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A Cooperative Multi-Agent Approach for Aerial Image Rectification

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A Cooperative Multi-Agent Approach for Aerial Image Rectification

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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.

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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

Imej udara memberi rekod visual yang lebih dekat dengan kawasan kajian. Maklumat spatial dapat diperolehi dari imej udara yang merupakan salah satu kaedah penderiaan jauh. Namun, herotan berlaku pada imej udara semasa pengambilan imej atas sebab berbeza misalnya kelengkungan bumi, kanta kamera dan penerbangan pesawat yang tidak konsisten. Herotan biasanya didapati dalam bentuk yang berbeza, bertimbun dan tidak sekata dalam imej udara. Kejadian sebegini telah membentuk kerumitan herotan dalam imej udara. Oleh itu, imej udara perlu diperbetulkan sebelum digunakan untuk analisis seterusnya. Rektifikasi imej merupakan satu langkah pra-pemprosesan penting dan diperlukan untuk menyelesaikan atau sekurang-kurangnya merendahkan kesan herotan. Pendekatan konvensional bukan parametrik memerlukan satu set titik kawalan yang sepadan dipilih secara manual dari imej rujukan dan imej udara. Titik-titik ini kemudiannya digunakan sebagai parameter pemetaan untuk menjana transformasi geometri. Prosedur pemilihan titik kawalan secara manual memakan masa dan dipengaruhi oleh faktor manusia seperti pengalaman dan sikap individu. Walaupun banyak kaedah pengekstrakan titik kawalan automatik dapat diguna untuk menghasilkan bilangan titik kawalan yang banyak, rektifikasi dengan titik kawalan yang berlebihan akan menyebabkan anjakan lain ke dalam imej. Banyak cubaan perlu diuji untuk menapis set asal titik kawalan bagi memilih set titik kawalan terbaik. Tambahan pula, taburan titik adalah dinasihatkan supaya membentuk taburan seragam. Namun, konsep penentuan keseragaman untuk taburan titik adalah subjektif. Proses rektifikasi yang rumit ini melibatkan manusia, perisian dan teknologi. Oleh itu, kajian ini memperkenalkan pendekatan kolaborasi multi-agen untuk membantu proses pemilihan titik kawalan bagi

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 diperolehi dari sistem cadangan multi-agen (MAS) dibandingkan dengan keputusan yang diperolehi 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

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CHAPTER 1

INTRODUCTION

1.1 Background

Remote sensing is defined as information acquisition and record of an object, area or phenomenon without direct physical contact with it (Shravan et al., 2013). Such technology is utilised in many applications to obtain a consistent view of the Earth and human activities. Besides satellite system, the aircraft-based remote sensing system is one of the major platforms which commonly used to acquire remote sensing images (Panda et al., 2015).

Aerial images provide instant visual records which are closer to the areas of interest. Although satellite images provide broader spatial coverage with fewer shots due to the height of the platform, aerial images are easier to adapt according to the specific needs of applications. For instance, the image details of an aerial image could be improved by adjusting the flying height of aircraft according to weather conditions. Aerial images are helpful especially in the regions where the cloudiness hinders optical satellite imaging since the acquisition sensor for aerial images could be carried out at a lower altitude under the clouds (Darwin et al., 2014). Furthermore, the types of data captured also could be controlled with changeable or multiple cameras (Zhang et al., 2017).

Aerial images are normally captured with a camera mounted vertically, which is attached to a manned-aircraft, unmanned aerial vehicle (UAV) or balloon (Zhang et al., 2017). Aerial images are captured overlap one after another with approximately 60% to 80% along the flight line and 20% to 30% between flight lines (Linder, 2014). As one of the extensively used methods of remote sensing, such images are ideal for mapping small

areas. Aerial images are involved in various fields such as digital maps generation (Boccardo et al., 2015), ecological management (Grabowski et al., 2014), region surveying (Yi et al., 2016) and crop growth monitoring (Bendig, 2015). Meanwhile, the temporal resolution of satellite images is restricted by the orbit characteristics of satellite platform which limits their usages especially for record updating purposes (Gotovac et al., 2017).

Conventionally, aerial images are acquired using metric aerial cameras which are specially designed in order to provide measurements from images under the discipline of photogrammetry. The main objective of using metric cameras is to reduce the gap between data acquisition and production (Oniga & Diac, 2013). With the advancement of digital technology, the study of aerial images acquired from non-metric digital cameras has become active research nowadays (Yuan et al., 2014). A non-metric camera refers to the consumer camera that is not designed for mapping purpose, for example, Canon EOS Rebel XSi, Nikon Coolpix 5200 and Sony Alpha 350 DSLR.

The main difference between metric and non-metric cameras is the interior orientation parameters. The interior orientation parameters of a non-metric camera such as coordinate of fiducial marks, calibrated focal length, principle points and distortion parameters are not identified (Yuan et al., 2014). Besides that, metric digital cameras are more expensive compared to non-metric digital cameras (Ahmad et al., 2013). Projects of mapping small areas with limited budget would have a restriction in financing to purchase metric cameras for capturing aerial images.

The potential of using non-metric digital cameras as aerial images acquisition tools are demonstrated and tested in lots of research with different purposes. For instance, Samad et al. (2010) assessed the capability of the digital cameras used in mapping stream and

determined the accuracy of measurement using the close range photogrammetric technique. In their study, the digital cameras used include the metric digital camera Rollei metric d30 and non-metric digital camera Nikon Coolpix 5200. They reported that although the image quality of the orthophoto is not as good as the quality of the orthophoto produced by the metric camera, the non-metric digital camera is still capable to produce the orthophoto used for close range photogrammetric. Besides that, Udin and Ahmad (2012) examined the use of non-metric digital camera in capturing aerial photograph. They utilised Canon Pentax W90 as acquisition tool. Their study also showed that the digital aerial imagery obtained can be used for large scale mapping. Li et al. (2016) successfully constructed and tested the accuracy of a three dimensional model of their study area using aerial images taken from a non-metric camera and a relevant software package to process the images. The camera used in their study is Sony Nex-7. Another example, Amrullah et al. (2016) studied the effect of non-metric oblique and vertical camera combination along with the configuration of the ground control points to improve the precision and accuracy in UAV-photogrammetry project. The non-metric digital camera Canon power shot S110 is used in their study.

1.1.1 Distortion in aerial images

Aerial images that captured using a non-metric digital camera are subjected to distortion just like other remotely sensed images (Dave et al., 2015). Distortion occurs when the remotely sensed two-dimensional domain images are attempt to accurately represent the real world (Toth & Józków, 2016). The main sources of distortion include earth curvature, camera lens, topographic relief and inconsistencies in the attitude of aircraft which involve roll, yaw and pitch (Richards, 2013). The variations of geometric distortion are discussed

in details by Richards (2013) and Jensen (2015). Some effects of geometric distortion are illustrated in Figure 1.1. These variations of geometric distortion are naturally merged in an aerial image. In brief, a raw un-calibrated aerial image, $g(x, y)$ contains the real image details, $f(x, y)$ with combination of distortion from difference sources which could be denoted as Equation 1.1.

$$g(x, y) = f(x, y) + \text{distortion} \quad (1.1)$$

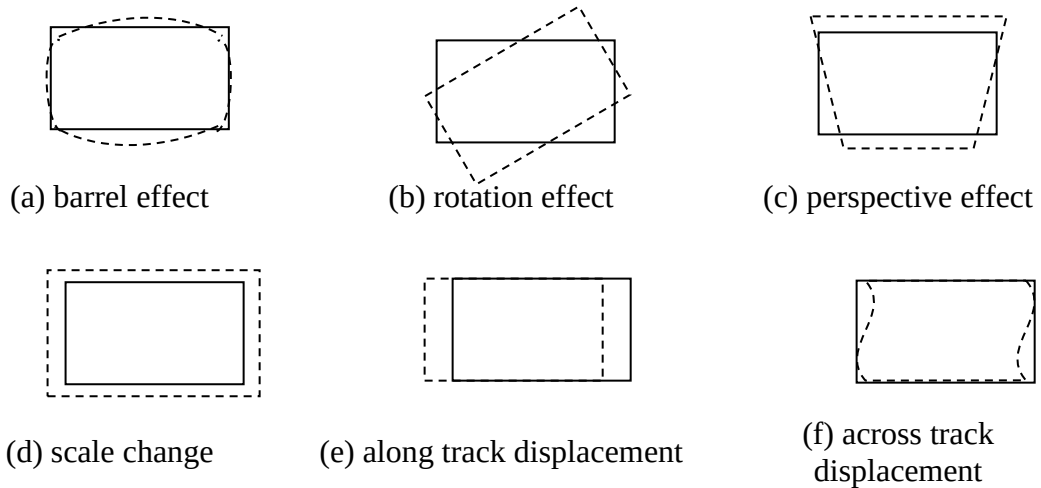


Figure 1.1: Some effects of geometric distortion are denoted by the dashed lines (Richards (2013) and Jensen (2015))

Geometric distortion is one of the common types of error encountered in the remotely sensed image (Jensen, 2015). Geometric distortion affects the relative position of objects in the scene (Pai, 2010) and degrades the quality of the data collected (Jensen, 2015). These effects are more seriously found in aerial images compare to satellite images (Wang et al., 2011b). This is due to the difference of the two platforms in height relation to the distance

from the Earth and the orbit of the satellite, which is relatively more stable compared to aircraft that usually moves unsteadily caused by atmospheric perturbations (Jensen, 2015).

Aerial images with zero distortion could provide useful spatial information. However, distortion is composited in aerial images which lead to deformation between the aerial images and the true environment. Consequently, the features in a distorted aerial image are not accurately representing the scene on ground or map position (Dave et al., 2015). Thus, the raw distorted aerial images must be rectified to ensure that the spatial information derived is correct. The accuracy of subsequent image analysis would be affected if it is used without undergoing rectification process.

1.1.2 Image rectification

Image processing techniques are used to rectify and enhance raw images acquired from cameras or sensors placed on satellites or aircraft. Image rectification is defined as a transformation process of correcting errors such as geometric errors of an image completely or partially (Xiangyang et al., 2010; Li et al., 2015). The geometrically rectified image can be used to extract distance, polygon area and direction information with certain accuracy (Dave et al., 2015). There are two main approaches used for image rectification: parametric and non-parametric approaches.

Parametric approach is based on the modelling of the occurrence of the distortion (Pai, 2010). The prior knowledge of the sources of distortion is required. It refers to the representation of the measurement with the parameters that can be directly interpreted as the characteristics of a physical model (Dufour et al., 2014). For instance, the characteristics, the position and attitude of the imaging sensor are used as the parameters for modelling the occurrence of the distortion (Wang et al., 2011b). However, this

approach is unsuitable when the imaging parameters are difficult to obtain and are not disclosed by providers due to the purpose of commercial technology protection (Xiangyang et al., 2010).

Conversely, the imaging mechanisms that cause distortions are not involved if using non-parametric approach. Non-parametric approach requires a set of corresponding control points from a reference image and a distorted image. Control points detection and selection process can be manual or automatic. The features should consist of salient and distinctive objects (closed-boundary regions, edges, contours, line intersections, corners, etc.) that are easily identifiable or physically interpretable (Patel & Shah, 2014). The feature set of the reference image must share sufficient common features with the distorted image. The control points are then applied with an appropriate mathematical mapping function to construct geometric transformation. The image rectification is carried out when the mapping transformation is performed through the matching of corresponding control points from the reference image and the raw aerial image.

The general procedure of non-parametric image rectification involves detection and selection of control points, matching of corresponding control points, geometric transformation, rectification evaluation with residual error estimation and image resampling and interpolation as depicted in Figure 1.2. Although non-parametric approach is an established approach which is usually implemented in geographic information system (GIS) and remote sensing software (Wang et al., 2011b), the implementation of each step has its typical problems, like the issues regards the selection of control points, the distribution of control points and the appropriateness of the geometric transformation applied would affect its accuracy as stated in the following problem statements.

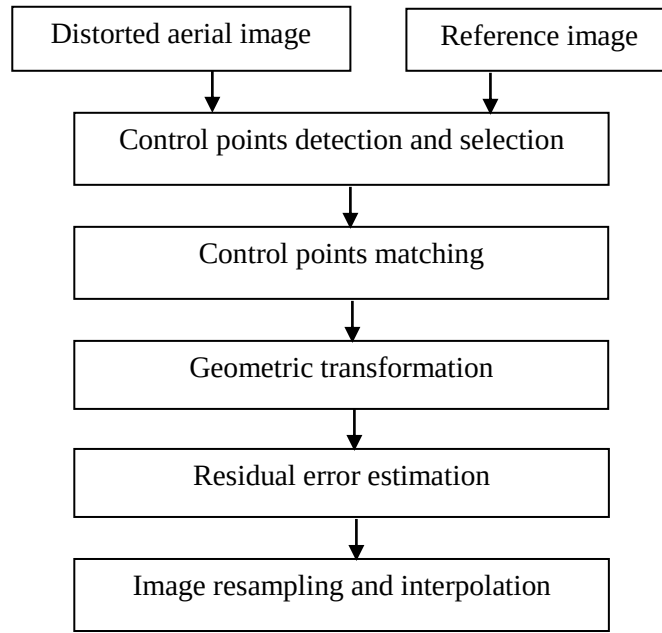


Figure 1.2: General procedure of non-parametric image rectification

1.1.3 Agent-based approach in image processing

Most of the conventional approaches involve human interventions in the rectification process. Many researchers have been working on developing semi-automated or automated image registration and rectification to handle the process. Since 1980's, new paradigms in the field of Computer Science such as parallel computing, object-oriented approach and agent models have emerged with the progress of computer systems (Yoon, 2008).

Agent-based approach is an emerging paradigm in recent years. There has been a strong demand to apply the agent paradigm in large and complex industrial applications and across different domains (Leitao et al., 2016). Agent-based system is a kind of intelligent computing entity that can sense the environment and affect the environment with a degree of autonomy (Liu et al., 2017). However, the definition of agents is depending on the applications of agents, different definitions have been made (Yoon, 2008). Agents are

often characterised with four basic properties: autonomous, reactivity, proactivity and social ability (Kristensen, 2016). Autonomous means that an agent could start by itself and able to operate without direct intervention of human. Reactivity means that the agent could monitor the environment and respond in a timely fashion to the changes that occur in the environment. Proactivity means that the agent should be able to exhibit goal-directed behaviour. Social ability means that the agent could interact and communicate with other agents.

Multi-agent system (MAS) is a distributed solution which composes two or more agents through consultation, cooperation and competition to realize the common goal. Single agent's ability is not enough to solve the whole problem. They must interact with each other in order to achieve the purpose of solving problems, planning, searching, decision-making and learning (Liu et al., 2017). A lot of work has already been done in the field of multi-agent systems and it is used for a wide variety of applications such as medical imaging (Bennai et al., 2017), transportation systems (Satunin & Babkin, 2014) and surveillance systems (Kariotoglou et al., 2015).

1.2 Problem statements

In an ideal case, accurate aerial images should have zero distortion and provide useful spatial information (Pai, 2010). However, it is impossible to achieve due to the distortion that is caused by different sources during the process of aerial images acquisition. Different types of geometric distortion usually are accumulated and not presents singly in an image (Gotovac et al., 2016). The effects of geometric distortion are found unequally in the entire image and cannot be directly measured (Jun, 2013). Furthermore, capturing imagery at low-altitude requires more image files for one application (Wenhao et al., 2014). Each

aerial image acquired during the same flight would not have the same appearance of distortions. Such ambiguous occurrence of distortion forms a higher complexity of degradation to the images. This diversity makes it impossible to have a universal method applicable to all rectification applications. Hence, image rectification has become a challenging and crucial foundation task in image processing for aerial remote sensing.

Generally, image registration and rectification can be done manually and automatically. The procedure involved in aerial image rectification, as shown in Figure 1.2 in Section 1.1.2, is tedious and time-consuming (Ahmand et al., 2013). The accuracy of rectification depends mainly on the selection of control points, the number of control points and the distribution of control points (Wang et al., 2012). A large number of control points are required to be well distributed on the whole scene captured in an aerial image. The selection of control points is commonly carried out manually which involves humans' factors such as experience, work attitude and ability to judge that might influence the accuracy of rectification. The traditional procedure for selection of control points is based on significant visible landmarks in images such as road intersections, building corners, edges and small circle points. However, the numbers of visible landmarks available that could be identified as control points in an image depending on the characteristics of the study areas (Nguyen, 2015).

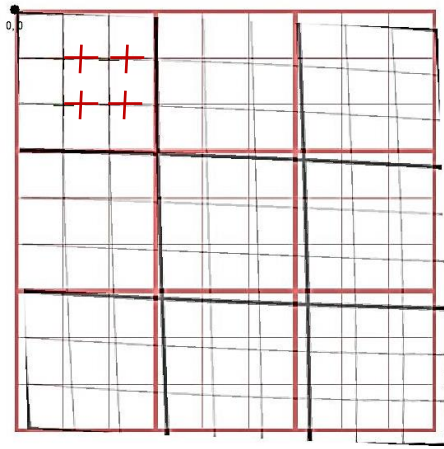
Manual registration is not feasible in the case when involving a large number of images and with times cited from a few hours to 4-5 days for registering a single image (Krishnan & Varghese, 2015). Although a lot of work has been done in automatic image registration and rectification, it is still considered as an open problem (Nag, 2017). Many automatic extraction methods from image processing field could be used conveniently to produce a

large number of corresponding control points. For example, a total of 2538 corresponding points could be extracted from the grid image used in the preliminary study as discussed in Chapter 5 with the Harris corner detection algorithm. More numbers of control points involved in rectification are not necessary would present better results. Excessive control points would introduce other displacements into the image and also lead to calculation difficulty (Wangfei et al., 2009). Hence, these prolific automatically-derived control points need to be filtered and selected in order to build the most accurate rectification model.

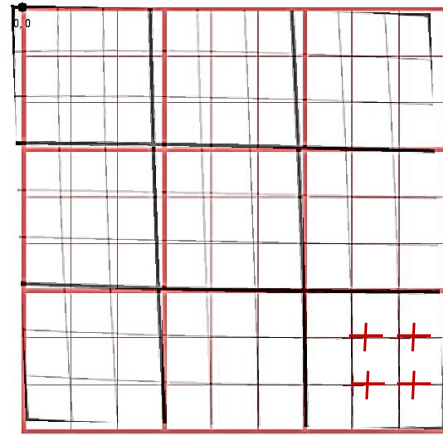
There were studies that tried to improve the accuracy of rectification by removing the control points which contribute to high residuals and lead to an increment to the total error (Nguyen, 2015). However, many trials usually have to be traversed to filter the original set of control points in order to select the best set of control points. Feature selection is the process of selecting relevant features for finding accurate data models. Finding the optimal feature subset is a difficult task in high-dimensional data (Kumar & Minz, 2014). The number of trials (N) involved in order to make the best transformation from a set of n original control points (C) by traversing all of the associated abilities among them under the condition of minimum limitation m of control points could be represented by Equation 1.2. With a certain n , the minimum of m leads to maximum of N , which is approximated to $2n$. Such computing complexity is claimed could not be solved by normal deployment of sequential searching algorithms (Nguyen, 2015). The same problem on using sequential approach is encountered when processing high resolution aerial images which will be discussed later. Therefore, other alternatives should be considered to handle the computing complexity and solve the tediousness of control points selection.

$$N = C_n^n + C_n^{n-1} + \dots + C_n^m \quad (1.2)$$

Control points are advised to be distributed evenly in the image. However, it is subjective to define the concept of evenly or uniformly distribution of control points. A different allocation of control points would cause the distorted image to be treated differently as shown in Figure 1.3. If the control points are crowded in some regions and sparsely distributed in other regions would result in over weighted model's coefficients around the crowded regions to influence the correction precision (Wang et al., 2011b). Though, most of the studies reviewed did not discuss in detail how their control points have been allocated or distributed.



(a) Four control points are allocated at the top left corner



(b) Four control points are allocated at the bottom right corner

Figure 1.3: Different allocation of control points would cause the distorted image to be treated differently

Precise geometric rectification of remotely sensed imagery normally requires knowing the geodetic location of features identifiable or ground control points in the image (Ren et al.,

2010). The determination of the exterior orientation parameters (e.g. position X, Y, Z) and attitude of an image at the time of exposure determined from the geo-referencing is an essential pre-requisite for the evaluation of imagery based on any type of data from terrestrial, airborne or satellite platforms (Elsharkawy & Habib, 2016). Ground control points from GPS/INS (Global Positioning System/Inertial Navigation System) based geo-referencing are generally the primary source for reliable geo-referencing information (Lo et al., 2015). However, as mentioned earlier, the deployment of ground control points is often expensive, requires fieldwork operations and is unpractical or even impossible for hazardous or inaccessible areas that lack a geodetic infrastructure and thus GPS/INS-based geo-referencing is not feasible (Zhuo et al., 2017). Although direct geo-referencing also could be acquired by the integration of on-board GNSS/IMU (Global Navigation Satellite System/Inertial Measurement Unit) localization sensors, the signals of ground control point could be vulnerable to interference such as broadcast television, ultra-wide band communications, over-the-horizon radar and cellular telephones (Oh et al., 2011). Hence, there is a need of alternative automated geo-referencing.

Aerial images have features of high resolution, complex background, and usually require large amounts of calculation (Chen et al., 2017). High resolution images could be obtained easily using a common digital camera (Tahar & Ahmad, 2011; Danielsson et al., 2016). One of the challenges faced is processing images with high resolution. In most digital imaging applications, it is desirable to have high resolution images rather than lower resolution images because more detailed information could be obtained from high resolution images (Zheng, 2014). Significant information might be lost if the high resolution images are simply reduced to lower resolution images. Features could be detected more accurately in a high resolution image but complex methods are required

(Gecen & Sarp, 2008). High data volume and complexity of the image processing algorithms used would affect the processing time (Hong & Zhang, 2007; Danielsson et al., 2016). Current image processing applications are mostly based on sequential approaches and image processing algorithms are getting more complex (Nini et al., 2010). Such advancement is claimed could not support the increasing use of high resolution remotely sensed images (Hussain et al., 2013; Rampi et al., 2014; Liao et al., 2017). The processes that require repetitive manual interaction, adjustment and adaption like processes in a conventional aerial images rectification are deemed to be labour-intensive and consequently error-prone (Hofmann et al., 2015). Thus, non-parametric aerial image rectification is a tedious process which involves human, software and technology.

1.3 Objectives

The general objective of this research is to construct a multi-agent system that automates the control point selection process for the non-parametric approach of aerial image rectification. The specific objectives of this research will focus on the following:

- i. To identify the local features that can be used to implement as the software agents for control point selection.
- ii. To design a multi-agent system that selects the control points for rectification based on the distribution and corner features of control points.
- iii. To integrate a cooperative multi-agent approach for the rectification process.

1.4 Scope of study

The study uses a set of grid images as a pilot study and aerial image from a fieldwork collection. The aerial image used in this study is captured using non-metric digital

cameras. The scenes of the aerial images are relatively flat areas and the evaluation of the study does not include different types of geographical surface. Satellite image is used as the reference image. The accuracy of satellite image is further validated with the map coordinates provided by the Land and Survey Department Sarawak.

Although the extraction and determination of corresponding control points in two images is a very important step, this study only covers the selection of control points. In this research, a number of corresponding control points in two images of a scene are given for the selection to produce the best set of control points to form the transformation function. Such controlled environment setting is to avoid or minimize the issues or problems that might bring from other phases such as multiple, duplicate and wrongly matched corresponding points.

This study focuses on enhancing control points selection of non-parametric aerial images rectification based on corner score and distribution impact index as their relevance of local features. The corner score of a control point is a measure derived using the Hessian determinant after the corner search for the control point with the Harris corner detection algorithm while the distribution impact index is calculated based on the area of Voronoi polygon.

Selection is tested with a different number of control points as the selection size and with various geometric transformations. The proposed approach is compared with expert selection and conventional residual selection. The performance of the rectification is measured using the total root mean square error (RMSE) of the same set of independent checkpoints from the reference image and the rectified one.

The proposed aerial images rectification with multi-agent approach is designed and developed according to the combination of agent-oriented methodologies, named ROADMAP (Role-oriented Analysis and Design for Multi-agent Programming) and RAP/AOR (Radical Agent-Oriented Process/Agent-Object-Relationship). The conceptual framework for the design is based on the Model-Driven Architecture (MDA) which consists of three phases, computation independent model (CIM), platform independent model (PIM) and Platform Specific Model (PSM). The implementation of the proposed approach is developed using Java Agent Development Framework (JADE) platform and Matlab programming.

1.5 Research significance

Aerial images are widely used for various purposes to assist in human's activities. Aerial images are used to monitor the changes of the earth environment. The increasing number of natural disasters recently due to climate change has also made the rapid development and usage of aerial images to collect near real time spatial information becomes an emerging trend and very critical.

Feature selection refers to pre-processing techniques that select the significant features to form the best subset from an input feature dataset. Feature selection is useful to reduce the cost of extracting features, to improve the classification accuracy and to improve the reliability of the estimation of performance. Control points selection and distribution are the key factors that contribute to the accuracy of rectification before being used in the process of transformation. Studying the feature selection and distribution of control points is believed could assist in improving the efficiency of rectification.

Most of the aerial images captured using common digital cameras are high resolution images. Such images require more time and memory to be processed. The increasing demand for aerial images has driven the studies of techniques involved in the processes of aerial image rectification and also prompted the requirement of developing new image processing software architectures. Since aerial image rectification is a complicated system which involving human, software and technology, a multi-agent system has the potential to assist in providing a way of structuring an aerial image rectification.

1.6 Structure of thesis

This section provides the outline of the chapters in this dissertation.

Chapter 2 presents a detailed literature review of this research. The discussion of this chapter begins with reviews on geometric distortion. Then, it discusses existing non-parametric image rectification of remote sensing, which includes control points extraction and selection, number of control points, control points distribution, geometric transformations and reference image accuracy assessment. Besides that, the review also includes the survey on software agents, which discusses the contributions of the multi-agent system in image processing, agent platforms and agent-oriented methodologies.

Chapter 3 presents the proposed methodology on agent-based control points selection. This chapter discusses the preliminary study, study site, the procedure of the research procedure. This chapter also discusses in details the design of the proposed multi-agent approach for aerial image rectification, which comprises of goal model, role model, organisation model, domain model, interaction, knowledge and agent behaviour model.

Chapter 4 discusses the implementation of multi-agent approach in aerial image rectification. This chapter presents the hardware and software used. This chapter also discusses the implementation of JADE based agent types named as Request agent, Rectifier agent, Corner agent and Distributor agent.

Chapter 5 discusses the experimental analyses and results evaluation. Firstly, this chapter presents the evaluation of the preliminary study. Then, the accuracy assessment of satellite image is discussed. After that, this chapter proceeds with the evaluation of control points selection by expert and proposed approach. The selections are evaluated based on the achieved RMSE of checkpoints when tested with different number of selected control points and with several geometric transformations. The achievement of the proposed approach is compared with the achievement of expert selection and conventional residual method. The agent communication of the proposed approach is presented.

Chapter 6 discusses the findings, accomplishments, limitations and future works for the research. This research demonstrates the accomplishment of integrating of a cooperative multi-agent system of aerial image rectification. The achievement shows the contribution of this research in the field of aerial image rectification.

1.7 Summary

This chapter gives an introduction and general description of remotely sensed aerial images. The discussion of background includes the description of distortion of aerial images, image rectification and agent-based approach in image processing. Problem statements are finalised before the objectives and scope of this research are discussed. The automatic registration techniques require a little or no operator supervision. However, current existing automated methods still facing problems with a large number of features

detected and uneven distribution of feature selected. These problems would influence the process of rectification and caused the optimal results could be produced at the end. The main goal of this research is to utilise a cooperative multi-agent system to non-parametric approach of aerial image rectification on feature selection. Besides that, this chapter also explains the research significance and the structure of the thesis. The following chapter would give a detailed discussion of the literature review of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The development of high resolution optical satellites has given a great contribution to the field of remote sensing. However, some areas in the world have cloudiness which is claimed as the biggest problem for photogrammetry due to their geographic localisation and atmospheric condition (Darwin et al., 2014). The problem of the cloudiness is claimed could delay beyond the normal stated period of two months estimated by the suppliers in order to get the high resolution satellite images. With the advancement of digital technology, the use of aerial images is suggested to overcome such problem instead of using satellite images (Darwin et al., 2014). Today, the study of aerial images acquired using non-metric digital cameras has become an active research field. Besides the concern of weather conditions, the acquisition of aerial images is adjustable with a different flying height of aircraft and controllable with different cameras (Zhang et al., 2017) which are flexible for various purposes with budget constraint (Tahar et al., 2014).

Aerial images are naturally distorted due to various sources. The occurrence of distortion in aerial images causes the images cannot be used directly for subsequent analysis before they are rectified. Image rectification is defined as an image pre-processing procedure to solve or reduce geometric errors found in a distorted image (Xiangyang et al., 2010; Liu et al., 2016). It is referred to as distortion correction in the perspective of photogrammetry and remote sensing. Another definition of image rectification found from the perception of digital image processing, it is referred to the process of projecting images onto a common image plane and aligning their coordinate systems (Bansal, 2011). Such process is used in

many computer vision applications, especially when merging images to build a composite map from many small images.

This chapter presents a detailed review of various related works on the non-parametric rectification for aerial images and satellite images. The discussion of this chapter begins with reviews on geometric distortion. Then, it presents the previous works on non-parametric image rectification approach such as the extraction of control points, the number of control points, the distribution of control points, geometric transformation and accuracy assessment for the performance evaluation of the rectification. Each process's functionalities and limitations are highlighted. This chapter also includes reviews on the reference image and accuracy assessment.

Besides that, the reviews on software agents and the multi-agent approach in the image processing are also discussed. Then, it continues with the reviews on agent platforms, agent-oriented methodologies and discusses a combination methodology of ROADMAP (Role-Oriented Analysis and Design for Multi-Agent Programming) and RAP/AOR (Radical Agent-Oriented Process/Agent-Object-Relationship) at the last section.

2.2 Geometric distortion

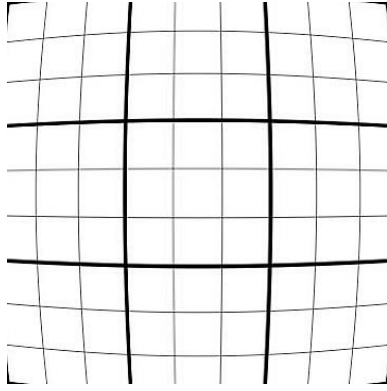
Geometric distortion is one of the common errors found in remotely sensed images (Jensen, 2015) and its effects are found unequally in the entire image (Wang et al., 2011b). Such occurrence causes great distortion between the remotely sensed image and the real world. Figure 2.1 shows the existence of distortion in an example of an aerial image overlaid with a satellite image of the same scene. In photography, Montabone (2010) agreed that image distortion in a photograph is not uniform. According to him, the two common types of image distortion in photography are lens distortion which is produced

inside the camera and perspective distortion which is produced by the relative position of the camera and the scene. Such distortions could be found significantly in digital aerial images (Aber et al., 2010; Li et al., 2011).

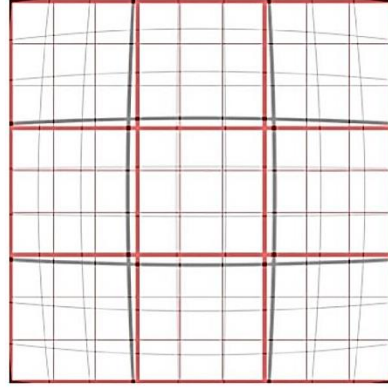


Figure 2.1: The overlaid of an aerial image with a satellite image of the same scene

Generally, a non-metric digital camera uses wide angle lens. Wide angle lens would bring along barrel effect into the aerial images captured (Aber et al., 2010). Figure 2.2 shows barrel effect on a grid image. Barrel effect would cause the straight lines to appear curved, bend toward the centre and shrink the image (Montabone, 2010; Linder, 2014) as shown in Figure 2.2 (a). It is found that the barrel effect has moved the points from their correct position which is depicted in Figure 2.2 (b) after overlaid the grid image with barrel effect with a grid image without barrel effect.



(a) Grid image with barrel effect

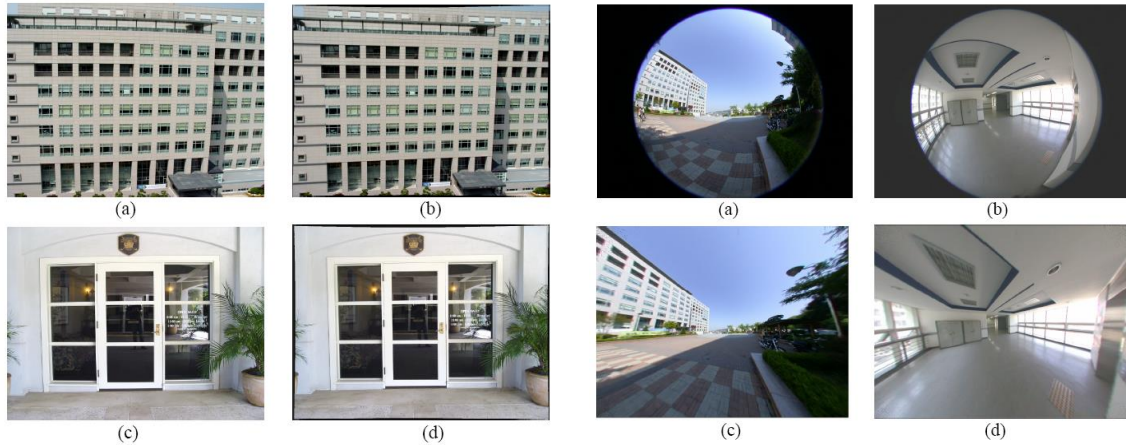


(b) Overlaid on grid image with barrel effect and grid image without barrel effect

Figure 2.2: A grid image with barrel effect

The methods of lens distortion correction are currently active in research too. Iterative bundle-adjustment is as the most exclusive method used in photogrammetry (Gonzalez-Aguilera et al., 2011; Fang & Zheng, 2016). However, its complex iterative manner due to lack of convergence, choosing an initial estimate and determining a stopping criterion (Hartley & Kang, 2007) has motivated researchers to look for alternative approaches.

For instance, Lee et al. (2009) discussed a non-iterative framework to determine the distortion vectors and distortion function directly using mapping and transformation technique. Their experimental results showed that their proposed method could handle the lens distortion presented in several indoor and outdoor testing images. The examples of the original testing image and corrected output image are illustrated in Figure 2.3. They only presented the result achieved using the corrected output image, there was no statistical value stated.



Result experimental #2:

Original images: (a) and (c), corrected
output images: (b) and (d)

Result experimental #3:

Original images: (a) and (b), corrected
output images: (c) and (d)

Figure 2.3: Experimental results by Lee et al. (2009)

In addition, the displacement caused by different types of lens used has been studied. For example, Xiang and Tian (2011) discussed the development of an automatic aerial image geo-referencing method for an unmanned aerial vehicle (UAV) based on navigation data and a camera lens distortion model. They showed the impact of radial and tangential distortion model on each pixel of the image. They found that points at the corners of the image are displaced by as much as 100 pixels for the 8 mm lens and 160 pixels for the 4.5 mm lens used in their test.

Aerial images are captured with a camera mounted on an aircraft. Inconsistencies in the attitude of the aircraft would indirectly bring in perspective effect into the images (Li et al., 2011; Liu et al., 2016). A certain degree of perspective distortion would appear if the camera is not parallel with the subject (Montabone, 2010). Aircraft attitude variations for example flight which rotates about x-axis would cause the image taken changes in scale along the y-axis, while flight which rotates about y-axis would cause the image taken

changes in scale along the x-axis (Paine & Kiser, 2012). Figure 2.4 shows the effect of horizontal perspective and vertical perspective in a grid image. Such effect has caused one side of the grid image appears as a different length than the other side.

