UNIVERSITI PUTRA MALAYSIA

SPECULAR REFLECTION REMOVAL AND BLOODLESS VESSEL SEGMENTATION FOR 3-D HEART MODEL RECONSTRUCTION FROM SINGLE VIEW IMAGES

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

February 2015

DEDICATIONS

This thesis is dedicated to my mother who taught me to use what I have learned to help people, it is also dedicated to my father who taught me that if I make a wish and work hard, it would come true.
To whom taught me to be brave and patient.
To my brothers, my wife, and my wonderful Kids.
To my supervisor and entire committee.
Finally, To All whom I love.

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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Chairperson: Associate Prof. Rahmita Wirza O.K. Rahmat, PhD
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Three Dimensional (3D) human heart model is attracting attention for its role in medical images for education and clinical purposes. Analysing 2D images to obtain meaningful information requires a certain level of expertise. Moreover, it is time consuming and requires special devices to obtain aforementioned images. In contrary, a 3D model conveys much more information. 3D human heart model reconstruction from medical imaging devices requires several input images, while reconstruction from a single view image is challenging due to the colour property of the heart image, light reflections, and its featureless surface.

Lights and illumination condition of the operating room cause specular reflections on the wet heart surface that result in noises forming of the reconstruction process. Image-based technique is used for the proposed human heart surface reconstruction. It is important the reflection is eliminated to allow for proper 3D reconstruction and avoid imperfect final output. Specular reflections detection and correction process examine the surface properties. This was implemented as a first step to detect reflections using the standard deviation of RGB colour channel and the maximum value of blue channel to establish colour, devoid of specularities. The result shows the accurate and efficient performance of the specularities removing process with 88.7% similarity with the ground truth.

Realistic 3D heart model reconstruction was developed based on extraction of pixel information from digital images to allow novice surgeons to reduce the time for cardiac surgery training and enhancing their perception of the Operating Theatre (OT). Cardiac medical imaging devices such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT) images, or Echocardiography provide cardiac information. However, these images from medical modalities are not adequate, to precisely simulate the real environment and to be used in the training simulator for cardiac surgery. The propose method exploits and develops techniques based on analysing real coloured images taken during cardiac surgery in order to obtain meaningful information of the heart anatomical structures.

Another issue is the different human heart surface vessels. The most important vessel region is the bloodless, lack of blood, vessels. Surgeon faces some difficulties in locating the bloodless vessel region during surgery. The thesis suggests a technique of identifying the vessels' Region of Interest (ROI) to avoid surgical injuries by examining an enhanced input image. The proposed method locates vessels' ROI by using Decorrelation Stretch technique. This Decorrelation Stretch can clearly enhance the heart's surface image. Through this enhancement, the surgeon become enables effectively identifying the vessels ROI to perform the surgery from textured and coloured surface images. In addition, after enhancement and segmentation of the vessels ROI, a 3D reconstruction of this ROI takes place and then visualize it over the 3D heart model.

Experiments for each phase in the research framework were qualitatively and quantitatively evaluated. Two hundred and thirteen real human heart images are the dataset collected during cardiac surgery using a digital camera. The experimental results of the proposed methods were compared with manual hand-labelling ground truth data. The cost reduction of false positive and false negative of specular detection and correction processes of the proposed method was less than 24% compared to other methods. In addition, the efficient results of Root Mean Square Error (RMSE) to measure the correctness of the z-axis values to reconstruction of the 3D model accurately compared to other method. Finally, the 94.42% accuracy rate of the proposed vessels segmentation method using RGB colour space achieved is comparable to other colour spaces. Experimental results show that there is significant efficiency and robustness compared to existing state of the art methods.

