan, imej panduan pembedahan yang efektif, rawatan, pemantauan dan tujuan diagnostik, melalui penemuan pemetaan ruang antara dua imej, untuk melihat perubahan struktur anatomi dan untuk menggabungkan maklumat dari pelbagai modaliti.

Seperti yang akan dibincangkan secara terperinci dalam tesis, untuk input imej, teknik yang dicadangkan tidak dapat disegmentasi secara tepat dalam banyak keadaan seperti diakhir diastole (87.3%) dan lebih separuh masa diakhir systole (61.7%). Walau bagaimanapun, untuk imej yang digabungkan, ia tidak dapat mengesan ketepatan segmentasi 24.6% daripada masa diakhir diastole, manakala hanya satu gagal diakhir systole (3.1%). Ini bermakna hasil gabungan dalam kualiti imej yang dipertingkatkan seterusnya akan membawa kepada segmentasi ventrikel yang berkesan.

Untuk penilaian, di samping ketidakpastian anggaran dan penilaian secara visual oleh pakar-pakar, penilaian kuantitatif dan kualitatif telah dijalankan. Untuk mengukur ketepatan secara kuantitatif, kesilapan pendaftaran sasaran (TRE) dikira sebelum dan selepas pendaftaran sebelum perbandingan dibuat. Selain itu, metrik prestasi yang berlainan juga dijalankan untuk memeriksa prestasi sistem gabungan yang dicadangkan.

Untuk kajian seterusnya, sistem navigasi yang digabungkan boleh direka untuk panduan pembedahan masa nyata. Tambahan pula, mengintegrasikan model maya dan imej ekokardiografi akan menyediakan panduan imej yang berpotensi yang melibatkan kedua-dua pengimejan fungsi dan anatomi.

Selain itu kajian selanjutnya akan melibatkan pendaftaran untuk keseluruhan kitaran jantung: mengaplikasikan penyelarasan temporal diantara CT dan ekokardiografi yang dicapai dengan menggunakan isyarat ECG. Hasilnya, keputusan visualisasi juga boleh diselidiki.

ACKNOWLEDGEMENTS

I would like to thank all the people without who this thesis would not have been possible. First to my supervisor, Dr Puteri Suhaiza Binti Sulaiman for providing support and guidance for my research along the way; also other members of committee who took their valuable time to offer advice, particularly Prof. Rahmita Wirza, Prof. Mohd Zamrin and Dr.Fatima Khalid.

Finally, and most importantly, I would like to thank my parents, and my wonderful husband for their support and unconditional love.

Samaneh Mazaheri
September 2016

I certify that a Thesis Examination Committee has met on 26 September 2016 to conduct the final examination of Samaneh Mazaherikalahroodi on her thesis entitled "Computed Tomography and Echocardiography Image Fusion Technique for Cardiac Images" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date:

Declaration by graduate student

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- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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2D	Two Dimensional
3D	Three Dimensional
ATV	Anterior Tricuspid Valve
CRT	Cardiac Resynchronization Therapy
CAD	Computer Aided Design
CTA	Computed Tomography Angiography
CT	Computed Tomography
CVD	Cardiovascular Diseases
CC	Correlation Coefficient
CS	Coronary Sinus
D	Dice coefficient
DICOM	Digital Imaging and Communications
DWT	Discrete Wavelet Transform
DSI	Dice Similarity Index
GVF	Gradient Vector Flow
GCL	Geometrically Constrained Level Set
GT	Ground Truth
GS	Gold Standard
HD	Hausdorff Distance
HU	Hounsfield Units
ICP	Iterative Closest point Algorithm
IQI	Image Quality Index
IOD	Inter-Observer Distance
IGS	Image Guided Surgery
ECG	Electrocardiogram Signals
ICE	Intra-cardiac Echocardiography
US	Ultrasound
Echo	Echocardiography
MAD	Mean Absolute Distance
MR	Magnetic Resonance
MRA	Magnetic Resonance Angiography
MRI	Magnetic Resonance Imaging
MI	Mutual Information