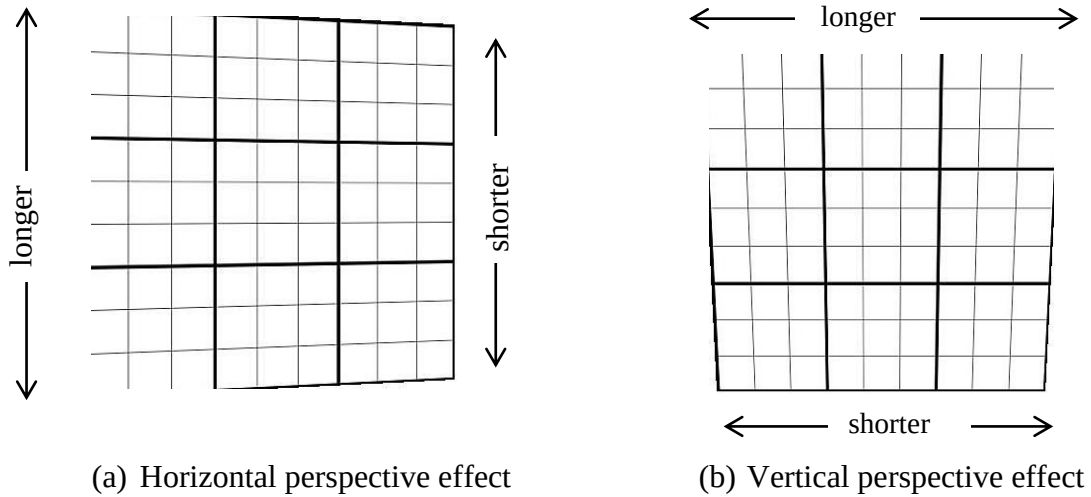


Figure 2.4: Perspective effect in a grid image

Different methods have been proposed by researchers to handle the distortion caused by inconsistencies in flight attitude. For instance, Yang et al. (2008) proposed real-time rectification based on the analysis of the aircraft flight height and attitude. They claimed that the imaging area would be changed with the changing of the aircraft height and attitude. They stated that the yaw of aircraft would cause rotation effect, the pitch and roll of aircraft would cause perspective effect while changing the flight height would cause images enlarged or scaled down. The rectification is done based on the height and attitude angle information. However, they have to depend on special devices such as radar altimeter and Inertial Navigation System for acquiring the height and attitude of aircraft.

Besides that, some studies have done on the image distortion evaluation. For example, Zhao et al. (2009) investigated image deformation caused by camera incline in multi-format aerial digital camera. They presented an inclined image would show as a regular trapezium. They formed the image deformation index with the ground sampled distance change ratio to the angle change of camera. The ratio of ground sampled distance change in an image derived in the study was based on single camera tilts in only one direction which is the y-axis with 15, 18 and 20 degrees.

2.3 Non-parametric image rectification

As mentioned in Section 1.1.2, image rectification can be done through parametric and non-parametric approaches. The parametric image rectification approaches need the imaging parameters such as sensor focal length, distance from the target, image acquire angle and etc. to process. However, often, these parameters are difficult to obtain and are not disclosed by providers due to the purpose of commercial technology protection (Xiangyang et al., 2010).

Non-parametric approach is the most commonly used because it is independent of the used platform for image acquisition or not requires any information about sensor used for the acquisition process (Tawfik et al., 2017). Many research works such as the study done by González et al. (2010) and Tsai & Lin (2017) have performed image rectification by applying non-parametric image rectification through image registration techniques. Image registration is the branch in computer image processing that aligns two or more overlapping images of the same scene that are taken at different times, from different viewpoints, and/or by different sensors. The general procedure of non-parametric image rectification is shown in Figure 1.2. The main advantage of using non-parametric approach

is that this approach does not require the knowledge of imaging mechanisms which could cause distortion. Moreover, the distortion caused by inconsistencies in the attitude of the aircraft is claimed can only be rectified using this approach (Jensen, 2015).

Control points, which consist of ground control points or image points play an important role in non-parametric image rectification. Control points are also called as tie points or reference points. These points are used to compute the transformation parameters of the sensed images to rectify the image (Tsai & Lin, 2017). Normally control points are chosen from the centre of gravity, line endings and distinctive points of salient objects in the image such as line intersections, edges and corners (Bisht et al., 2014; Patel & Shah, 2014).

Ground control points (GCPs) are points on the surface of the earth where both image coordinates and map coordinates can be identified. It means that the remotely sensed images could be rectified by generating the mapping transformation through the matching of the control points in the remotely sensed images with the corresponding true positions in ground coordinates (e.g. latitude and longitude) measured from a Global Positioning System (GPS) ground reference device. This ground coordinate is known as the ground control points (GCPs).

There is a problem when using GCPs to rectify remotely sensed images. Surveying and collecting GCPs is costly and time-consuming (Tsai & Lin, 2017). Therefore, instead of relying only on GCPs when rectifying a remotely sensed image, one may geo-register the image, which is generated without GCPs, to a previously geocoded image over the same area (Eltohamy & Hamza, 2009; Tsai & Lin, 2017). This is known as the image-to-image registration. Image-to-image registration would use several discernible image points identified from the distorted image to transform with coordinates of corresponding points

from a reference image which has been rectified or corrected before. Such image rectification approach should project the distorted images into a certain reference image and simultaneously keep the geometric position, shape, dimension and orientation of objects unchanged (Wang et al., 2011b). A summary of previous works on image registration on the remotely sensed image is shown in Table 2.1.

Eltohamy and Hamza (2009) mentioned that image rectification could be performed through image registration and image resampling. In their work, the authors used two images acquired in Cairo, Egypt, in the year 1999 by LANDSAT 5. The sizes of the image are 490 x 697 pixels and 745 x 939 pixels, respectively. The two satellite raw images are then rectified by referring to two geometrically corrected LANDSAT images of the same area which has been corrected using ground control points. The authors manually extracted and matched the control points in both reference and sensed images. The author did not explicitly discuss the setting that they have used in their paper and therefore it is impossible to repeat the experiment. However, the authors concluded that to obtain high accuracy of geometric correction of remote sensing satellite images, the location and distribution of selected GCPs are important.

González et al. (2010) have also studied image rectification via image registration. The authors presented an automatic method to extract control points for accurate registration of high-resolution QuickBird images (0.6 metres/pixel). They extracted a set of control points using Harris corner detection. Then, they generated a minimal distribution of these control points based on the relief information provided by digital terrain models (DTM). Later, the control points in the sensed image are matched with the points in the reference image using an affinity-based feature tracker that considered multiple scales for the images and relied

on a variant of the sum of square differences (SSD). The authors claimed that they achieved significant speedup in the process. In order to evaluate the method performance, they have compared the registration accuracy obtained using the resultant control point set with respect to uniform and random distributions. The uniform distribution is obtained by selecting control points according to a regular grid of squared cells of 50 pixels of side, while the random distribution is obtained by arbitrarily selecting the same number of control points than the uniform one. The accuracy of the registration process has been accessed by comparing two geometric errors: root mean square error (RMSE) and circular error (CE90%) of a set of independent control points manually identified, achieving errors under 1.4 metres with control points distributed according to the DTM information. The result is better when compared with respect to uniform and random distributions, yielding better results in terms of accuracy and efficiency. The findings of this paper confirmed that the distribution of control is critical to the accuracy of image rectification process through image registration.

Tsai and Lin (2017) introduced a novel Accelerated Binary Robust Invariant Scalable Keypoints (ABRISK) algorithm to extract features points from aerial images and filter out the uncorrected features points using “Sorting Ring” algorithm to speed up the matching process of features points to identify control points. The authors claimed that the proposed ABRISK approach outperforms the vector-based Scale Invariant Feature Transform (SIFT) approach where radiometric variations exist. Radiometric variation usually occurs in multitemporal remote sensing images due to the variation in solar elevation and cloud shadow. In their testing, ABRISK is 19.2 times and 312 times faster than SIFT for square image sizes of 1,000 and 4,000 pixels, respectively. They also reported that ABRISK is 4.7 times faster than Binary Robust Invariant Scalable Keypoints (BRISK). Furthermore, the

positional accuracy of the UAV orthoimage after applying the proposed image registration scheme is improved by an average of root mean square error (RMSE) of 2.58 metres for six test orthoimages whose spatial resolutions vary from 6.7 centimetres to 10.7 centimetres. Their research demonstrates that selecting the “correct” control points is more important than selecting more control points for image registration accuracy and speed.

Sedaghat and Mohammadi (2018) also proved that image registration technique can be applied to automatically select and match the control points in a sensed image and reference image in order to reduce the distortion in the sensed image. In their paper, they proposed the uniform competency (UC) based local feature detector, aims to extract robust local features (control points) with the desired quantity and distribution quality. The proposed UC method is implemented and compared in five feature detectors which include scale-invariant feature transform (SIFT), speeded up robust features (SURF), scale-invariant feature operator (SFOP), maximally stable external region (MSER) and Hessian-Affine. The quality and density of the features is controlled using a novel competency constraint and a multi-level gridding strategy, which provides a better representation of local feature quality and spatial distribution. The authors presented all experiment results in the graph format and no specific numerical result is mentioned. Base on the graph, it can be concluded that the UC based local feature detector work best with SIFT and SURF algorithms for remote sensing image matching. UC-SIFT and UC-SURF could match three times more matching points than the original SIFT and SURF. However, with more matching points, the RMSE does not reduce significantly. Averagely, only 0.1 pixels of RMSE reduction is observed.

Table 2.1: Previous works on non-parametric approach remotely sensed image rectification

Author	Image	Feature Extraction	Feature Matching	Comment
Eltohamy & Hamza (2009)	Two geometrically corrected mages, (of the same area, size, and imaging band) are used as reference images. Reference images are acquired in 1999 by LANDSAT 5, were geometrically corrected using maps (image-to-map) registration.	Manually select a set of 10 control points at “good” locations. The defined “good” control points identified are road intersections, airport runway intersections, and bends in rivers features which are identifiable.	Manual matching	Stated that the number of control points is depending on the mapping function. The 1 st , 2 nd and 3 rd order polynomial transformation are used. The paper describes a “good” distribution of GCPs means that the first 3 GCPs (min number in case of 1st order) should be distributed far away from each other. However, it does not specifically specify how far they should be.
González et al. (2010)	Reference and sensed images: old and new Panchromatic QuickBird image pairs & Digital Terrain Model.	Harris corner and edge detector.	Control points in the sensed image are matched with points in the reference image using an affinity-based feature tracker that considers multiple scale for the images and relies on a variant of the sum of square differences (SSD) (Lucas & Kanade, 1981).	Proposed an algorithm to use the information from DTM to decide the density of CPs on each region of the image to generate a minimal distribution of control points thus achieving significant speedup in the process without sacrificing accuracy. The accuracy of the registration

Table 2.1 Continued

				process has been assessed by comparing the geometric errors (RMSE and CE90%) of a set of independent control points manually identified and achieves errors under 1.4 metres on QuickBird image pairs (0.6 metres/pixel).
Tsai & Lin (2017)	The input images were a UAV orthoimage derived without exploiting any GCPs and an accurate reference orthoimage produced by a traditional photogrammetric process.	Accelerated Binary Robust Invariant Scalable Key-points (ABRISK).	The author uses “Sorting Ring” to filter uncorrected features pairs.	This paper provides a good review and justification on which features descriptor is chosen. The ABRISK improve by average RMSE of 2.58 metres for six test orthoimages whose spatial resolutions vary from 6.7 centimetres to 10.7 centimetres.

Table 2.1 Continued

Sedaghat & Mohammadi (2018)	Two different dataset classes, synthetic images (ETM, WorldView2) and real images (IRS-1C, SPOT 4, SPOT 6, SPOT 5, Worldview2, QuickBird, GeoEye1, ASTER). In the synthetic image, three different transformations are applied for the simulation: scaling, rotation and viewpoint changes.	Five local feature detectors: SIFT, SURF, SFOP, MSER and Hessian-Affine are used.	The proposed approach, namely uniform competency (UC) based local feature detector, aims to extract robust local features with the desired quantity and distribution quality, as well as for various detectors with different properties. The quality and density of the features are controlled using a novel competency constraint and a multi-level gridding strategy, provides a better representation of local feature quality and spatial distribution.	Most local feature detectors and current image matching approaches do not provide any idea of the quality of the feature distribution in both the spatial and scale space. There have been a few papers that explicitly address the problem of the quality of the feature distribution, especially for scale space and remote sensing images.
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The review of the previous works also draws the conclusion that the important factors that could contribute to the non-parametric image rectification comprise of the selection of control points, the distribution of control points and the geometric transformation used. Rectification accuracy would be affected if lacks of control points and not evenly distributed (Deng et al., 2014). A proper transformation function would smooth the noise and the small inaccuracies among the control point correspondences (Nag, 2017). The review on reference image, extraction of control points, the distribution of control points and the geometric transformation are discussed in the next section, respectively.

2.4 Reference image

Image-to-image based registration is gaining research and practical interest (Oh et al., 2010; Chen & Tseng, 2016; Zhou et al., 2017). Through the image-to-image registration, reference images provide the newly acquired or rectified images with the ground control information to obtain geo-referencing. Hence, the reference data quality has become one of the key components to achieve accurate geo-referencing and the success of image-to-image registration.

It is hardly the case to obtain the ideal reference images that are acquired with the same sensor at a similar geometry, at a similar time and season as the target remotely sensed image. The sensor used for the reference image is recommended to be of high spatial resolution, high temporal resolution and high potential accuracy (Oh et al., 2010). However, different images such as satellite images, orthophotos and geo-referenced images have been studied and used as reference image data in the image-to-image approach for image registration and geo-referencing.

Oh et al. (2010) proposes an automatic geo-referencing method based on high-resolution stereo satellite images to overcome the requirement of “true” ortho-rectified images and accurate digital surface model (DSM). They have carried out an experiment for a strip of aerial images and IKONOS stereo images with the combination of SIFT (Scale-Invariant Feature Transform) and RANSAC (RANdom SAmples Consensus) as feature extraction and matching method. Before the real experiment, a simulation was performed to check how accurate exterior orientation parameters (EOPs) can be estimated based on 1 metre high resolution satellite images. Nine ground control points were evenly distributed over the entire aerial image. The EOPs of aerial images are estimated from ground control information obtained from the matching points. The EOPs were compared to reference EOPs known from the bundle adjustment using accurate ground control points. The result showed that most aerial images have EOPs positional accuracy of less than 20 metres. The ground restitution accuracy for tie points was computed. The bundle adjustment without outlier removal shows horizontal accuracy up to 3.45 metres and vertical accuracy up to 5.77 metres. However, the bundle adjustment with outlier removal improves horizontal accuracy to 2.18 metres and vertical accuracy to 4.53 metres. Hence, they concluded that accurate EOPs could be obtained and the ground restitution accuracy can be improved up to the level that can be expected from the positional accuracy of stereo satellite images and confirmed that stereo satellite images could be used as reference data.

Chen and Tseng (2016) developed an automatic process of matching historical aerial images by SFIT for handling the great number of images by computer vision. They proposed to use image feature points of more photographs to build control image database. Every new image will be treated as a query image. If feature points of query image match the features in the database, it means that the query image probably is overlapped with

control images. They manually selected control points from the FORMOSAT-2 satellite image for registration of historical aerial photographs. A total of 1357 tie points and 17 control points are used. These control points were added to network adjustment to calculate the parameters of two-dimensional affine transformation and two-dimensional projective transformations for coordinate transformation. They assessed the accuracy of control point after network adjustment. The precisions of transformation achieved are all less than one pixel. The registration accuracy of the control point is about one meter for two-dimensional projective transformation and it is better than two-dimensional affine transformation which is several meters.

Zhou et al. (2017) investigated automatic geo-registration of an individual UAV image by matching the UAV image with a previously taken geo-referenced image such as an individual aerial or satellite image. They proposed to use histogram voting instead of the common used RANSAC scheme to extract correct matched features. The matched features are used to geo-register the whole UAV image block towards the reference image data. They stated that the UAV images can be geo-localized in a global coordinate system when the reference images offer high geo-referencing accuracy. They created ground truths of feature points correspondences using manually selected and automatically detected matching correspondences. Six to seven evenly distributed ground checkpoints were selected across the survey area and their actual coordinates were measured using an RTK GNSS (Real-time Kinematic Global Navigation Satellite Systems) receiver. The ground checkpoints were marked in the UAV images and their theoretical coordinates were computed by triangulating the geo-registered UAV images. The errors calculated are around 2 meters. Besides that, the coordinates triangulated by geo-registered UAV images were compared with the identical points on the reference image to validate the accuracy of

co-registration. Since the reference image was an aerial orthophoto, the corresponding coordinates of the reference image were manually looked up in the orthophoto. They reported a comparable global accuracy as the reference images with the evaluation of points from geo-registered UAV images and terrestrial measurements from RTK GNSS shows the achievement of 0.5 metres horizontal and 1.5 metres vertical deviations.

As satellite optical sensor technology progresses, high resolution satellite images have been globally available and newer high resolution satellite images offer better spatial resolution with decreasing revisit time and increasing positional accuracy up to sub-pixel when bundle adjusted using ground control points (Oh et al., 2010). Many high-resolution satellite images have been available such as IKONOS (0.82 metres), QuickBird (0.65 metres), SPOT-6 (1.5 metres), WorldView-1 (0.46 metres) and GeoEye-1 (0.46 metres). High resolution satellite images have a relatively large swath width which usually more than 10km and are used to create worldwide image maps such as Google Earth.

Satellite images can be acquired at different processing levels regarding their geometric quality. Commercial satellite images already have much of the predictable systematic errors removed using ephemeris of the platform and known internal sensor distortion characteristics (Thenkabail, 2015). Resolutions of less than 1m are common nowadays and enable users to distinguish fine detail on the earth's surface such as buildings and trees (Agrafiotis & Georgopoulos, 2015). Other errors can be corrected by matching image coordinates of physical features recorded by the image to the geographical coordinates of the same features collected from a map or global positioning system (Dave et al., 2015). Due to high efficiency, large coverage and not being limited by spatial regulation, satellite imagery becomes one of the important means to acquire geospatial information (Ma et al.,

2017). Hence, high resolution satellite images have good potential as a ground control source for aerial image geo-referencing and image registration (Oh et al., 2010).

2.5 Extraction and selection of control points

Control points are usually the key input for the process of image rectification (Eltohamy & Hamza, 2009). Hence, the selection of control points is a crucial step for image rectification (Tsai & Lin, 2017; Sedaghat & Mohammadi, 2018). Control points should be the features that could be easily identified like building corners, river crossing, road intersections and centre of special shape (Gu et al., 2011). Selection of control points that are done manually is affected by individual experience, work attitude and time-consuming (Nguyen, 2015).

A lot of corner extraction, feature extraction, feature description and matching algorithms from the field of image processing have been applied to automate the selection of control points. Feature extraction refers to the process of identifying interest points in an image that can be used to describe the contents of the image such as edges, corners and blobs (Salahat & Qasaimeh, 2017). A feature descriptor is denoted as a numerical vector that encodes the properties of the local feature image neighbourhood (Sedaghat & Mohammadi, 2018). Table 2.2 shows some of the commonly used corner extraction, feature extraction and description algorithms that have been utilised for that purpose.

The popular corner extraction, feature extraction and feature description methods that normally used in automated selection of control points include Harris, SUSAN (Smallest Univalued Segment Assimilation Nucleus), MSER (Maximally Stable Extremal Regions), Hessian, SIFT (Scale-Invariant Feature Transform), SURF (Speeded up Robust Features) and BRISK (Binary Robust Invariant Scalable Keypoints) (Hassaballah et al., 2016;

Salahat & Qasaimeh, 2017; Sedaghat & Mohammadi, 2018). Salahat and Qasaimeh (2017) stated that most of the automated feature extraction and description algorithms require intensive computations especially when the algorithms are used with high-definition video stream or with high-resolution satellite imagery applications.

Combination methods and improved methods have been studied and proposed as well. For instance, Xiaolian et al. (2008) introduced an adaptive ground control point extraction algorithm for remote sensing image by introducing gray gradient tracking method. The proposed corner extraction algorithm would confirm the direction of the corner by analysing eight-direction of gray gradients and adopting neighbourhood gray gradient with two thresholds of gray gradient in order to determine the correct corner. They claimed that although SUSAN operator is non-directional, and easy eliminating noise which seems to be a good corner extraction method, there is a difficulty in choosing the correct luminance and geometry threshold. Other examples like Konugurthi et al. (2016) proposed to apply SIFT and genetic algorithms in their study on orthorectification of very high resolution remote sensing images and Yuan et al. (2017) proposed to use the combination of SIFT, SURF and FAST algorithms for poor textural images based on graph theory.

After local features detection and description from the reference and sensed images, the correspondence matching process is established using a particular similarity measure such as the Euclidean or Mahalanobis distance. The matching is to find the best correspondence point in one image by comparing with the points from another image. The detected features can be matched by means of the image intensity values in their close neighbourhoods, the feature spatial distribution, or the feature symbolic description (Kaur, 2012).

Table 2.2: Corner extraction, feature extraction and description algorithms that have been applied for selection of control points

Corner/Feature Extraction Techniques	Description	Rotation Invariant	Scale Invariant	Affine Invariant
Harris corner detection (Harris & Stephens, 1988)	Corner and edge detector based on local auto-correlation function.	Yes	No	No
SUSAN (Smith & Brady, 1997)	Corner and edge detector based on gradient convolution of a circular mask of fixed radius to every pixel.	Yes	No	No
MSER (Matas et al., 2004)	Surface based multi-scale homogeneous affine region detector. Absolute difference between average intensity of all pixels inside the regions and its boundary.	Yes	Yes	Yes
Hessian (Beaudet, 1978)	Blob based detector based on second-order image derivatives computed using Gaussian function.	Yes	No	No
SIFT (Lowe, 2004)	Blob based detector and histogram-based descriptor. Identifies potential points in scale space by using a difference-of-Gaussian function.	Yes	Yes	No
SURF (Bay et al., 2008)	Blob based detector and descriptor. Detects feature points using Hessian matrix and second-order Gaussian partial derivatives with a set of box filters.	Yes	Yes	No
BRISK (Leutenegger et al., 2011)	Blob based detector and descriptor. Detect feature by computing the brightness comparisons to form a binary descriptor string.	Yes	Yes	No

2.5.1 Harris corner detection

Features based on point localization are the most commonly used for image registration (Patel & Shah, 2014). Most algorithms used for point detection rely on the idea of “corner”, a salient point well perceived by human observers and invariant to geometrical transformations. The variation of an image should be intense around corners and relatively mild around edges and surfaces (Yang et al., 2017). Methods based on first derivative analysis, such as Harris detector, are claimed more robust than the methods that using the second derivative or Gaussian curvature because the latter is very sensitive to noise (Patel & Shah, 2014).

The basic idea of Harris corner detector is to give a mathematical approach for determining whether a point shows a significant change in all the directions to designate as a corner point (Hassaballah et al., 2016). The Harris corner detector is a popular interest-point detector due to its simple extraction algorithm with strong invariance to translation, rotation and illumination variation with relative tolerance of image noise (Fan, 2011). It is claimed that Harris corner detector has been proved to be more stable and anti-noise compared to Moravec and SUSAN operator (Pang et al., 2015).

The Harris corner detection algorithm measures the change, E , at certain point location (x, y) after a small displacement (u, v) as shown in Equation 2.1. Based on Equation 2.1, $I(x, y)$ represents the image intensity, $I(x + u, y + v)$ is the image intensity after change and w is a window function, which usually a Gaussian function as shown in Equation 2.2. Equation 2.2 can be expressed in matrix form as shown in Equation 2.3, where M is a 2×2 matrix computed from image derivatives as shown in Equation 2.4. Harris corner response, R , is measured using Equation 2.5, where $\det(M)$ is the value of the determinant

of matrix M , $tr(M)$ is the trace of matrix M and k is an adjusting value which give the best results with 0.04 to 0.06 (Ye et al., 2009).

$$E(x, y) = \sum_{u,v} w_{u,v} [I(x + u, y + v) - I(u, v)]^2 \quad (2.1)$$

where (x, y) is the point location, w is window function, (u, v) is a small displacement, $I(x, y)$ is the image intensity and $I(x + u, y + v)$ is the image intensity after change.

$$w_{u,v} = \exp - (u^2 + v^2)/2\sigma^2 \quad (2.2)$$

$$E(x, y) \cong [x \ y] M \begin{bmatrix} x \\ y \end{bmatrix} \quad (2.3)$$

where M is a 2×2 matrix computed from image derivatives I_x and I_y in x and y directions, respectively.

$$M = \sum_{u,v} w_{u,v} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \quad (2.4)$$

$$R = \det(M) - k (tr(M))^2 \quad (2.5)$$

where $\det(M) = I_x^2 \times I_y^2 - (I_x I_y)^2$, $tr(M) = I_x^2 + I_y^2$.

The Harris corner detector is not invariant to scale and affine transformations (Mikolajczyk & Schmid, 2004; Tuytelaars & Mikolajczyk, 2008). Mikolajczyk and Schmid (2004) have improved the Harris corner detector with Laplacian-based scale selection and named it as

Harris-Laplace detector which is invariant to scale. The Harris-Laplace detector computes a multi-scale representation for the Harris corner detector and selects points at which a local measure is maximal over scales. In the case of an affine transformation, the scaling can be different in each direction. However, the Harris-Laplace detector is designed to deal with uniform scale changes. Hence, it fails in the case of significant affine transformations. The Harris-Laplace detector is then extended to deal with significant affine transformation which named as Harris-Affine detector.

2.5.2 Scale-invariant feature transform

Besides corner extraction methods, some researchers investigate the methods of using feature descriptors to select the control points. For example, Deng et al. (2010) proposed to use Scale-invariant feature transform (SIFT) feature descriptors with least squares matching for processing the UAV remote sensing images. SIFT feature extractor was developed by Lowe (2004) for the detection and description of local features. SIFT is proven to be invariant of rotation, scale, illumination and even a certain degree of changes in viewpoint (Karim et al., 2017).

SIFT extracts the interest points in an image using a series of Difference of Gaussian (DoG) scale space filtering operators. Equation 2.6 shows the convolution of DoG computed at a constant multiplicative factor, k and scale, σ with image $I(x,y)$. A descriptor is then computed for each detected point based on local image information. SIFT descriptor is composed of a gradient orientation histogram weighed by the gradient magnitude of sample points within a region around the feature point (Hassaballah et al., 2016).

$$D(x, y, \sigma) = (G(x, y, k\sigma) - (G(x, y, \sigma)) * I(x, y) \quad (2.6)$$

where G is Gaussian operator, I is image, (x, y) is location coordinates of pixels in an image, k is a constant multiplicative factor and σ is scale parameter.

Deng et al. (2010) attempted to solve the problems of images with characteristics of instability, large swing-tilt angle and uneven overlap. SIFT would choose the feature points and calculate the local neighbourhood's gradient direction histogram of the feature points as descriptors. They remarked that using SIFT could obtain a larger number of feature points; however, this would cause the matching time increased. It is also commented that the least squares matching has the advantage of giving high precision that could reach up to sub-pixel level, but if the initial value is not determined, the matching would produce greater error rate.

Another improvement on SIFT has also been developed by Yu and Morel (2011) through Affine-SIFT (ASIFT). ASIFT simulates a set of sample views of the initial images, obtainable by varying the two camera axis orientation parameters, namely the latitude and the longitude angles, which are not treated by the SIFT method. Then it applies the SIFT method itself to all images thus generated. Thus, ASIFT covers effectively all six parameters of the affine transform. The method is mathematically proved by them in their earlier study (Morel & Yu, 2009) to be fully affine invariant.

2.5.3 Speeded up robust features

Another frequently used feature descriptors in feature extraction are Speeded up robust features (SURF) as reported by Pang et al. (2015). The SURF algorithm was proposed by

Bay et al. (2008) to extract feature points. It is invariant to image scale, rotation and illumination. It is partially invariant to affine transformation.

Pang et al. (2015) proposed a hybrid SAR (Synthetic Aperture Radar) image registration algorithm which is based on SURF and mutual information (MI). SURF algorithm was used to look for the regional extreme value of the corresponding feature points. The process was then followed by Harris corner detection algorithm to extract corner features from the detected feature points which attempt to achieve good initial value in the first stage. They computed the root mean square error (RMSE) to evaluate the algorithm performance. Their result showed that the proposed hybrid method gives a better registration result with lower RMSE of 5.31 pixels, compared to the result obtained using the single method of SURF with RMSE of 9.62 pixels and mutual information with RMSE of 8.73 pixels. It is reported that SURF has a similar process with SIFT algorithm but SURF has higher computation speed compare to SIFT.

SURF is improved by using fast Hessian matrix to detect interest points and using second order Gaussian partial derivatives based on box filters to filter the image points. It uses a scale invariant blob detector based on the determinant of Hessian matrix for both scale selection and locations (Hassaballah et al., 2016). Hessian matrix, $H(p, \sigma)$ is described as Equation 2.7, where $p = (x, y)$ is a point, σ is scale and $L_{x_i y_i}(p, \sigma)$ is the convolution between second-order derivative and image I at point p . The same procedure is done for other parameters: $L_{x_{i+1} y_i}$, $L_{x_i y_{i+1}}$ and $L_{x_{i+1} y_{i+1}}$. It approximates the second order Gaussian derivatives with the help of integral images using a set of box filters. The integral image ($I_{\Sigma(p)}$) at point $p = (x, y)$ is used for summing up intensities of each pixel in the image (I) as denoted by Equation 2.8. SURF is based on sums of two-dimensional Haar wavelet

responses and makes an efficient use of integral images. The SURF scale space is built by maintaining the same image and changing the box filter size (Jolhip et al., 2017).

$$H(p, \sigma) = \begin{bmatrix} L_{x_i y_i}(p, \sigma) & L_{x_{i+1} y_i}(p, \sigma) \\ L_{x_i y_{i+1}}(p, \sigma) & L_{x_{i+1} y_{i+1}}(p, \sigma) \end{bmatrix} \quad (2.7)$$

where $p = (x, y)$ is a point, σ is scale and $L_{x_i y_i}(p, \sigma)$ is the convolution between second-order derivative and image I at point p .

$$I_{\Sigma(p)} = \sum_{i=0}^{i \leq x} \sum_{j=0}^{j \leq y} I(i, j) \quad (2.8)$$

2.5.4 Genetic algorithm

Nguyen (2015) proposed to use genetic algorithm (GA) as an approach to optimise the selection of ground control points. They suggested an optimal criterion for accuracy assessment through consideration of global accuracy of the transformation. A genetic algorithm is an optimization technique operated on a population of n artificial individuals (Nguyen, 2015). Individuals are characterised by chromosomes and the chromosome is a string of symbols known as genes. Individuals are evaluated by the calculation of a fitness function. The global accuracy expression ($\bar{s}$) as denoted in Equation 2.9 which is used as the fitness function and is computed for a given set of control points. Genetic algorithm performs three basic genetic operators, which are selection, mutation and crossover to evolve through successive generations. It is claimed that genetic algorithm search for the optimal solution using the fitness function through the evolution. The author stated that this

method is able to provide an optimal selection based on all the test results obtained, however, it is computationally demanding.

$$\bar{s} = \frac{1}{m} \sum_{i=1}^m (v_{x'j}^2 + v_{y'j}^2)^{1/2} \quad (2.9)$$

where m is the total of pixels in image space and $v_{x'j}^2, v_{y'j}^2$ are the variances of the map coordinates calculated at pixel i .

2.6 Number of control points

Although it is claimed that the rectification image areas should be surrounded by control points (Linder, 2014), it is reminded that too many control points would bring other displacements into the image and lead to calculation difficulty (Wangfei et al., 2009). The accuracy of rectification is reported could be improved by removing the control points that contribute to high residuals which lead to an increment to the total error rate (Nguyen, 2015). Hence, many trials have to be carried out repeatedly to obtain a set of control points that could suit the transformation model used and give the lowest error.

The number of control points used in the rectification is affected by several factors such as the geometric transformation model, the method of collection, physical environment of the study site and the user's expected accuracy (Toutin, 2004, Wu et al, 2008). For instance, the minimum number of control points used could be determined based on the order of the Polynomial transformation as shown in Equation 2.10 (Tawfeik et al, 2016). These numbers of control points are necessary to fulfil the mathematical requirement to evaluate the transformation.

$$N = \frac{(t + 1)(t + 2)}{2} \quad (2.10)$$

where N = minimum number of GCPs, t = order of the polynomial.

Commonly statistics texts suggest that a sample size of at least 30 is required to achieve reliable estimates, but Mather and Koch (2011) stated that their experience suggests that ten (10) to fifteen (15) control points are an acceptable number for a first order fit and a small image area (up to 1024^2 pixels) with medium resolution imagery. However, they also agreed that more control points are needed in areas of moderate relief or for images acquired by instruments with a wide field of view. According to Tahar (2013), a number of eight (8) to nine (9) GCPs is usually established for an area of dimension $400 \times 300\text{m}$ and fifteen (15) to twenty (20) checkpoints are established for data validation and accuracy assessment.

The impact of using a different number of control points also has been studied by Wang et al. (2011b). The purpose of their study is to confirm the cell size for the uniform distribution. In their study, control points have been manually selected started from a total number of six control points to twenty-four control points for an interval of two. A line graph of control points' number against root mean square error rate was plotted at the end of their study as illustrated in Figure 2.5. It was shown that the curve is almost flat when the number of control points is more than sixteen with root mean square error (RMSE) around six pixels. Their result shows that the achievement of RMSE is high when using less than ten control points. The achievement of RMSE starts to decrease when the number of control points used is increased from ten to sixteen. The achievement of RMSE seems to be consistently low when using sixteen to twenty-four control points in their study.

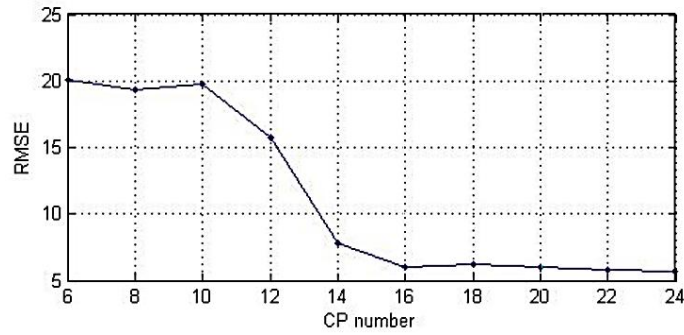


Figure 2.5: The RMSE curve with different number of control points (Wang et al. (2011b))

2.7 Distribution of control points

The distribution of control points also plays an important role in image rectification. Most local feature detectors and current image matching approaches do not provide any idea of the quality of the feature distribution in both the spatial and scale space (Sedaghat & Mohammadi, 2018). A few papers have explicitly addressed the problem of the quality of the feature distribution, especially for scale space and remote sensing images. The impact of different distributions of control points was found in the study done by Zagorchev and Goshtasby (2006); and Guang and Weili (2011).

There were four sets of distribution of control points used in the test done by Zagorchev and Goshtasby (2006) as showed in Figure 2.6. The distribution is classified based on the influence of the spacing of the control points. They commented that when the distribution of the control points is very irregular, large errors might be found in areas where large gaps exist between the control points and the equations of transformation might become ill-conditioned.

Guang and Weili (2011) tested on seven different kinds of distribution of ground control points and checkpoints in their experiments as shown in Figure 2.7. The residuals of ground control points and checkpoints are used to evaluate the image correction results. They found that the residual error of checkpoints is relative to the distance between checkpoints and the area of control points. They also described that the area near to the ground control points is more accurate and the well-distributed control point in the entire image can improve the accuracy and reliability of the results.

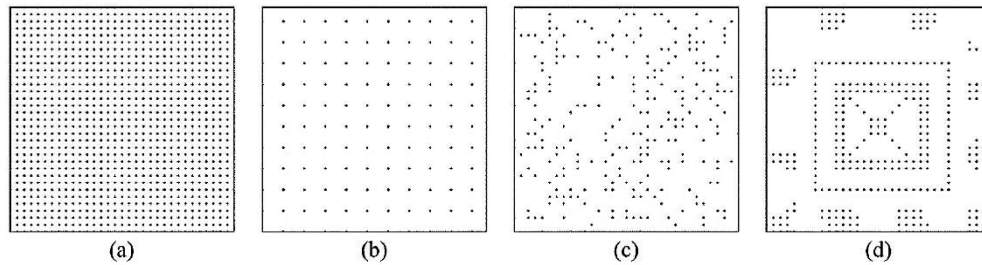


Figure 2.6: Grid of control points with (a) uniformly spaced, (b) larger uniform spacing, (c) randomly spaced and (d) varying density (Zagorchev & Goshtasby, 2006)

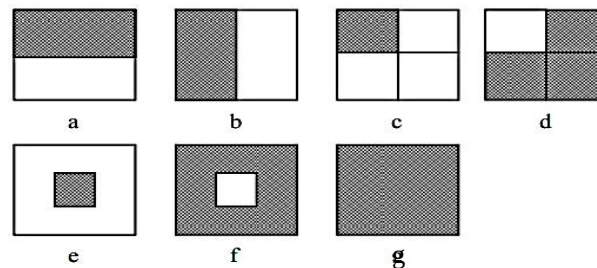


Figure 2.7: Design of distributions where ground control points are placed in the shadow area and checkpoints placed in the blank area (Guang & Weili, 2011)

Richards (2013) stated that good control points' distribution is defined as when the points are distributed as nearly as possible in a uniform manner around the edge of the image segment with some points located across the centre of the image as shown in Figure 2.8. The distribution techniques done in previous works which are reviewed include random

distribution, regular grid, uniform index and Voronoi diagram. These methods are described in the subsection below. Regular grid and random distributions are implemented in most of the popular commercial packages of remote sensing like ERDAS, ENVI and PCI (González et al., 2010).