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

PENYINGKIRAN REFLEKSI SPEKULAR DAN PENSEGMENAN PEMBULUH DARAH TANPA DARAH BAGI PEMBINAAN SEMULA 3-D MODEL JANTUNG DARIPADA IMEJ PANDANGAN TUNGGAL

Oleh

AQEEL ABDULLAH AHMED AL-SURMI

Februari 2015

Pengerusi: Profesor Madya Rahmita Wirza O.K. Rahmat, PhD
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Model jantung manusia tiga dimensi (3D) menarik perhatian kerana peranannya dalam imej perubatan untuk tujuan pendidikan dan klinikal. Proses menganalisa imej 2D untuk mendapatkan maklumat yang signifikan memerlukan tahap kepakaran yang tertentu. Selain itu, proses untuk mendapatkan imej tersebut turut memakan masa dan memerlukan alatan khas. Sebaliknya, model 3D boleh memberikan banyak maklumat. Pembinaan semula model jantung manusia 3D daripada peranti pengimejan perubatan memerlukan beberapa input imej, dan pembinaan semula daripada imej sudut pandang tunggal merupakan proses yang mencabar disebabkan oleh ciri warna imej jantung, pantulan cahaya dan permukaan tanpa sifat imej berkenaan.

Lampu dan keadaan pencahayaan di dalam dewan bedah memberikan pantulan spekular pada permukaan jantung yang lembab telah menyebabkan hingar dalam proses pembinaan semula. Teknik berasaskan imej telah dicadangkan untuk pembinaan semula permukaan jantung manusia. Oleh itu, pantulan ini perlu disingkirkan bagi membolehkan pembinaan semula model 3D yang tepat. Teknik pengesanan pantulan spekular dan pembetulan dengan mengenalpasti sumber cahaya dan ciri-ciri permukaan sebenar juga dicadangkan. Analisis statistik antara sisihan piawai bagi saluran warna RGB dan nilai maksimum saluran biru telah dijalankan untuk mewujudkan warna tanpa pantulan spekular. Hasil keputusan menunjukkan teknik ini telah mencapai prestasi ketepatan dan kecekapan iaitu 88.7% bersamaan dengan data 'ground truth'.

Pembinaan semula model jantung 3D yang realistik telah dibangunkan berdasarkan pengekstrakan maklumat daripada piksel imej digital bagi meningkatkan persepsi mereka terhadap persekitaran sebenar dan mampu mengurangkan masa untuk latihan pembedahan jantung. Peranti pengimejan perubatan jantung seperti Pengimejan Resonans Magnetik (MRI), Tomografi Berkomputer (CT), atau Ekokardiografi menyediakan maklumat mengenai jantung. Walau bagaimanapun, imej daripada peranti ini tidak mencukupi dan kurang tepat untuk diguna pakai bagi tujuan latihan pembedahan jantung melalui peranti simulasi. Kaedah yang dicadangkan adalah dengan

membangunkan teknik berasaskan analisis imej berwarna sebenar yang diambil semasa pembedahan jantung untuk mendapatkan maklumat struktur anatomi jantung yang tepat.

Selain itu, setiap pembuluh darah permukaan jantung manusia adalah berbeza dimana rantau pembuluh darah tanpa darah adalah kawasan paling penting. Pakar bedah menghadapi kesukaran dalam mengenalpasti kawasan pembuluh darah tanpa darah semasa proses pembedahan. Teknik mengenal pasti 'Region of Interest' (ROI) pembuluh darah untuk mengelakkan kecederaan semasa proses pembedahan turut diperkenalkan dengan memeriksa input imej tertingkat. Penyelesaiannya adalah mengenal pasti ROI pembuluh darah dengan menggunakan teknik regangan nyahkolerasi. Teknik ini jelas boleh meningkatkan imej permukaan jantung. Melalui peningkatan ini, pakar bedah mampu mengenalpasti ROI pembuluh darah secara efektif untuk melakukan pembedahan daripada imej bertekstur dan permukaan yang berwarna. Di samping itu, selepas peningkatan dan pensegmenan ROI pembuluh darah, pembangunan semula ROI 3D ini dilakukan dan kemudian digabungkan dengan model jantung 3D.

