
UNIVERSITI PUTRA MALAYSIA

# IMPROVING PERFORMANCE OF AUTOMATED CORONARY ARTERIAL TREE CENTER-LINE EXTRACTION, STENT LOCALIZATION AND TRACKING

FARSAD ZAMANI BOROUJENI

FSKTM 2012 28

# IMPROVING PERFORMANCE OF AUTOMATED CORONARY ARTERIAL TREE CENTER-LINE EXTRACTION, STENT LOCALIZATION AND TRACKING

**FARSAD ZAMANI BOROUJENI**

**DOCTOR OF PHILOSOPHY**
**UNIVERSITI PUTRA MALAYSIA**

**2012**

# IMPROVING PERFORMANCE OF AUTOMATED CORONARY ARTERIAL TREE CENTER-LINE EXTRACTION, STENT LOCALIZATION AND TRACKING

**By**

**FARSAD ZAMANI BOROUJENI**



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

**December 2012**

*To my family:*

*My respectable parents who share their lives with me, my dear wife, Shiva, whose infinite support, incredible understanding and ultimate kindness are immeasurable, and my small son, Faraz, to whom I owe a lot of attention and weekend activities.*

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

**IMPROVING PERFORMANCE OF AUTOMATED CORONARY ARTERIAL TREE CENTER-LINE EXTRACTION, STENT LOCALIZATION AND TRACKING**

By

**FARSAD ZAMANI BOROUJENI**

**December 2012**

**Supervisor:** **Associate Professor Rahmita Wirza O.K. Rahmat, PhD**

**Faculty:** **Computer Science and Information Technology**

Stent placement is a common procedure in Percutaneous Transluminal Coronary Angioplasty which helps many patients to avoid emergency heart bypass surgery or heart attack. In this procedure, a stent is implanted at the narrowing part of an artery to keep its lumen open allowing blood to flow normally through the artery. A potential risk of this treatment is the inaccurate placement of the stent (geographic miss), which could result in serious complications for the patient such as development of new stenotic lesions, increasing the likelihood of blood clot formation and the need for revascularization.

Over the last decade, many algorithms have been developed to address this problem. However, most of them either fail to meet the demanding requirements of real-time assistant systems or to provide quantitative analysis for verification of stent placement

task. In this research work, we report on new contributions to the major parts of a computer assisted stent positioning system.

The first contribution is automatic detection of seed points which serve as a prerequisite step for centerline extraction algorithm. The solution consists of an algorithm for automatic collection of candidate seed points using efficient grid line searching mechanism and a validation method which uses local geometric and intensity based features as effective validation rules to discriminate between the actual seed point and false alarms. The experimental results show that combining the advantages of the geometric based validation and contrast based filtering as well as avoiding large quantization errors, lead to significant enhancement in the performance of the seed point detection algorithm in terms of balancing between the precision and recall.

The second contribution is related to the robust and accurate extraction of centerlines for all vessel segments of the arterial tree in the angiogram images. This problem is addressed by proposing an accurate and robust centerline extraction method. Starting at each detected seed point, the centerline extraction method utilizes eigenvalues and eigenvectors of Hessian matrix for the pixels located on a semi-circular scanning profile for robust estimation of the next centerline point. The experimental validations show that the use of Hessian matrix results in significant improvement in the robustness of the tracing algorithm.

The stent localization and tracking in angiogram image sequence is the topic of the third contribution. The proposed method combines special fast filtering, region of interest

processing and graph based trajectory analysis approach to localize and track the radio-opaque markers of the stent in fluoroscopic frame sequences. The most interesting finding was that the validation of the potential markers prior to building tracks of marker pairs, causes the landmark detection process to avoid dealing with a large number of outliers and misdetections. In total, the current study found that the proposed algorithms outperform their well-established existing counterparts indicating their suitability to be adopted in practical computer assisted stent positioning systems.

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

**MENINGKATKAN PRESTASI PENGEKSTRAKAN GARIS-TENGAH PEPOHON ARTERI, PENYETEMPATAN DAN PENGESANAN STENT SECARA AUTOMATIK**

Oleh

**FARSAD ZAMANI BOROUJENI**

**Disember 2012**

**Pengerusi: Profesor Madya Rahmita Wirza O.K. Rahmat, PhD**

**Fakulti: Sains Komputer dan Teknologi Maklumat**

Penempatan stent adalah prosedur biasa dalam perkutanus transluminal Angioplasti Koronari yang membantu ramai pesakit untuk mengelakkan kecemasan pembedahan pintasan jantung atau serangan jantung. Dalam prosedur ini, stent diimplan di bahagian penyempitan arteri untuk memastikan lumen terbuka membenarkan darah mengalir melalui arteri. Satu potensi risiko rawatan ini adalah penempatan stent yang tidak tepat, yang boleh mengakibatkan komplikasi yang serius bagi pesakit seperti pembangunan lesi stenotik yang baharu, meningkatkan kemungkinan pembentukan darah beku dan keperluan untuk revaskularisasi. Penempatan stent adalah prosedur biasa dalam perkutanus transluminal Angioplasti Koronari yang membantu ramai pesakit untuk mengelakkan kecemasan pembedahan pintasan jantung atau serangan jantung. Dalam prosedur ini, stent diimplan di bahagian penyempitan arteri untuk memastikan lumen terbuka membenarkan darah mengalir yang biasanya melalui arteri. Satu potensi risiko

rawatan ini adalah penempatan stent yang tidak tepat, yang boleh mengakibatkan komplikasi yang serius bagi pesakit seperti pembangunan lesi baru stenotik, meningkatkan kemungkinan pembentukan darah beku dan keperluan untuk revaskularisasi.