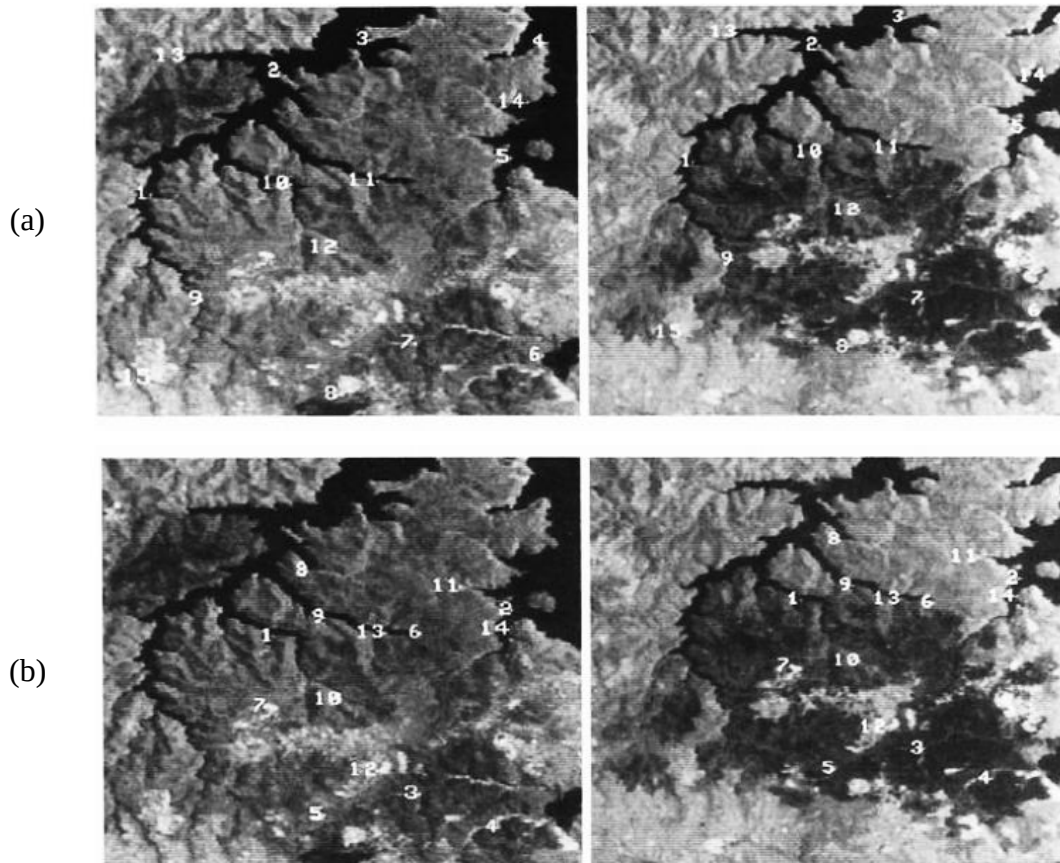


Figure 2.8: Distribution of control points used in the image to image registration: (a) good distribution, (b) poor distribution (Richards, 2013)

2.7.1 Random distribution

Random distribution is normally applied when the control points are selected randomly. It is a kind of distribution when the control points are selected with equal probability and independently from each other (Wang et al., 2012). Random distribution is claimed easy to implement in practice but it would not consider the uniformity of the distribution.

2.7.2 Regular grid

Regular grid method is a common method that divides the region of interest with regular grids and allocates the same number of control points to each grid (Li & Cheng, 2008). An example of using a regular grid method for allocating control points is shown in Figure 2.9. This method is easy to be implemented but the weakness of this method is the region of interest is not necessarily a regular region. For instance, a region marked as 1 as shown in Figure 2.9. If each grid is allocated with two control points in order to achieve even distribution, it might be questionable to place the same number of control points at region 1 compared to other grids such as the region marked as 2, 3 and 4. This is because region 1 is not completely covered by a regular grid and the number of control points placed should be less. Besides that, there is not always an obvious feature point in each grid to be selected as control point.

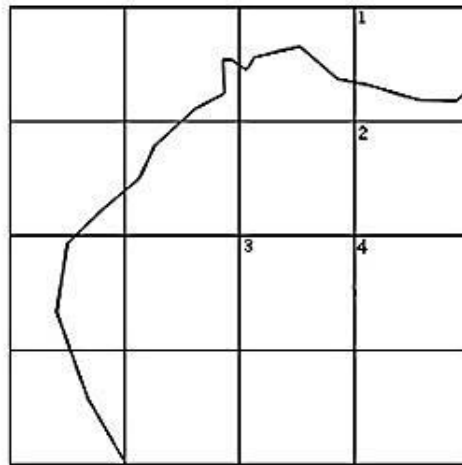


Figure 2.9: Example of regular method for allocating control points (Li & Cheng, 2008)

2.7.3 Uniform index

The distribution method proposed by Zhang and Cheng (2009) firstly considers the distance between tie points derived from the image matching based on cluster analysis by applying the Longest Distance Principle. The distance (d_{pk}) between two tie points $((x_p, y_p)$ and $(x_k, y_k))$ in the image is defined in Equation 2.11. Initially the points are as individual clusters. The distance (D_{pq}) between two cluster (G_p and G_q) is defined as the minimum distance between elements of each cluster as Equation 2.12. Then, the two clusters with the maximum distance would be assigned to a new cluster (G_r). The distance between the new cluster and other clusters is continually calculated until the criteria of the preserved number of points, error or the uniform index is achieved.

$$d_{pk} = \sqrt{(x_p - x_k)^2 + (y_p - y_k)^2}, (k \neq p) \quad (2.11)$$

$$D_{pq} = \min\{d_{jk} | j \in G_p, k \in G_q\} \quad (2.12)$$

The uniform index (L) is used as a relative index to measures the evenness of tie points based on the theory of monopolised circle used for plants distributed patterns as shown in Equation 2.13. The concept of monopolised circle is described as for a certain scope of spatial points set, with the assumption that the distance between a point at random and its nearest neighbour is s , then a circle is made by taking $s/2$ as radius as shown in Figure 2.10. Based on the Equation 2.13, the total area of monopolised circles is denoted as a while the rectangular area is denoted by A as the area of unregistered image measured by

pixel. The weakness remarked is the monopolised circles might have the phenomenon of boundary violation.

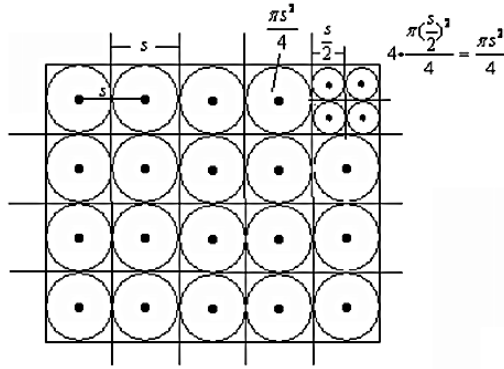


Figure 2.10: The concept of monopolised circle (Zhang & Cheng, 2009)

$$L = \frac{4a}{\pi A} \quad (2.13)$$

The combination method of the regular grid and the uniform index has been studied by Sedaghat and Mohammadi (2018). They emphasised on the distribution quality of control point by introducing a uniform competency (UC) based on local feature detector for scale and location distribution constraints. The proposed UC method uses a regular gridding strategy based on an adaptive feature competency ranking in the feature selection. It is based on a weighted ranking process to combine three quality measures, which are robustness, spatial saliency and feature size, in a multi-layer gridding schema, to form one single feature competency value. The proposed method is tested and compared in five different local feature detectors. It is claimed that the proposed method can be easily applied to any local feature detector for different applications.

2.7.4 Voronoi diagram

Voronoi diagram is another distribution technique that has been applied to manage the distribution of control points. Li and Cheng (2008) introduced an automatic optimisation of control points based on a function that considers the accuracy and points important value. At first, the geographic coordinates and image coordinates of ground control points are loaded to compute the position error for each point. The position error of the i^{th} control points (E_i) is computed based on polynomial geometric correction model with the principle of least-squares method as defined in Equation 2.14 where ε_{xi} and ε_{yi} are errors on the x and y axes, respectively. The normalised position error for each point ($\overline{\overline{error_i}}$) is defined in Equation 2.15.

$$E_i = \sqrt{\varepsilon_{xi}^2 + \varepsilon_{yi}^2} \quad (2.14)$$

$$\overline{\overline{error_i}} = \frac{E_i}{(E_i)_{max}}, (i = 1, 2, \dots, n) \quad (2.15)$$

where n is the total number of control points and $(E_i)_{max}$ is the maximum value of E_i .

The Voronoi diagram is constructed based on the point vector layer of the ground control points by taking the border of region of interest (ROI) as the map boundary. The important value of each control point (inv_i) is calculated using Equation 2.16 where S_i is denoted as the polygon area of the i^{th} control point. It is stated that the larger the polygon area the more important the control point is. The normalised important value for each point ($\overline{\overline{inv_i}}$) is defined as Equation 2.17. The distribution of control points could be measured by the ratio of the maximum and minimum of polygon area. The ideal state of uniform

distribution recommended is when the equality of important value of each control points is achieved.

$$imv_i = \frac{S_i}{S_{ROI}} = S_i / \sum_{i=1}^n S_i \quad (2.16)$$

$$\overline{\overline{imv_i}} = \frac{\overline{imv_i}}{(\overline{imv_i})_{max}} \quad (2.17)$$

where $\overline{imv_i} = 1 - imv_i$.

The combination of $\overline{\overline{error_i}}$ and $\overline{\overline{imv_i}}$ form function (f) is then used to determine the retention of control points as defined in Equation 2.18. The w is the weighting coefficient and it is set to 0.2 in the study of Li and Cheng (2008). A certain number of control points which have the largest values of f will be deleted in order to select a better set of control points that is with less error and more even distribution.

$$f_i = w \cdot \overline{\overline{error_i}} + (1 - w) \cdot \overline{\overline{imv_i}} \quad (2.18)$$

Besides Li and Cheng (2008), Wangfei et al. (2009) also suggested defining the concept of uniform distribution scientifically and proposed to use Voronoi diagram as a measurement of control points' affected area by calculating the area of Voronoi diagram of each selected control point. The larger the area region means the generating point of the region has more influence compared to other points. They tried to build the relationship between the number of control points used and uniform distribution. In their research, the weighted

Voronoi diagram is used to reduce the influence of terrain with the slope and relief as apex weighted factors.

Voronoi diagram, also named as Voronoi tessellation or Voronoi decomposition was researched expansively in Computational Geometry. Generally, Voronoi diagram is a way of distributing space around points (Paun, 2014). It is a mathematical structure that represents the relationship between a given point set and is depicted as a convex polygon which is called a Voronoi region (Ying et al., 2015).

Suppose that $s = \{p_1, p_2, \dots, p_n\}$ is a set of points on the Euclidean plane, where the location of a point p_i is denoted as (x_{i1}, x_{i2}) . Voronoi diagram of the set of points is defined as a collection of regions that divide up the plane (Dobrin, 2005) as denoted by Equation 2.19. The collection of all Voronoi regions is referred as the Voronoi diagram as denoted as Equation 2.20 (Dobrin, 2005).

$$V(p_i) = \{\vec{x} | \|\vec{x} - \vec{x}_i\| \leq \|\vec{x} - \vec{x}_j\|\} \quad (2.19)$$

where the corresponding vector is $\vec{x}$, $p_i \neq p_j, i \neq j, \forall i, j = 1, 2, \dots, n$ is the set of generator points.

$$V = \{V(p_1), V(p_2), \dots, V(p_n)\} \quad (2.20)$$

An example of Voronoi diagram is shown in Figure 2.11. Each region contains only one generating point from the set of points. Assume that the generating points are $\{p_1, p_2, p_3, p_4, p_5, p_6\}$ as illustrated in Figure 2.11. Any point data that is located in a region is closer to the generating point of the same region compared to any generating points from other regions, for instance point p is nearer to p_1 . When any point data is on a region's

edge (p') between two generating points (p_1 and p_3), the distance between the point (p') and the generating point on one side of the edge (p_1) is equal to the distance between the point (p') and the generating point on the other side (p_3) as displayed in Figure 2.11.

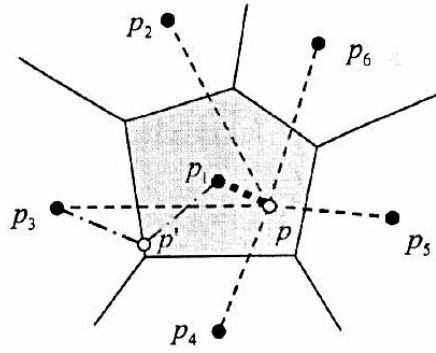


Figure 2.11: Voronoi diagram of a set of points (Dobrin, 2005)

2.8 Geometric transformation

Geometric transformation is a function that describes the geometric differences between two images; one denotes as reference and the other as target image, which have the same contents (Goshtasby, 2012). The reference image is kept unchanged and the target image is resampled to take the geometry of the reference image. For example, the coordinates of N corresponding control points in two images of a scene is defined as $\{(x_i, y_i), (X_i, Y_i): i = 1, \dots, N\}$, the coordinates (X, Y) of the target image could be rectified by referring to the coordinates (x, y) of the reference image through a proper geometric transformation function, $h(x, y)$ as denoted in Equation 2.21 (Xiangyang et al., 2010).

$$\begin{aligned} X_i &= h_x(x_i, y_i) \\ Y_i &= h_y(x_i, y_i), \end{aligned} \quad i = 1, \dots, N \quad (2.21)$$

The geometric transformation is constructed after the correspondence of control points has been established. The transformation model maps the distorted image to the reference image. The control points from the distorted image that correspond to the control points from the reference image should be as close as possible after the distorted image transformation is employed in the mapping function design (Patel & Shah, 2014) to maximize the accuracy. Hence, choosing an appropriate geometric transformation and its parameters for the transformation process is not a simple task.

Images, which are two-dimensional, allow us to visualise a scene and locate each point of longitude and latitude within this scene (Baghdadi & Zribi, 2016). Two-dimensional transformation can be used to project image $f(u, v)$ coordinates to the ground $g(x, y)$ coordinates (Tawfeik et al, 2016). The transformation involves scale factors in x and y directions, two translations from the origin and a rotation of x and y axes about the origin. If images represent different views of a three-dimensional scene, the geometric differences describe the three-dimensional structure of the scene. Many of the transformation functions for registration of two-dimensional images can be extended to registration of three-dimensional images with three components (Goshtasby, 2012).

Different transformations have been applied in image rectification. Geometric transformations have different ability in handling different distortions complexity. Generally, geometric transformations are divided into global transformations and local transformations. A global transformation uses all the control points to estimate a set of mapping parameters to form one general mapping function for all parts of the whole image, which is also known as rigid transformation (Patel & Shah, 2014). Therefore, one of the weaknesses of using global transformations is changing a single coefficient in the

transformation function would affect the entire resampled image (Goshtasby, 2012). Thus a global transformation has limitation and could not fit the whole image properly (Guo et al., 2010). Examples of global transformation are similarity, affine and polynomial transformations as discussed in Section 2.8.1, Section 2.8.2 and Section 2.8.3, respectively.

A transformation function could adapt to the local geometric difference between the images. In many cases, the geometric distortions in images are due to local factors such as scene elevation, atmospheric turbulence and sensor nonlinearity (Richards, 2013). A local transformation transforms one image into another image part by part (Goshtasby, 2012). It treats the image as a composition of patches and the mapping function parameters depend on the location of their support in the image (Patel & Shah, 2014). It means that only the relevant local parts of the image are used for each set of local parameters in determining the local transformation. It is claimed that local transformations are able to rectify an image locally and resample only the revised area which would keep the inaccuracies in the correspondences locally without spreading them to the entire image (Siddiqi et al., 2007). Local transformations are normally used in medical imaging and in airborne imaging (Patel & Shah, 2014). Examples of local transformation are thin-plate spline and piecewise linear transformations as discussed in Section 2.8.4 and Section 2.8.5, respectively.

2.8.1 Similarity transformation

Similarity transformation is the transformation which consists of rotation, translation and scaling only (Patel & Shah, 2014). The equation for similarity transformation is described by Equation 2.22 where (x, y) are coordinates in the reference image, (X, Y) are coordinates in the sensed image, s is scaling, θ is rotation and (h, k) are the translation differences between the images. A similarity transformation does not modify the shape of

an input object. Straight lines remain straight, and parallel lines remain parallel. The four parameters of scaling, rotational and translation can be determined from the corresponding coordinates of the images.

$$\begin{aligned} X &= x s \cos \theta - y s \sin \theta + h \\ Y &= x s \sin \theta + y s \cos \theta + h \end{aligned} \quad (2.22)$$

where (x, y) and (X, Y) are coordinates in the reference image and the sensed image, respectively; while s, θ and (h, k) are scaling, rotation and translation differences between the images, respectively.

2.8.2 Affine transformation

Similarity transformation is a subset of affine transformations. Affine transformation is a linear transformation that involves translation, scale, rotation, and shear transform. In an affine transformation, parallel lines remain parallel and straight lines remain straight. An affine transformation can be defined by vector addition and matrix multiplication (Bazargani et al., 2012) as shown in Equation 2.23. It has six parameters: $\theta_0, \theta_1, \theta_2, \theta_3, \theta_4$ and θ_5 where θ_2 and θ_5 specify the translation while $\theta_0, \theta_1, \theta_3$ and θ_4 aggregate of rotation, scaling and shearing.

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} \theta_0 & \theta_1 & \theta_2 \\ \theta_3 & \theta_4 & \theta_5 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \quad (2.23)$$

2.8.3 Polynomial transformation

Polynomial models are the common approach used as global transformation for rectification (Babiker & Akhadir, 2016). These transformation models could be expressed in different orders. The order of polynomial model is the highest exponent used in the equation which specifies the level of complexity that it could handle. Each polynomial model requires a minimum number of control points as discussed in Section 2.6. The relationship between the order of polynomial (t) and the number of coefficients (M) involved is shown in Equation 2.24 (Eltohamy & Hamza, 2009).

$$M = (t + 1)(t + 2) \quad (2.24)$$

where M = number of coefficients, t = the order of the polynomial model

Polynomials offer many advantages such as simple form, moderate flexibility of shapes, well-known, understood properties and ease of use computationally (Tawfeik et al., 2016). First order polynomial transformation is a linear transformation. It is a combination of translation, scaling, rotation and shearing transformation, which has been claimed as the simplest transformation in image processing (Baboo & Thirunavukkarasu, 2014). Six parameters are needed to form the expression of first order transformation as shown in Equation 2.25 which is defined by three control points (Kasli & Dihkan, 2010).

$$\begin{aligned} u &= a_0 + a_1x + a_2y \\ v &= b_0 + b_1x + b_2y \end{aligned} \quad (2.25)$$

Second, third or higher order polynomial transformations can be used to suit the availability of the numbers of control points, to achieve precision requirement and to solve distortion with higher complexity. Such transformations are considered as non-linear transformations. At least six control points are needed to perform second order polynomial transformation while ten control points are required to carry out third order polynomial transformation (Kasli & Dihkan, 2010). The second order polynomial transformation can be written as Equation 2.26.

$$\begin{aligned} u &= a_0 + a_1x + a_2y + a_3x^2 + a_4xy + a_5y^2 + \dots \\ v &= b_0 + b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 + \dots \end{aligned} \quad (2.26)$$

Application of polynomial transformations is claimed to have certain constraints such as only effective to the flat area and ineffective to correct projection errors caused by both curvature of the earth and relief (Wang et al., 2011a, Venkatesan & Selvaragini, 2017), viewing angle is the same when images are obtained, the area to be imaged is small compared to the distance of the camera to the scene and the effect of atmospheric turbulence or other distortions is insignificant (Goshtasby, 2017). Images obtained from different viewing angles from a 3-D scene would have local geometric distortion that depends on the environment structure of the scene. Besides that, sensor nonlinearity and atmospheric turbulence could bring local geometric distortion to the images too. Goshtasby (2017) claimed that polynomial transformations which use all control points to generate only a general mapping function would average local geometric distortion equally all over the image. Furthermore, Soykan (2010) also commented that polynomials with higher order than first degree would cause unwanted stretching or squeezing to the images. Hence, Patel and Shah (2014) advised that a mapping function should use information

about local geometric distortion to register local areas of the images and should not use that information to register all image areas identically.

2.8.4 Thin plate Spline transformation

Thin plate Spline (TPS) transformation is a widely used local transformation. It is formulated in terms of an affine transformation and a weighted sum of radially symmetric basis functions (Zhou et al, 2013). It became popular in digital image processing after being first used by Goshtasby (1988) and Bookstein (1989) in image registration.

The TPS transformation is defined as Equation 2.27 for N number of corresponding points (x, y) , where A_1 , A_2 and A_3 are coefficients of the affine transformation, w_i is the weight determined from the condition depicted by $f(x_i, y_i) = v_i$, where v_i ($i = 1, \dots, N$) are the target values, $r_i^2 \ln r_i^2$ is the radial basis function and $r_i = \|(x_i, y_i) - (x, y)\|$ as the distance from the observed point (x, y) to all N points $i(x_i, y_i)$. Three additional orthogonal conditions as shown in Equation 2.28 are introduced since it is necessary to determine $N + 3$ unknown parameters from N equations $f(x_i, y_i) = v_i$ (Zhou et al, 2013; Tuno et al, 2017).

$$f(x, y) = A_1 + A_2x + A_3y + \sum_{i=1}^N w_i r_i^2 \ln r_i^2 \quad (2.27)$$

where A_1 , A_2 and A_3 = coefficients of affine transformation, w_i = weight from the condition depicted by $f(x_i, y_i) = v_i$, v_i ($i = 1, \dots, N$) are the target values, $r_i = \|(x_i - y_i) - (x, y)\|$, and N = number of corresponding points.

$$\sum_{i=1}^N w_i = \sum_{i=1}^N x_i w_i = \sum_{i=1}^N y_i w_i = 0 \quad (2.28)$$

According to Tuno et al. (2017), TPS transformation is one-segment transformation method with a single formula covers the entire transformation area. They studied the enhancement of the positional accuracy in digital cadastral maps by using TPS transformation. They stated that TPS transformation interpolates the values for all points, new corresponding points can be subsequently added with unsatisfactory transformation. They also claimed that TPS transformation is a locally sensitive transformation since the influence of individual corresponding points is localised and rapidly diminishes with distance.

2.8.5 Piecewise Linear transformation

Piecewise linear transformation has been studied periodically by researchers from the field of image processing as local transformation. Piecewise linear transformation is also known as piecewise affine transformation. It divides images into regions by triangulation. It is done by firstly triangulating the control points from the reference image (Goshtasby, 2017). After the control points in the reference image are triangulated, the homologous triangles in the distorted image could be obtained by knowing homologous points in the images. This makes it possible to compute an affine transformation from the vertices of homologous triangles and resample triangular regions in the distorted image one by one to the corresponding triangles in the reference image. The overall transformation becomes a composite of affine transformations.

The triangulation of control points in the reference image is done using Delaunay triangulation. Delaunay triangulation is a set of lines connecting each point from a set of given points to its natural neighbours (Matlab, 2013). Delaunay triangulation of the points would ensure that the circumference associated with each triangle contains no other point in its interior. Delaunay triangulation is also very closely related to the Voronoi diagram. Delaunay triangulation could be formed by joining all the generator points in a Voronoi diagram as shown in Figure 2.12.

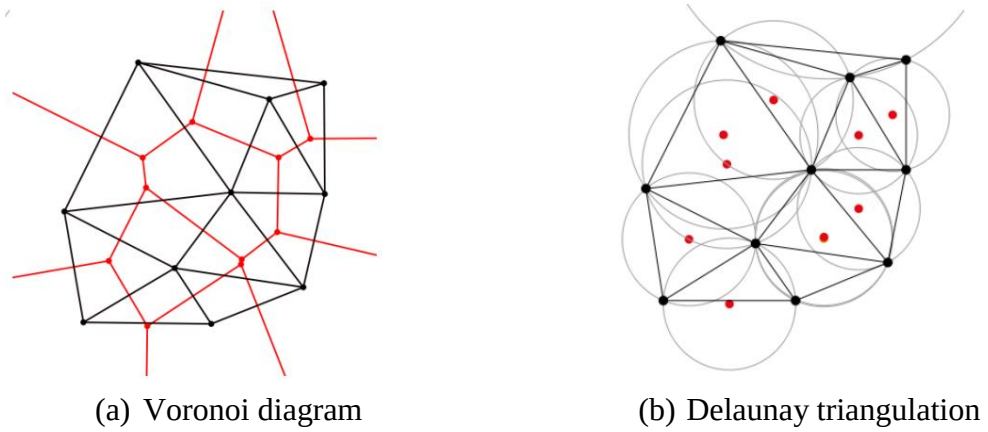


Figure 2.12: Example of Voronoi diagram and its Delaunay triangulation (Paun, 2014)

Piecewise linear structure, also known as a mesh comprises of triangular faces that put together along by their edges and vertices (González & Arévalo, 2010). A triangular mesh is defined as $M = (K, V)$, where $V = \{v_i | i = 1, \dots, m\}$ is a set of vertex position and K is a topological space of the triangular mesh which determines the connectivity of the vertices, edges and faces.

Suppose that given a set of corresponding points $\{(v_i, v'_i) | i = 1, \dots, n\}$ where $v_i \in V$ and $v'_i \in V'$ are identified from two isomorphic triangular meshes in the reference and distorted images, the piecewise linear transformation that geometrically maps a point p

within the part s of the mesh as denoted by Equation 2.29 to another point p' as denoted by Equation 2.30 could be defined with Equation 2.31 and Equation 2.32 as discussed by González and Arévalo (2010).

$$p = (x, y)^T \in \phi_V(|s|) \quad (2.29)$$

where $\top$ is the transformation, ϕ is the linear mapping and ϕ_V makes explicitly to a particular vertex set.

$$p' = (x', y')^T \in \phi_{V'}(|s|) \quad (2.30)$$

$$p' = f_{\phi_V(|s|)}(p) = \begin{cases} f_1(p) & \text{if } p \in \phi_V(|t_1|) \\ \dots & \dots \\ f_m(p) & \text{if } p \in \phi_V(|t_m|) \end{cases} \quad (2.31)$$

where m is the number of triangular faces (t_i) and f_i is the estimated affine transformation as expressed in Equation 2.32.

$$p' = f_i(p) \equiv \begin{cases} x' = a_{11} + a_{12}x + a_{13}y \\ y' = a_{21} + a_{22}x + a_{23}y \end{cases} \quad (2.32)$$

where a_{ij} ($i = 1, 2$ and $j = 1, 2, 3$) are the transformation coefficients.

One of the advantages claimed is that the insertion and deletion of a point triangulated using Delaunay triangulation would just have a local effect without causing a rippling effect throughout the image (Marzouki, 2016). The corresponding triangles in the target image are then determined from the correspondence between the control points. After that, a linear transformation is used to map each triangular region in the target image to its corresponding triangular region in the reference image. Unlike global transformations,

different linear transformations are employed separately to triangular regions instead of using a single transformation as the rectification model for the entire image.

Zagorchev and Goshtasby (2006) reported the use of piecewise linear transformation for non-rigid image registration. They explored the properties and examined the behaviours of piecewise linear transformation with the comparison of thin-plate spline, multi-quadric and weighted mean transformations. They claimed that the piecewise linear transformation would keep inaccuracies in the correspondences local without spreading them over the entire image domain.

Besides that, Guo et al. (2010) presented an automatic registration approach based on Speed Up Robust Features (SURF) and piecewise linear transformation. They discussed the parallel implementation of both methods in order to accelerate the speed of registration procedure. However, they only stated that the results of experiments could achieve acceptable accuracy without providing analyses on the registration error.

There are also research works that studied the combination of local transformations with other transformations. For instance, Wang et al. (2011b) introduced Piecewise Polynomial correction method to solve the problem of nonlinear variability of geometric distortions in different imaging angles. They used piecewise quadratic polynomial model to partition the whole image into contiguous subspaces. They claimed that the piecewise polynomial correction method consistently outperforms the whole image-based correction in their experiments.

2.8.6 Other methods

Xiangyang et al. (2010) proposed geometric correction algorithm of remote sensing images based on support vector machines (SVM) to overcome the disadvantage of least square methods. The SVM clustering algorithm is employed to cluster all control points according to the coordinate. The quadratic programming model is constructed on the basis of corrected points, the elevation, and the coordinate of corresponding image points. The proposed cluster algorithm is applied to select 20, 30, 40, and 50 control points for the correction of the remote sensing image, and the rest are the checkpoints. They made comparisons of the proposed method with various algorithms in terms of fitting errors, check errors and generalization ability. The algorithms used in the comparison are direct linear transformation, general quadratic polynomial, improved quadratic polynomial, quadratic rational function and neural network. There is no further explanation about these algorithms. They only showed their results in graphical form which is difficult to get the exact value of the comparison result.

The combination of different transformations is another approach that has been tried by some researchers. For instance, Kasli and Dihkan (2010) utilised six geometric transformations which included non-reflective similarity, similarity, affine, projective, polynomial and piecewise linear for image registration. The result images were generated using a combination of six geometric and three resampling methods in order to model geometrical errors on images covering the test area. However, they only tested their proposed approach with a simple rotated image with a 38×22 grids as distorted image.

Besides that, there are also researchers that proposed an improved version of the conventional method. For example, Wang et al. (2011a) introduced a partitioning-based

adaptive polynomial transformation to rectify geometric distortions of images with large view angles. ESRI (2016) provides a transformation known as Adjust transformation. The adjust transformation optimizes for both global least square fitting and local accuracy. It is built upon an algorithm that combines a polynomial transformation and TIN interpolation techniques. The adjust transformation performs a polynomial transformation using two sets of control points, then adjusts the control points locally to better match the target control points using a TIN interpolation technique. Adjust requires a minimum of three control points.

2.9 Accuracy assessment

Root mean square error (RMSE) is used as a quantitative measurement in the evaluation of image rectification (Gonçalves et al., 2009). The RMSE reflects the difference between the reference image and the transformed image (Pourmohammad et al., 2012; Zhang & Zhang, 2013), which measures the differences between values predicted and the actual values. The smaller RMSE means the smaller the difference between the two images. This value describes how consistent the transformation is between the different control points (ESRI, 2016). RMSE has the advantage of independently taking into account the unit scales of the quantities to evaluate (Pang et al., 2015).

The RMSE is one of the most common accuracy criteria for sets of points (Tomaščík et al., 2017). According to Jensen (2015), in order to calculate the RMSE, a control point with coordinates (x, y) is firstly identified in the image. The position of the same control point is then measured from the reference image. The coordinates of these two sets of control points and other selected control points are used to compute the coefficients of the transformation used. After the transformation equation has been formed, the coordinates of

the first control point is placed back into the transformation equation to get computed value of x' and y' that are supposed to be the location of this point in the image. Ideally, x' would equivalent to x and y' would equivalent to y . However, this is rarely happen in the real situation and the difference between the values represents image geometric distortion.

Some of the control points are omitted from the transformation process to be used as checkpoints. Checkpoints are used to perform an independent, quantitative assessment of image location error (Sedorovich et al., 2010). Conventionally the RMSE of checkpoints is calculated to assess the accuracy of the resultant geometric correction (Nguyen, 2015). It is calculated based on the resultant vector from the residual in x and y axes of the independent checkpoints. Checkpoints are also referred as validation points and survey points. The difference between the initial and the computed positions of the checkpoints gives an estimation of the accuracy of the model.

The total RMSE measurement is denoted in Equation 2.23. The n is the number of control points. It also indicates how good the derived transformation is (ESRI, 2016). It is a measure of the fit between the true locations and the transformed locations of the output control points. The RMS error is a good assessment of the accuracy of the transformation, but a low RMS error does not mean with an accurate registration. The transformation may still contain significant errors due to a poorly entered control point.

Besides calculating the total RMSE, Wu et al. (2008) tested the rectification accuracy using mean error (D) of the image. The mathematics model is as shown in Equation 2.34.

$$total\ RMSE = \sqrt{\frac{1}{n} \left(\sum_i ||(x, y)_i - (x', y')_i||^2 \right)} \quad (2.33)$$

where n is the number of control points

$$D = \sqrt{\frac{\sum_{i=0}^n (Ds_i)^2}{n}} \quad (2.34)$$

where $Ds = \sqrt{(Dx_g)^2 + (Dy_g)^2}$, $Dx_g = x'_g - x_g$, $Dy_g = y'_g - y_g$

In Equation 2.34, (x'_g, y'_g) represents the coordinates of the rectified image while (x_g, y_g) represents the coordinates of the reference image. In addition, Dx_g and Dy_g means the error of x direction and y direction, respectively and Ds is the positional distance accuracy of points. The mean error of the image is denoted by D , whereas n is the number of test points.

Gonçalves et al. (2009) proposed several measures for an objective evaluation of the geometric correction process as a complement to the RMSE and visual inspection. They suggested bad point proportion index which is the computation of the number of residuals that lie above a certain threshold. This index is related to the stage of control points' identification. They used Spearman and Pearson correlation coefficient to identify the presence of a preference axis on the residual distribution as skew measurement. Besides that, they computed the distances from each control point to the remaining control points using boxplots to study its dispersion.

Users of some commercial software are encouraged to remove control points that are identified as 'erroneous' that their associated residual error is considered to be

unacceptably high where the residual error is defined as a value more than one standard deviation distant from the mean. However, Mather and Koch (2011) advised that one should seek for the reasons of the error which might be caused by inaccurate digitisation, measurement or the consequence of image distortion such as brought by high relief.

2.10 Software agents and multi-agent approach

Aerial image rectification involves different processes as discussed in previous sections. The increasing use of remotely sensed images not only has driven the studies of techniques involved in the processes of aerial image rectification, but it also prompts the requirement of developing new image processing software architectures in order to meet the demand (Nolan et al., 2001b; Hussain et al., 2013).

High resolution images are easily captured using a common digital camera and such images would require more time and memory to be processed. Processes that require repetitive manual interaction, adjustment and adaption are deemed to be time-consuming, labour-intensive and consequently error-prone (Hofmann et al., 2015). Conventionally, a high resolution image is usually reduced to a lower resolution image which might eliminate some significant information (Zheng, 2014). Besides that, existing architectures for large-scale image processing of space-borne, remotely sensed images have either been monolithic and stand-alone or in the client-server paradigm (Nolan et al., 2001b). Most of the image processing applications are based on sequential approaches and image processing algorithms are getting more complex (Nini et al., 2010) in order to process the high resolution images obtained. Hence, studying the architecture or paradigm is necessary. Efforts have been tried to transfer the generic knowledge to software packages and integrate with different paradigms such as object-based approach (Rampi et al., 2014)

and agent-based approach (Liao et al., 2017) to automate the process or at least reduce the dependency of manual involvement.

An agent is a computational entity such as software program or hardware entities that could perceive and act upon its environment to perform some sets of task on behalf of users (Mishra et al., 2011), while a multi-agent system consists of a community of agents situated in an environment that would interact with each other to pursue a common goal (Long, 2010; Heppenstall et al., 2011). Each software agent is provided with sensors and effectors to interact with its environment and to achieve predefined goals (Hofmann et al., 2016). Interaction among agents means the ways agents communicate through a set of actions such as cooperation, coordination and negotiation. Environment is a common space to all agents in the system where they perceive and interact with. Each software agent has a specific role and equips with role-dependent abilities and goals which could decide individually based on its own strategy when and how to act in a particular situation (Hofmann et al., 2016) as shown in Figure 2.13.

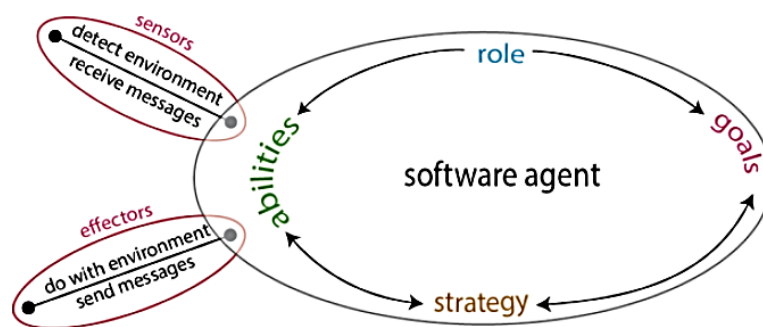


Figure 2.13: Principle components of a software agent (Hofmann et al., 2016)

Multi-agent systems are based on an algorithmic description of individuals, agents, that simulate the expected behavior (Rousset et al., 2016). Multi-agent approach has been

revealed as a research field in expansion especially for segmentation, registration and analysis of medical images and high resolution remote sensing images (Pereira et al., 2014; Hofmann et al., 2015; Liao et al. 2017). For instance, Jallouli et al. (2007) presented an iterative technique for 3D images alignment based on multi-agent approach. They tried to reduce the dependency on the initial transformation of the traditional iterative methods. They introduced region agent, segmentation agent and global agent. The region agent would cooperate with segmentation entity to establish a region matching. They claimed that each homologous region must provide their optimal transformation. The global agent that has a global view of transformation would help region agent to select the best transformation for the next iteration.