Eksperimen bagi setiap fasa dalam kerangka penyelidikan telah dijalankan dan dianalisa secara kualitatif dan kuantitatif. Sebanyak 213 imej jantung manusia yang sebenar telah dikumpulkan sebagai dataset diambil menggunakan kamera digital semasa sesi pembedahan jantung. Keputusan eksperimen kaedah yang dicadangkan telah dibandingkan dengan data 'ground truth' iaitu pelabelan tangan secara manual. Teknik pengesanan spekular dan proses pembetulan telah menunjukkan kos positif palsu dan negatif palsu berkurangan 24% berbanding dengan kaedah lain. Selain itu, keputusan Ralat Punca Min Kuasa Dua (RMSE) untuk mengukur ketepatan nilai-nilai paksi Z untuk pembinaan semula model 3D juga lebih efisyen berbanding dengan kaedah lain. Akhir sekali, kaedah pensegmenan pembuluh darah yang menggunakan ruang warna RGB telah mencapai kadar ketepatan 94.42% berbanding dengan penggunaan ruang warna lain. Keputusan eksperimen semua rangka kerja di atas menunjukkan kaedah ini berkesan dan tegap berbanding dengan kaedah sedia ada.

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I certify that a Thesis Examination Committee has met on 5 February 2015 to conduct the final examination of Aqeel Abdullah Ahmed Al-Surmi on his thesis entitled “Specular Reflection Removal and Bloodless Vessel Segmentation for 3-D Heart Model Reconstruction from Single View 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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Name of Member of Supervisory Committee: ______________________________

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional
CABG	Coronary Artery Bypass Graft
CSG	Constructive Solid Geometry
CT	Computed Tomography
CTA	Computed Tomography Angiography
CTC-UiTM	Clinical Training Centre Universiti Teknologi MARA
CVD	Cardiovascular Diseases
DOP	Degree of Polarization
DSFM	Deformable Shape-from-Motion
EGC	Extruded Generalized Cylinders
FN	False Negative
FP	False Positive
GC	Generalized Cylinders
GS	Greyscale
GUI	Graphical User Interface
HSI	Hue, Saturation, and Intensity
HSV	Hue, Saturation and Value
LA	Left Atrium
LV	Left Ventricle
MOH	Ministry of Health
MRA	Magnetic Resonance Angiogram
MRI	Magnetic Resonance Imaging
NURBS	Non-Uniform Rational Basis Splines
OT	Operating Theatre
PCMRI	Phase Contrast Magnetic Resonance Imaging
PET	Positron Emission Tomography
PPUKM	Pusat Perubatan Universiti Kebangsaan Malaysia
R^3	Real Coordinate Space with Three Dimension
R3DHH	Reality Three Dimensional Human Heart
RA	Right Atrium
RCSS	Ramphal Cardiac Surgery Simulator
RGB	Red, Green and Blue
RMSE	Root Mean Square Error
ROI	Region of Interest
RV	Right Ventricle
SD	Standard Deviation
SFM	Shape-from-Motion
SPECT	Single Positron Emission Tomography
SR	Specular Reflection
TN	True Negative
TP	True Positive
UKMMC	Universiti Kebangsaan Malaysia Medical Center
VB6	Visual Basic 6.0
VR	Variance
YUV	Luminance Y and Chrominance UV

CHAPTER 1

INTRODUCTION

This chapter presents a brief background about the 3D model in the computer graphics along with related concerns in medical images particularly three dimensional reality model from the human heart images. This is followed by the motivation of the research interest in a realistic 3D heart model reconstruction and vessel segmentations to identify the region of interest for surgical operation. This chapter will next give the details of the research problems, research significance, objectives, and the scope of this research. Finally, this chapter concludes with the organization of the thesis.

1.1. Background

There are increasing needs for realistic 3D models in several fields such as augmented reality, virtual environments, and especially in the medical field. Moreover, in computer graphics and computer vision fields, 3D modelling techniques remains one of the active technologies that many researchers focus on. In computer, a 2D image with depth perception is described as 3D. The 3D models give a feeling of the reality of the object in the scene.

