A Cooperative Multi-Agent Approach for Aerial Image Rectification

Liew Lee Hung

Doctor of Philosophy
2019
A Cooperative Multi-Agent Approach for Aerial Image Rectification

Liew Lee Hung

A thesis submitted
In fulfilment of the requirements for the degree of Doctor of Philosophy
(Computer Science)

Faculty of Computer Science and Information Technology
UNIVERSITI MALAYSIA SARAWAK
2019
DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citation, which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Liew Lee Hung

14 June 2019
ACKNOWLEDGEMENT

First of all, I would like to sincerely thank my main supervisor, Prof Dr Wang Yin Chai, for his patient supervision, excellent guidance and encouragement throughout this research. I also would like to express my gratitude and appreciation to my co-supervisor, Dr Cheah Wai Shiang who has shared his knowledge and guided me in the integration of multi-agent approach.

Thanks to the Faculty of Computer Science and Information Technology and all fellow researchers for providing a friendly research environment.

Lastly, I would like to thank my beloved husband, mother and the rest of my family for your love, care, prayers and support that have been my great inspiration and have endured me through all the difficult times.
ABSTRACT

Aerial images provide instant visual records which are closer to the areas of interest. As one of the extensively used methods of remote sensing, accurate aerial images could provide useful spatial information. However, aerial images are distorted during the process of acquisition by different reasons such as earth curvature, camera lens and inconsistencies in the attitude of aircraft. Distortion is usually composited differently, collectively and irregularly in the entire aerial image which forms the complexity of degradation to the images. Hence, the aerial images should be rectified before proceeding to subsequent analysis. Image rectification is an essential pre-processing step to eliminate or at least reduce the effect of distortion. The conventional non-parametric approach requires a set of corresponding control points to be selected manually from a reference image and a distorted image as mapping parameters for rectification transformation. The procedure of manual selection is time-consuming and influenced by humans factors such as experience and attitude. Although many automatic extraction methods could be used conveniently to produce a large number of corresponding control points, excessive control points would also introduce other displacements into the image. Many trials usually have to be traversed to filter the original set of control points in order to select the best set of control points. Furthermore, the selected control points are advised to be distributed evenly or uniformly which is subjective to be defined. Such tedious process involves human, software and technology. Hence, this research introduces a cooperative multi-agent system approach to support the selection of control points for aerial image rectification. It incorporates the distribution of control points using Voronoi diagram and corner score through the cooperation and interaction of software agents. The proposed approach is tested on rectifying a two dimensional (2D) aerial image. The aerial image size used is 4000 × 2250
pixels. The area of interest covers a relatively flat area of almost 270,000 square meters. The coordinates of ground control points are retrieved from the Sarawak Land and Survey Department, which has an orthophoto system with 0.2 metres resolution. The performance of the rectification is measured using the total root mean square error of a set of checkpoints. The results obtained from the selection by the proposed multi-agent system are compared with results obtained from the selection by expert and conventional residual. The selection of ground control points is performed with the selection size of 3, 6, 9, 12, 15, 18, 21, 24 and 27. The selected ground control points based on the selection size are used in coefficients calculation for various transformations. From the finding, it is observed that the proposed multi-agent system achieved 0.91 meters as its lowest total RMSE of checkpoints when using the selected 18 ground control points and with the second order polynomial transformation. The proposed multi-agent selection achieved the highest percentage of reduction in the total RMSE of checkpoints with selection size of six and the second order polynomial transformation. The selection by the proposed multi-agent system achieved a decrement of the total RMSE of checkpoints with 58.31% when compared to the achievement by expert selection. The proposed multi-agent system selection also has a decrement of 12.41% total RMSE of checkpoints as the highest when compared to the achievement by the conventional residual method. Experiments show that the proposed multi-agent system provides reliable results. The study demonstrates that multi-agent approach is a way of representing task allocation, team planning and open environments which could support in providing a systematic way of structuring an aerial image rectification.