MASS	Mitral Annular Septal Site
MV	Mitral Valve
NCC	Normalized Cross Correlation
OT	Operating Theatre
OCE	Over-all Cross Entropy
PB	Powell-Brent Search Strategy
PCA	Principal Component Analysis
PET	Positron Emission Tomography
PDF	Probability Density Function
PTI	Points to Image
R3	Real Coordinate Space with Three Dimension
SNR	Signal-to-Noise Ratio
SSD	Sum of Squared Difference
RMSE	Root Mean Square Error
ROI	Region of Interest
SD	Standard Deviation
SPECT	Single Positron Emission Tomography
STV	Septal Tricuspid Valve
TEE	Trans-Esophageal Echocardiography
TTE	Transthoracic Echocardiography
TRE	Target Registration Error
VTK	Visual Tool Kit

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Heart is the most energetic organ in the body. Beating about every second, it continuously supplies the body with vital oxygen carrying blood. Heart disease is the leading cause of death in modern countries (Kasper D. et al., 2008, Fuster V. et al., 2007, Mani V. et al., 2013). The mortality rate of CVD (Cardiovascular Disease) is estimated to be 17 million in 2005 and thus is ranked as the top killer worldwide (Mani V. et al., 2013, Centers for Disease Control and Prevention).

According to the AHA (American Heart Association), CVD is the cause of 10% of days of lost productivity in low- and middle-income countries, and 18% of days of lost productivity in high income countries. CVD morbidity rates are estimated to rise from around 47 million days globally in 1990 to 82 million days in 2020 (Centers for Disease Control and Prevention, Centers for Medicare and Medicaid Services, Rettig R. et al., 1994).

Analysis of the cardiac function using imaging instruments has shown to be effective in reducing the mortality and morbidity of CVD. Myocardial motion analysis is time consuming and suffers from inter and intra-observer variability. Computerized analysis can help clinicians to interpret the medical conditions objectively (Kasper D. et al., 2008, Webb A. et al., 2003, Hedrick W. et al., 2004, Catherine O. et al., 2009).

Cardiac image processing techniques, mainly categorized as segmentation and registration, have been used widely to assess the functionality of the heart (Sutton D. et al., 2002, Fred D. et al., 2005, Young Y. et al., 2005, Santana C. et al., 2004, Faber T. et al., 1999). Cardiac image segmentation provides high quality structural information of the heart while registration techniques calculate the local functional analysis, which are helpful in diagnosis and planning of treatment of patients. Modeling of the cardiac shape, motion and physical structure have played a major role in the development of the image analysis algorithms.

1.1.1 Medical Image Registration

During the past decade, image registration has become an essential tool for medical treatment in clinics, by finding the spatial mapping between two images, observing the changes of anatomical structure and merging the information from different modalities (Jingfeng H. et al., 2009). On the other hand, the matching of appropriately selected features is becoming more and more important for further improvement of registration methods.

In this thesis, we are seeking the optimal way to integrate the knowledge of two cardiac modalities from segmentation and intensity values of the images, into image registration framework. In other words, we are going to answer this question that how to utilize segmentation information of cardiac features such as any characteristics of ventricles, into a non-rigid registration framework along with intensity values; therefore, a high quality spatial mapping can be achieved.

In this research, an approach based on the segmentation result information and intensity value information of common features for two different cardiac modalities which are widely used in cardiac fields is developed and a consistent set of transformations to match them is estimated.

The presented thesis deals with a specific problem of medical image analysis in cardiac filed, namely image registration, also known as image matching. Image registration is the process of finding an optimal geometric transformation, so that two given images are correctly aligned to each other. The concrete form of "optimal geometric transformation" varies a lot in different situations, but all these transformations define a point-to-point correspondence between the image pair.

Image registration has plenty of applications in the field of medical image processing. For instance, the typical requirements from physicians are to compare images acquired at different times, from different perspectives, of different patients or by different imaging modalities. It is a fundamental and crucial processing step to determine the correspondence between the given images, and then performing fusion. In the following, the effect of registration is illustrated in Figure 1.1.