This section presents a brief background about 3D heart model from different graphics software, tools, or imaging devices. Lighting effect on 3D modelling is also discussed. This section also highlights the need of realistic 3D heart model for cardiac surgery training. Furthermore, the techniques that have been used to acquire the human heart images for the purpose of obtaining a realistic 3D heart model are highlighted.

1.1.1. 3D Model of the Human Heart

Realistic 3D models play important roles to provide an exciting opportunity for learning the heart anatomy and aiding cardiac surgery training. Several approaches can be used to obtain a realistic heart model even by 3D computer graphics software's, 3D scanner devices, or image-based modelling algorithms. Computer-Aided Design (CAD) software is a common software's in assisting the creation of 3D model from scratch. The CAD software produces a fairly good model. Although the model can be further improved, via coloured surface, the final result is still unrealistic, costly and time consuming. On the other hand, the 3D scanner is a device used to collect object data and then project them as a 3D model. Unfortunately even with its texture, it is still unrealistic due to the scanned model is not from a real object.

Furthermore, medical imaging researchers use image based modelling approaches to model the heart. The researchers acquire several images of the human body organs to study the anatomy of the internal organs of the patients or to provide information for diagnosis. Data from such devices consists of 2D slices that are used for the reconstruction process to produce a 3D model of the organ under examination, which will convey more information about the organ and ease understanding and learning of the human internal organs by novice medical students.

In addition, the 3D model is useful for surgical training and preparation, hence surgeons will be familiar with what they will come across in the operating theatre. However, it is time consuming and several processes are required to get the final model. As well, the cost and time needed to learn and use these tools or devices. Figure 1.1 shows an unrealistic solid 3D heart model from medical imaging.

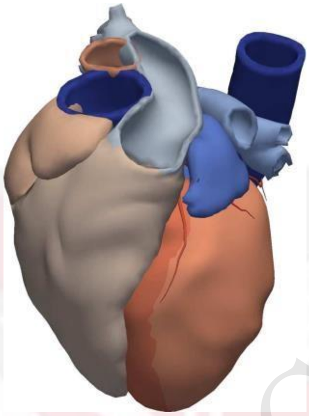


Figure 1.1: 3D surface of the heart (original image courtesy of Google biodigital human)

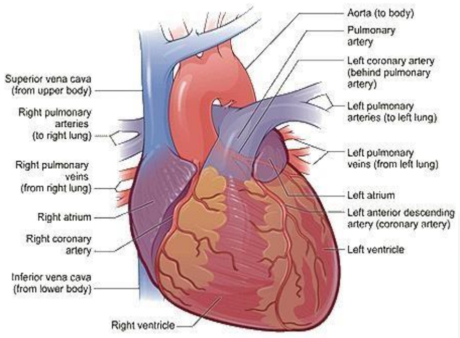
1.1.2. Lighting Effect on 3D Modelling

The presence of light is inevitable in each scene for any image processing or modelling. Once the light hits the object surface under examination, it is reflected or absorbed. The analysis and reconstruction of the object surface are made complicated by the presence of the specular reflection of light. In order to obtain meaningful information about the object from its surface, complex reflection effects such as specular must be removed, even when the lighting sources of a scene can be controlled. This is the case for photometric stereo methods, such as the image acquisition from a fixed viewpoint under multiple known lighting sources. The specularities from the wet surfaces make the reconstruction of a realistic 3D model a difficult task.