Another example of using multi-agent approach is shown by Zhao and Pan (2015) in their research on remote sensing image feature selection. They presented a classification method based on rough set theory and multi-agent system to optimise the spatial attributes for better classification and improve the classification accuracy. The rough set theory would indicate spatial subsets of features that could provide them with the information of the full set of objects and features. However, not all features are useful for algorithm training. Furthermore, redundant information might lead to a confused state of classification and low accuracy. Hence, they proposed the coordination of three types of agents named as feature agent, feature selection result agent and control agent to solve the feature selection problem.

Another motivation that inspired Liao et al. (2017) to propose agent-based approach is it could mimic more closely on how experts perform image registration as a process of sequential actions. They studied on using artificial agents for robust 3D medical image

registration. Instead of one shot mapping the raw image to the registration parameters, they trained agents to decompose the registration task to find the best action among a limited set of possible solutions. Hence, the multi-agent approach allows the disaggregation of systems into individual components that could potentially have their own characteristics and rule sets.

2.10.1 Advantages of using multi-agent approach

With the increase in the complexity of projects associated with software development, the agent concepts have been devised as a new approach for handling complex systems (Akbari, 2010). A complex system is defined as a system that can be analysed into many components having relatively many relations among them, so that the behaviour of each component depends on the behaviour of others (Rousset et al., 2014). Thus the complexity of the dependencies between the phenomena that drive the entities behaviour makes it difficult to define a global law that models the entire system. Agent-based approach is a suitable tool for building complex systems (Corral, 2011).

Agent-based approach in software development could also be defined as transitioning from the prototyping to the development of applications (Xie & Liu, 2017). It is claimed that agent-based approach has the ability to represent high level abstractions and address important requirements in building complex systems (Kardas, 2013). Besides that, one of the significant advantages of using an agent-based approach in image analysis is its ability in designing systems based on decoupled units (Hassan, 2008). It means that agent-based approach is flexible and allows new processing functions or new computing resources to be easily inserted into the system (Nolan et al, 2001a). The new members join the agent community without the need of reconfiguring or restarting the whole system. New

members only need to check in to the communication system and all other agents update their list of external agents by comparing it from time to time to the central list of the agent name service.

Another advantage of utilizing agent-based approach includes its ability to provide parallel computing (Rousset et al., 2016) and cooperation (Iantovics et al., 2016). A multi-agent system consists of several individual modules running on a distributed system and cooperating to solve common problems. During parallel processing of an image processing program, several individual image operators could work in a distributed system and communicate via data streams to perform a common task. Its ability in performing parallel computing is expected could speed up the processing (Rousset, 2014). Agents work together as different ‘users’ in the community and may have different plans and interests but all agents have one common goal and cooperate to achieve it.

Cooperation essentially performs during delegating tasks to other agents or while gathering information about the tasks (Rousset et al., 2014). The cooperation enables agents to share different collected information and thus increases the quality of output by confronting the information provided (Nachour et al., 2016). It means that agent-based approach is able to perform control strategies to choose the best processing methods or results (Hassan, 2008). Compare to single processing method or result, multiple and simultaneous results could lead to multiple possible interpretations, where selecting best score represents one of the possible ways on how to conclude a single, perhaps the best possible result among all potentials (Machálek & Olševičová, 2013).

Scalability is an important property of distributed systems and one of the big advantages of multi-agent based systems (Alberola et al., 2013; Manfredi, 2016). The size of a multi-

agent system may easily change by adding or deleting single agents due to its flexibility and can be done dynamically. It means that if more agents are necessary than currently available to solve a problem, new ones may be created. For instance, if an agent needs help of others, but all available agents work on other tasks and cannot help, new agents could be initialized, passed with its knowledge and delegated tasks to them. In contrast, if an agent is idle for a long time, it could decide to terminate. The agent could signal the termination via a broadcast message and provide its knowledge to all others on the blackboard before stops working.

Other advantages include the ease of construction and maintenance. It is commented that with multi-agent approach it is easier to build and repair a collection of partially independent modules than a single huge program (Rousset et al., 2016). Agents can be used for management of distributing resources and gathering results. A standard for communication between the agents was defined for industrial and commercial multi-agent systems and was released for public use (Koster, 2011). The formal IEEE standard called FIPA (Foundation for Intelligent Physical Agent) is commonly used and focuses on facilitating the interoperability of agents and multi-agent systems across different software platforms (Kravari & Bassiliades, 2015). The development of multi-agent platforms and programming languages also makes the implementation of multi-agent systems much easier and makes it possible to create multi-agent systems that are used in actual operations.

2.10.2 Agent platforms

A survey of agent platforms has been discussed by Kravari and Bassiliades (2015) which presented a comparative review of all available agent platforms that are or can be used in

simulating real-life study cases based on universal comparison and evaluation criteria for multi-agent system development. Their study analysed a total of twenty-four agent platforms developed by different groups, academic or industrial oriented. Among the total of twenty four agent platforms, the ‘high’ popularity agent platforms listed in their study includes JACK (Winikoff, 2005), JADE (Bellifemine et al., 2003), Jadex (Braubach & Pokahr, 2013), Jason (Bordini et al., 2007) and NetLogo (Tisue & Wilensky, 2004). They figured out JADE remains the most popular platform since it is purely designed in Java and supports different kinds of operating systems. The comparisons of selected agent platforms with high popularity based on properties, usability, security management, operating ability and pragmatics criteria are shown in Table 2.3.

Table 2.3: Comparison of agent platforms with high popularity based on properties, usability, security management, operating ability and pragmatics criteria (Kravari & Bassiliades, 2015)

Agent platform	Properties		Usability		Security management	Operating ability		Pragmatics	
Name	Developer/ Organization	Open source	Simplicity/ GUI features	FIPA compliance	Platform security	Programming languages	Operating systems	User support	Technological maturity
JACK	Agent Oriented Software Group	No	User friendly/ rich	Full	Strong	Java, JACK Agent Language (JAL) (plus use of XML)	Windows, Macintosh, Unix	High (extensive documentation and supporting tools)	Stable release, development status (Active)
JADE	Telecom Italia (TILAB)	Yes	User-friendly/ many	Full	Strong	Java	Any with JVM	High (FAQ, mailing list, defect list, API, docs)	Stable release, development status (Active)
Jadex	Hamburg University	Yes	User-friendly /many	Full	Strong	Java (plus use of XML)	Any with JVM	Average (docs, mail contact)	Stable release, development status (Active)
Jason	Federal University of Rio Grande do Sul and University of Santa Catarina	Yes	Simple/ some	Partial	Average	Java, AgentSpeak	Windows, MacOS, Linux	High (manual, book, news/mail list, API)	Stable release, development status (Active)
NetLogo	The Center for Connected Learning (CCL) and Computer-Based Modeling, Northwestern University	No	Simple/ some	No	Average	NetLogo	Any with JVM	Good (FAQ, docs, mail contact, tutorials, examples)	Stable release, development status (Active)

2.10.3 JADE

JADE (Java Agent Development Framework) is a multi-agent software framework fully implemented using Java programming language. It simplifies the implementation of multi-agent systems through a middle-ware according to the Foundation for Intelligent Physical Agents (FIPA) specification standards and a set of graphical tools that support the debugging and deployment phases.

It is a free, open source under the terms and conditions of LGPL (Lesser General Public License Version 2) license and stable software distributed by Telecom Italia, the copyright holder. It offers agent platform that can be distributed across different machines and controlled via a remote graphical user interface for the deployment of the application (Sandita & Popirlan, 2015). The configuration can be changed at run-time by moving agents from one machine to another, as and when required. Agent tasks are implemented through the use of behaviours which are logical execution threads that can be composed in various ways and can be initialised, suspended and spawned at any time (Bong, 2014).

JADE is completely implemented in Java programming language. Besides agent abstraction, it provides a simple and powerfull task execution and composition model, peer to peer agent communication based on the asynchronous message passing paradigm and a yellow pages service where agents can publish their services (Sandita & Popirlan, 2015).

2.11 Agent-oriented methodologies

Agent-oriented software engineering (AOSE) is an emerging field in computer science and it proposes systematic ideas for multi-agent systems analysis, implementation and maintenance (Ghandehari et al., 2015). Compared to traditional software engineering

methodologies, AOSE allows for improved functionalities and security (Abdalla & Mishra, 2018). Numerous agent-oriented methodologies have been introduced and currently available for guiding a programmer in developing agent-oriented software system. Some of the popular methodologies include ROADMAP (Juan & Sterling, 2003), Tropos (Bresciani et al., 2004), RAP/AOR (Taveter & Wagner, 2005), Gaia (Zambonelli et al., 2005), Prometheus (Padgham et al., 2008) and O-MaSE (DeLoach & Garcia-Ojeda, 2014).

A survey of agent-oriented methodologies has been reported by Akbari (2010). She has grouped and listed down the methodologies introduced before and after the year 2000. Her report outlines the overall state of agent-oriented methodologies and identifies its weaknesses. Since each methodology has weakness in different aspects, a hybrid methodology is usually proposed to overcome the challenge (Ghandehari et al., 2015).

2.12 Combination of ROADMAP and RAP/AOR methodology

The combination of ROADMAP and RAP/AOR methodology has been introduced by Sterling and Taveter (Sterling & Taveter, 2009). The ROADMAP (Role-Oriented Analysis and Design for Multi-Agent Programming) methodology was actually extended from the Gaia methodology. It is designed to support the development of complex open systems (Juan & Sterling, 2003) with formal environment and knowledge models, and a dynamic role hierarchy to constrain behaviour of agents in the organisation (Juan et al., 2002). The RAP/AOR (Radical Agent-Oriented Process/Agent-Object-Relationship) methodology is introduced by Taveter and Wagner (2005). It is aimed at creating distributed organisational information systems. It focuses on declarative models of communication and interaction. The RAP/AOR models the behavior of an agent as founded on its perceptions and on its basic mental state components: beliefs and commitments.

The combined ROADMAP and RAP/AOR methodology introduces a more unified way to engineer a multi-agent system from analysis to design and implementation and supports rapid prototyping of multi-agent systems (Sterling & Taveter, 2009). The ROADMAP emphasises on domain and systems analysis while the RAP/AOR gears toward design. The combination of the ROADMAP and the RAP/AOR methodology provides strong support for the abstraction layer of platform-independent computational design.

Based on the combination of ROADMAP and RAP/AOR, the requirements for the system and the problem domain of the system, as well as the environment in which the system is to be situated are described by computation independent models (CIM). CIM plays an important role in bridging the gap between domain experts and experts in designing and constructing sociotechnical systems (Sterling & Taveter, 2009). The requirements are analysed using goal model, role model, organisation model and domain model at different abstraction levels. Platform independent model (PIM) shows the part of the system design specification that does not change from one platform to another (Sterling & Taveter, 2009). It covered the interaction model, knowledge model and behaviour model.

2.12.1 Goal model

The goal model describes the purpose of the system and outlines a high-level overview of the system requirements (Sterling & Taveter, 2009). The main objective of goal model is to enable both domain experts and developers to identify the goals of the system. A goal is associated with a specific role which indicates the actor or agent that is involved in accomplishing the goal. A quality goal is attached to the main goal to express the result. A quality goal is a non-functional requirement of the system. It reflects intangible

requirements of a system such as privacy, security and performance. The notations for goal model are listed in Table 2.4.

Table 2.4: Notations used in goal model (Sterling & Taveter, 2009)

Symbol	Representation	Description
	Goal	Corresponds to functional requirements.
	Roles	Responsible for specific goals.
	Quality goals	Corresponds to requirement on system quality attributes.

2.12.2 Role model

Roles are determined by the goals. A role model represents a role schema which consists of a role name, role description, responsibilities and constraints. The description of the four elements of a role model is explained by Sterling and Taveter (2009) as shown in Table 2.5. A role is required to perform common tasks and subtask under it. It lists the duties of an agent and the constraints that applied to the agent when carries out the duties. A role can be played by a human or software agent (Weyns & Michel, 2015). Therefore, the roles played by human are also characterised by responsibilities and constraints.

Table 2.5: Explanation of elements used in a role model (Sterling & Taveter, 2009)

Element	Explanation
Role name	A name identifying the role.
Description	A textual description of the role.
Responsibilities	A list of responsibilities that agent(s) playing the role must perform in order for a set of goals and their associated quality goals to be achieved.
Constraints	A list of conditions that agent(s) playing the role must take into consideration when exercising its responsibilities.

2.12.3 Organisation and domain model

The organisation model denotes the arrangement of the roles involved in task achievement. It provides a foundation and helps to define the interactions between agents. The domain model denotes the knowledge required accomplishing the goals by decomposing the knowledge into modular entities and specifying their relationships (Lu, 2013). A domain entity describes a resource that is used for achieving one or more goals (Cheah, 2010).

2.12.4 Interaction model

Interaction model represents the interaction patterns between agents in details based on responsibilities defined for the corresponding roles (Sterling & Traveter, 2009). The interaction-frame diagram is used to generalise the types of action events occurring between agents and the types of agents themselves. It models possible interactions between two or more types of agents and all interaction alternatives for both physical interactions and communication. The sequence of action events performed and received by agents is labelled using numbers in ascending order and shown in an interaction-sequence diagram.

2.12.5 Knowledge model

The knowledge model generates a framework of knowledge about the agent and the objects within the problem domain (Sterling & Taveter, 2009). It extends the domain model by interpolating the entities with attributes and their inter-relationships which provide a common knowledge to be shared among agents. The activities that an agent performs depend on the decisions made by the agent.

2.12.6 Behaviour model

An agent behaviour model describes the behaviour of an agent making decisions and performing activities (Sterling & Taveter, 2009). This model is addressed by scenarios showing how the goals can be achieved by agents of the system. A scenario could be defined as a collective activity that models how a particular goal is achieved by agents enacting particular roles. Scenarios focus on how a multi-agent system achieves the goals rather than the performance of individual agents. An agent behaviour model describes the behaviour of an agent of the given type and addresses what individual agents do. An agent's behaviour is determined by a controller based on the agent's perceptions and knowledge. The controller can be modelled in terms of rules.

2.13 Summary

This chapter discussed the literature review on non-parametric aerial image rectification. The review included geometric distortion that could be found in aerial images, non-parametric image rectification, the main rectification procedures which consist of the reference image, the algorithms based extraction and selection of control points, the number and distribution of control points, geometric transformation and accuracy assessment. The functionalities and limitations of each process are highlighted. Besides that, the review also included the area of software agents and multi-agent approach in image processing, agent-oriented methodologies and the Combination of ROADMAP and RAP/AOR methodology.

From the review, it is found that an automatic image rectification is highly desirable in the remote sensing field to deal with large volumes of data available and for quick and accurate rectification. Basically, control points are the key input for image rectification and

a large number of control points are required. The control points should be salient and distinctive and distributed evenly over the images. Conventionally, the selection of control points is commonly carried out manually. Computer-based image processing techniques are able to assist and facilitate the automation of image rectification. Many existing feature extraction and feature matching algorithms could conveniently provide a large number of matched corresponding control points.

This research would like to study on how to select the optimised set of control points from the number of matched corresponding control points when the feature detection and matching have no more issue. This research proposed to consider the contribution of individual point as the criteria for selection. Since the control points should be salient, distinctive and distributed evenly, this research proposed to study the contribution of individual point based on the point corner score and distribution impact index. Nevertheless, the automatic image rectification requires an elaborate software framework to represent the overall process which simultaneously could enable the concentration on the feature selection as proposed. Image rectification is a complicated system involving human, software and technology. Agent-based system is an intelligent computing entity and a suitable tool for building complex systems. Hence, this research would like to simulate the rectification process by integrating a cooperative multi-agent approach.

The next chapter discusses the methodology of this research. The description of preliminary study, study site and details of each research procedures of the proposed aerial image rectification are presented. It also includes the framework design of the cooperative multi-agent approach in handling the aerial image rectification.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Image rectification is a crucial process in remote sensing application. Image rectification resamples or changes the pixel grids of an image to fit with a map projection or a reference image (Ayele et al., 2016). Aerial image rectification involves different procedures. From the literature review, the accuracy of image rectification depends on each procedure performance which includes the extraction, matching, quantity, distribution of control points and the geometric transformation. The implementation of each step has its typical problems and conventional approach requires repetitive manual interaction and is time-consuming.

This research proposes a novel approach to the selection of control points based on individual point corner score and distribution impact index for aerial image rectification in a multi-agent framework. The proposed approach introduces software agents to facilitate the procedure of aerial image rectification. It consists of four types of agents namely the Request agent, the Rectifier agent, the Corner agent and the Distributor agent. Each agent actually operates the task coherently with other agents based on the information generated in its local process with its partial knowledge and the information available from some external events in the network to enact the desired common goal as a combined problem solving and provide reliable performance. The main purpose of using multi-agent approach is to improve the selection of control points through cooperation and therefore could later combine with an automatic control point extraction method, work with a massive amount

of data, and thus reduce the tedious manual interaction process and improve the rectification performance.

This chapter firstly describes the preliminary study. The study site of this research is then described. Next, this chapter presents the research procedures of the proposed point selection for aerial image rectification. Lastly, it describes the research design of the proposed multi-agent framework for aerial images rectification.

3.2 Preliminary study

The preliminary study is carried out to investigate the effect of control points' distribution. In order to present barrel, perspective and rotation effects as the distortion that commonly exist in aerial images, the preliminary study was carried out using replicated data of grid image with added defects. The grid images consist of a reference and a distorted grid image. The reference image is created with 21×14 grid lines as illustrated in Figure 3.1. The size of the reference image is 4272×2848 pixels. The distorted grid image is built using the reference image with added combination of the four defects as illustrated in Figure 3.2. The defects are added into the grid image using the distort functions from Adobe Photoshop CS3 software with the barrel of value -10, vertical perspective of value +10, horizontal perspective of value +10 and rotation of 5 degrees in a counter clockwise direction around its centre point. The size of the distorted grid image is 4504×3210 pixels.

A set of 33 corresponding control points is manually selected and matched between the reference image and the distorted image. The number of 33 control points is slightly more than the most common number of control points obtained by the manual geometric correction (Gonçalves et al., 2009) to ensure that the number of control points used is sufficient as in common practice and could be located properly in the images according to

the distribution tested. The control points are selected based on visible grid corner points found in both reference and distorted grid image.

A1		C1		E1		G1		I1		K1		M1		O1		Q1		S1		U1
	B2		D2		F2		H2		J2		L2		N2		P2		R2		T2	
A3		C3		E3		G3		I3		K3		M3		O3		Q3		S3		U3
	B4		D4		F4		H4		J4		L4		N4		P4		R4		T4	
A5		C5		E5		G5		I5		K5		M5		O5		Q5		S5		U5
	B6		D6		F6		H6		J6		L6		N6		P6		R6		T6	
A7		C7		E7		G7		I7		K7		M7		O7		Q7		S7		U7
	B8		D8		F8		H8		J8		L8		N8		P8		R8		T8	
A9		C9		E9		G9		I9		K9		M9		O9		Q9		S9		U9
	B10		D10		F10		H10		J10		L10		N10		P10		R10		T10	
A11		C11		E11		G11		I11		K11		M11		O11		Q11		S11		U11
	B12		D12		F12		H12		J12		L12		N12		P12		R12		T12	
A13		C13		E13		G13		I13		K13		M13		O13		Q13		S13		U13
	B14		D14		F14		H14		J14		L14		N14		P14		R14		T14	

Figure 3.1: Grid image that is used as reference image

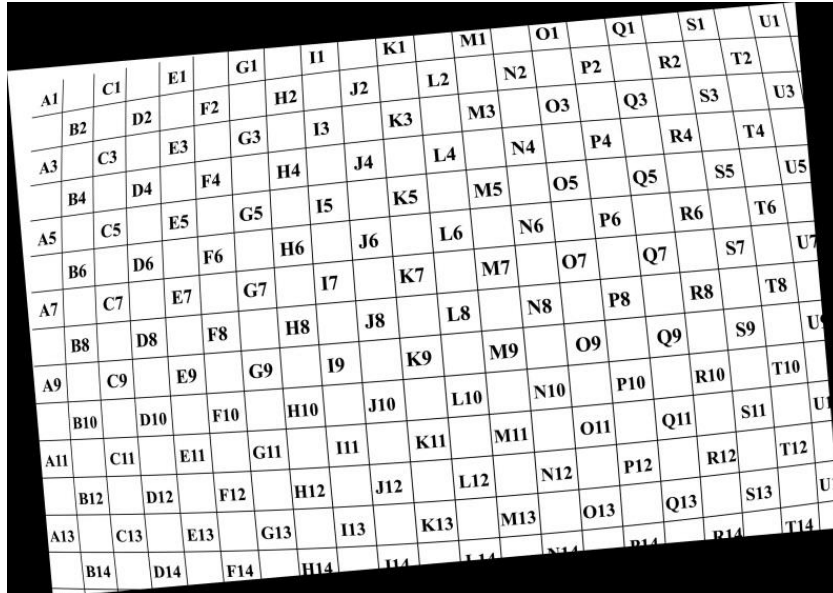


Figure 3.2: Distorted grid image with accumulation of barrel, vertical perspective, horizontal perspective and rotation effect

Four scenarios of distribution which comprise of centre, border, corner and uniform distribution are tested. Centre distribution represents control points that are assembled at the middle of the image; border distribution means control points are placed at image boundary or periphery; corner distribution indicates that control points are positioned at four ends of the image; while uniform distribution denotes that control points are evenly located at the whole image.

Among the total of 33 corresponding control points, 9 of the control points are used as checkpoints while 24 of the remanding points are used in the transformation process. The same set of checkpoints is used in all the scenarios of distribution. The checkpoints are selected from the control points where their positions are located at different parts of the image and cover the whole image. The checkpoints are marked with blue circles and the control points used in the transformation process are marked with red triangles for the distribution of centre, border, corner and uniform as shown in Figure 3.3, Figure 3.4, Figure 3.5 and Figure 3.6, respectively.

The positions of checkpoints are listed in Table 3.1, while the positions of control points for each distribution are listed in Table 3.2. Each distribution is tested with four geometric transformations: similarity, affine, second order polynomial and third order polynomial transformations. The different geometric transformations are used in order to provide different viewpoints to analyse the result obtained (Dibs et al, 2014). The evaluations of the rectification are measured using the total root mean square error (RMSE) of the checkpoints as denoted in Equation 2.33. The results obtained are discussed in Chapter 5.

A1		C1		E1		G1		I1		K1		M1		O1		Q1		S1		U1
	B2		D2		F2		H2		J2		L2		N2		P2		R2		T2	
A3		C3		E3		G3		I3		K3		M3		O3		Q3		S3		U3
	B4		D4		F4		H4		J4		L4		N4		P4		R4		T4	
A5		C5		E5		G5		I5		K5		M5		O5		Q5		S5		U5
	B6		D6		F6		H6		J6		L6		N6		P6		R6		T6	
A7		C7		E7		G7		I7		K7		M7		O7		Q7		S7		U7
	B8		D8		F8		H8		J8		L8		N8		P8		R8		T8	
A9		C9		E9		G9		I9		K9		M9		O9		Q9		S9		U9
	B10		D10		F10		H10		J10		L10		N10		P10		R10		T10	
A11		C11		E11		G11		I11		K11		M11		O11		Q11		S11		U11
	B12		D12		F12		H12		J12		L12		N12		P12		R12		T12	
A13		C13		E13		G13		I13		K13		M13		O13		Q13		S13		U13
	B14		D14		F14		H14		J14		L14		N14		P14		R14		T14	

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

A1		C1		E1		G1		I1		K1		M1		O1		Q1		S1		U1
	B2		D2		F2		H2		J2		L2		N2		P2		R2		T2	
A3		C3		E3		G3		I3		K3		M3		O3		Q3		S3		U3
	B4		D4		F4		H4		J4		L4		N4		P4		R4		T4	
A5		C5		E5		G5		I5		K5		M5		O5		Q5		S5		U5
	B6		D6		F6		H6		J6		L6		N6		P6		R6		T6	
A7		C7		E7		G7		I7		K7		M7		O7		Q7		S7		U7
	B8		D8		F8		H8		J8		L8		N8		P8		R8		T8	
A9		C9		E9		G9		I9		K9		M9		O9		Q9		S9		U9
	B10		D10		F10		H10		J10		L10		N10		P10		R10		T10	
A11		C11		E11		G11		I11		K11		M11		O11		Q11		S11		U11
	B12		D12		F12		H12		J12		L12		N12		P12		R12		T12	
A13		C13		E13		G13		I13		K13		M13		O13		Q13		S13		U13
	B14		D14		F14		H14		J14		L14		N14		P14		R14		T14	

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

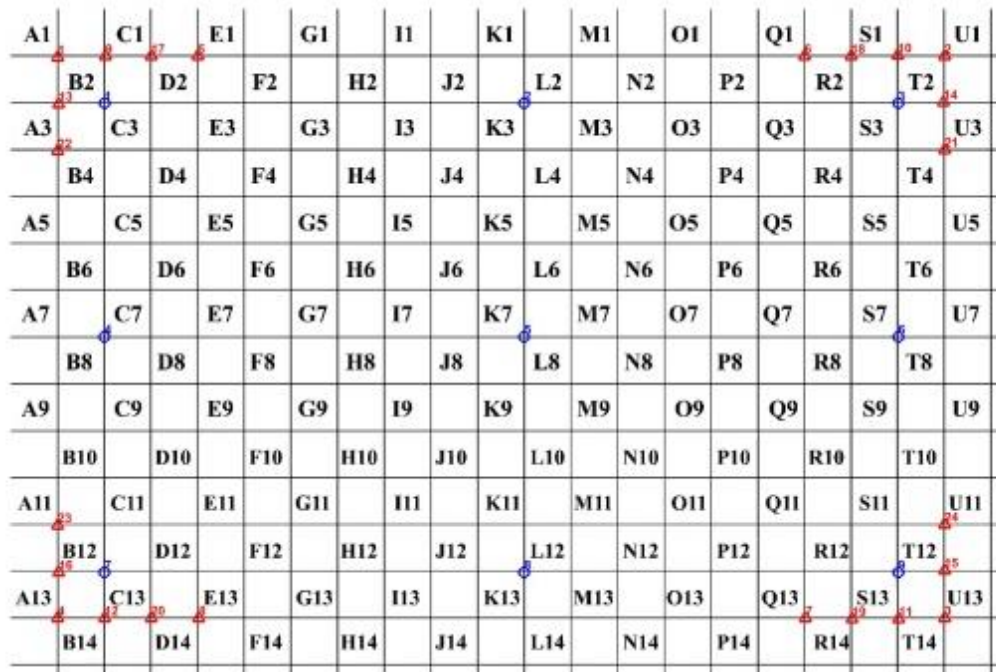


Figure 3.5: The checkpoints (marked with blue circles) and the corner distribution of control points (marked with red triangles) used in the preliminary study

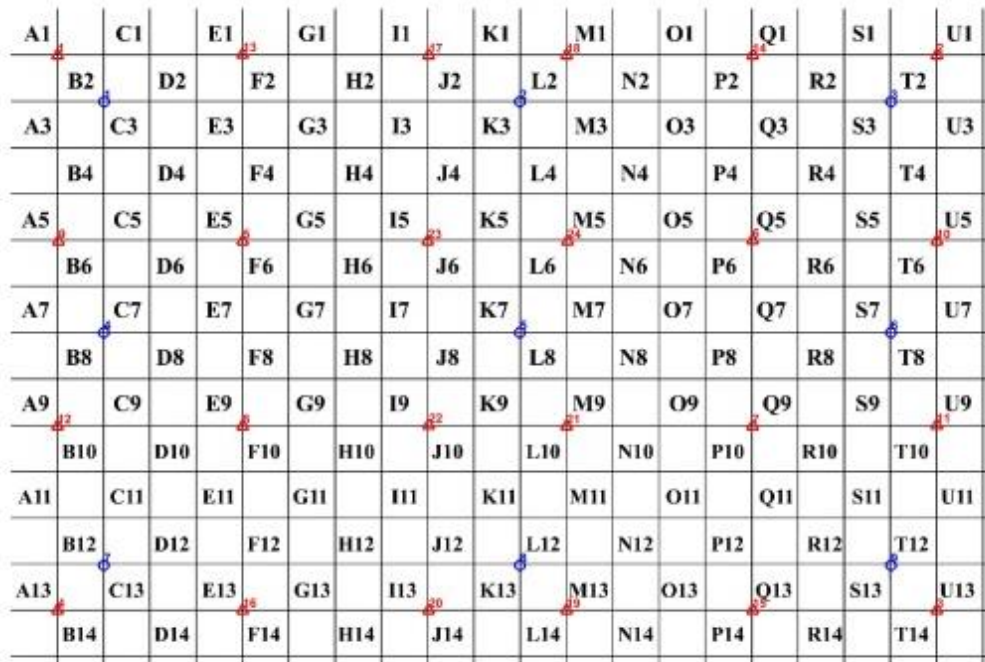


Figure 3.6: The checkpoints (marked with blue circles) and the uniform distribution of control points (marked with red triangles) used in the preliminary study

Table 3.1: The position of checkpoints

Checkpoint no.	Reference image		Distorted image	
	X	Y	X	Y
1	402.50	403.10	466.51	753.69
2	2200.58	403.10	2226.49	515.26
3	3804.52	403.10	3891.11	393.89
4	402.46	1401.20	483.85	1737.72
5	2200.58	1401.20	2317.52	1572.99
6	3804.52	1401.20	4047.16	1425.60
7	402.46	2407.06	557.54	2773.77
8	2200.58	2407.06	2417.23	2691.40
9	3804.52	2407.06	4164.21	2518.00

Table 3.2: The position of control points used in each distribution

Control point no.	Centre distribution				Border distribution				Corner distribution				Uniform distribution			
	Reference image		Distorted image		Reference image		Distorted image		Reference image		Distorted image		Reference image		Distorted image	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
1	1802.5	998.5	1849.4	1178.5	206.5	198.5	301.8	597.6	202.5	206.5	306.1	597.6	202.5	202.5	297.4	593.3
2	2606.5	1002.5	2720.7	1096.1	4002.5	198.5	4042.8	194.5	4002.5	202.5	4042.8	194.5	4002.5	202.5	4038.5	190.1
3	2606.5	1802.5	2811.7	1989.1	4002.5	2606.5	4381.0	2704.4	4002.5	2602.5	4381.0	2708.7	4002.5	2602.5	4381.0	2704.4
4	1806.5	1802.5	1918.7	2062.8	202.5	2606.5	392.8	2977.5	202.5	2602.5	397.1	2973.2	202.5	2602.5	397.1	2973.2
5	2002.5	1206.5	2087.8	1382.3	602.5	202.5	648.6	541.3	802.5	202.5	817.6	510.9	1002.5	1006.5	1034.4	1269.5
6	2402.5	1202.5	2525.6	1330.2	3602.5	202.5	3657.0	211.8	3402.5	202.5	3457.6	220.5	3206.5	1002.5	3375.3	1048.5
7	2406.5	1602.5	2569.0	1776.7	3606.5	2606.5	3969.1	2756.4	3406.5	2602.5	3756.7	2782.4	3206.5	1806.5	3475.0	1924.1
8	2006.5	1606.5	2118.1	1811.4	598.5	2602.5	756.9	2977.5	806.5	2602.5	956.4	2968.8	1002.5	1806.5	1077.7	2114.9
9	2602.5	1202.5	2746.7	1312.9	1002.5	198.5	1008.4	480.6	406.5	202.5	470.8	567.3	206.5	1006.5	297.4	1360.6
10	1806.5	1198.5	1866.7	1399.6	3206.5	198.5	3249.5	237.8	3802.5	198.5	3852.1	203.1	4002.5	1006.5	4190.2	987.8
11	1802.5	1602.5	1905.7	1841.8	3202.5	2606.5	3548.7	2808.5	3806.5	2606.5	4177.2	2730.4	4002.5	1802.5	4302.9	1846.1
12	2602.5	1598.5	2790.0	1755.1	998.5	2602.5	1160.1	2964.5	402.5	2602.5	579.2	2977.5	202.5	1806.5	327.8	2162.5
13	2006.5	1002.5	2066.1	1165.5	1402.5	198.5	1394.2	428.6	206.5	406.5	288.8	784.0	1002.5	198.5	1008.4	480.6
14	2406.5	1002.5	2503.9	1117.8	2802.5	202.5	2833.4	268.2	3998.5	398.5	4081.8	385.2	3206.5	202.5	3249.5	237.8
15	2402.5	1806.5	2586.3	2006.5	2802.5	2606.5	3106.5	2856.1	4002.5	2398.5	4368.0	2492.0	3206.5	2602.5	3548.7	2808.5
16	2006.5	1806.5	2144.1	2041.2	1402.5	2602.5	1567.6	2947.2	206.5	2406.5	379.8	2769.4	1002.5	2602.5	1155.8	2968.8
17	2602.5	1402.5	2764.0	1534.0	1806.5	202.5	1801.7	376.5	602.5	202.5	639.9	541.3	1806.5	202.5	1797.3	372.2
18	2206.5	1802.5	2360.9	2028.2	2402.5	202.5	2417.2	307.2	3602.5	202.5	3652.7	211.8	2402.5	202.5	2417.2	307.2
19	1802.5	1402.5	1888.4	1616.3	2406.5	2606.5	2664.3	2895.1	3606.5	2606.5	3973.5	2760.8	2402.5	2602.5	2664.3	2890.8
20	2202.5	1006.5	2287.2	1143.8	1802.5	2602.5	1996.7	2934.2	602.5	2602.5	761.3	2973.2	1806.5	2602.5	1992.4	2934.2
21	2406.5	1402.5	2542.9	1555.7	202.5	1002.5	293.1	1356.2	4002.5	602.5	4116.5	584.6	2402.5	1806.5	2586.3	2002.2
22	2206.5	1602.5	2343.5	1798.4	4002.5	1002.5	4185.9	992.1	202.5	606.5	293.1	970.4	1806.5	1802.5	1918.7	2054.2
23	2006.5	1402.5	2109.5	1599.0	4002.5	1802.5	4307.3	1841.8	202.5	2206.5	358.1	2574.4	1802.5	1006.5	1849.4	1182.8
24	2202.5	1202.5	2308.9	1351.9	202.5	1806.5	336.5	2162.5	4002.5	2202.5	4346.3	2275.3	2406.5	1006.5	2503.9	1122.2

3.3 Study site

The area of study is located at Kota Samarahan, Sarawak, Malaysia. It is part of the Samarahan Campus 2, Universiti Teknologi MARA Sarawak as shown in Figure 3.7. It approximately lies between the latitudes of 1.453316 to 1.448275, the longitudes of 110.428674 to 110.432794. It covers an area of almost 270,000 square meters. It consists of parking lots, green areas and buildings.

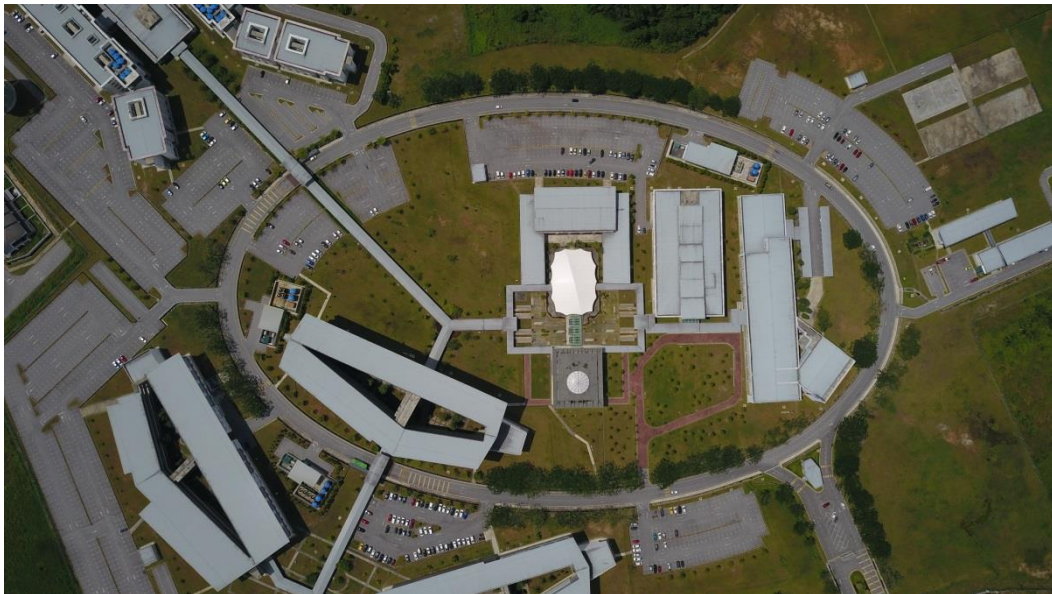


Figure 3.7: The study site

3.4 Research procedure

The overall research procedure is illustrated in Figure 3.8. The procedure starts with image acquisition, follows with potential control points identification, map coordinates detection, control points selection and also accuracy assessment and comparison. Each part of the procedure is discussed separately in the following subsections.