**Keywords:** Aerial image rectification, cooperative multi-agent, Voronoi diagram
Pendekatan Kolaborasi Multi-Agen Untuk Rektifikasi Imej Udara

ABSTRAK

rektifikasi imej udara. Kajian ini menggabungkan gambarajah Voronoi dan nilai ciri sudut dalam pemilihan titik kawalan melalui kerjasama dan interaksi ejen perisian. Pendekatan cadangan diuji untuk membetulkan imej udara dua dimensi (2D) dengan saiz imej 4000 × 2250 piksel. Kawasan kajian adalah kawasan rata dengan keluasan 270,000 meter persegi. Koordinat titik kawalan diperolehi dari Jabatan Tanah dan Survei Sarawak yang mempunyai sistem ortophoto dengan resolusi 0.2 meter. Prestasi rektifikasi diukur dengan menggunakan “total root mean square error” bagi satu set titik pemeriksaan. Keputusan yang diperoleh dari sistem cadangan multi-agen (MAS) dibandingkan dengan keputusan yang diperoleh dari pemilihan titik kawalan oleh pakar dan cara konvensional. Pemilihan titik kawalan dilakukan mengikut saiz (bilangan titik) 3, 6, 9, 12, 15, 18, 21, 24 dan 27. Titik kawalan yang terpilih berdasarkan saiz pemilihan digunakan untuk pelbagai transformasi. Daripada hasil kajian, adalah diperhatikan bahawa sistem cadangan MAS mencapai jumlah RMSE titik pemeriksaan terendah sebanyak 0.91 meter apabila menggunakan saiz 18 dan dengan transformasi "second order polynomial". Pemilihan sistem cadangan MAS mencapai peratusan pengurangan tertinggi bagi saiz enam dan transformasi "second order polynomial". Penurunan jumlah RMSE titik pemeriksaan sebanyak 58.31% apabila dibandingkan dengan pencapaian oleh pemilihan pakar. Pemilihan sistem cadangan MAS juga mempunyai pengurangan sebanyak 12.41% jumlah RMSE titik pemeriksaan sebagai pencapaian yang tertinggi jika dibandingkan dengan pencapaian kaedah konvensional. Eksperimen menunjukkan bahawa sistem cadangan MAS dapat memberikan pencapaian yang mantap. Kajian ini menunjukkan bahawa pendekatan multi-agen sesuai dalam peruntukan tugas dan perancangan pasukan yang boleh membantu dalam menstrukturkan rektifikasi imej udara secara sistematik.

Kata kunci: Rektifikasi imej udara, kerjasama agen pelbagai, gambarajah Voronoi
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td>i</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>v</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xv</td>
</tr>
<tr>
<td>CHAPTER 1: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1  Background</td>
<td>1</td>
</tr>
<tr>
<td>1.1.1 Distortion in aerial images</td>
<td>3</td>
</tr>
<tr>
<td>1.1.2 Image rectification</td>
<td>5</td>
</tr>
<tr>
<td>1.1.3 Agent-based approach in image processing</td>
<td>7</td>
</tr>
<tr>
<td>1.2  Problem statements</td>
<td>8</td>
</tr>
<tr>
<td>1.3  Objectives</td>
<td>13</td>
</tr>
<tr>
<td>1.4  Scope of study</td>
<td>13</td>
</tr>
<tr>
<td>1.5  Research significance</td>
<td>15</td>
</tr>
<tr>
<td>1.6  Structure of thesis</td>
<td>16</td>
</tr>
</tbody>
</table>
1.7 Summary........................................................................................................................................ 17

CHAPTER 2: LITERATURE REVIEW .............................................................................................. 19

2.1 Introduction ................................................................................................................................ 19

2.2 Geometric distortion ..................................................................................................................... 20

2.3 Non-parametric image rectification ............................................................................................ 25

2.4 Reference image ............................................................................................................................ 33

2.5 Extraction and selection of control points .................................................................................... 37

2.5.1 Harris corner detection ............................................................................................................. 40

2.5.2 Scale-invariant feature transform .......................................................................................... 42

2.5.3 Speeded up robust features ................................................................................................... 43

2.5.4 Genetic algorithm ................................................................................................................. 45

2.6 Number of control points ............................................................................................................. 46

2.7 Distribution of control points ....................................................................................................... 48

2.7.1 Random distribution ............................................................................................................... 50

2.7.2 Regular grid ............................................................................................................................ 51

2.7.3 Uniform index ........................................................................................................................ 52