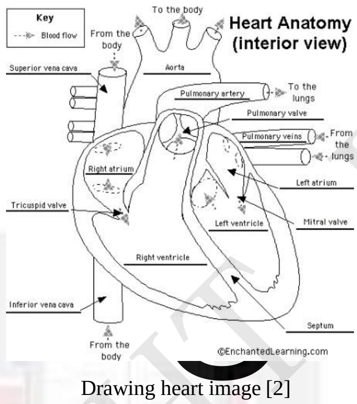
1.2. Motivation and Importance of the Research

The use of computers in various fields has been increasing dramatically over the last decade. In medical contexts, nearly all aspects of medical care have been improved by the introduction of computer-based tools. The application domain of those tools is for education or clinical purposes such as learning, training, diagnoses assistance, and planning of surgical procedures. Therefore, several techniques such as image acquisition, processing, segmentation, rendering, reconstruction, and registration are required.

Currently, traditional education and learning system totally depends on written text with conventional 2D images. These images are coloured or sketched, which do not convey enough information about the object under examination. Learning the anatomy of the human internal organs such as a human heart can be affected due to insufficient information, as shown in Figure 1.2. 3D model offers additional benefits over conventional 2D images, the benefits include ability to have in-depth visualization, perceive more information, obtain views from different perspectives, and the ability to control object size.



Coloured heart image [1]



Drawing heart image [2]

Figure 1.2: Human heart images used in traditional learning system

Meanwhile, formal courses for surgical skills or simulations have been used to assist in surgical training, but no method can replace the feel of the operating room environment itself [3]. Some video-based training applications have been developed using the concept of watch and learn. However, these applications are in 2D views showing the surgical procedures, which are not precise and do not give a real feeling about the operating environment. Researcher's need to investigate methods that convey more information and knowledge for training purposes, such as a real 3D model, which provide a better understanding instead of 2D medical images.

Realistic 3D model reconstruction of an object from images is a fundamental problem in computer vision. Design of a computer vision application that performs the same tasks as a human visual system has been a challenge to researchers for a past decades. The realistic 3D heart model reconstruction problem requires the depth estimation of the input images of the object and real texture of the model surface. In addition, surface reflections and deformation also need to be considered.

Most importantly, the realistic 3D model is vital and can be used in learning environment for the novice cardiac students as traditional learning system requires longer time to master. The ability of professional cardiac surgeons is measured through the period of their work to make a real difference, to raise the expectancy and improve life quality for thousands of patients. The Society of Thoracic Surgeons [4] reported that in the next decade 50% of the current professional surgeons in US are expected to retire, hence the need for novice surgeons to fill those positions. According to the American Board of Thoracic Surgery in the US, to become a board certified cardiothoracic surgeon required one of four different pathways [5], as illustrated in Table 1.1. Furthermore, according to the Malaysian Ministry of Health (MOH), health human resources reported that doctors profession population ratio is 1:758 from 38,718 total number of doctors in public and private health care centres [6].

Table 1.1: Pathways training to obtain cardiothoracic surgery board certification in US [5]

Pathway	Total length of training	Components	Duration of each components	Board certification
Classical	7-8 years	General surgery residency	5 years	General surgery (optional)
		Thoracic surgery fellowship	2-3 years	Thoracic surgery
Fast-track (4+3)	7 years	General surgery residency	4 years	General surgery (optional)
		Thoracic surgery fellowship	3 years	Thoracic surgery
Integrated	6 years	Integrated cardiothoracic surgery residency	6 years	Thoracic surgery
Vascular + Thoracic	7-8 years	Integrated vascular surgery residency	5 years	Vascular surgery
		Thoracic surgery fellowship	2-3 years	Thoracic surgery

Moreover, this statistic clearly states that the demand for novice surgeons is increasing. However, the long-time training of cardiac surgery will lead to delay in surgical operations while the number of the heart disease patients' is continuously increasing. These motivated to develop a realistic human heart 3D model, which can reduce the training and learning time of cardiac surgery for novice surgeons.

1.3. Research Problem

Medical applications make extensive use of high quality 3D models. Several 3D models are manually created, with the help of the available modelling tools. However, it is costly and time consuming to learn how to use these tools [7]. An interesting and easier alternative is modelling from images. Modelling of medical images to produce a 3D model of human internal organs is done via image sequences acquired from medical imaging devices.