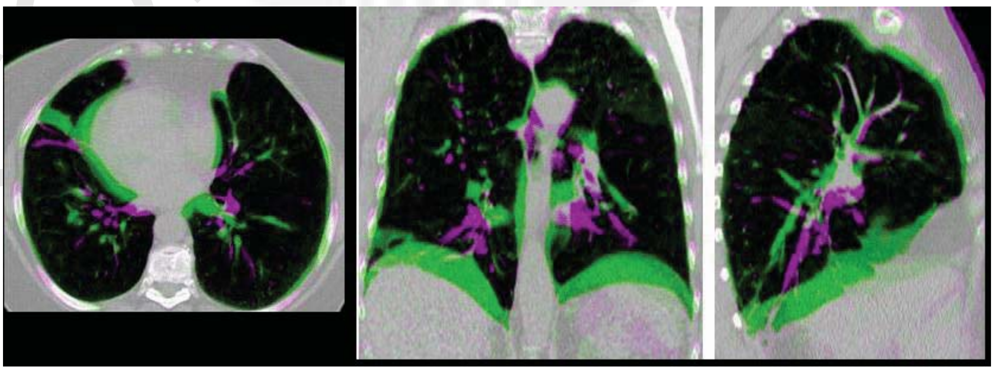

Figure 1.1: Registration example of lung CT scans. An overlay of inhale (green) and exhale (magenta) phase.

Figure 1.2 shows the X-ray Computed Tomography (CT) and echocardiography (cardiac ultrasound) images of the same patient. These two modalities visualize different information: CT provides high-resolution images of density distribution from different tissues, which can effectively shows the anatomy of the patient and structures and contours; while echocardiography modality shows chamber and blood cavity and in other words, functional and physiological activities of organs.

The merge between these two modalities, e.g. CT as a fixed image and echocardiography as a moving image, is very useful for diagnose, surgery plan as well as the observation of the follow-up. The research on image registration has developed rapidly in last twenty years. A substantial part of research on medical image processing deals with image registration. This trend was proven in a recent review study of image registration (Fuster V. et al., 2007, Mani V. et al., 2013).

(a) (b)

Figure 1.2: X-ray Computed Tomography (CT) and cardiac ultrasound (Echocardiography) images of the same patient

Image registration turned out to be more difficult than researchers expected. There are still several topics in the field of registration, for which many researchers are actively investigating more satisfactory solutions. In the following, we focus on these two challenges: multi-modal registration and non-rigid registration in field of cardiac images.

1.1.2 Multi-modal Registration

In the past three decades, progress in medical imaging techniques and image processing methods has led to the fact that different imaging modalities with high resolution are available for medical treatments today. Currently, the most imaging modalities can be roughly classified into morphological and functional imaging modalities. For example, X-ray imaging, CT and Magnetic Resonance (MRI) are considered morphological imaging modalities, whereas ultrasound imaging, functional MR imaging (fMRI) and molecule imaging techniques, like Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT), are functional imaging modalities.

These imaging modalities provide complementary information and the registration of these data brings significant clinical benefits for diagnosis and surgical planning. Even though a large number of methods have been invented in the past, the registration of different imaging modalities is still far away from being perfect. The fundamental reason is that the individual imaging modality cannot provide enough correlated information and sufficient contrast for a reliable registration. Simple intensity based similarity measures, typically computing of statistical dependencies, cannot reflect the correspondence of the same underlying anatomical structures in different modalities. The lack of knowledge of image contents is now more and more likely to be a bottleneck for further improvement of registration algorithms.

1.1.3 Non-rigid Registration

Non-rigid registration is known by many different names, such as "non-linear", "elastic", "non-parametric" or "deformable" registration, as well. Non-rigid registration is a critical issue in many clinical applications. For instance, in computer assisted neurosurgery, the deformation of brain between pre- and intra-operative MRI data, referred to as the brain shift, needs to be corrected by non-rigid registration.

A drawback of most current non-rigid registration algorithms is that they model all tissue as having the same degree of rigidity. However, physicians expect that the different tissues or different organs have different degree of rigidity, e.g. bone structures or instruments should be transformed rigidly. However, most algorithms uniformly compute the deformation, regardless of the underlining tissue classes.

The second drawback is the inconsistency of the deformation field. Consistency of transformation means that if one computes the transformation from A to B and then switches the roles of A and B to compute the second transformation B from A, the two transformations should be inverse to each other. Consistent registration is not only more sound in the mathematical sense, but also very important for applications, where one is interested in determining the one-to-one correspondence of the same anatomical structures in different images, e.g. non-rigid registration for atlas construction (Rueckert D. et al., 2003, Marsland S. et al., 2003) or historical biological images (Sorzano C. et al., 2005, Carreras I. et al., 2006).