2.7.4 Voronoi diagram .................................................................................................................... 54

2.8 Geometric transformation ............................................................................................................ 57

2.8.1 Similarity transformation ........................................................................................................ 59

2.8.2 Affine transformation ............................................................................................................. 60

2.8.3 Polynomial transformation ..................................................................................................... 61

2.8.4 Thin plate Spline transformation ............................................................................................ 63
2.8.5 Piecewise Linear transformation ......................................................... 64
2.8.6 Other methods .................................................................................. 68
2.9 Accuracy assessment .......................................................................... 69
2.10 Software agents and multi-agent approach ............................................. 72
2.10.1 Advantages of using multi-agent approach ....................................... 75
2.10.2 Agent platforms ............................................................................. 77
2.10.3 JADE .............................................................................................. 80
2.11 Agent-oriented methodologies ............................................................. 80
2.12 Combination of ROADMAP and RAP/AOR methodology ...................... 81
2.12.1 Goal model ..................................................................................... 82
2.12.2 Role model ..................................................................................... 83
2.12.3 Organisation and domain model ....................................................... 84
2.12.4 Interaction model ............................................................................ 84
2.12.5 Knowledge model .......................................................................... 84
2.12.6 Behaviour model .......................................................................... 85
2.13 Summary ............................................................................................. 85

CHAPTER 3: METHODOLOGY ...................................................................... 87
3.1 Introduction .......................................................................................... 87
3.2 Preliminary study ................................................................................ 88
3.3 Study site ............................................................................................. 95
3.4 Research procedure ............................................................................. 95
3.4.1 Image acquisition .......................................................................... 96
3.4.2 Ground control points identification ................................................. 99
3.4.3 Ground control points coordinates determination ................................. 100
3.4.4 Control points selection ..................................................................... 104
3.4.5 Accuracy assessment and comparison .................................................. 106

3.5 Proposed multi-agent approach for aerial image rectification ...................... 108
   3.5.1 Goal model ..................................................................................... 109
   3.5.2 Role model ................................................................................... 110
   3.5.3 Organisation model ....................................................................... 112
   3.5.4 Domain model ............................................................................... 112
   3.5.5 Agent-role coupling ...................................................................... 113
   3.5.6 Interaction model ........................................................................... 115
   3.5.7 Knowledge model .......................................................................... 119
   3.5.8 Behaviour model ............................................................................ 121

3.6 Summary ............................................................................................. 127

CHAPTER 4: IMPLEMENTATION ..................................................................... 129
  4.1 Introduction ........................................................................................ 129
  4.2 Hardware and software ........................................................................ 129
  4.3 Multi-agent based aerial image rectification in JADE platform ............... 130
  4.4 Implementation of Request agent based on JADE ................................. 132
  4.5 Implementation of Rectifier agent based on JADE ............................... 133
  4.6 Implementation of Corner agent based on JADE ................................. 135
  4.7 Implementation of Distributor Agent based on JADE ......................... 139
# CHAPTER 5: EXPERIMENTAL ANALYSES AND EVALUATION