The vast development of imaging acquisition devices in recent years led to an increase of the dimensionality of these images to 3D and Four Dimensional (4D) based on a scan of multiple 2D slices in one axial direction. To generate a more intuitive representation of the obtained images, a 3D model is reconstructed from segmented 2D slices [8]. The 3D model is useful for learning the internal human organ anatomy as well as training for cardiac surgery. In addition, a 3D model helps reduce learning time. The input images are acquired as a stack of parallel slices and collectively represent a 3D model of the heart. Then a several analysis and processing are required to these slices such as, camera calibration, noise removal, filtering, features extraction and matching, and the depth determination. Finally, the model reconstruction were done. However, a reconstructed model of medical imaging such as Computed Tomography Angiography (CTA) requires several processes that are costly and time consuming in terms of data acquisition and data storage, and has the potential to produce unrealistic 3D solid model.

A realistic 3D model is an important issue for education or clinical purposes since it shows the reality of the human heart that is helping the novice medical student to be familiar with what they will face during real surgery. Realistic 3D model reconstruction is one of the important challenging issues for most researchers in the field of computer graphics and computer vision [9]. In addition, further issues occur during the reconstruction process, such as the highlight reflections from the wet surface of the heart. These reflections deform the reality of the final 3D model [10] and need to be removed before obtaining the final 3D model.

The necessity of realistic 3D model in the learning environment of cardiac surgery comes with various challenges such as difficulties to create or obtain a realistic heart model for each patient, costly, time consuming and insufficient professional surgeons [11, 12]. These lead the researchers to produce ways to solving these issues, especially to produce a realistic 3D model of the human heart to help in cardiac surgery training. This is done through reducing the long-time curve of cardiac surgery training for novice surgeons. Traditional cardiac surgery performed on a plastic model or corpse bodies do not convey much more information about the real heart.

Furthermore, during cardiac surgery, the professional surgeon can involve two or three novice surgeons to learn and assist during surgery, one of them can assist the professional surgeon directly [13] and the rest can only learn by watching, as shown in Figure 1.3.

Figure 1.3: Novice surgeon watching expert during cardiac surgery. Image taken in UKMMC

Another issue that occurs during cardiac surgery is that the surgeons need to locate the vessels' ROI to perform the cardiac surgery and avoid surgical injuries [14]. Naturally, the vessels lie over the heart surface. In some cases, vessels ROI might be covered by the heart surface fats, which needs time to locate. Up to date, the professional surgeons depend on their own expertise to deal with this situation. The literature review demonstrated that identification of the vessels ROI on the real heart surface image is an unsolved problem.

Meanwhile, detection and correction of the specular reflections that occur on the input heart surface image caused by the lighting sources of the OT are important. Providing a realistic 3D heart model from a single image, as well as achieving better identification of the vessels ROI by enhancing the input data can help surgeons during the cardiac surgery to locate the vessels where to perform the surgery.

1.4. Research Significance

The significance of the algorithms in computer vision is on automatic and realistic 3D model reconstruction of the object with minimum or no user interaction. Such an algorithm is capable of realistic reconstruction and it has immense applications in modelling education, industry, medical, virtual and augmented reality.

The significance of this research is to obtain a realistic 3D heart model built using only a single colour image. 3D model built using multiple images is unrealistic, needs more effort, costly and time consuming. In addition, multiple images 3D model results in a 3D solid model without texture, as shown in Figure 1.4. The unrealistic 3D model does not give a real impact on the human heart for training of the cardiac surgery. Therefore, the significance of this research is to produce a realistic 3D model of the human heart that later helps the novice surgeons to practice their skills without touching a real patient in an augmented reality environment. The realistic 3D model can potentially reduce the mistakes and the complicated issues that occur during the real surgery. Furthermore, it helps the surgeons to locate the vessels ROI where to perform the surgery.