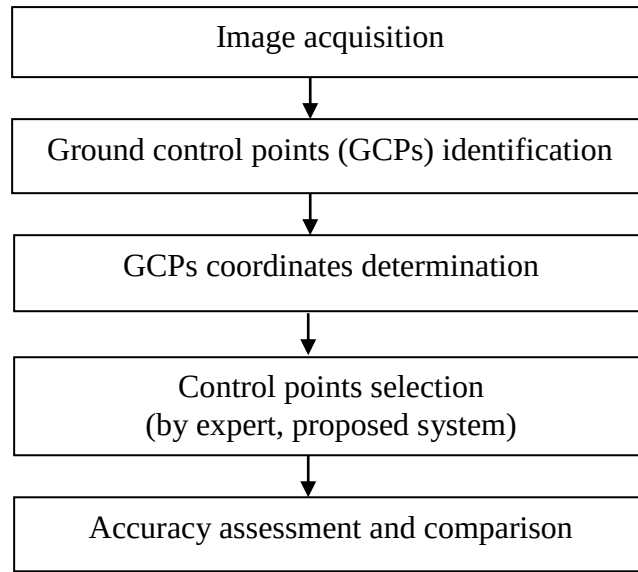


Figure 3.8: Overall research procedure flow diagram

3.4.1 Image acquisition

As mentioned in Section 2.4, it is difficult to obtain an ideal reference image that is acquired with the same sensor at a similar geometry, at a similar time and season as the target remotely sensed image. Different images such as satellite images, orthophotos and geo-referenced images are used as reference image data in the research of image registration and rectification. Since the reference data quality is one of the key components in achieving the success of image-to-image registration and rectification, the accuracy of the reference image needs to be validated or the reference data should be obtained from a qualified organisation. Hence, a small dataset which consists of reliable reference image data and aerial images as target image is normally used in the research domain. In this study, two types of images have been acquired, an aerial image and a satellite image.

3.4.1.1 Specification of aerial image

In this research, an aerial image is taken using the DJI Mavic Pro multi-rotor drone at the UiTM Sarawak Campus Samarahan 2. The camera sensor on the multi-rotor drone is 1/2.3 inch Complementary Metal-Oxide-Semiconductor (CMOS) with effective pixels of 12.35 megapixels. The lens of the camera has a field of view (FOV) of 78.8 degrees with 26 millimetres focal length and aperture of f/2.2. The maximum sensitivity of the sensor when taking still photo is ISO 1600. The camera takes still image at 4000×2250 pixels and stores using Joint Photographic Experts Group (jpeg) file format. The multi-rotor drone was flying at the height of approximate 400m when taking the aerial image. The spatial resolution of the image is 15 centimetres per pixel.

3.4.1.2 Satellite image

A Pleiades-1A satellite image is obtained from the Remote Sensing Agency of Malaysia. The Pleiades-1A satellite can provide orthorectified colour data at 0.5 metres resolution and revisiting any point on Earth as it covers a total of 1 million square kilometres daily. The Pleiades-1A satellite features four spectral bands (blue, green, red, and IR), as well as image location accuracy of 3 metres (CE90) without ground control points. Image location accuracy can be improved even further, up to an exceptional 1 meter, by the use of GCPs (Satellite Imaging Corporation, 2018).

The satellite image received was taken on 2018-08-15 and has gone through sensor level geometric processing and basic level of radiometric processing. The dataset framing of the satellite is shown in Table 3.3. The region of interest in the satellite image is shown in Figure 3.9. The quality of the satellite image is tested. The accuracy of the satellite image

is validated with a set of checkpoints as discussed in Section 3.4.3 and its accuracy assessment is discussed in Chapter 5.

Table 3.3: The dataset framing of the satellite image

Vertices	Longitude (DEG)	Latitude (DEG)	Row	Col
#1	110.425177	1.475203	1	1
#2	110.455823	1.475246	1	6801
#3	110.455771	1.440031	7803	6801
#4	110.425137	1.440011	7803	1

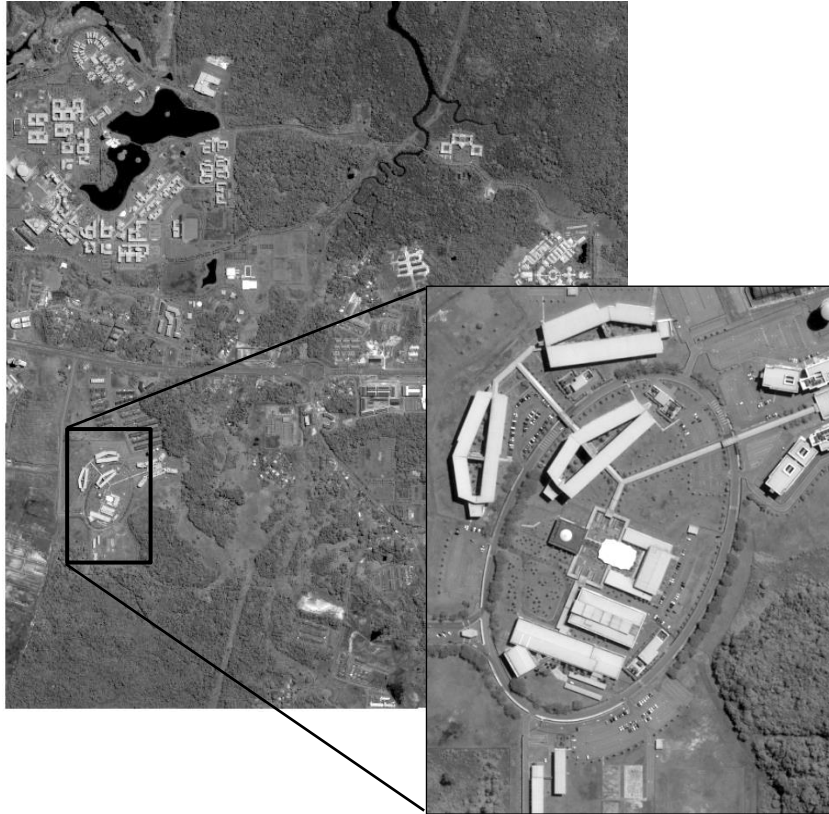


Figure 3.9: The region of interest in the satellite image

3.4.2 Ground control points identification

Although extraction of corresponding control points is important and there are many automatic extraction methods could be used, this study would like to highlight the selection of control points from a group of existing matched control points. A controlled experiment is setup with a number of control points which are manually identified. Such a setting is to minimize the effect that might cause by extraction and matching of control points, for example, the problems of multiple duplicates and wrongly matched corresponding points.

A set of 50 ground control points (GCPs) is identified manually by a surveyor, Sr. Dr. Khairul Nizam Tahar (Tahar, 2013). He is currently a Senior Lecturer in Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture Planning and Surveying, Universiti Teknologi MARA (UiTM), Malaysia. Besides as an academician, he is actively involved with research. His major research includes aerial photogrammetry, geodesy, geographic information system, remote sensing, surveying computing, surveying engineering and unmanned aerial vehicle applications. He has published his research works over forty articles in conference proceedings and journals with high impact.

The aerial image with the 50 GCPs is marked with red triangles and labelled with rectangles as shown in Figure 3.10. According to Sr. Dr. Khairul Nizam Tahar, these GCPs are determined based on the four criteria: location (proper geometry), identification (on the ground and not on the elevated object), distribution (must be well distributed) and type of object (either man-made or natural object).

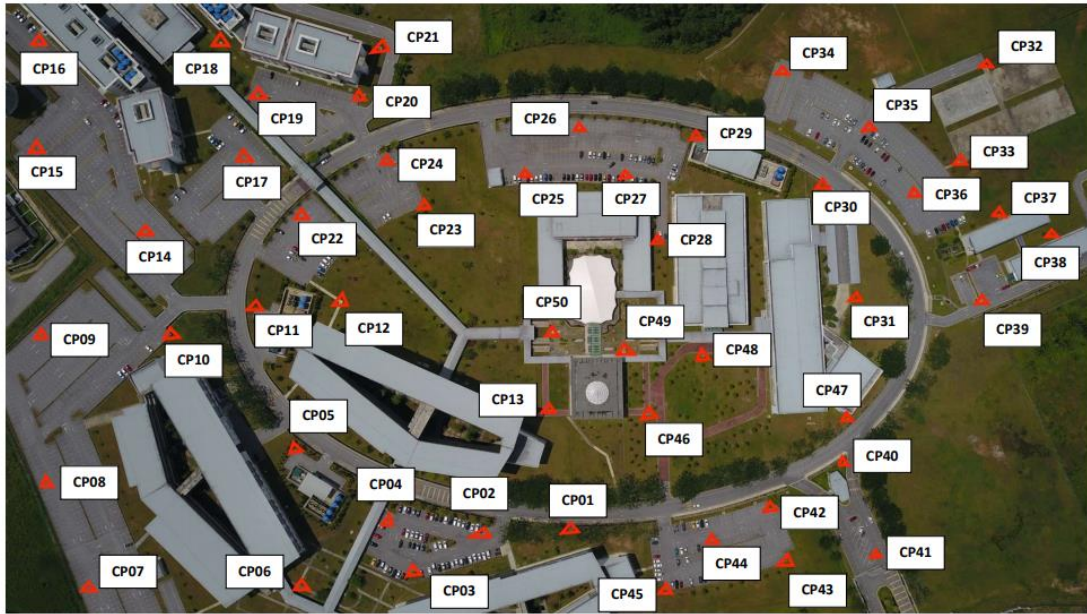


Figure 3.10: The study area and the position of the GCPs

3.4.3 Ground control points coordinates determination

The image with the 50 ground control points (GCPs) marker with the information of the landmark at the specific location is sent to the Land and Survey Department Sarawak (LNSD) to acquire the coordinates of the GCPs. The Land and Survey Department Sarawak is a leading agency in land management and land administration in Sarawak. The agency is committed to providing quality services to facilitate the development of land through proactive leadership at all levels supported by a competent workforce, efficient work processes and relevant technologies.

The LNSD retrieves the coordinates of the GCPs by referring to their orthophoto system, on 2018-08-24. The orthophoto system has 0.2 metres resolution (Sarawak Land and Survey Department, 2018). Some of the GCPs identified in the aerial image cannot be

identified in the LNSD database, only 40 coordinates are received from the LNSD. The coordinates of the GCP given by the LNSD are shown in Table 3.4.

In this research, out of the 40 GCPs obtained, 70% of them which consists of 28 GCPs with the control point id of CP01, CP03, CP05, CP06, CP10, CP12, CP18, CP20, CP21, CP23, CP24, CP26, CP27, CP28, CP30, CP32, CP33, CP34, CP35, CP37, CP39, CP40, CP41, CP43, CP45, CP46, CP48 and CP50 are used to calculate the transformation coefficients for transformation model. These GCPs are selected by Sr. Dr. Khairul Nizam Tahar, who has helped in identifying the 50 GCPs as mentioned in Section 3.4.2. The distribution of the 28 GCPs is shown in Figure 3.11. The remaining 30% of GCPs obtained which consists of 12 GCPs with the control point id of CP04, CP11, CP13, CP17, CP19, CP25, CP29, CP36, CP38, CP42, CP47, CP49 are used as checkpoints to validate the accuracy of the transformation and results in comparison purpose.

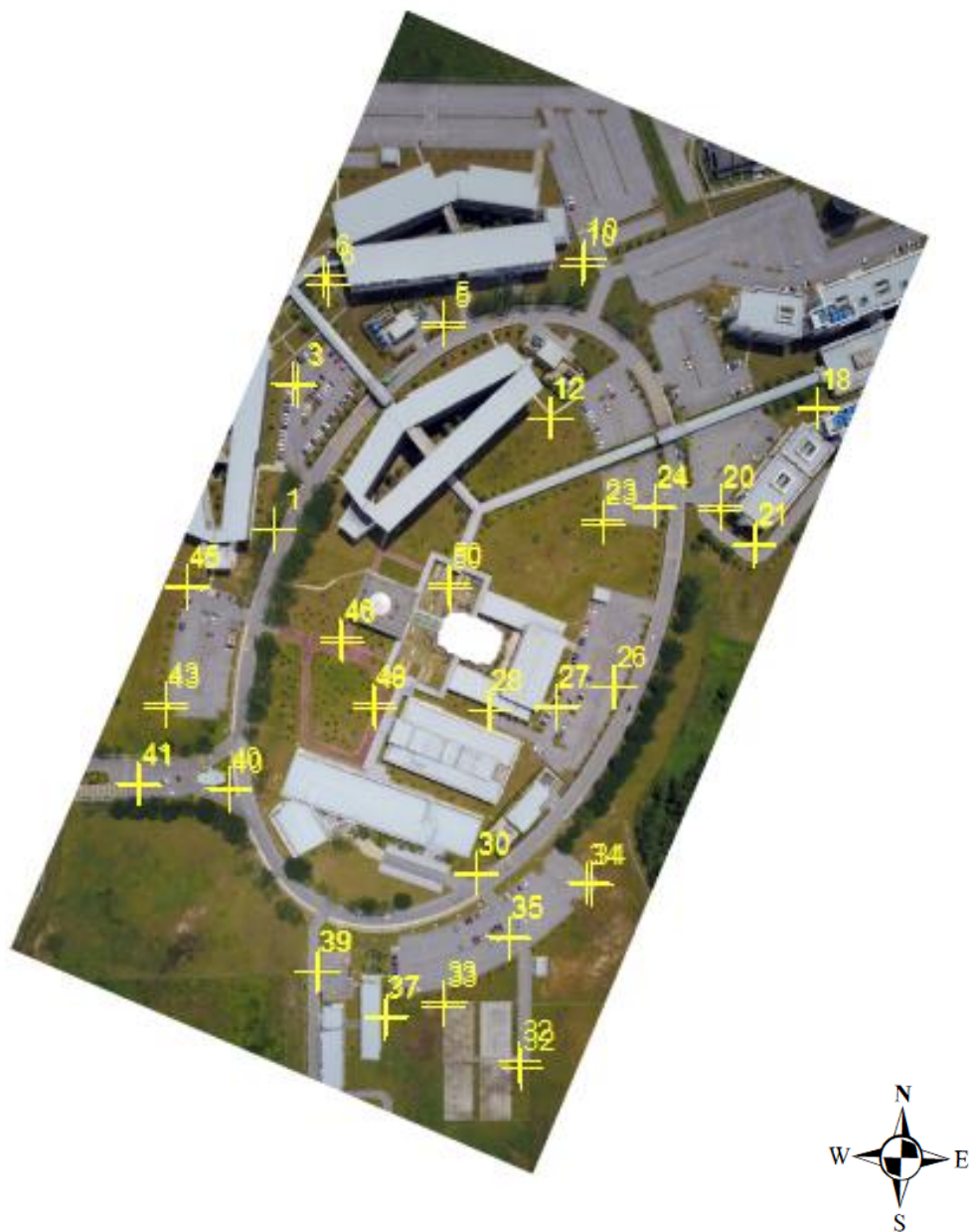


Figure 3.11: The distribution of the 28 GCPs used for similarity transformation

Table 3.4: The 40 coordinates (Timbalai BRSO) of the GCPs identified in the study area

GCP Id	X Image Source	Y Image Source	X Map (Easting)	Y Map (Northing)
CP01	2078.115472	1935.232060	2082348.9	5160490.3
CP02	1757.047330	1954.908291	Null	Null
CP03	1519.092065	2089.872253	2082361.9	5160574.8
CP04	1412.159166	1914.139928	2082391.3	5160579.3
CP05	1064.943126	1639.983993	2082448.4	5160610.3
CP06	1084.048057	2144.392942	2082379.9	5160635.0
CP07	307.731276	2154.621318	Null	Null
CP08	146.069356	1753.880850	Null	Null
CP09	131.603330	1222.963172	Null	Null
CP10	620.016938	1219.747086	2082530.7	5160646.3
CP11	917.112475	1118.110168	2082527.7	5160600.9
CP12	1243.066644	1097.966819	2082511.7	5160556.1
CP13	2001.900257	1497.977393	2082412.6	5160475.9
CP14	517.156714	842.006858	Null	Null
CP15	116.050083	533.638860	Null	Null
CP16	128.884813	151.973395	Null	Null
CP17	878.621590	566.249528	2082605.4	5160575.6
CP18	793.171873	139.025090	2082670.0	5160561.9
CP19	925.971795	336.912252	2082634.8	5160555.5
CP20	1308.893616	342.035626	2082612.5	5160504.2
CP21	1386.919311	160.695812	2082633.0	5160482.6
CP22	1089.921630	782.672674	Null	Null
CP23	1544.932309	747.933604	2082542.9	5160495.2
CP24	1405.995260	583.263644	2082573.2	5160504.7
CP25	1913.932193	630.036736	2082538.1	5160437.3
CP26	2114.985317	456.892534	2082549.3	5160397.2
CP27	2284.112682	632.886288	2082516.0	5160386.0
CP28	2397.077973	873.904526	2082475.9	5160383.9
CP29	2542.059707	489.797097	2082520.8	5160341.3
CP30	3003.985870	670.761544	2082468.4	5160287.1
CP31	3120.194901	091.070044	Null	Null
CP32	3613.100737	223.986184	2082494.8	5160171.2
CP33	3514.661922	588.817566	2082449.1	5160208.3
CP34	2863.952315	250.711475	2082535.8	5160280.5
CP35	3181.988415	455.004034	2082488.1	5160247.8
CP36	3345.988655	701.105799	2082441.3	5160239.1
CP37	3653.917557	778.905144	2082414.3	5160200.7
CP38	3845.929678	854.828837	2082392.3	5160178.0
CP39	3596.739776	1095.237031	2082373.1	5160228.3
CP40	3090.478594	1695.667571	2082321.4	5160337.4
CP41	3209.146504	2034.048748	2082268.3	5160340.3
CP42	2814.117785	1864.225442	2082315.0	5160385.9
CP43	2888.024455	2056.837436	2082284.6	5160387.1
CP44	2602.120662	1977.040653	Null	Null
CP45	2426.434607	2167.496477	2082297.4	5160456.9
CP46	2376.061361	1517.899163	2082388.1	5160425.7
CP47	2817.860830	1527.848335	2082342.8	5160325.0
CP48	2565.019254	1297.007823	2082407.1	5160386.7
CP49	2272.846655	1279.831692	2082425.8	5160425.3
CP50	2014.306957	1207.620532	2082452.0	5160457.9

3.4.4 Control points selection

The experiments conducted in this research are categorised into expert selection and proposed system selection. The same set of 28 control points with their map coordinates determined in Section 3.4.3 is used for the selection of control points with a different number of selection size which comprises of 3, 6, 9, 12, 15, 18, 21, 24 and 27 number of control points. Sr. Dr. Khairul Nizam Tahar is appointed as the expert to perform the selection. The profile of the expert has been discussed in Section 3.4.2. He performs the selection based on his expertise and experience in the field. Meanwhile, the proposed system optimises the selection of control points based on the local feature using the Harris corner score and point distribution impact index.

Corners are essential local features in images (Ghosh et al., 2015), which are naturally invariant to translation and rotation, as well as robust to illumination changes and limited changes of view-point (Sedaghat & Mohammadi, 2018). Besides that, corners also are claimed as the image feature points which able to generate gradients of more prominent values (Ghosh et al., 2015). Harris corner detector is widely used in image registration and has been proved to be one of the best corner detection algorithms (Kaur, 2012).

The corner search of the detected control points is performed using the Harris corner detection algorithm as denoted by Equation 2.1 in Chapter 2. The corner score of each control point is then measured using the Hessian (H) determinant as shown in Equation 3.1, where I_{xx} , I_{xy} and I_{yy} are the second derivatives of the image point. The Harris-Hessian detector was firstly proposed in 2009 by Xie et al. (2010) and further researched in 2010 (Danielsson et al., 2016).

$$\det(H) = I_{xx}I_{yy} - I_{xy}^2 \quad (3.1)$$

where I_{xx} , I_{xy} and I_{yy} are the second derivatives of the image point

In the proposed multi-agent approach, the task of corner score calculation is carried out by a software agent named Corner agent. Each control point will be assigned with a Corner agent. Corner agent will perform the corner search and corner score calculation iteratively. The iteration is started with an initial neighbourhood size of two pixels and continued each time with an increment of neighbourhood pixel size of two until the corner score of the GCP is calculated. The design of Corner agent is explained in Section 3.5. The implementation of Corner agent is discussed in Chapter 4.

The distribution impact index represents the point important value contributed by each control point in terms of Voronoi polygon area through the Voronoi diagram as highlighted by Li and Cheng (2008), Wangfei et al. (2009), and Guang and Weili (2011). When the distribution impact index of each control points has the same value, it means that the set of control points are uniformly distributed. The Voronoi diagram is constructed based on the control points by taking the border of the region of interest as the map boundary. Then, the distribution impact index of each point is measured by using Equation 2.16 as discussed in Section 2.7.4. It is calculated based on the area polygon over the total area polygon. In the proposed multi-agent approach, the task of distribution impact index is carried out by a software agent named Distributor agent. The design of Distributor agent is explained in Section 3.5. The implementation of Distributor agent is discussed in Chapter 4.

The combination of corner score and distribution impact index is then used to determine the retention of control points. Rank-based method is used to combine the two criteria of

corner score and distribution impact index as a single point selection value. Each control point is ranked accordingly from the lowest to highest value by each selection criteria. The selection value (S_i) of each control points is computed using Equation 3.2. The control points with the highest selection value is treated the most relevant selection. The control point with the lowest selection value will be discarded from the iteration of selection. If there are control points having the same lowest selection value, then the control points with the lower rank in distribution impact index will be excluded. The selection process is continued by using the updated set of control points after earlier selection until it reaches the required number of control points.

$$S_i = r_i^c + r_i^d \quad (3.2)$$

where r_i^c is the rank value for corner score and r_i^d is the rank value for distribution impact index of the i th control point.

3.4.5 Accuracy assessment and comparison

The selected GCPs according to the selection size are used to perform coefficients calculation for various transformations. Geometric transformations have different ability in handling different distortions complexity. Since the scenes of the aerial images are relatively flat areas and the scope of the study does not include different types of geographical surface, the global transformations are used in the study. The geometric transformations used are similarity transformation, affine transformation, second order polynomial transformation and third order polynomial transformation as applied in preliminary study. As mentioned in Section 3.4.3, twelve GCPs are used as checkpoints. Figure 3.12 shows the location and distribution of the twelve checkpoints. These points are used only in the assessment and not involved in the rectification process.

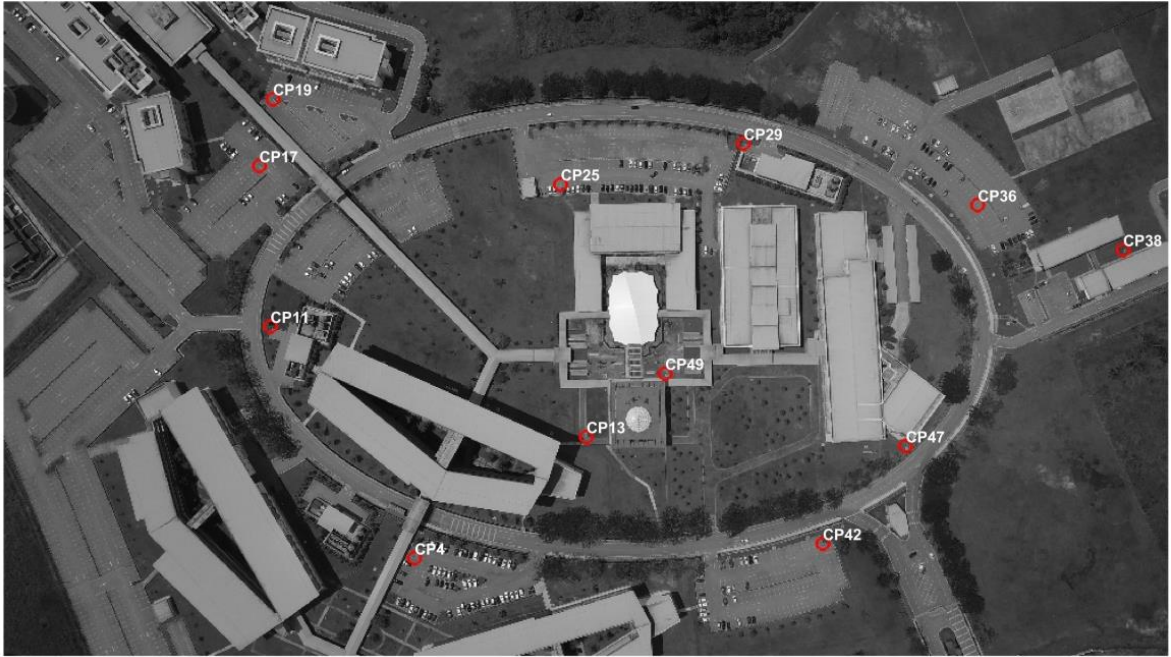


Figure 3.12: Location and distribution of checkpoints

Checkpoints, like ground control points, are clearly identified on the image, intersections of roads, sidewalk or curbs, permanent, not subject to erosion, located at ground level and not rooftops of buildings. The total root mean square error (RMSE) as shown in Equation 2.33 of the twelve checkpoints is calculated as geometric accuracy for evaluating the rectification based on the selection. The proposed multi-agent system is evaluated by comparing the total RMSE of checkpoints achieved with the total RMSE of the selection done by expert. After identified the proper transformation from the achievement of the lowest total RMSE of checkpoints, the proposed multi-agent system selection is compared with a conventional residual method. The comparison of results is further discussed in Chapter 5.

3.5 Proposed multi-agent approach for aerial image rectification

Multi-agent approach is a way to represent the design, implementation and analysis of complex software systems (Ghorbani, & Dignum, 2013). The rationale for integrating with multi-agent approach in this research includes scalability, modularity, openness, cooperative and communication as highlighted in Chapter 2. Although many auto extraction methods from image processing field could conveniently produce a large number of corresponding control points, this research would like to study on how to select the optimised set of control points from the number of detected and matched points. From the review, the current image processing applications which mostly based on sequential approaches and algorithms are getting more complex and unable to support the increasing use of high resolution remotely sensed images (Liao et al., 2017). This research proposes a novel approach on control point selection based on individual point corner score and distribution impact index for aerial image rectification with the integration of cooperative multi-agent system. The proposed approach introduces software agents to facilitate the procedure of aerial image rectification.

As discussed in Section 2.11, a hybrid methodology is usually recommended to overcome weakness when using a single methodology. The design of the proposed multi-agent approach for aerial images rectification is built according to the agent-oriented methodology named ROADMAP (Role-oriented Analysis and Design for Multi-agent Programming) and RAP/AOR (Radical Agent-Oriented Process/Agent-Object-Relationship). The conceptual framework for the design is based on the Model-Driven Architecture (MDA) which includes computation independent models (CIMs) and platform independent models (PIMs). In the CIMs, the requirements of the system are

analysed using goal model, role model, organisation model and domain model. In the PIMs, the requirements of the system are further analysed using knowledge model and agent behaviour model for rectification of aerial images.

3.5.1 Goal model

The goal model for the development of aerial image rectification is illustrated in Figure 3.13. The overall goal of the system is to rectify aerial image, expressed by the overall goal “Rectify aerial image”. As shown in Figure 3.13, two roles named as User and Image processing manager, are indicated as relevant to the overall goal. The image processing manager role is responsible for achieving this goal. The quality goal “Appropriate result” indicates that the output should be appropriate. The goal “Rectifies aerial image” can be achieved via several sub-goals which are known as “Extract control points”, “Generate corner score”, “Generate distribution impact index”, “Transform image” and “Measure error”. A quality goal of “Accurate matched points” is attached to the sub-goal of “Detect control points”. The sub-goal of “Generate distribution impact index” is also attached with a quality goal of “Well distribution”. Subsequently, the roles identified by the goal model are described later by role model in the next section.

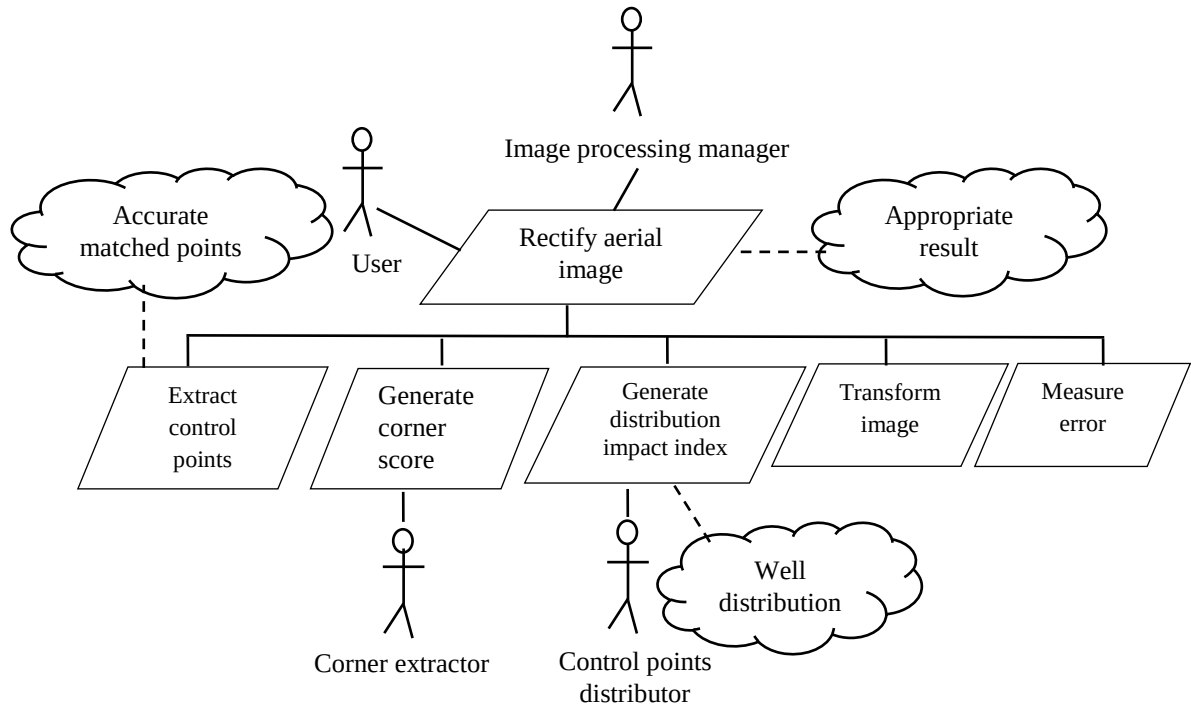


Figure 3.13: An overview of goal model for rectifying aerial images

3.5.2 Role model

The proposed multi-agent approach for aerial image rectification involves human and software agents. Table 3.5, Table 3.6, Table 3.7 and Table 3.8 show the role models for *User*, *Image processing manager*, *Corner extractor* and *Control points distributor*, respectively.

Table 3.5: Role model for user

Role name	User
Description	Request aerial image rectification.
Responsibilities	Provide reference source and aerial image.
Constraints	Reference source and aerial image must be available.

Table 3.6: Role model for image processing manager

Role name	Image processing manager
Description	Handles and manages image rectification process.
Responsibilities	Acquires aerial image and reference source. Set and start the rectification process. Extract matched control points. Send request to generate corner score. Receive corner score generated. Send request to generate distribution impact index. Receive distribution impact index generated. Select control points based on the corner score and distribution impact index. Transform aerial image using various transformations. Measure RMSE. Terminate rectification process.
Constraints	Reference source and aerial image must be available.

Table 3.7: Role model for corner extractor

Role name	Corner extractor
Description	Generate corner score.
Responsibilities	Calculate the Harris corner score of the detected control points.
Constraints	Accurately matched control points must be available.

Table 3.8: Role model for control points distributor

Role name	Control points distributor
Description	Generate distribution impact index.
Responsibilities	Construct Voronoi diagram using the detected control points. Calculate distribution impact index of each control point based on the Voronoi polygon area.
Constraints	Accurately matched control points must be available.

3.5.3 Organisation model

Figure 3.14 depicts an organisation model for rectifying aerial images. The organisation model is arranged in such a way that the image processing manager coordinates the interactions among the roles played in the multi-agent system. The user and image processing manager rely on each other when performing the task. The user relies on the image processing manager to start the process of aerial image rectification while the image processing manager relies on the user to receive the request of image rectification and provide the reference and aerial image.

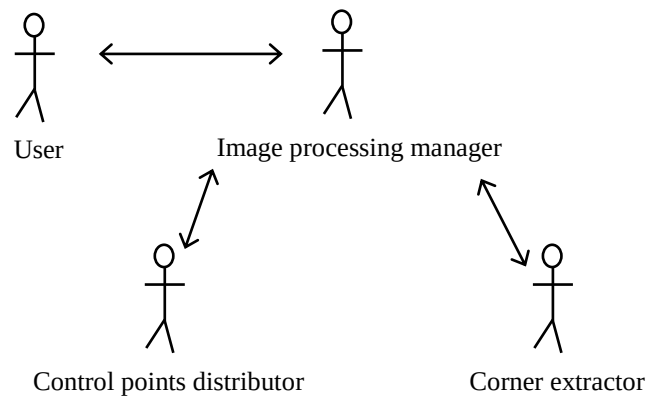


Figure 3.14: Organisation model for aerial image rectification

3.5.4 Domain model

Figure 3.15 shows the domain model for the rectification of aerial images. The ReferenceSource and AerialImg are domain entities that represent the reference source and aerial image provided by the user when requesting for image rectification. Both of these images are used to detect matched control points by image processing manager. The MatchedCPs domain entity represented the matched control points. Not all the matched

control points are used for image rectification. The matched control points are selected based on corner response and distribution impact index, which are modelled as CPsCornerScore and CPsDistributionImpactIndex domain entity. The image processing manager uses the selected control points to rectify the aerial images.

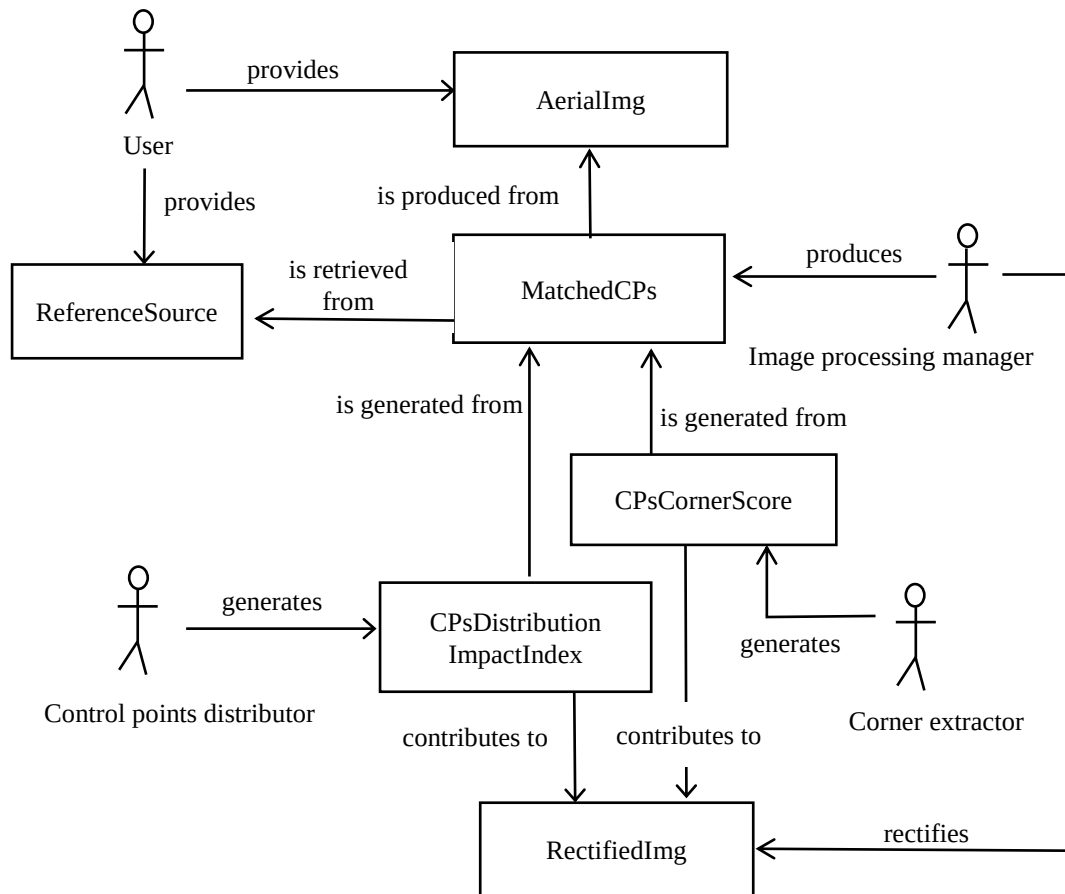


Figure 3.15: The domain model for rectification of aerial images

3.5.5 Agent-role coupling

Agent-role coupling shows how the responsibilities of roles in the rectification of aerial images have been mapped into agents. It helps to check the role assignments against the fulfilment of goals. A role might need to carry out various functionalities in order to achieve a goal. Therefore, a role might have to be mapped to different agent types.