## 5.1 Introduction

## 5.2 Evaluation of preliminary study

## 5.3 Accuracy assessment of satellite image

## 5.4 Evaluation of expert selection

## 5.5 Evaluation of proposed multi-agent system (MAS) selection

## 5.6 Results analyses and comparisons

## 5.7 Agent communication in JADE

## 5.8 Summary

# CHAPTER 6: CONCLUSION AND FUTURE WORKS

## 6.1 Introduction

## 6.2 Research findings and contributions

## 6.3 Future works

## 6.4 Conclusion

# REFERENCES
### LIST OF TABLES

| Table 2.1 | Previous works on non-parametric approach remotely sensed image rectification | 30 |
| Table 2.2 | Corner extraction, feature extraction and description algorithms that have been applied for selection of control points | 39 |
| Table 2.3 | Comparison of agent platforms with high popularity based on properties, usability, security management, operating ability and pragmatics criteria (Kravari & Bassiliades, 2015) | 79 |
| Table 2.4 | Notations used in goal model (Sterling & Taveter, 2009) | 83 |
| Table 2.5 | Explanation of elements used in a role model (Sterling & Taveter, 2009) | 83 |
| Table 3.1 | The position of checkpoints | 93 |
| Table 3.2 | The position of control points used in each distribution | 94 |
| Table 3.3 | The dataset framing of the satellite image | 98 |
| Table 3.4 | The 40 coordinates (Timbalai BRSO) of the GCPs identified in the study area | 103 |
| Table 3.5 | Role model for user | 110 |
| Table 3.6 | Role model for image processing manager | 111 |
| Table 3.7 | Role model for corner extractor | 111 |
| Table 3.8 | Role model for control points distributor | 111 |
| Table 3.9 | Descriptor of the type Request agent | 114 |
| Table 3.10 | Descriptor of the type Rectifier agent | 115 |
Table 3.11  Descriptor of the type Corner agent  
Table 3.12  Descriptor of the type Distributor agent  
Table 3.13  A scenario for handling rectification of aerial images  
Table 3.14  A scenario for rectifying aerial images  
Table 3.15  A scenario for generating corner score  
Table 3.16  A scenario for generating distribution impact index  
Table 3.17  The models of rules R1 until R9 for rectifying aerial images  
Table 4.1  Hardware specification  
Table 5.1  The residuals of each checkpoint before transformation  
Table 5.2  The total RMSE of the control points (CPs) and checkpoints (ChPs)  
Table 5.3  Positional accuracy validation of satellite image  
Table 5.4  GCPs selection by expert according to selection size  
Table 5.5  The total RMSE at the GCPs and checkpoints achieved using similarity transformation based on expert selection  
Table 5.6  The total RMSE at the GCPs and checkpoints achieved using affine transformation based on expert selection  
Table 5.7  The total RMSE at the GCPs and checkpoints achieved using second order polynomial transformation based on expert selection  
Table 5.8  The total RMSE at the GCPs and checkpoints achieved using third order polynomial transformation based on expert selection  
Table 5.9  The neighbourhood pixel size used for corner score calculation of each GCP by Corner agent  
Table 5.10  The rank of the corner score for each GCP  
Table 5.11  Selection values of 28 GCPs
<p>| Table 5.12 | Selection values of 27 GCPs | 176 |
| Table 5.13 | Selection values of 26 GCPs | 177 |
| Table 5.14 | Selection value of 25 GCPs | 178 |
| Table 5.15 | GCPs selection by the proposed multi-agent system according to selection size | 180 |
| Table 5.16 | The total RMSE of the GCPs and checkpoints achieved using similarity transformation based on the proposed MAS selection | 190 |
| Table 5.17 | The total RMSE of the GCPs and checkpoints achieved using affine transformation based on the proposed MAS selection | 191 |
| Table 5.18 | The total RMSE of the GCPs and checkpoints achieved using 2nd order polynomial transformation based on the proposed MAS selection | 191 |
| Table 5.19 | The total RMSE of the GCPs and checkpoints achieved using 3rd order polynomial transformation based on the proposed MAS selection | 191 |
| Table 5.20 | The range between maximum and minimum of total RMSE of checkpoints | 199 |
| Table 5.21 | GCPs selection based on residual | 201 |
| Table 5.22 | The total RMSE of the GCPs and checkpoints achieved using second order polynomial transformation based on residual of GCPs | 202 |
| Table 5.23 | Average distance according to selection size among the selection done by expert, the proposed MAS and residual method | 203 |</p>
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Some effects of geometric distortion are denoted by the dashed lines (Richards (2013) and Jensen (2015))</td>
<td>4</td>
</tr>
<tr>
<td>1.2</td>
<td>General procedure of non-parametric image rectification</td>
<td>7</td>
</tr>
<tr>
<td>1.3</td>
<td>Different allocation of control points would cause the distorted image to be treated differently</td>
<td>11</td>
</tr>
<tr>
<td>2.1</td>
<td>The overlaid of an aerial image with a satellite image of the same scene</td>
<td>21</td>
</tr>
<tr>
<td>2.2</td>
<td>A grid image with barrel effect</td>
<td>22</td>
</tr>
<tr>
<td>2.3</td>
<td>Experimental results by Lee et al. (2009)</td>
<td>23</td>
</tr>
<tr>
<td>2.4</td>
<td>Perspective effect in a grid image</td>
<td>24</td>
</tr>
<tr>
<td>2.5</td>
<td>The RMSE curve with different number of control points (Wang et al. (2011b))</td>
<td>48</td>
</tr>
<tr>
<td>2.6</td>
<td>Grid of control points with (a) uniformly spaced, (b) larger uniform spacing, (c) randomly spaced and (d) varying density (Zagorchev &amp; Goshtasby, 2006)</td>
<td>49</td>
</tr>
<tr>
<td>2.7</td>
<td>Design of distributions where ground control points are placed in the shadow area and checkpoints placed in the blank area (Guang &amp; Weili, 2011)</td>
<td>49</td>
</tr>
<tr>
<td>2.8</td>
<td>Distribution of control points used in the image to image registration:</td>
<td>50</td>
</tr>
</tbody>
</table>
Figure 2.9  Example of regular method for allocating control points (Li & Cheng, 2008) 51