(a) **(b)** **(c)**

Figure 1.4: 3D modelling procedure for the human heart using images from medical imaging device. (a) A human heart slices images. (b) Segmented border of the heart slices. (c) Reconstructed 3D model [15]

The realistic 3D human heart model will help to reduce the cardiac surgery training time, thus will lead to increase in number of professional heart surgeons, accordingly contributing to decrease the death rate of the heart disease patients. Moreover, the novice surgeons still follow the one-to-one, traditional methods of training, which training is conducted with close supervision of novice by an experienced surgeon.

1.5. Research Objectives

The main objective of this research is to reconstruct a realistic 3D model of the human heart. This model can be used in a cardiac surgery learning exercise for novice medical students. The training using realistic 3D model adds a new perspective to the traditional approach to review heart anatomy to perform the cardiac surgery. Vessel ROI has to be identified in relation to some features. In addition, surgeons must decide which vessel to perform the surgery, keeping in mind the functional consequences of these actions. Finally, it provides an opportunity to integrate training concepts to practice surgery before performing a real procedure on a patient.

Hence, to achieve those objectives, the following sub-objectives will be considered:

1. To propose new algorithms for specular reflection detection and correction from human heart single view image datasets based on the L-inverse shape that is accurate and fast specularities detection and correction.

2. To propose a realistic 3D human heart model reconstructed from a single view image using a fast and robust approach based on intensity value that shows the closeness of the 3D model. Subsequently, smooth the 3D surface model using a Bezier curve approximation.

3. To introduce a new vessels segmentation approach by identifying and accurately locating the correct vessel ROI to avoid surgery injuries and perform the surgery based on RGB colour space.

1.6. Research Scope

This thesis focuses on realistic 3D model reconstruction of a real human heart rather than the computer graphics creation of artificial models using graphics software, tools, or imaging devices. This realistic 3D model is to be used in cardiac surgery training environment. Furthermore, the thesis identifies the vessels ROI where to perform the surgery by using patient heart images. The input data will be taken during an open-heart surgery. However, for the purpose of this research, the focus is limited to using only a digital camera to acquire the input data, the acquiring data are images or videos whereas the video will be converted to still images. Chosen images will be used as an input in this research, i.e. images without obstacles, such as surgical tools, surgeon's head or hands.

1.7. Thesis Organization

A brief background and motivation of the research are presented in this chapter, as well as the research problem, significance, objectives, and research scope. Furthermore, the rest of this thesis is organized as follows.

Chapter 2 introduces a review of state of the art literature of specular reflection detection methods prior to inpainting methods to correct the specularities. Then, it presents a 3D reconstruction method from multiple and single images. Furthermore, reviews about the existing vessel segmentation techniques are presented.

Chapter 3 describes the overall research framework. In addition, this chapter explains about the data acquisition, pre-processing of data, and brief details for the rest of the research chapters.

Chapter 4 presents a specular reflections algorithm, which is detected by a proposed threshold value using colour information. Then, an inpainting algorithm is proposed to correct the detected specular pixel using L-inverse surrounding pixels. Hence, the input image is corrected and will be used to obtain realistic 3D heart surface model.

Chapter 5 describes the obtaining of the realistic 3D model algorithm of the real human heart images that have been corrected from the specular reflections algorithm. It assumes the pixel intensity value used as a third axis for 3D reconstruction. The three axes are then estimated for each pixel by using positions and intensities. Moreover, the surface model is then smoothed by applying the Bezier curve approximation technique.

In chapter 6, according to different characteristics of the vessels, hybrid algorithm is applied to segment the surface vessels of the human heart image. It combines a vessel segmentation and 3D vessel model reconstruction to create a realistic 3D model of the human heart surface. In this chapter, an approximation technique to the extracted surface vessels using a Bezier curve was perform. The segmented vessels are correctly guiding the surgeons where to perform the surgery.

For validation of each proposed method, several experiments are conducted on a digital data and presented at the end of each chapter along with their results and discussions. Finally, a conclusion of the whole thesis, limitations and potential future work is given in chapter 7.

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