However, the roles for aerial images rectification only involve one-to-one mapping as shown in Figure 3.16. The agent types are modelled by the corresponding agent descriptor as described in Table 3.9, Table 3.10, Table 3.11 and Table 3.12. After mapping roles to agent types, the interactions between enactors of the roles are sketched using interaction-frame diagrams which would be discussed in the interaction model.

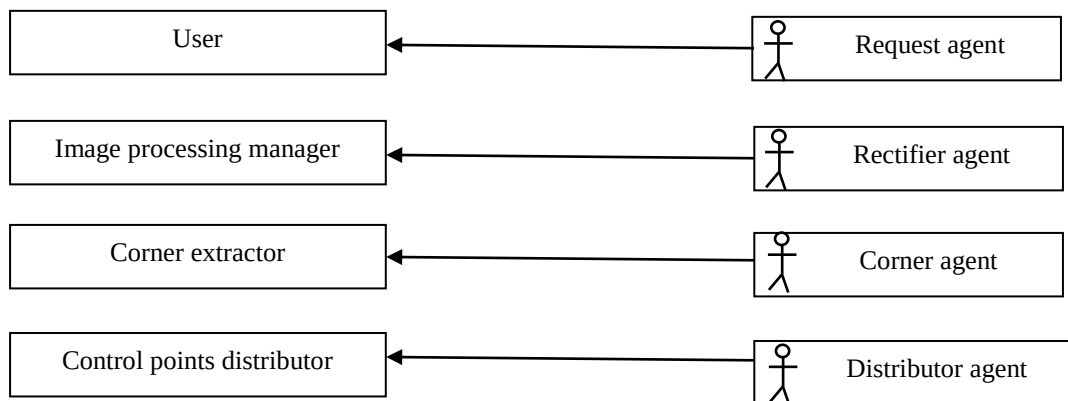


Figure 3.16: The agent-role coupling diagram for rectification of aerial images

Table 3.9: Descriptor of the type Request agent

Agent type	Request agent
Description	An agent of the Request agent type provides reference image and aerial image. It sends rectification request.
Goals achieved	Provide reference image and aerial image and send rectification request to start the rectification system.
Creation	The first use of the system.
Destruction	The rectified image has been received.

Table 3.10: Descriptor of the type Rectifier agent

Agent type	Rectifier agent
Description	An agent of the Rectifier agent type receives a request from the user, extracts and matches control points, receives corner score, receives distribution impact index and rectify aerial image.
Goals achieved	Rectify aerial image.
Creation	Initialisation.
Destruction	The aerial image has been rectified.

Table 3.11: Descriptor of the type Corner agent

Agent type	Corner agent
Description	An agent of the Corner agent type receives a request from Rectifier agent and generates corner score.
Goals achieved	Generate corner score using Hessian determinant after corner search with Harris corner detection algorithm.
Creation	Corner score is requested.
Destruction	The corner score has been generated.

Table 3.12: Descriptor of the type Distributor agent

Agent type	Distributor agent
Description	An agent of the Distributor agent type receives a request from Rectifier agent and generates distribution impact index.
Goals achieved	Generate distribution impact index based on Voronoi polygon area.
Creation	Distribution impact index is requested.
Destruction	The distribution impact index has been generated.

3.5.6 Interaction model

The interaction-frame diagram for rectification of aerial images is depicted in Figure 3.17. It consists of three interaction frames that have been derived from the role models. The first interaction frame is between the Request agent and the Rectifier agent, the second

interaction frame is between the Rectifier agent and Corner agent, and the third interaction frame is between the Rectifier agent and the Distributor agent.

Messages in the interaction frames involve two modalities, request and inform. The request modality is a message from an agent asks another agent to carry out certain actions while the inform modality is a message that would notify or update another agent on the occurred events. Each action event is characterised by its number which represents the order of interaction between the agents involved. The interaction-sequence diagram for rectifying aerial images as depicted in Figure 3.18 shows the sequence of action events performed and received by agents.

The model starts with the request from Request agent by providing a reference source and aerial image. Rectifier agent would request Corner agent to generate the corner score. A message would be sent back to Rectifier agent when the task is done. Rectifier agent also would ask Distributor agent to generate the distribution impact index. Distributor agent would send a message back to Rectifier agent once the distribution impact index has been generated. Rectifier agent would continue the flow by rectifying the image using the selected control points. Lastly, Rectifier agent would inform Request agent about the termination of the process to retrieve the overall result.

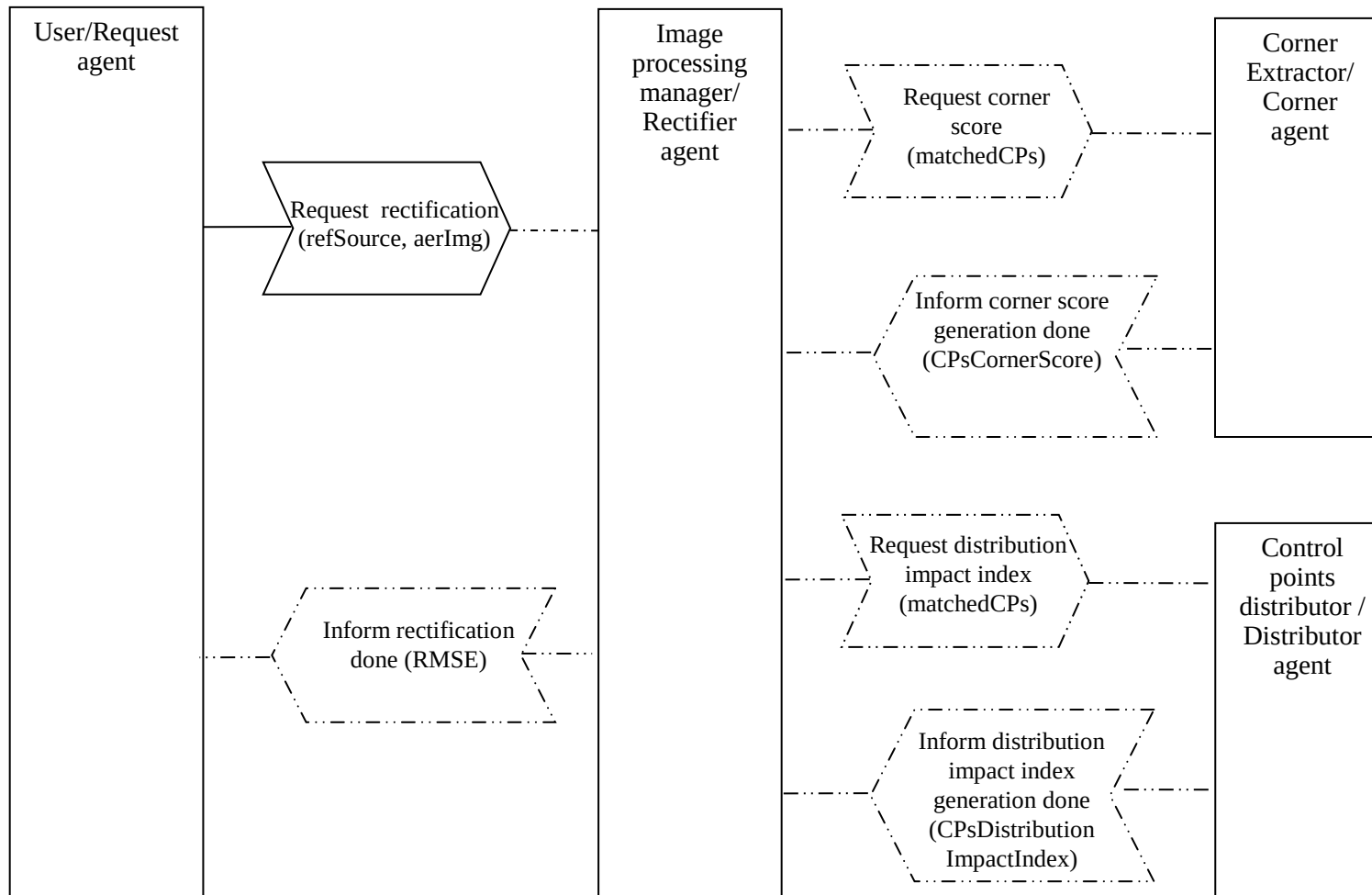


Figure 3.17: Interaction-frame diagram for rectification of aerial images

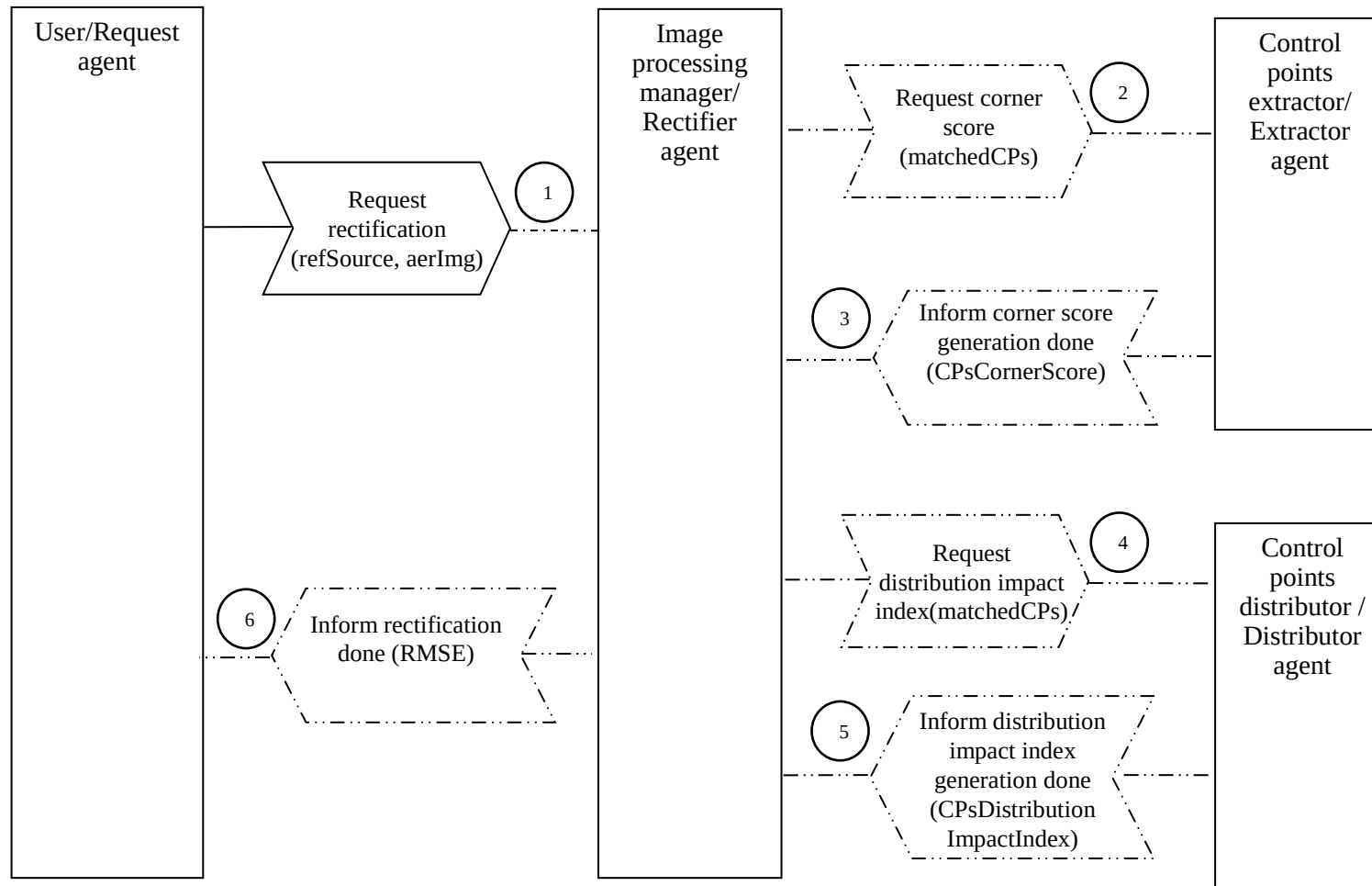


Figure 3.18: Interaction-sequence diagram for rectification of aerial images

3.5.7 Knowledge model

The knowledge model for rectification of aerial images is illustrated in Figure 3.19. The tasks of rectifying aerial images are allocated among the three agents with own specific defined responsibility. Rectifier agent coordinates various tasks that need to be performed between user and agents. Rectifier agent manages the user interaction. The initial set of matched control points will be prepared by Rectifier agent and sent to Corner agents and Distributor agents.

Each Corner agent calculates Harris corner score for each detected control point using Hessian determinant after corner search with Harris corner detection algorithm. Corner agents repeat the corner search with different size of pixel neighbourhood until it obtained the corner score. The corner score of each control point will be sent to Rectifier agent. Rectifier agent will receive the corner responses and rank them accordingly.

Distributor agent is designed to manage the generation of distribution impact index. It firstly generates Voronoi diagram using the initial set of matched control point received from Rectifier agent. The distribution impact index of each polygon is calculated based on its area polygon over the total area polygon. The distribution impact index of each control point will be sent to Rectifier agent. Rectifier agent will receive the distribution impact indices and rank them accordingly too. Rectifier will combine the rank value of the corner score and distribution impact index as a selection value to make the selection decision. The control point with the lowest selection value will not be chosen. The selection process will iterate by resending the set of control points after earlier selection until a required number of control points is reached. Rectifier agent will perform the transformation using the selected control points and calculate the RMSE of checkpoints.

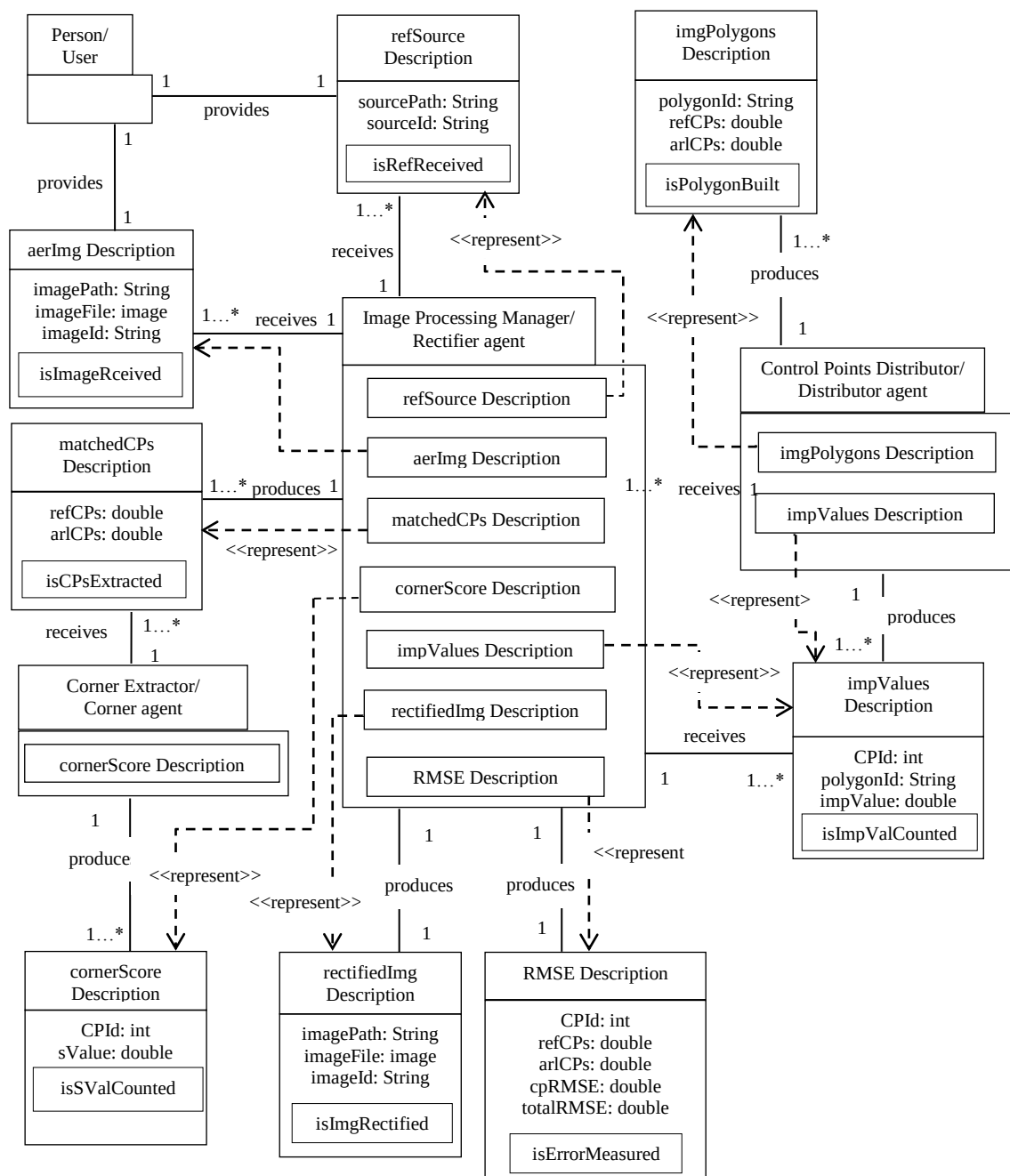


Figure 3.19: Knowledge model for rectification of aerial images

3.5.8 Behaviour model

The overall process for the rectification of aerial images is presented in three scenarios. The first scenario for managing rectification of aerial images is given in Table 3.13. It has two simple steps. The first step starts with the request from a user by providing the resources of reference and aerial image. The second step is the notification of the completeness of the rectification process with an appropriate result of rectified image and RMSE by Image processing manager to the User at the end of the process.

The second scenario corresponds to the goal of “Rectify aerial images” as modelled in Figure 3.13. It has seven steps. It realises the respective sub-goals of “Extract control points”, “Generate corner response”, “Generate distribution impact index”, “Select control points”, “Transform image” and “Measure error” as shown in Table 3.14. Among them, the step of “Generate corner response” involves a third level of scenario and the step of “Generate distribution impact index” involves a fourth level of scenario.

Table 3.15 displays the third scenario. The third scenario corresponds to the goal of “Generate corner response”. It has a step of activity calculating the corner score which is carried out by Corner agent. Table 3.16 shows the fourth scenario. The fourth scenario corresponds to the goal of “Generate distribution impact index”. It has two steps which involve activities building Voronoi polygon and calculating distribution impact index. These activities are carried out by Distributor agent.

The rules modelled for rectifying aerial images are depicted in Table 3.17. The table lists the rule, its trigger, condition and the action prescribed by the rule. The rectification process is triggered by the start event and is activated if a request is received from the user which is modelled with the help of rule R1 as illustrated in Figure 3.20. An activity type of

"Rectify aerial image" is started by rule R2. The condition attached to rule R2 means that the rule is triggered only if there is a reference source and an aerial image. When triggered, this rule starts an activity of type "Extract control points". When the matched control points have been extracted, an activity type of "Calculate corner score" is started by rule R3. The activity type of "Generate distribution impact index" contains sub-activities. Its sub-activity of type "Build polygon" is started by rule R4. After that, it is followed by an activity of type "Calculate distribution impact index" which is modelled by rule R5. Then, rule R6 models an activity type of "Select points" after the activity of type "Calculate distribution impact index". The activity type of "Transform image" is modelled by rule R7, is started when there exists selected control points. Rule R8 starts the activity type of "Measure error", the second last sub-activity of activity type "Rectify aerial image". The enclosing activity of type "Rectify aerial image" is modelled by rule R9 which includes the notification to the user by presenting the rectified image and RMSE measurement.

Table 3.13: A scenario for handling rectification of aerial images

Scenario 1					
Goal	Managing rectification of aerial images				
Initiator	Rectifier agent				
Trigger	Request agent sends a request of image rectification				
Failure	-				
Description					
Condition	Step	Activity	Agent types and roles	Resources	Quality goals
When a user requests to rectify aerial images.	1	Rectify aerial images (Scenario 2)	Request agent, Rectifier agent	Reference source, aerial image	Appropriate result
	2	Inform rectification is completed	Rectifier agent, Request agent	RMSE	

Table 3.14: A scenario for rectifying aerial images

Scenario 2					
Goal	Rectify aerial images				
Initiator	Rectifier agent				
Trigger	A request to rectify image is received				
Failure	Produce inappropriately rectified image				
Description					
Condition	Step	Activity	Agent types and roles	Resources	Quality goals
When a request for aerial images rectification has been received.	1	Extract control points	Rectifier agent	Reference source, aerial image	Accurate matched points
	2	Generate corner score (Scenario 3)	Corner agent	Matched control points, size of neighbourhood	
	3	Inform corner score is generated	Corner agent, Rectifier agent	Corner score	
	4	Generate distribution impact index (Scenario 4)	Rectifier agent, Distributor agent	Matched control points	Well distribution
	5	Inform distribution impact index is generated	Distributor agent, Rectifier agent	Distribution impact index	
	6	Select control points	Rectifier agent	Corner score, distribution impact index	
	7	Transform image	Rectifier agent	Selected control points	
	8	Measure error	Rectifier agent	Checkpoints	

Table 3.15: A scenario for generating corner score

Scenario 3					
Goal	Generate corner score				
Initiator	Corner agent				
Trigger	A request to generate corner score is received				
Failure	-				
Description					
Condition	Step	Activity	Agent types and roles	Resources	Quality goals
When a request of generating corner response has been received and repeats if necessary.	1	Calculate corner score	Corner agent	Matched control points, size of neighbourhood	

Table 3.16: A scenario for generating distribution impact index

Scenario 4					
Goal	Generate distribution impact index				
Initiator	Distributor agent				
Trigger	A request to generate distribution impact index is received				
Failure	Produce poor distribution of control points				
Description					
Condition	Step	Activity	Agent types and roles	Resources	Quality goals
When a request of generating distribution impact index has been received and repeated if necessary.	1	Build polygon	Distributor agent	Matched control points	Well distribution
	2	Calculate distribution impact index	Distributor agent	Voronoi polygons	
	3	Select control points			

Table 3.17: The models of rules R1 until R9 for rectifying aerial images

Rule	Trigger	Condition	Action if condition true	Action if condition false
R1	Start event	User's request is accepted	Start "Rectify aerial image" activity	-
R2	Start "Rectify aerial image" activity	There exist reference source and aerial image	Start "Extract control points" activity	-
R3	End of "Extract control points" activity	There exists matched control points	Start "Calculate corner score" activity	-
R4	End "Calculate corner score" activity	There exist corner scores	Start "Build polygon" activity	-
R5	End "Build polygon" activity	There exist Voronoi polygons	Start "Calculate distribution impact index" activity	-
R6	End "Calculate distribution impact index" activity	There exists distribution impact index	Start "Select point" activity	-
R7	End "Select point" activity	There exists points selection result	Start "Transform image" activity	
R8	End "Transform image" activity	There exists a transformed image	Start "Measure error" activity	-
R9	End "Measure error" activity	There exists RMSE of check points	Start "Inform user" activity	-

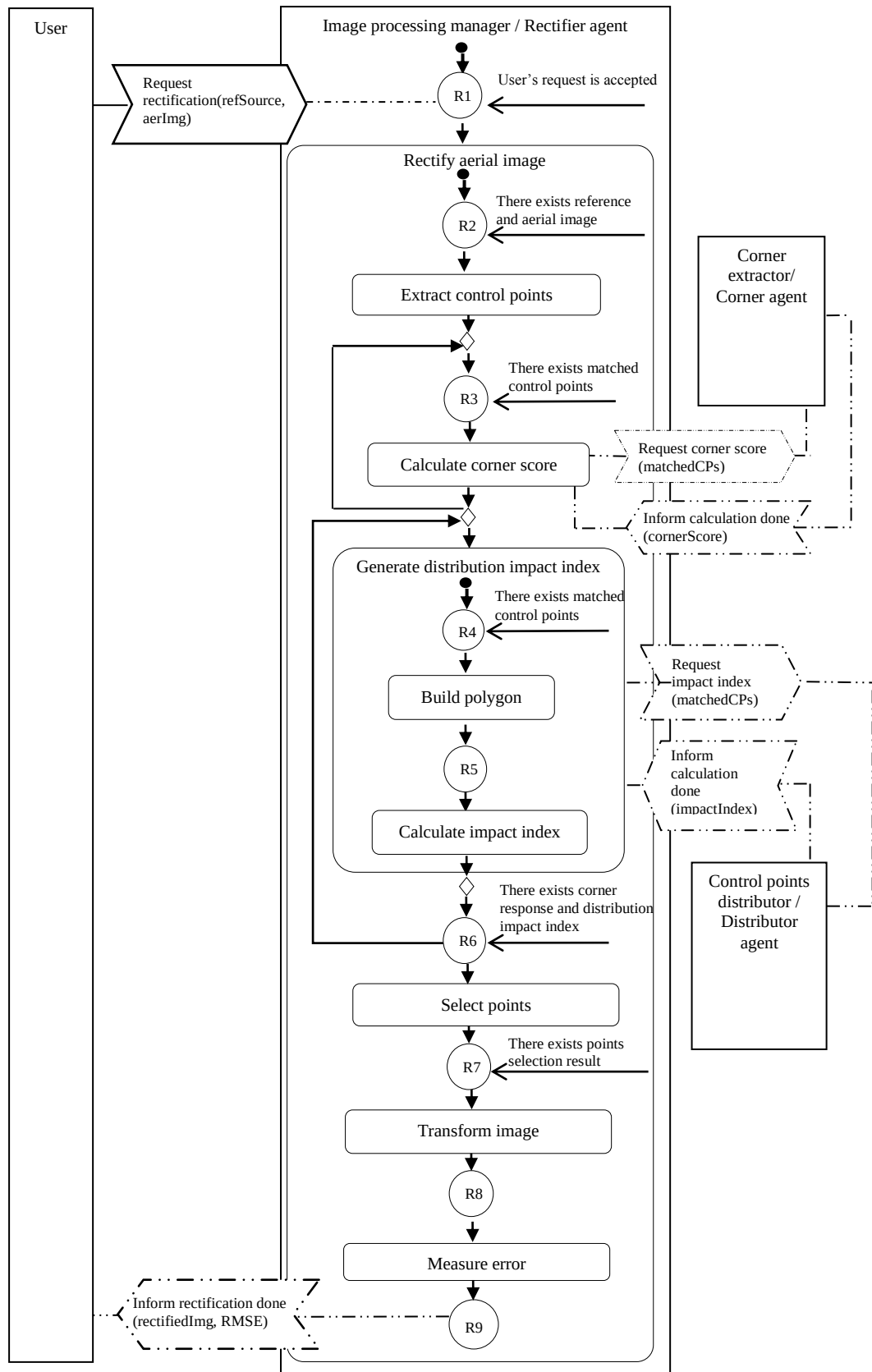


Figure 3.20: An agent behaviour model for rectifying aerial image

3.6 Summary

This chapter discusses the methodology of control point selection for aerial image rectification. The chapter started with the discussion on preliminary study to learn the distribution effect of control points on image rectification. Then, it continued with the description on the study site and then the presentation on the details of each research procedures of the proposed aerial image rectification. It also includes the framework design of the cooperative multi-agent approach in handling the aerial image rectification.

The research testing is conducted under a controlled environment with a number of ground control points which are manually determined by a surveyor. The selection of control points is then made from these existing matched control points in order to avoid or at least to minimise the issues and effects that might cause by extraction and matching of control points. The coordinates of the ground control points are provided by the Land and Survey Department Sarawak. The experiments on the selection of control points are categorised into expert selection and proposed multi-agent system selection. The selections of ground control points are 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. The total root mean square error of the same set of twelve checkpoints is calculated as the geometric accuracy for evaluating the rectification of each selection.

The cooperative multi-agent approach is proposed for aerial images rectification. The components of the multi-agent framework for designing the control points selection are discussed. It includes the computation independent model for rectification of aerial images which contains the goal model, role model, organisation model, domain model and

interaction model. Besides that, this chapter also considers the platform independent model for rectification of aerial images which comprises of knowledge model and agent behaviour model for rectification of aerial images.

The next chapter will describe the platform specific model for aerial image rectification which concentrates on the implementation of the proposed framework.

CHAPTER 4

IMPLEMENTATION

4.1 Introduction

Agent-based systems technology has been addressed as a new paradigm for conceptualising, designing, and implementing software systems. Agents are defined as sophisticated computer programs that could act autonomously on behalf of their users, across open and distributed environments. Hence, agent-based system is able to solve a growing number of complex problems.

The Platform Specific Models (PSM) for aerial image rectification is presented in this chapter. It discusses the details on implementation of the proposed approach which is developed using JADE (Java Agent Development Framework) agent platform and MATLAB functions. This chapter firstly describes the specification of hardware and software used. Then, it discusses multi-agent based aerial image rectification in JADE platform. Next, the implementations of JADE based Request agent, Rectifier agent, Corner agent and Distributor agent are presented.

4.2 Hardware and software

The experiments are carried out using computer hardware as specified in Table 4.1. The multi-agent system is developed using JADE platform of version 4.4 with Java programming and the image processing algorithms are deployed using functions from MATLAB version R2017b.

Table 4.1: Hardware specification

Operating system	Windows 7 Professional
Processor	Intel® Core™ i5-3570 CPU
Installed memory (RAM)	4.00 GB
System type	64-bit OS

4.3 Multi-agent based aerial image rectification in JADE platform

When starting a JADE container, JADE creates a graphical user interface named RMA (Remote Management Agent) which shows all participating agents and containers (Bellifemine et al., 2007). JADE has three main agents that are necessary to FIPA standard which include Director Facilitator (DF), Agent Communication Channel (ACC) and Agent Management System (AMS). DF provides yellow pages services to the platform where one agent could search for other agents required when achieving its goals. Agents in the system need to register their services with DF for providing services to the community. ACC manages the communication between agents by forwarding messages between local and remote entities. AMS manages the life cycle of agents in the system by providing the naming service and ensures each agent in the platform has a unique name. It administers the creation of agents, the registration of agents, their authentication, access and use of the system. These three agents are activated each time when starting the platform.

A user-defined JADE agent is implemented as an instance of the Java class named as `jade.core.Agent`. It can perform several tasks simultaneously in response to different events. During the development with JADE, four different agent classes are created to describe the four types of agent designed. These four agents that have been created and registered in the environment could be viewed with the use of RMA GUI (Bellifemine et al., 2007) provided by JADE as shown in Figure 4.1. The behaviours of a JADE agent are

implemented as instances of Java class named as `java.core.behaviours.Behaviour`.

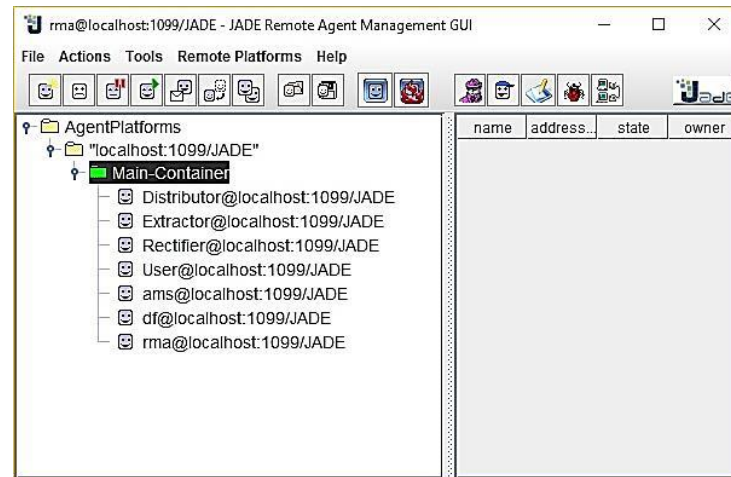


Figure 4.1: Agents created and added in the JADE RMA GUI

The interaction between agents is done through messages passing. Each agent can send messages using the FIPA ACL that provides the types of required message. The example of Java code implementation for message passing between agents is as shown in Figure 4.2. The reception of message is assured using the JAVA code as shown in Figure 4.3. The interaction and communication among agents could be observed and monitored in real-time by JADE Sniffer Agent. It intercepts the messages sent between agents that live in the platform.

```
...
ACLMessage Message = new ACLMessage(ACLMessage.INFORM);
Message.addReceiver(new AID("..", AID.ISLOCALNAME));
Message.setContent(" ...");
send(message);
...
```

Figure 4.2: Java code implementation of message passing between agents

```

...
ACLMMessage message_Recu = receive();
String Text = message_Recu.getContent();
...

```

Figure 4.3: Java code implementation of message reception

4.4 Implementation of Request agent based on JADE

The Request agent is implemented using a JADE agent class named as “RequestAgent”. The Request agent firstly needs to register with DF as shown in Figure 4.4. When it is ready, it will send out a request to Rectifier agent. This is the main task of Request agent in order to prompt the rectifying process. The extracted implementation code of the sending request behaviour is shown in Figure 4.5.

```

...

public class RequestAgent extends Agent{
//-----

...

protected void setup() {
// -----
// set this agent main behaviour
    ServiceDescription sd = new ServiceDescription();
    DFAgentDescription dfd = new DFAgentDescription();
    sd.setType("Request");
    sd.setName(getName());
    dfd.setName(getAID());
    dfd.addServices(sd);
    try {
        DFService.register(this, dfd);
        System.out.println(getLocalName() + " is ready.");

        //doWait(3000);
        SendRequest sur = new SendRequest(this);
    } catch (Exception e) {
        e.printStackTrace();
    }
}

...

```

Figure 4.4: Extracted “RequestAgent” implementation code for registration

```

...
private class SendRequest extends OneShotBehaviour {
// -----
// send request to Rectifier for image rectification

    public SendRequest(Agent a){
        super(a);
    }
    public void action() {
        ACLMessage msg = new ACLMessage(ACLMessage.REQUEST);
        try{
            msg.addReceiver(ImageRectifier);
            System.out.println("User sends request to Image Rectifier
Agent.");
            msg.setContent("rectify");
            send(msg);
        }
    }
}
...

```

Figure 4.5: Extracted “RequestAgent” implementation code for sending request to Rectifier agent

4.5 Implementation of Rectifier agent based on JADE

The Rectifier agent is implemented using a JADE agent class named as “RectifierAgent”. As usual, the Rectifier agent is firstly required to be registered in the yellow pages. Figure 4.6 shows the implementation code for registration. The Rectifier agent sends the request for corner score calculation after receiving the request from Request agent as shown in Figure 4.7.

```

...

public class RectifierAgent extends Agent{
// -----
...
protected void setup() {
// -----

    // Set this agent main behaviour
    SequentialBehaviour sb = new SequentialBehaviour();
    sb.addSubBehaviour(new RegisterInDF(this));
    ...
    addBehaviour(sb);
}
class RegisterInDF extends OneShotBehaviour {
// Register in the DF for the client agent be able to retrieve its AID
    RegisterInDF(Agent a) {
        super(a);
    }

    public void action() {

        ServiceDescription sd = new ServiceDescription();
        sd.setType("ImageRectifier");
        sd.setName(getName());
        DFAgentDescription dfd = new DFAgentDescription();
        dfd.setName(getAID());
        dfd.addServices(sd);
        try {
            DFAgentDescription[] dfds = DFService.search(myAgent, dfd);
            if (dfds.length > 0 ) {
                DFService.deregister(myAgent, dfd);
            }
            DFService.register(myAgent, dfd);
            System.out.println(getLocalName() + " is ready.");
        }
    }
}
...

```

Figure 4.6: Extracted “RectifierAgent” implementation code for registration

```

...
private class SendCalCRRequest extends OneShotBehaviour {
// -----
// send request to Corner agent for corner respond calculation

    public SendCalCRRequest(Agent a){
        super(a);
    }
    public void action() {
        ACLMessage msg = new ACLMessage(ACLMessage.REQUEST);
        try{
            msg.addReceiver(Corner);
            System.out.println("Agent "+getLocalName()+" sends request
to Corner Agent.");
            msg.setContent("corner");
            send(msg);
        }
    }
}
...

```

Figure 4.7: Extracted “RectifierAgent” implementation code for sending request to Corner agent

4.6 Implementation of Corner agent based on JADE

The Corner agent is implemented using a JADE agent class named as “CornerAgent”. The Corner agent also needs to be registered with the DF as shown in Figure 4.8. Corner agent waits for the request from Rectifier agent for corner score calculation. When the request received, the response message will be sent out as shown in Figure 4.9. It then proceeds to invoke a Java caller named as “callCornerMatlab” as shown in Figure 4.10.

```

...
public class CornerAgent extends Agent {
...

    protected void setup() {
// -----
// Registration with the DF
        DFAgentDescription dfd = new DFAgentDescription();
        ServiceDescription sd = new ServiceDescription();
        sd.setType("Corner");
        ...
        dfd.addServices(sd);

        try {
            DFService.register(this, dfd);
            System.out.println(getLocalName() + " is ready.");

            addBehaviour(new CyclicBehaviour(this) {
                public void action() {
                    ACLMessage msg =
receive(MessageTemplate.MatchSender(ImgRectifier));
                    if(msg == null){ block(); return; }
                    else{

                        addBehaviour(new
CornerAndReply(myAgent, msg));
                    }
                } // end method action
            }); // end CyclicBehaviour

        } catch (FIPAException e) {
            System.out.println("Agent " + getLocalName() + " - Cannot
register with DF.");
            e.printStackTrace();
            doDelete();
        }
    } // end method setup
...