Figure 2.10  The concept of monopolised circle (Zhang & Cheng, 2009) 53

Figure 2.11  Voronoi diagram of a set of points (Dobrin, 2005) 57

Figure 2.12  Example of Voronoi diagram and its Delaunay triangulation (Paun, 2014) 65

Figure 2.13  Principle components of a software agent (Hofmann et al., 2016) 73

Figure 3.1  Grid image that is used as reference image 89

Figure 3.2  Distorted grid image with accumulation of barrel, vertical perspective, horizontal perspective and rotation effect 89

Figure 3.3  The checkpoints (marked with blue circles) and the centre distribution of control points (marked with red triangles) used in the preliminary study 91

Figure 3.4  The checkpoints (marked with blue circles) and the border distribution of control points (marked with red triangles) used in the preliminary study 91

Figure 3.5  The checkpoints (marked with blue circles) and the corner distribution of control points (marked with red triangles) used in the preliminary study 92

Figure 3.6  The checkpoints (marked with blue circles) and the uniform distribution of control points (marked with red triangles) used in the preliminary study 92

Figure 3.7  The study site 95

Figure 3.8  Overall research procedure flow diagram 96
Figure 3.9  The region of interest in the satellite image  
Figure 3.10  The study area and the position of the GCPs  
Figure 3.11  The distribution of the 28 GCPs used for similarity transformation  
Figure 3.12  Location and distribution of checkpoints  
Figure 3.13  An overview of goal model for rectifying aerial images  
Figure 3.14  Organisation model for aerial image rectification  
Figure 3.15  The domain model for rectification of aerial images  
Figure 3.16  The agent-role coupling diagram for rectification of aerial images  
Figure 3.17  Interaction-frame diagram for rectification of aerial images  
Figure 3.18  Interaction-sequence diagram for rectification of aerial images  
Figure 3.19  Knowledge model for rectification of aerial images  
Figure 3.20  An agent behaviour model for rectifying aerial image  
Figure 4.1  Agents created and added in the JADE RMA GUI  
Figure 4.2  Java code implementation of message passing between agents  
Figure 4.3  Java code implementation of message reception  
Figure 4.4  Extracted “RequestAgent” implementation code for registration  
Figure 4.5  Extracted “RequestAgent” implementation code for sending request to Rectifier agent  
Figure 4.6  Extracted “RectifierAgent” implementation code for registration  
Figure 4.7  Extracted “RectifierAgent” implementation code for sending request to Corner agent  
Figure 4.8  Extracted “CornerAgent” implementation code for registration  
Figure 4.9  Extracted “CornerAgent” implementation code for responding to the request received
| Figure 4.10 | Extracted Java code for calling Matlab script calCornerR | 138 |
| Figure 4.11 | Extracted Matlab script calCornerR | 139 |
| Figure 4.12 | Extracted “DistributorAgent” implementation code for registration | 140 |
| Figure 4.13 | Extracted “DistributorAgent” implementation code for responding to the request received | 141 |
| Figure 4.14 | Extracted Java code for calling Matlab script calDistImpact | 142 |
| Figure 4.15 | Extracted Matlab script calDistImpact | 142 |
| Figure 5.1  | Total RMSE of checkpoints in preliminary study | 147 |
| Figure 5.2  | Rectified grid image with centre distribution and similarity transformation | 148 |
| Figure 5.3  | Rectified grid image with centre distribution and affine transformation | 149 |
| Figure 5.4  | Rectified grid image with centre distribution and second order polynomial transformation | 149 |
| Figure 5.5  | Rectified grid image with centre distribution and third order polynomial transformation | 150 |
| Figure 5.6  | Rectified grid image with border distribution and similarity transformation | 150 |
| Figure 5.7  | Rectified grid image with border distribution and affine transformation | 151 |
| Figure 5.8  | Rectified grid image with border distribution and second order polynomial transformation | 151 |
| Figure 5.9  | Rectified grid image with border distribution and third order polynomial transformation | 152 |
Figure 5.10  Rectified grid image with corner distribution and similarity transformation  152
Figure 5.11  Rectified grid image with corner distribution and affine transformation  153
Figure 5.12  Rectified grid image with corner distribution and second order polynomial transformation  153
Figure 5.13  Rectified grid image with corner distribution and third order polynomial transformation  154
Figure 5.14  Rectified grid image with uniform distribution and similarity transformation  154
Figure 5.15  Rectified grid image with uniform distribution and affine transformation  155
Figure 5.16  Rectified grid image with uniform distribution and second order polynomial transformation  155
Figure 5.17  Rectified grid image with uniform distribution and third order polynomial transformation  156
Figure 5.18  The distribution of expert selection size 27 for similarity transformation  159
Figure 5.19  The distribution of expert selection size 24 for similarity transformation  160
Figure 5.20  The distribution of expert selection size 21 for similarity transformation  161
Figure 5.21  The distribution of expert selection size 18 for similarity transformation  162
Figure 5.22  The distribution of expert selection size 15 for similarity transformation