1.2 Objectives of the thesis

The research objectives are to:

1. To fuse multiple sequence of echocardiography images using proposed pixel-based method of integration PCA and DWT with high accuracy
2. To segment ventricle boundaries from echocardiography images by using proposed geometrically constrained level set technique with high accuracy

3. To register features from CT to echocardiography images based on intensity-based information and segmentation result information with high accuracy

1.3 Contributions of the thesis

The main contribution of this study is overall IFI hybrid registration scheme (Integration of Feature- and Intensity-based Registration) which is enable to register intensity information, and segmented anatomical contour features that influences the registration to produce more medically reasonable contour feature alignments (Jingfeng H. et al., 2005).

Matching of features intuitively could be a natural criterion that drives as well as evaluates the image registration algorithms. Integration of knowledge of image segmentation with intensity values information is a promising way to improve the registration method. To obtain a good quality image which gives good segmentation result, and leads to good registration outcome, another aim is considered as improving echocardiography images' quality by fusing multiple images together.

For the first contribution, a new fusion method which particularly intends to improve the contrast and increase the segment-ability of echocardiography features, such as ventricle contours is presented. In addition, it tries to expanding the field of view, decreasing impact of noise and artifacts and enhancing the signal to noise ratio of the echo images. The proposed technique weights the image information regarding an integration feature between all the overlapping images, by using a combination of Principal Component Analysis (PCA) and Discrete Wavelet Transform (DWT). For evaluation, a comparison has been done between results of some well-known techniques and the proposed method. Also, different performance metrics are implemented to examine the performance of the proposed technique. It has been concluded that the proposed pixel-based method based on the integration of PCA and DWT has the best result for improving segment-ability of cardiac ultrasound images and showed better performance in all metrics.

Image segmentation is the key to find better solution for the registration challenge outlined in the preceding sections. Generally speaking, image segmentation and image registration are two closely related problems. The goal of image segmentation is to simplify or to change the representation of an image into something that is more meaningful and easier to analyze (Shapiro L. G. et al., 2001), usually we call them "features". Image segmentation is typically used to locate objects or to find boundaries, i.e. lines, curves, among images. Whereas the task of image registration is to determine the correspondence between images. Ideally the same underlying anatomies are mapped to each other.

Since the segmentation is an important part of the proposed fusion system, finding the best segmentation techniques for two different modalities, echocardiography and

CT scans, was a challenge of this work. Several criteria are considered for the selection of algorithm in both modalities: Whether the algorithm is robust with respect to noise, whether it can maximize the degree of automation and reproducibility and whether the parameterizations need to adapt to different cardiac image data. The segmentation of contour features in echocardiography images is solved by proposing a geometrically constrained level set technique in chapter 6 (Mazaheri S. et al., 2015). The target corresponding structures in CT images are computed by a k-means clustering algorithm (Guoqiang M. et al., 2014).

For the second contribution, a geometrically constrained level set method for segmenting echocardiographic images with intensity non-uniformity presented. The proposed technique combines the information about neighboring pixels belonging to the same class, which makes it strong in separating the desired borders from the background and the rest of the image. As a result, the segmentations are found to be robust to the initialization of the level set function, making it useful for automatic applications. The experiments on real clinical images have demonstrated the effectiveness and the advantages of the proposed technique.

For the third contribution, a new hybrid approach in the framework of non-rigid registration is proposed. The algorithm was formulated to emphasize the contour feature correlation beside intensity value information. The superiority of the algorithm is that it can achieve correspondences of two images using the anatomical features information plus intensity information.

This fusion system integrates echocardiography images with their context by registering them to high quality pre-operative models based on computed tomography images. Mapping is completed using proposed transformation which is performed by a two-level registration method that first approximately aligns two images as a starting point to an automatic registration procedure. The mentioned system enhances the simplicity and precision of cardiac disease diagnosis and also help in operation planning and guidance.