Lebih sedekad yang lalu, banyak algoritma telah dibangunkan untuk menangani masalah ini. Walau bagaimanapun, kebanyakannya sama ada gagal untuk memenuhi keperluan mendesak sistem pembantu masa sebenar atau untuk menyediakan analisis kuantitatif bagi pengesahan tugas penempatan stent. Dalam penyelidikan ini, kami melaporkan suatu sumbangan baharu kepada bahagian utama sistem kedudukan stent berbantukan komputer.

Sumbangan pertama adalah pengesanan automatik bagi titik benih yang berfungsi sebagai langkah prasyarat bagi algoritma pengekstrakan garis-tengah. Penyelesaian terdiri daripada algoritma untuk koleksi calon titik benih automatik menggunakan mekanisma pencarian garis grid yang cekap dan kaedah pengesahan yang menggunakan tempatan ciri-ciri geometri dan kaedah validasi yang menggunakan geometri tempatan dan intensiti berasaskan ciri-ciri pengesahan yang berkesan untuk membezakan antara titik benih sebenar dan penggera palsu. Keputusan eksperimen menunjukkan bahawa menggabungkan kelebihan validasi berasaskan geometri dan kontras berasaskan penapisan serta mengelakkan kesilapan pengkuantuman yang besar, membawa kepada peningkatan yang ketara dalam prestasi algoritma pengesanan titik benih dari segi mengimbangi antara ketepatan dan ingatan.

Sumbangan kedua adalah berkaitan dengan pengekstrakan garis-tengah yang mantap dan tepat untuk semua segmen vesel pohon arteri dalam imej angiogram. Masalah ini ditangani dengan mencadangkan suatu kaedah pengekstrakan garis-tengah yang tepat dan mantap. Bermula pada setiap titik benih yang dikesan, kaedah pengekstrakan tengah menggunakan eigen dan vektor eigen matriks Hessian piksel yang terletak di profil pengimbasan separuh bulat untuk anggaran teguh titik tengah yang berikut. Validasi ujikaji menunjukkan bahawa penggunaan hasil matriks Hessian dalam peningkatan yang ketara dalam keteguhan algoritma mengesan.

Penempatan stent dan pengesanan dalam jujukan imej angiogram merupakan topik bagi sumbangan ketiga. Kaedah yang dicadangkan menggabungkan penapisan khas cepat, kawasan rantau kepenting pemprosesan dan graf analisis trajektori berasaskan pendekatan untuk membatasi dan mengesan petanda radio-legap stent dalam urutan bingkai fluoroskopi. Penemuan yang paling menarik ialah bahawa validasi petanda yang berpotensi sebelum membina trek penanda berpasangan, menyebabkan proses pengesanan mercu tanda untuk mengelakkan berurusan dengan sebilangan besar titik terpencil dan kegagalan pengesanan. Secara keseluruhan, kajian semasa mendapati bahawa algoritma yang dicadangkan mengatasi saingan-saingan yang sedia ada dan menunjukkan kesesuaian mereka untuk diguna pakai dalam praktikal sistem kedudukan stent berbantukan komputer.

## ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor, Associate Prof. Dr. Rahmita Wirza O.K Rahmat, for the patient guidance, encouragement and advice she has provided throughout my time as her student. Her comments and suggestions for further development as well as her financial and spiritual support during my candidature were immeasurable. I also would like to express my sincere thanks and appreciation to my supervisory committee members Associate Prof. Dr. Oteh Maskon, Associate Prof. Dr. Norwati Mustapha and Dr. Lilly Suriani Affendey for their guidance, valuable suggestions and advice throughout this research work. I must express my deep gratitude to Associate Prof. Dr. Oteh Maskon and Dr. Alireza Khosravi and medical staff of cardiology department of HUKM Hospital (Malaysia) and Speahan Hospital and Khorshid Hospital (Iran) not only for providing a lot of scarce data which allowed me to undertake this research, but also for giving me the opportunity to attend their work place and gain a lot of experience by observing many real examination procedures as well as getting familiar with so many interesting people.

I would like to express my gratefulness to Shiva, my wife, for her continued support and encouragement. I also appreciate the patience of my mother, father for their unconditional love and support, but I know very well that my absence from home has never been easy for them.

FARSAD ZAMANI BOROUJENI

December 2012

I certify that a Thesis Examination Committee has met on 14 Dec 2012 to conduct the final examination of **Farsad Zamani Boroujeni** on his thesis entitled **"Improving Performance of Automated Coronary Arterial Tree Center-Line Extraction, Stent Localization and Tracking"** in accordance with the Universities and University Colleges Act 1971 and Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Masrah Azrifah Azmi Murad, PhD**
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Chairman)

**Lili Nurliyana Abdullah , PhD**
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Internal Examiner)

**Shyamala A/p C. Doraisamy, PhD**
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Internal Examiner)

**Sudhir Pandurang Mudur, PhD**
Professor
Department of Computer Science and Software Engineering
Concordia, Canada
(External Examiner)

_____
**NORITAH OMAR, PhD**
Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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:

**Rahmita Wirza O.K. Rahmat, PhD**
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Chairperson)

**Norwati Mustapha, PhD**
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

**Lilly Suriani Affendey, PhD**
Senior Lecturer
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

**Oteh Maskon, MBBCh, MRCP and MSc**
Associate Professor
Department of Medicine
Universiti Kebangsaan Malaysia
(Member)

_____
**BUJANG BIN KIM HUAT, PhD**
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

## DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at University Putra Malaysia or other institution.

_____

**FARSAD ZAMANI BOROUJENI**

Date: 14 December 2012

## TABLE OF CONTENTS