```

Figure 4.8: Extracted “CornerAgent” implementation code for registration

```

...
private class CornerAndReply extends SimpleBehaviour {
//-----
// perform rectifier request and send reply after done

private boolean finished = false;
private ACLMessage msg;

public CornerAndReply(Agent a, ACLMessage msg) {
    super(a);
    this.msg = msg;
}

public void action() {
    if (msg == null) { block(); return; }
    else{
        String content = msg.getContent();
        if(msg.getPerformative()== ACLMessage.REQUEST){
            if ((content != null) && (content.indexOf("corner") !=
-1)){

                System.out.println("Agent "+getLocalName()+" -
Received Corner Request from "+msg.getSender().getLocalName());
                HandleCornerCall();
                System.out.println("count corner response is in
progress...");

                doWait(60000);

                ACLMessage reply = msg.createReply();
                reply.addReceiver(ImgRectifier);
                reply.setPerformative(ACLMessage.INFORM);
                reply.setContent("countCornerR_Done");
                send(reply);
                finished = true;

            }
        }
    }
} // end method action
...

```

Figure 4.9: Extracted “CornerAgent” implementation code for responding to the request received

```

...
public class CallCornerMatlab{
public CallCornerMatlab(){
}

public void callCornerMethod(){
    try{
        Runtime rt = Runtime.getRuntime();
        Process pr = rt.exec("cmd /c matlab -nosplash -r calCornerR()");
        InputStreamReader isr = new InputStreamReader(pr.getInputStream());
        BufferedReader input = new BufferedReader(isr);

        String line = null;
        while((line = input.readLine())!=null){
            System.out.println(line);
        }//end while

        int exitVal = pr.waitFor();
        if(exitVal == 0)
            System.out.println("Calling for Corner succeeded. Please
wait.");
        else
            System.out.println("Exited with error code " + exitVal);
        }//end try
...

```

Figure 4.10: Extracted Java code for calling Matlab script calCornerR

The Java caller will then invoke the Matlab script named as “calCornerR” as shown in Figure 4.11. The function named `detectHarrisFeatures` from Matlab R2017b is applied to calculate the corner score of the control points. This function uses the Harris-Stephens algorithm to find the feature points. The initial size of pixel neighbourhood is 2, the scale factor used is 0.04. The corner score value describes the strength of the detected corner.

```

...

%Iterate all identified GCPs in the image
for i =1: length(targetPts)
    %loop until the loc.Metric of the ROI is greater than zero and
    the ROI is
    % not out of boundary
    R(i) = 0;
    while R(i) == 0 && (targetPts(i,1)+px_size) < imgWidth &&
(targetPts(i,2)+px_size) < imgHeight
        p = [(targetPts(i,1)-(px_size/2)), (targetPts(i,2)-
(px_size/2))];
        loc = detectHarrisFeatures(targetImg,'MinQuality','0.04',
'ROI', [p(i,1) p(i,2) px_size px_size]);
        if (loc.Metric~=0)
            locR(i) = loc.Location;
            R(i) = loc.Metric;
        else
            px_size = px_size +2;
        end
    end
end
end
dlmwrite('cornerR.txt',R);

...

```

Figure 4.11: Extracted Matlab script calCornerR

4.7 Implementation of Distributor Agent based on JADE

The Distributor agent is implemented using a JADE agent class named as “DistributorAgent”. The Distributor agent is required to register with the DF too as shown in Figure 4.12. When it is ready, Distributor agent waits for the request from Rectifier agent for distribution impact index calculation. When the request received, the response will be sent out as shown in Figure 4.13. It then proceeds to invoke a Java caller named as “callDistributeMatlab” as shown in Figure 4.14. The Java caller will then invoke the Matlab script named as “calDistImpact” as shown in Figure 4.15. The function named `voronoin` from Matlab R2017b is applied to construct the Voronoi diagram of the control points. It returns Voronoi vertices and the Voronoi cells of the Voronoi diagram.

Then, the function named `polyarea` is used to calculate the area of the polygon specified by the vertices.

```
...
public class DistributorAgent extends Agent {
...

    protected void setup() {
// -----
// Registration with the DF
        DFAgentDescription dfd = new DFAgentDescription();
        ServiceDescription sd = new ServiceDescription();
        sd.setType("Corner");
        ...
        dfd.addServices(sd);

        try {
            DFService.register(this, dfd);
            System.out.println(getLocalName() + " is ready.");

            addBehaviour(new CyclicBehaviour(this){
                public void action(){
                    ACLMessage msg =
receive(MessageTemplate.MatchSender(Rectifier));
                    if(msg == null){ block(); return; }
                    else{

                        addBehaviour(new
DistributeAndReply(myAgent, msg));
                    }
                } // end method action
            }); // end CyclicBehaviour

...
}
```

Figure 4.12: Extracted “DistributorAgent” implementation code for registration

```

...
private class DistributeAndReply extends SimpleBehaviour {
//-----
// perform rectifier request and send reply after done

private boolean finished = false;
private ACLMessage msg;

public DistributeAndReply(Agent a, ACLMessage msg) {
    super(a);
    this.msg = msg;
}

public void action() {
    if (msg == null) { block(); return; }
    else{
        String content = msg.getContent();
        if(msg.getPerformative()== ACLMessage.REQUEST){
            if ((content != null) && (content.indexOf("distribute")
!= -1)){

                System.out.println("Agent "+getLocalName()+" -
Received Distribute Request from "+msg.getSender().getLocalName());
                HandleDistributeCall();
                System.out.println("count impact index is in
progress...");

                doWait(60000);

                ACLMessage reply = msg.createReply();
                reply.addReceiver(Rectifier);
                reply.setPerformative(ACLMessage.INFORM);
                reply.setContent("countImpact_Done");
                send(reply);
                finished = true;

            }
        }
    }
} // end method action
...

```

Figure 4.13: Extracted “DistributorAgent” implementation code for responding to the request received

```

...

public class CallVoronoiMatlab{

public CallVoronoiMatlab(){

}

public void callVoronoiMethod(){

    try{
        Runtime rt = Runtime.getRuntime();
        Process pr = rt.exec("cmd /c matlab -nosplash -r calDistImpact()");
        InputStreamReader isr = new InputStreamReader(pr.getInputStream());
        BufferedReader input = new BufferedReader(isr);

        String line = null;
        while((line = input.readLine())!=null){
            System.out.println(line);
        }//end while
    }

...

```

Figure 4.14: Extracted Java code for calling Matlab script calDistImpact

```

...
[v,r] = voronoin(B2);

...

%calculate the area of each voronoi region
areaR = zeros(0,0);
for i = 1: length(r)
    if all(r{i}~=1)
        areaR(i,1)=polyarea(v(r{i},1),v(r{i},2));
    end
end
...

```

Figure 4.15: Extracted Matlab script calDistImpact

4.8 Summary

This chapter presents the Platform Specific Models (PSMs) of the implementation for aerial image rectification using JADE as designed in the previous chapter. The discussion includes multi-agent based aerial image rectification in JADE platform, the implementation of Request agent, the implementation of Rectifier agent, the implementation of Corner agent and the implementation of Distributor agent. The corner score used by Corner agent is based on the Harris corner detection algorithm while the distribution impact index used by Distributor agent is based on Voronoi diagram.

The next chapter will discuss the evaluation of control points selections by expert and the proposed multi-agent system. The overall results analyses and comparison will be presented.

CHAPTER 5

EXPERIMENTAL ANALYSES AND EVALUATION

5.1 Introduction

Multi-agent system basically is a blended area of artificial intelligence, distributed computer systems and software engineering. In the previous chapter, the implementation of the proposed multi-agent approach was discussed. This chapter discusses the analyses and evaluation of the implementation of the proposed approach.

This chapter firstly presents the evaluation of the preliminary study. Then, it proceeds with the accuracy assessment of satellite image. Experiment was carried out with an aerial image. The results obtained with the proposed approach are compared to the results obtained with the selection of expert. The proposed cooperative multi-agent approach could be evaluated by showing the interaction between the agents.

5.2 Evaluation of preliminary study

As discussed in Chapter 3, the preliminary study has been carried out using a reference grid image and a grid image with added combination defects of barrel, vertical perspective, horizontal perspective and rotation. A total of 24 control points (CPs) with four distributions which consist of centre, border, corner and uniform distributions are applied to similarity, affine, second order polynomial and third order polynomial transformations to calculate the transformation coefficients. A number of 9 control points is used as the checkpoints for comparison.

The displacement and residual of each checkpoint before transformation as shown in Table 5.1 indicate that distortion exists in the image. The displacement of each checkpoint is

marked by $(\Delta X, \Delta Y)$. The residuals of the checkpoints are ranged from 87.08 pixels as the lowest value to 398.15 pixels as the highest value. The total RMSE of the checkpoints before the transformation is 297.84 pixels. Such large RMSE is caused by the added combination defect of barrel, vertical perspective, horizontal perspective and rotation. It reflects that the occurrence of distortion is not regular and not forming any pattern in different regions of an image.

Table 5.1: The residuals of each checkpoint before transformation

Checkpoint no.	Reference image		Distorted image		ΔX	ΔY	Residual
	X	Y	X	Y			
1	402.50	403.10	466.51	753.69	-64.01	-350.59	356.38
2	2200.58	403.10	2226.49	515.26	-25.91	-112.16	115.11
3	3804.52	403.10	3891.11	393.89	-86.59	9.21	87.08
4	402.46	1401.20	483.85	1737.72	-81.39	-336.52	346.22
5	2200.58	1401.20	2317.52	1572.99	-116.94	-171.79	207.81
6	3804.52	1401.20	4047.16	1425.60	-242.64	-24.40	243.86
7	402.46	2407.06	557.54	2773.77	-155.08	-366.71	398.15
8	2200.58	2407.06	2417.23	2691.40	-216.65	-284.34	357.47
9	3804.52	2407.06	4164.21	2518.00	-359.69	-110.94	376.41

The total RMSE of the control points (CPs) and checkpoints (ChPs) achieved with the four distributions when using various transformations are shown in Table 5.2. Overall, the total RMSE of the checkpoints for all the four distributions are reduced using the transformations tested. The total RMSE of checkpoints is reduced to 145.75 pixels as the highest total RMSE achieved when using the third order polynomial transformation with centre distribution and 4.55 pixels as the lowest total RMSE achieved when using the third order polynomial transformation with uniform distribution. It is noticed that larger errors are found when checkpoints are not surrounded by control points and are situated outside

the image area covered by control points. In the scenario of centre distribution, the total RMSE of control points and the total RMSE of checkpoints for the transformations tested have differences of approximately 100 pixels. Compare to other scenarios, the differences are less than 21 pixels. This indicates that the transformation formed with centre distribution is insufficient to rectify different regions of an image.

Table 5.2: The total RMSE of the control points (CPs) and checkpoints (ChPs)

	Similarity		Affine		2 nd order Polynomial		3 rd order Polynomial	
	CPs	ChPs	CPs	ChPs	CPs	ChPs	CPs	ChPs
Centre	5.65	107.13	5.09	106.67	4.44	103.57	4.19	145.75
Border	51.33	50.59	49.08	49.95	22.51	23.82	2.42	6.34
Corner	53.37	55.76	53.51	55.45	11.73	32.02	3.12	11.64
Uniform	47.88	48.30	45.43	47.32	26.63	21.98	3.45	4.55

The comparison of the total RMSE of checkpoints for the four distributions is shown in Figure 5.1. It is noticed that uniform distribution has the lowest total RMSE of checkpoints for each transformation tested. The achievements of the total RMSE of checkpoints with uniform distribution are 48.30 pixels using similarity transformation, 47.32 pixels using affine transformation, 21.98 pixels using second order polynomial transformation and 4.55 pixels using third order polynomial transformation. The result shows that the achievements of the total RMSE of checkpoints for the various transformations tested with centre distribution are the highest. The total RMSE of checkpoints achieved with centre distribution are 107.13 pixels using similarity transformation, 106.67 pixels using affine transformation, 103.57 pixels using second order polynomial transformation and 145.75 pixels using third order polynomial transformation. The result also demonstrates that border distribution achieves the second lowest while corner distribution achieves the

second highest of the total RMSE of checkpoints for the various transformations tested. The preliminary study shows that the distribution of control points affects the rectification result and rectification with uniform distribution is better compared to other distributions as tested.

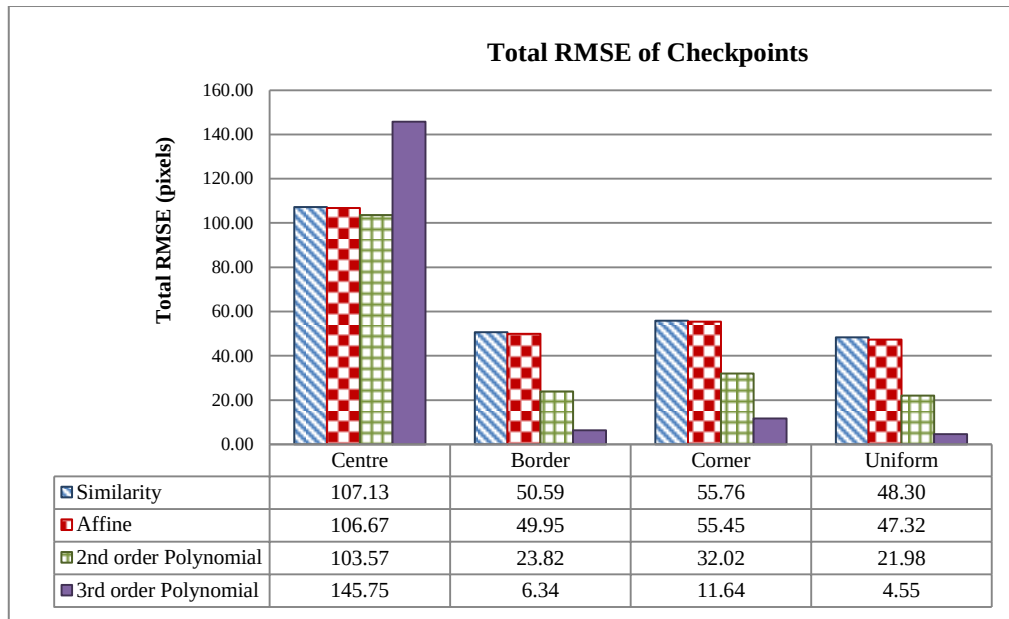


Figure 5.1: Total RMSE of checkpoints in preliminary study

The rectified grid images with centre distribution after using similarity transformation, affine transformation, second order polynomial transformation and third order transformation are shown in Figure 5.2, Figure 5.3, Figure 5.4 and Figure 5.5, respectively. Whereas for border distribution, the rectified grid images after using similarity transformation, affine transformation, second order polynomial transformation and third order transformation are displayed in Figure 5.6, Figure 5.7, Figure 5.8 and Figure 5.9, respectively. Meanwhile, the rectified grid images with corner distribution when using similarity transformation, affine transformation, second order polynomial transformation

and third order transformation are depicted in Figure 5.10, Figure 5.11, Figure 5.12 and Figure 5.13, respectively. The rectified grid images with uniform distribution when using similarity transformation, affine transformation, second order polynomial transformation and third order transformation are illustrated in Figure 5.14, Figure 5.15, Figure 5.16 and Figure 5.17, respectively. The checkpoints are marked with green circles and the control points are marked with magenta triangles in each rectified grid image.

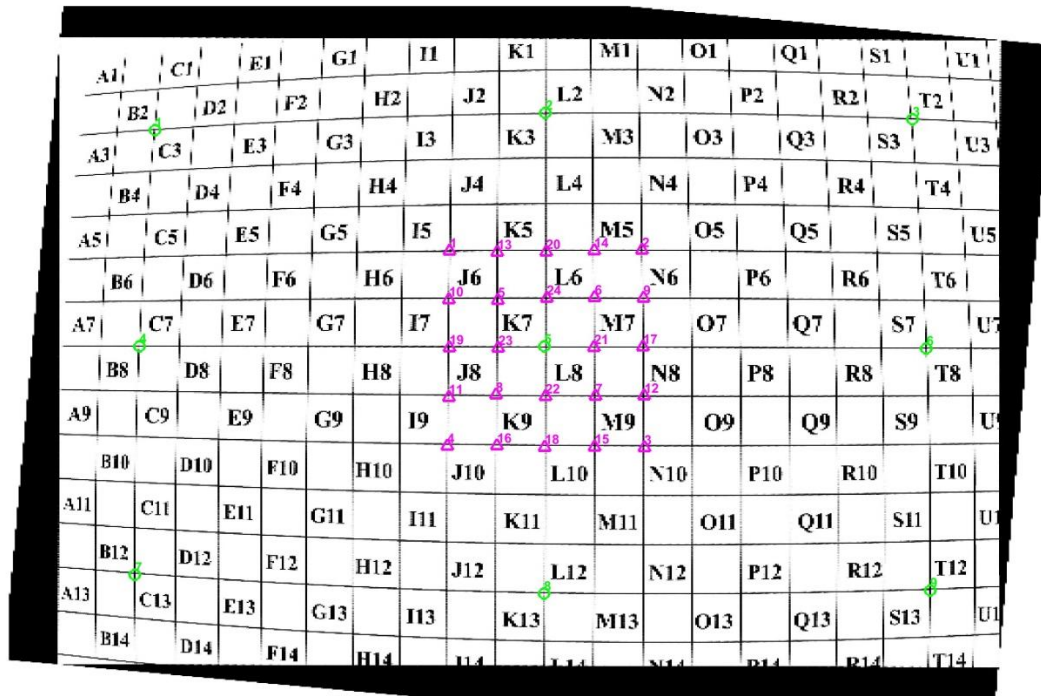


Figure 5.2: Rectified grid image with centre distribution and similarity transformation

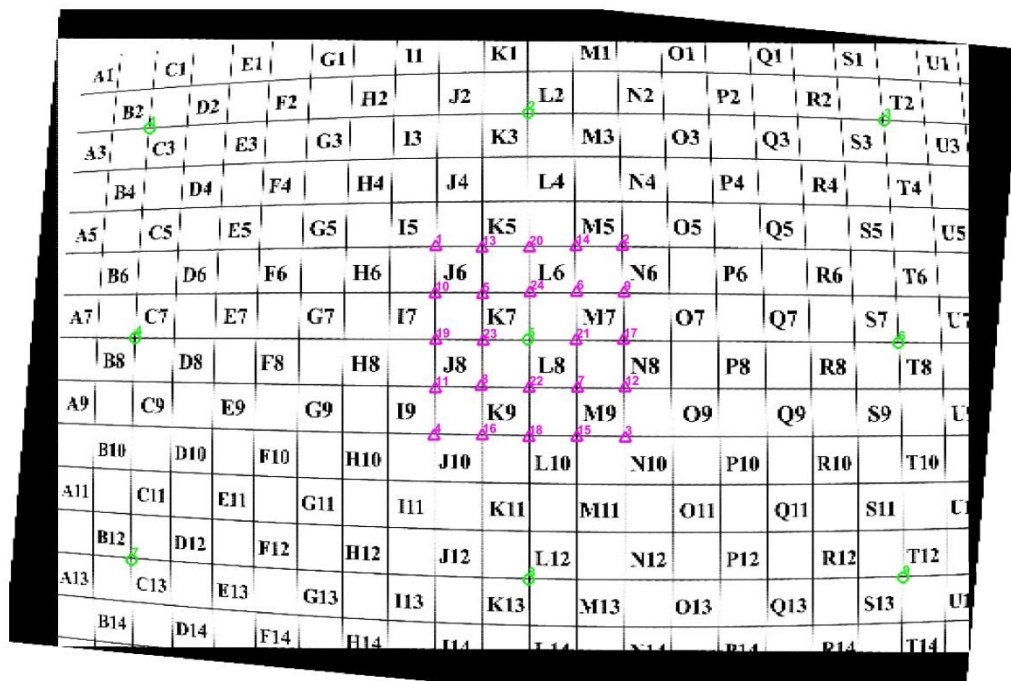


Figure 5.3: Rectified grid image with centre distribution and affine transformation

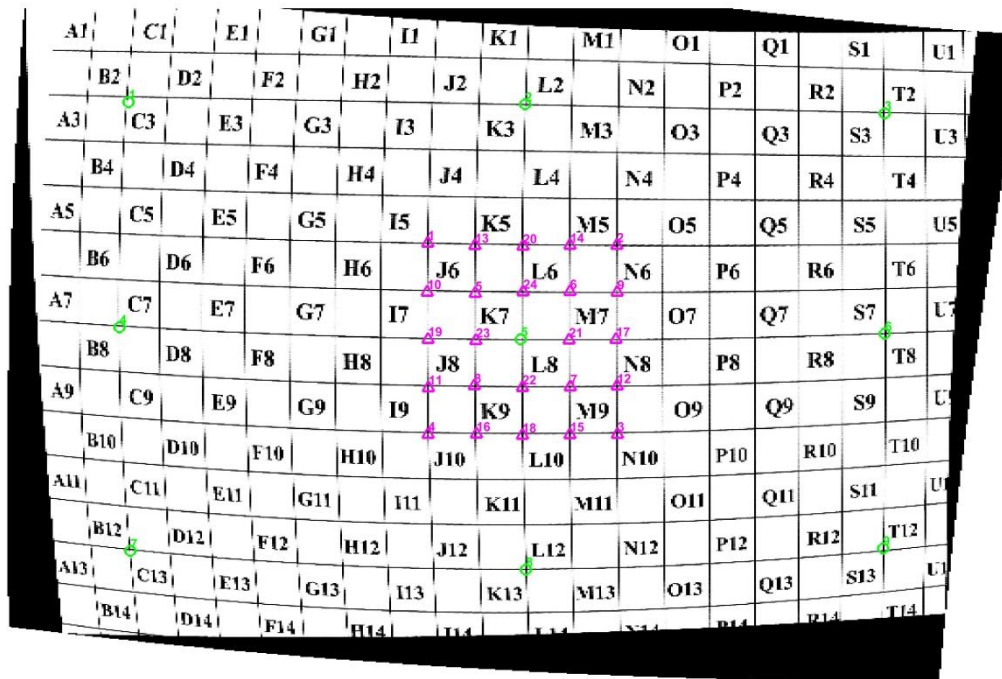


Figure 5.4: Rectified grid image with centre distribution and second order polynomial transformation

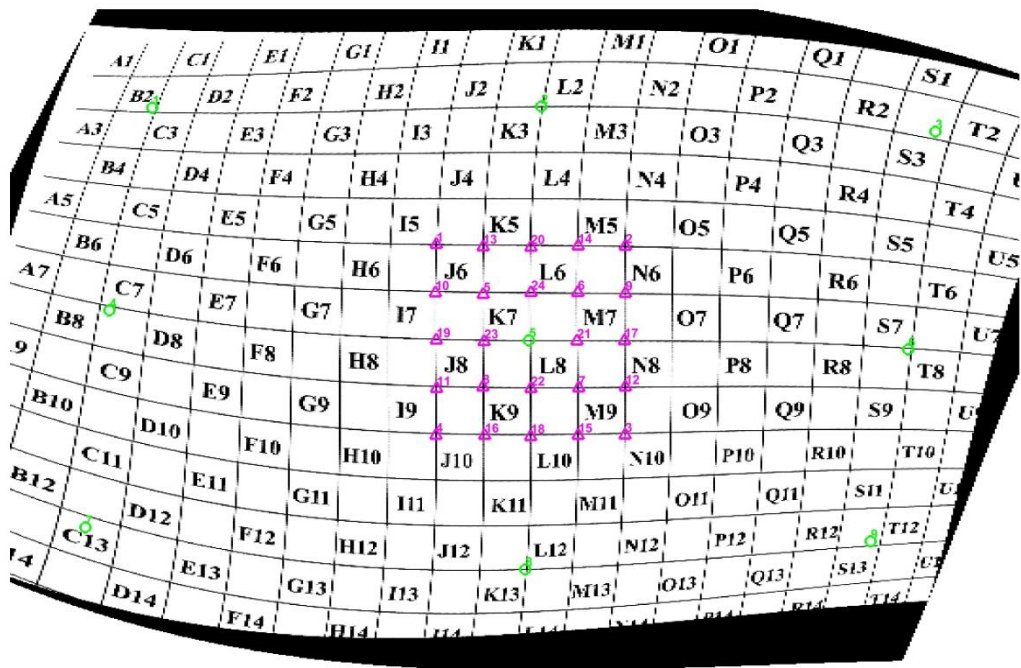


Figure 5.5: Rectified grid image with centre distribution and third order polynomial transformation

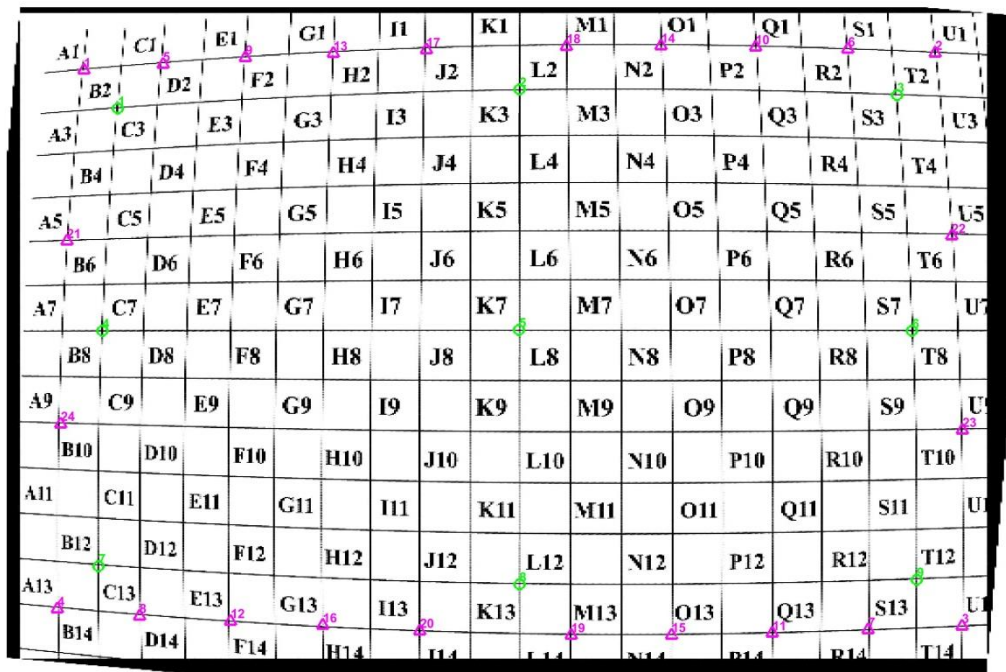


Figure 5.6: Rectified grid image with border distribution and similarity transformation

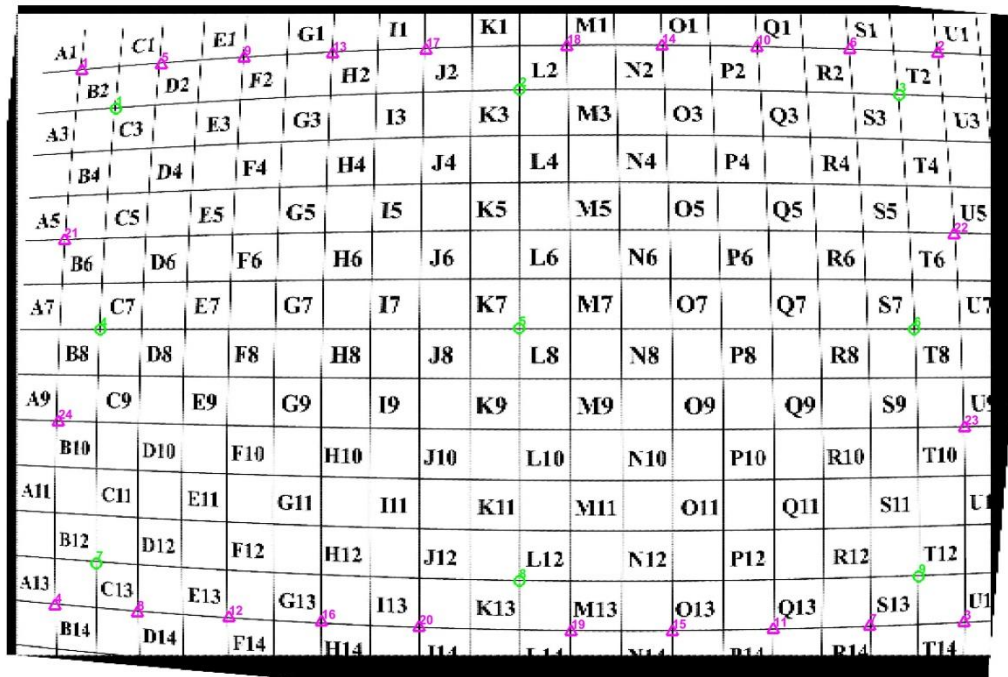


Figure 5.7: Rectified grid image with border distribution and affine transformation

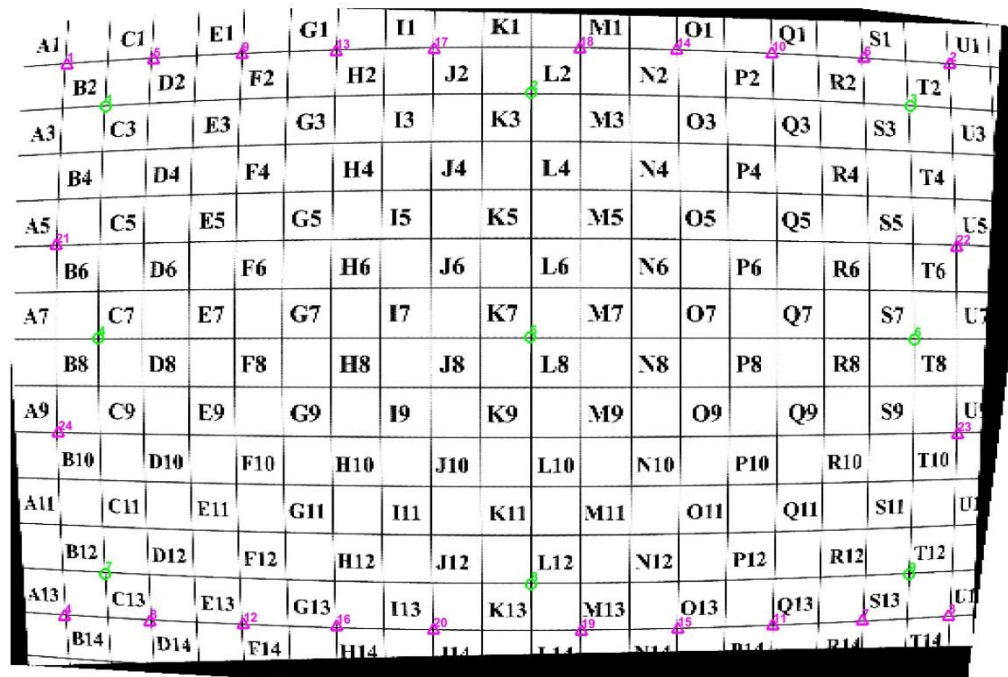


Figure 5.8: Rectified grid image with border distribution and second order polynomial transformation

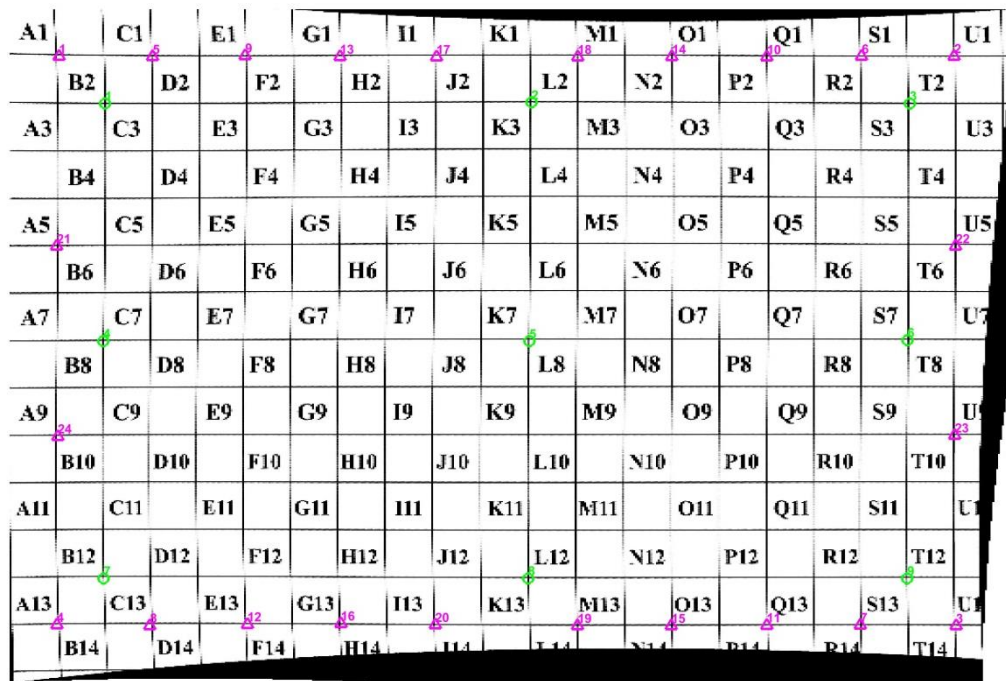


Figure 5.9: Rectified grid image with border distribution and third order polynomial transformation

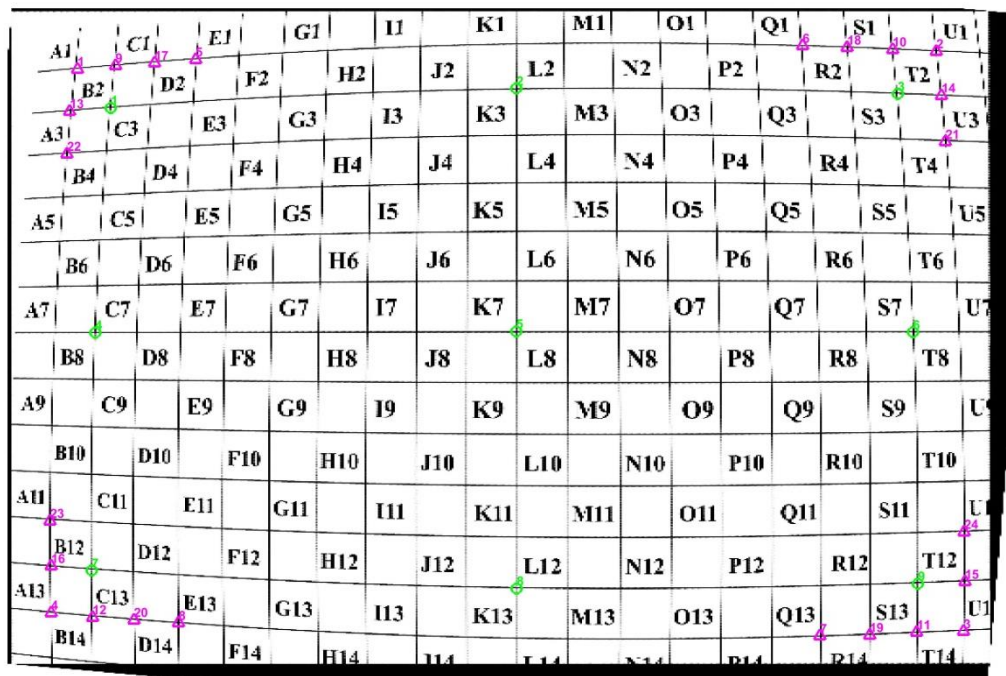


Figure 5.10: Rectified grid image with corner distribution and similarity transformation

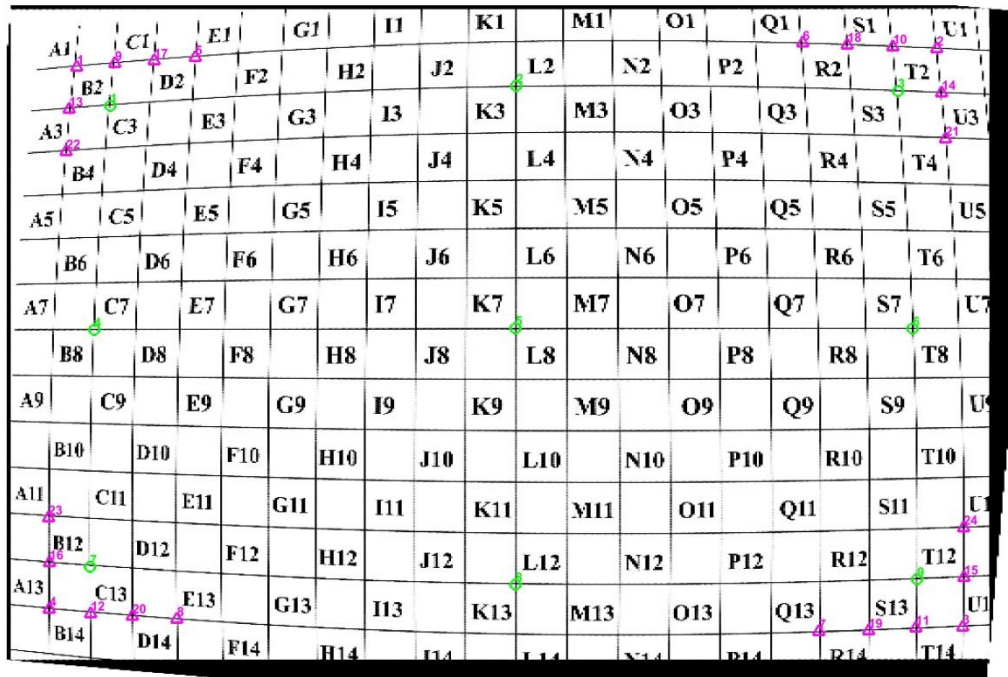


Figure 5.11: Rectified grid image with corner distribution and affine transformation