Figure 5.23  The distribution of expert selection size 12 for similarity transformation

Figure 5.24  The distribution of expert selection size 9 for similarity transformation

Figure 5.25  The distribution of expert selection size 6 for similarity transformation

Figure 5.26  The distribution of expert selection size 3 for similarity transformation

Figure 5.27  Comparison of the total RMSE of checkpoints by expert selection

Figure 5.28  Voronoi diagram constructed using 28 GCPs

Figure 5.29  Voronoi diagram constructed using 27 GCPs

Figure 5.30  Voronoi diagram constructed using 24 GCPs

Figure 5.31  The distribution of proposed MAS selection size 27 for similarity transformation

Figure 5.32  The distribution of proposed MAS selection size 24 for similarity transformation

Figure 5.33  The distribution of proposed MAS selection size 21 for similarity transformation

Figure 5.34  The distribution of proposed MAS selection size 18 for similarity transformation

Figure 5.35  The distribution of proposed MAS selection size 15 for similarity transformation
Figure 5.36  The distribution of proposed MAS selection size 12 for similarity transformation 186
Figure 5.37  The distribution of proposed MAS selection size 9 for similarity transformation 187
Figure 5.38  The distribution of proposed MAS selection size 6 for similarity transformation 188
Figure 5.39  The distribution of proposed MAS selection size 3 for similarity transformation 189
Figure 5.40  Comparison of the total RMSE of checkpoints by proposed MAS selection 192
Figure 5.41  Total RMSE of checkpoints achieved using similarity transformation on selection done by expert and proposed system 194
Figure 5.42  Total RMSE of checkpoints using affine transformation on selection done by expert and proposed system 194
Figure 5.43  Total RMSE of checkpoints using second order polynomial transformation on selection done by expert and proposed system 195
Figure 5.44  Total RMSE of checkpoints using third order polynomial transformation on selection done by expert and proposed system 196
Figure 5.45  The range of total RMSE of checkpoints when using similarity transformation 197
Figure 5.46  The range of total RMSE of checkpoints when using affine transformation 197
Figure 5.47  The range of total RMSE of checkpoints when using second order polynomial transformation 198
Figure 5.48  The range of total RMSE of checkpoints when using third order polynomial transformation 198

Figure 5.49  Total RMSE of checkpoints using the second order polynomial transformation on selection by residual method and the proposed MAS 202

Figure 5.50  Interaction between agents monitored using JADE Sniffer Agent 204

Figure 5.51  Messages sent and receives by the various agents 205