1.4 Scope

Although real-time 3D echocardiography is being adapted to heart surgery (Suematsu Y. et al., 2004, Suematsu Y. et al., 2005), it is still a new and relatively expensive procedure compared to 2D echocardiography and the limited access to the streaming 3D data makes it poorly suited to fusion with other images. Real-time 2D echocardiography imaging, such as the routinely used Trans-Esophageal Echocardiography (TEE) and Trans-Thoracic Echocardiography (TTE) systems, has relatively high spatial and temporal resolution.

1.5 Main Contribution of the thesis

Fusion is performed in three phases; first, compounding multiple echocardiography sequences (Chapter 5); then, apply segmentation on both CT scan and echocardiography images (Chapter 6); and lastly, apply the two-level hybrid registration method (Chapter 7).

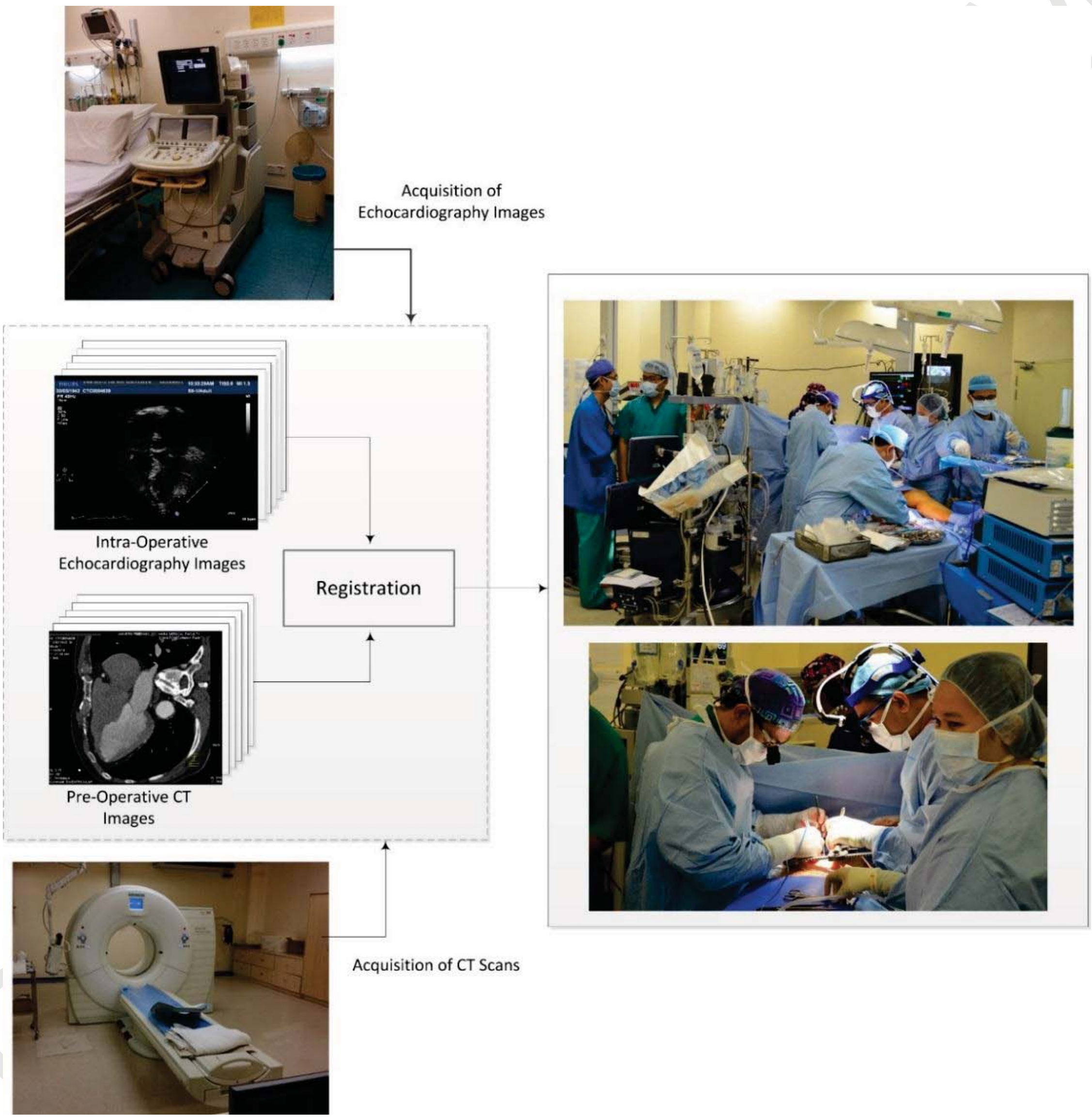

Figure 1.3: Overview of how echocardiography and CT images guidance can be integrated for surgery assist. Both images are available to the surgeon during the operation. The focus of this thesis is the dashed area of the figure, which addresses the problem of CT to echocardiography registration.

The registration method first approximately aligns two images by help of segmentation result information, as a starting point to an automatic registration procedure (see Figure 1.3). The proposed registration method is applied twice; one in systolic phase on both images, CT and echocardiography, and another one in diastolic phase on both images, as well. In evaluation, attempts towards improving registration accuracy by help of measuring uncertainty estimation have been performed. Also, registration accuracy is measured by calculating the Target Registration Error (TRE).

1.6 Organization of Thesis

Chapter 1: This chapter gives the motivation as well as challenges of image registration in the field of medical image analysis which is an obligated process operation for clinic routines. In addition, non-rigid image registration and multi-modal image registration challenges related to cardiac data are discussed. Objectives and contributions of the thesis are described, as well.

Chapter 2: This chapter gives a literature review on multiple echocardiography fusion, endocardial segmentation, multi-modal registration for cardiac images and also for other organs, as well as describing the current challenges in each field.
Moreover, it gives a general introduction of heart structure as well as registration methods. Knowledge of an image properties can be used to improve the performance of a registration algorithm. In addition, current systems and modalities which are used widely in cardiac field are discussed. Then, a concentrated elaboration of properties for both modalities, echocardiography and CT images is presented in two parts. First, a brief description of image formation is presented, then in following, properties of the imaging modality which are important in proposed hybrid image registration technique are discussed.

Chapter 3: Chapter 3 presents the research methodology of the proposed fusion system generally, which is used to accomplish the research project. It discusses on research steps taken to conduct this study from the problem statement to performance evaluation. It will quickly review what is going to be discussed in every contribution in the following chapters, Chapters 4 to 6.

Chapter 4: Chapter 4 presents a fusion method which particularly intends to increase the segment-ability of echocardiography features such as ventricle contours and improving their contrast. The presented method is also capable of enhancing the contrast, decreasing the impact of echo artifacts, expanding the field of view and improving the signal to noise ratio. At first, it provides a brief background and reviews some related image fusion concepts; then outlines proposed method for multiple echocardiography fusion, and explains the proposed algorithm in detail. Lastly, experimental results and evaluation of the proposed algorithm and discussion on results is presented.

Chapter 5: In this chapter, a new geometrically level Set algorithm for the segmentation of the endocardial contours in echocardiographic images in presence of intensity non-uniformity is proposed. This chapter presents an accurate and robust segmentation technique, which its results are going to use as input for fusion system that will be investigated in Chapter 6.

This chapter begins with covering the concept of active contour. Then it presents an overview of the proposed segmentation model, formulations and conditions which are used, followed by explaining the energy function that should be minimized. Next, it discusses segmentation results which obtained from real clinical echocardiography data and finally, it will be concluded with final remarks and future research areas.

Chapter 6: A novel hybrid registration technique, which integrates the concepts of feature- and intensity-based approaches is proposed in this chapter (IFI registration: Integration of Feature- and Intensity-based approaches). In the proposed IFI registration algorithm, the segmentation result information and intensity value information of both images are utilized to apply the registration. The experiments prove that the proposed approach achieves a better match of fine structures respect to cardiac images. In this chapter, at first the registration algorithm is described in detail. Then, the numerical implementation of the proposed registration, experimental results and discussion for the clinical dataset is explained.

Chapter 7: In this chapter, through a brief summary of the thesis and the whole fusion system has been shown that the proposed system will enhance the simplicity and precision of cardiac disease diagnosis and also help in operation planning and guidance. In addition, discussion of future research directions is also presented.

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