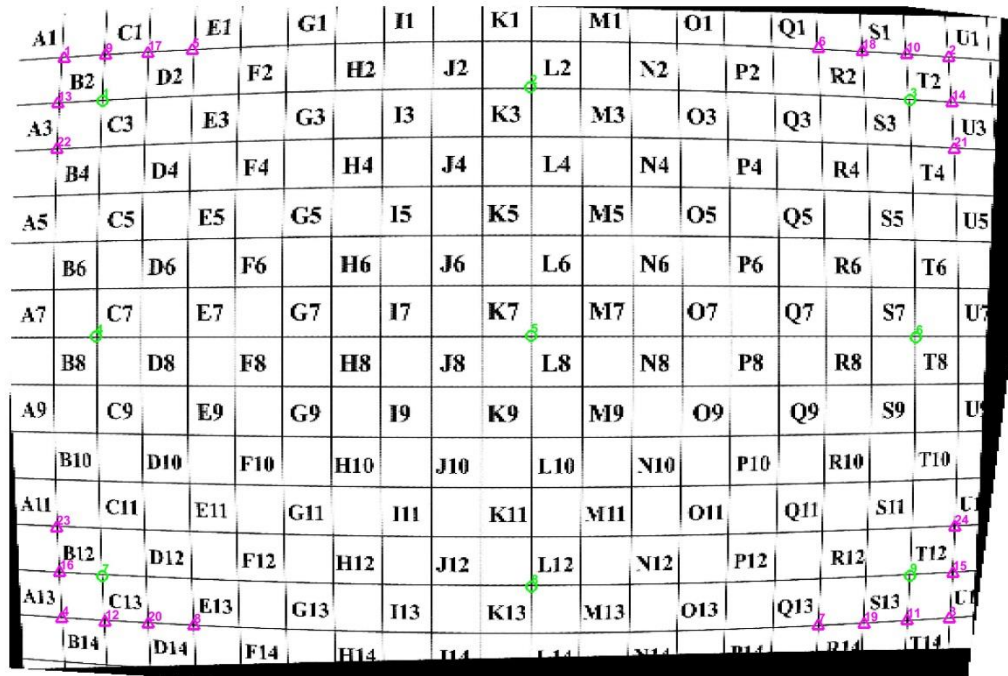


Figure 5.12: Rectified grid image with corner distribution and second order polynomial transformation

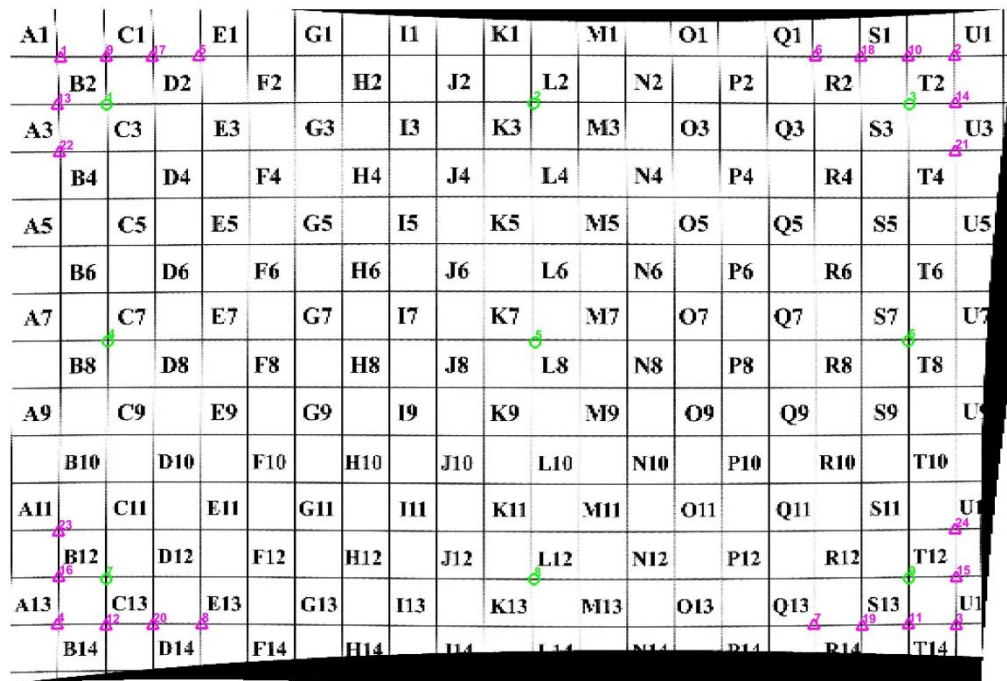


Figure 5.13: Rectified grid image with corner distribution and third order polynomial transformation

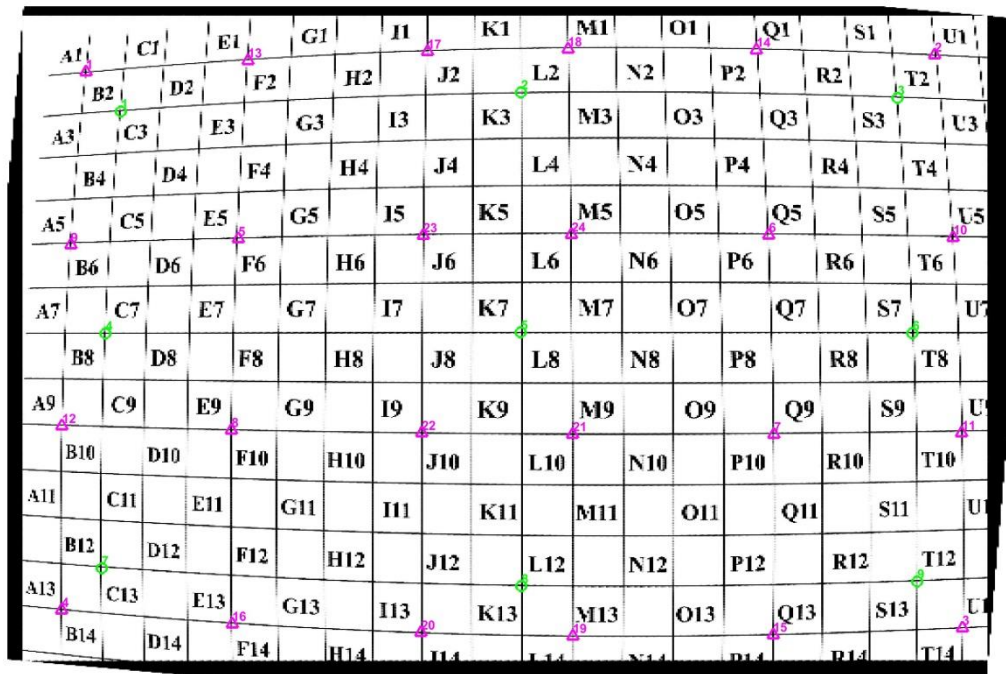


Figure 5.14: Rectified grid image with uniform distribution and similarity transformation

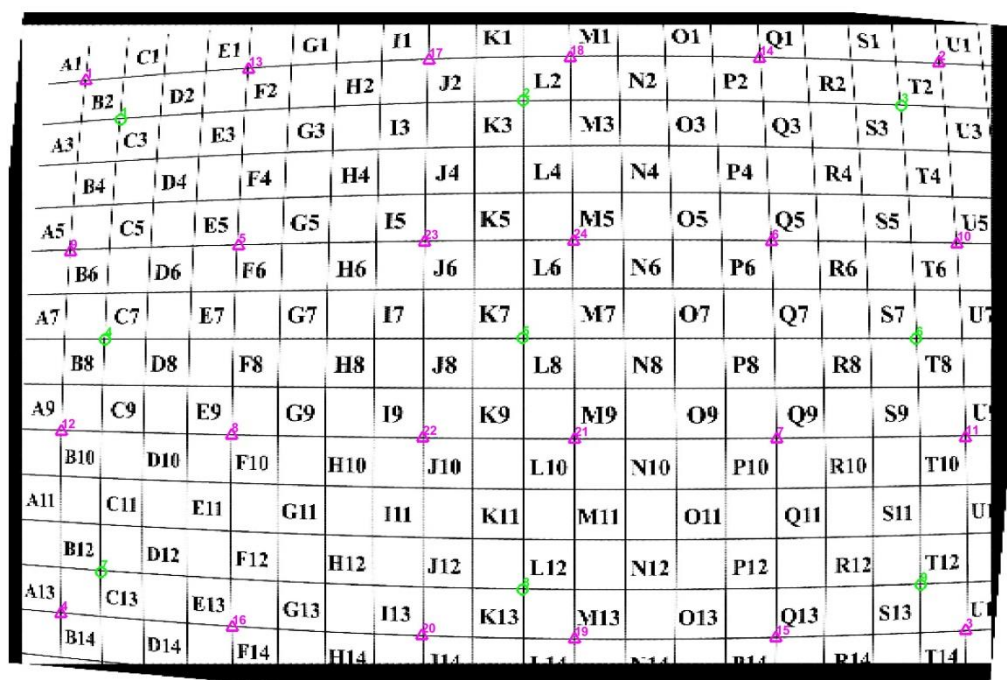


Figure 5.15: Rectified grid image with uniform distribution and affine transformation

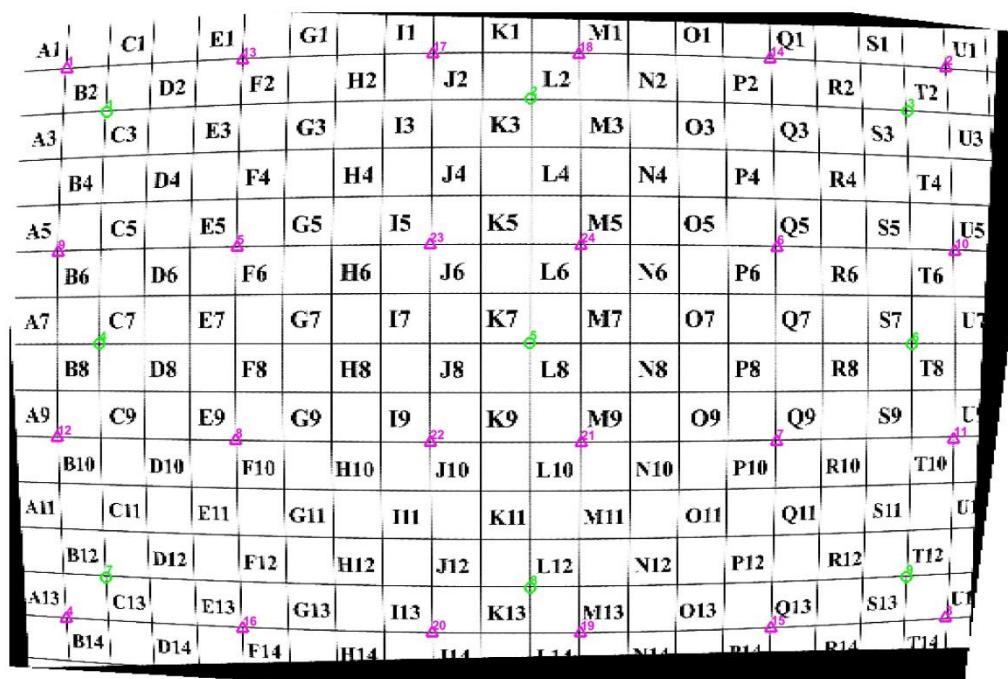


Figure 5.16: Rectified grid image with uniform distribution and second order polynomial transformation

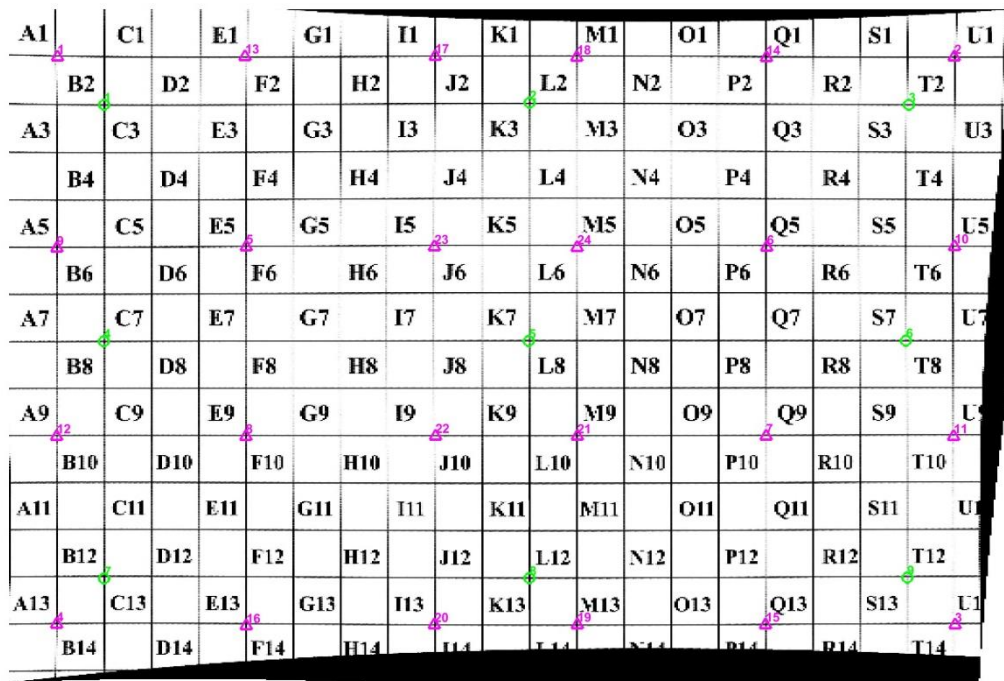


Figure 5.17: Rectified grid image with uniform distribution and third order polynomial transformation

5.3 Accuracy assessment of satellite image

Positional accuracy of the twelve checkpoints from Pleiades satellite image is validated using coordinates provided by Land and Survey Department Sarawak (LNSD). The residual and total RMSE of checkpoints are shown in Table 5.3. The total RMSE of the checkpoints is 3.80. Since the total RMSE of checkpoints is more than 1 meter and LNSD is a leading agency in land management and administration which provides survey data, the coordinates of the GCPs retrieved from LNSD are used in this research.

Table 5.3: Positional accuracy validation of satellite image

GCP Id	LNSD		Pleiades		ΔX	ΔY	Residual
	X	Y	X	Y			
CP04	2082391.3	5160579.3	2082388.5	5160581.1	2.73	-1.88	3.31
CP11	2082527.7	5160600.9	2082524.2	5160602.8	3.48	-1.93	3.98
CP13	2082412.6	5160475.9	2082410.3	5160481.6	2.28	-5.75	6.18
CP17	2082605.4	5160575.6	2082602.4	5160577.2	2.96	-1.60	3.37
CP19	2082634.8	5160555.5	2082630.6	5160556.6	4.13	-1.08	4.27
CP25	2082538.1	5160437.3	2082535.3	5160439.3	2.86	-1.96	3.47
CP29	2082520.8	5160341.3	2082519.3	5160341.9	1.45	-0.62	1.57
CP36	2082441.3	5160239.1	2082438.2	5160241.4	3.11	-2.29	3.86
CP38	2082392.3	5160178.0	2082389.2	5160179.7	3.06	-1.69	3.49
CP42	2082315.0	5160385.9	2082312.1	5160387.3	2.92	-1.40	3.24
CP47	2082342.8	5160325.0	2082341.0	5160327.6	1.79	-2.66	3.20
CP49	2082425.8	5160425.3	2082423.5	5160428.0	2.34	-2.67	3.55

5.4 Evaluation of expert selection

A set of 28 control points with their map coordinates is given to an expert in order to perform selection of control points for the different selection size of 3, 6, 9, 12, 15, 18, 21, 24 and 27 number of control points. As discussed in Section 3.4.4, the expert selects the points according to his expertise and experience in the field. The selection of GCPs given by expert according to selection size is shown in Table 5.4. It is noticed that the first three GCPs selected by the expert are CP18, CP 32 and CP45. The locations of these three GCPs are at the border of the image. The next three GCPs added are CP06, CP26 and CP41 to form the selection size of six. Then, another three GCPs (CP10, CP39 and CP50) located in the middle of the image are selected for selection size of nine. CP24 is not selected to be used in all the selection size. The distribution of selection size 27, 24, 21, 18, 15, 12, 9, 6 and 3 is used for similarity transformation as shown in Figure 5.18, Figure 5.19, Figure

5.20, Figure 5.21, Figure 5.22, Figure 5.23, Figure 5.24, Figure 5.25, and Figure 5.26, respectively.

Table 5.4: GCPs selection by expert according to selection size

Size	28	27	24	21	18	15	12	9	6	3
CP01	✓	✓	✓	✓						
CP03	✓	✓	✓	✓	✓					
CP05	✓	✓	✓	✓						
CP06	✓	✓	✓	✓	✓	✓	✓	✓	✓	
CP10	✓	✓	✓	✓	✓	✓	✓	✓		
CP12	✓	✓	✓	✓	✓	✓				
CP18	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP20	✓	✓								
CP21	✓	✓	✓	✓	✓	✓				
CP23	✓	✓	✓	✓	✓	✓	✓			
CP24	✓									
CP26	✓	✓	✓	✓	✓	✓	✓	✓	✓	
CP27	✓	✓	✓							
CP28	✓	✓	✓	✓						
CP30	✓	✓	✓	✓	✓	✓				
CP32	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP33	✓	✓		✓	✓					
CP34	✓	✓	✓	✓	✓	✓	✓			
CP35	✓	✓								
CP37	✓	✓	✓							
CP39	✓	✓	✓	✓	✓	✓	✓	✓		
CP40	✓	✓	✓							
CP41	✓	✓	✓	✓	✓	✓	✓	✓	✓	
CP43	✓	✓	✓	✓	✓					
CP45	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP46	✓	✓	✓							
CP48	✓	✓	✓	✓	✓	✓	✓			
CP50	✓	✓	✓	✓	✓	✓	✓	✓		

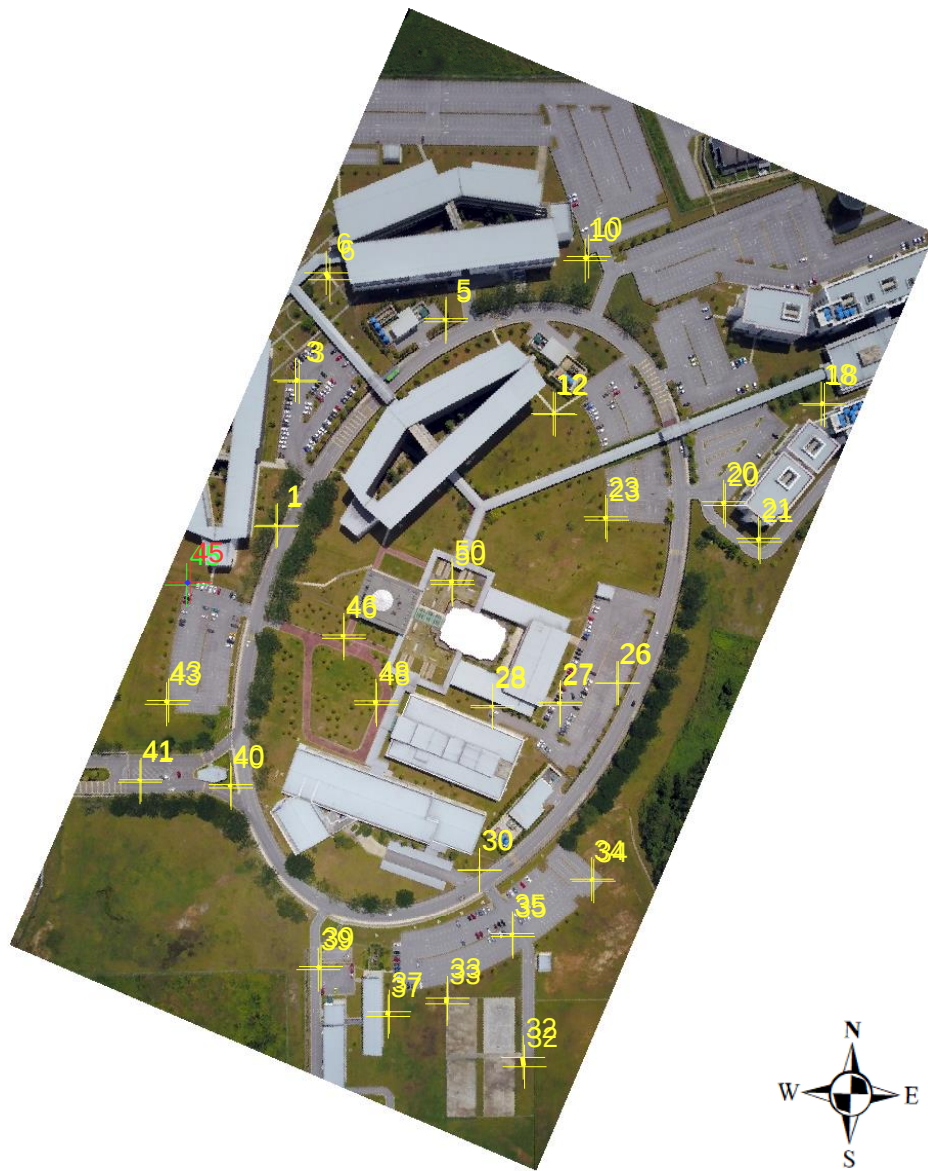


Figure 5.18: The distribution of expert selection size 27 for similarity transformation

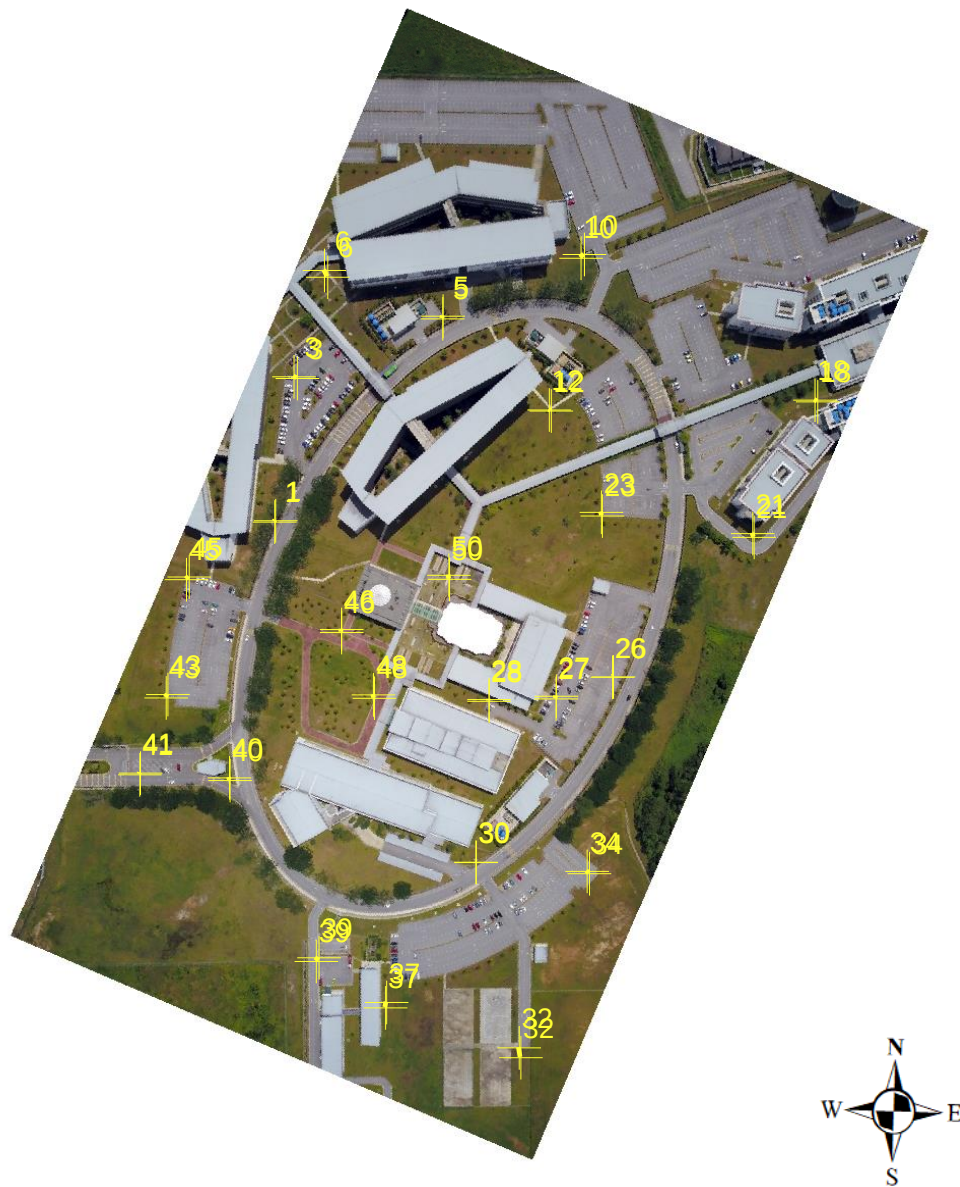


Figure 5.19: The distribution of expert selection size 24 for similarity transformation

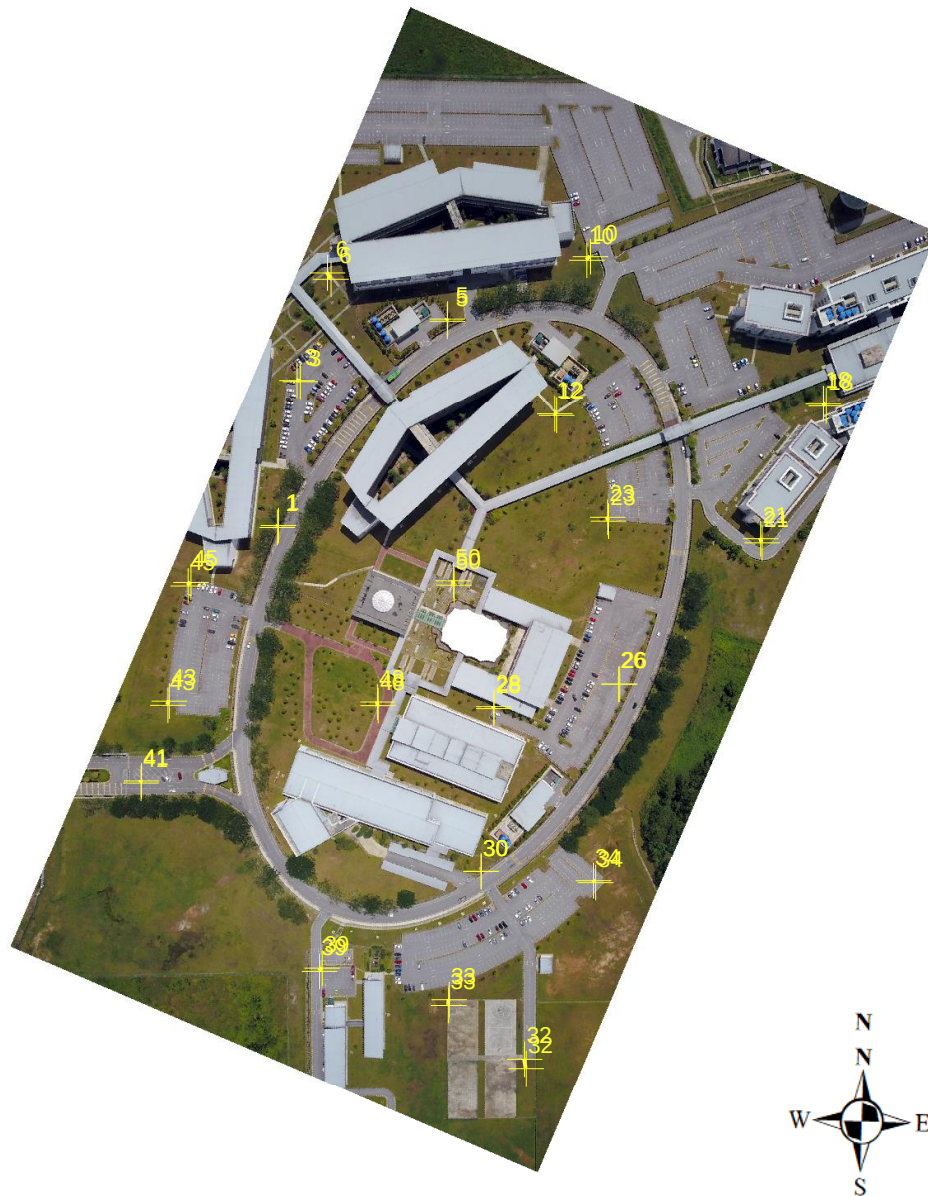


Figure 5.20: The distribution of expert selection size 21 for similarity transformation



Figure 5.21: The distribution of expert selection size 18 for similarity transformation

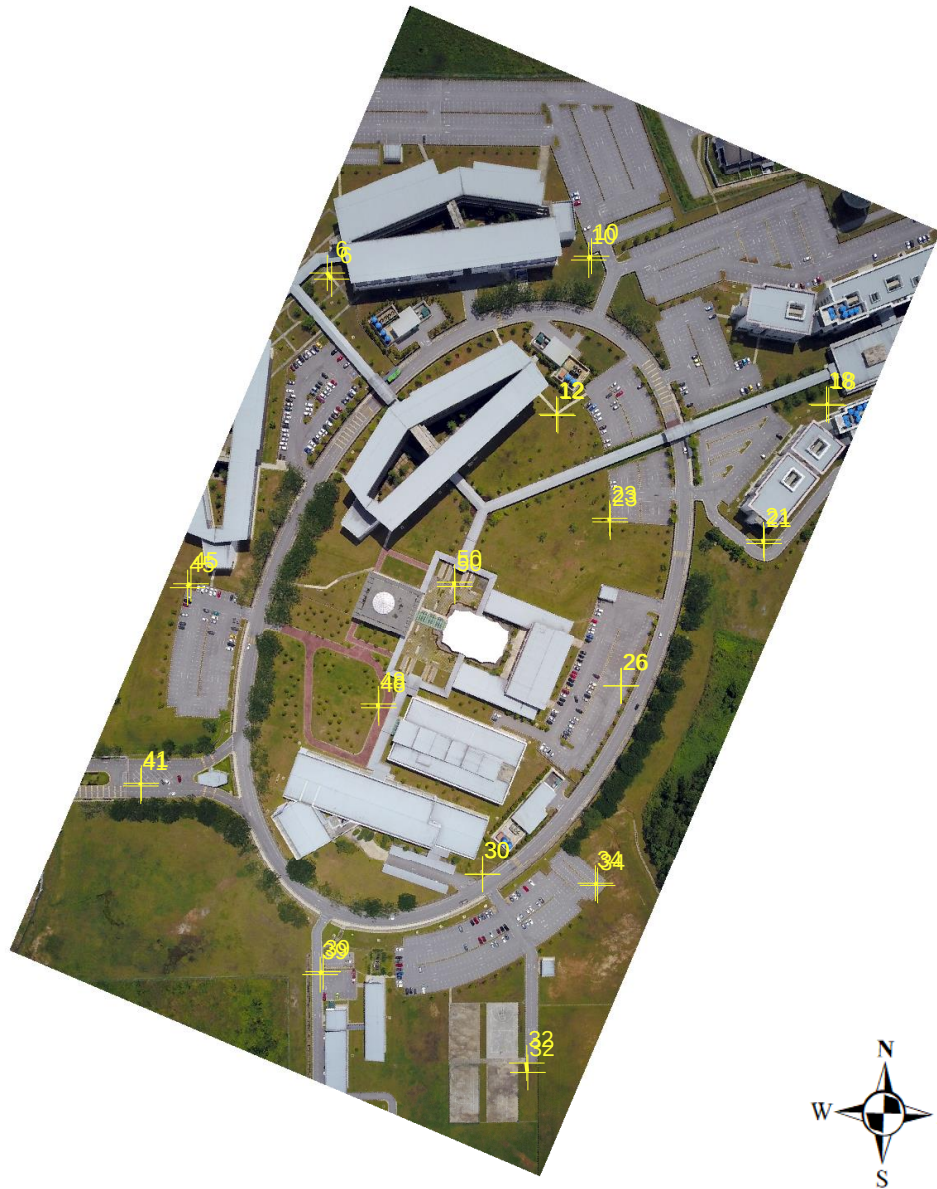


Figure 5.22: The distribution of expert selection size 15 for similarity transformation

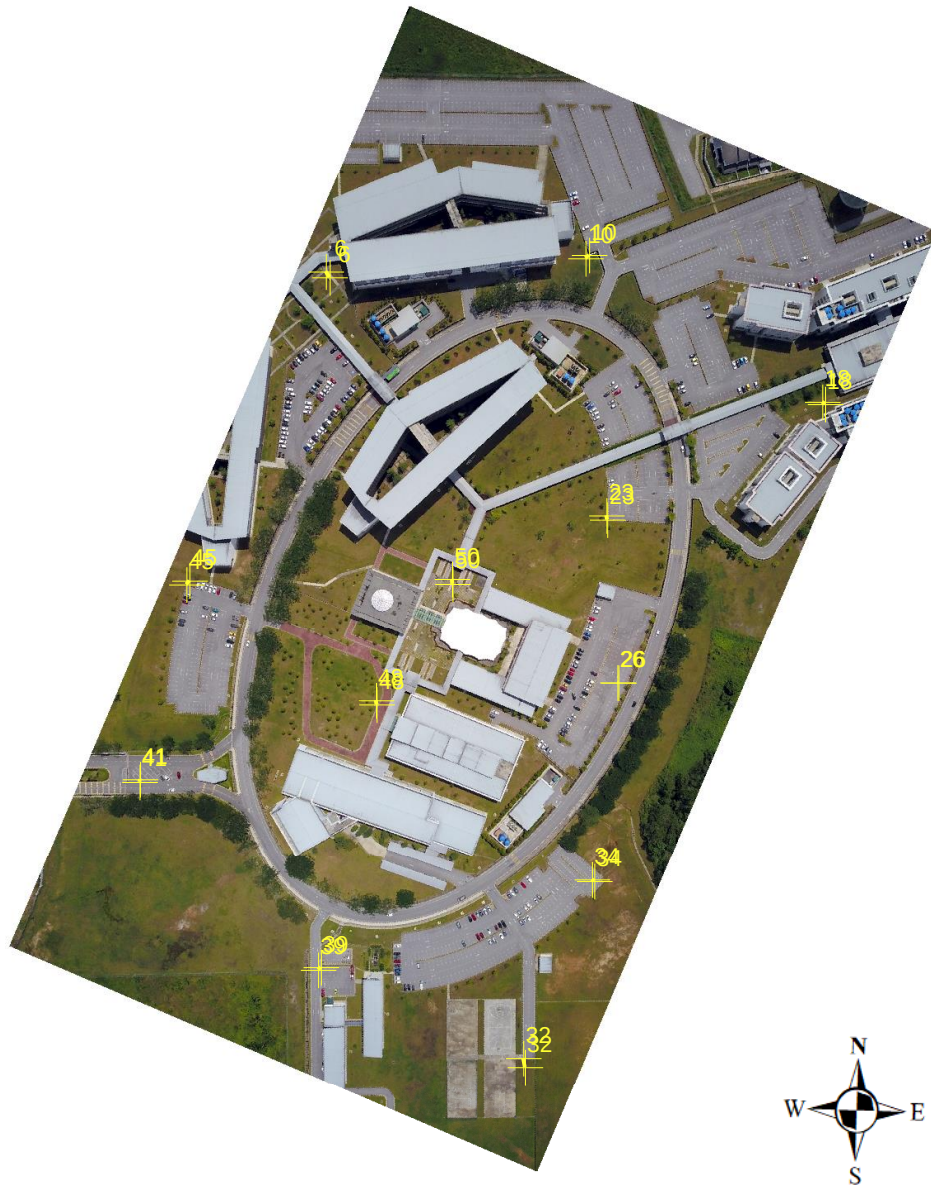


Figure 5.23: The distribution of expert selection size 12 for similarity transformation

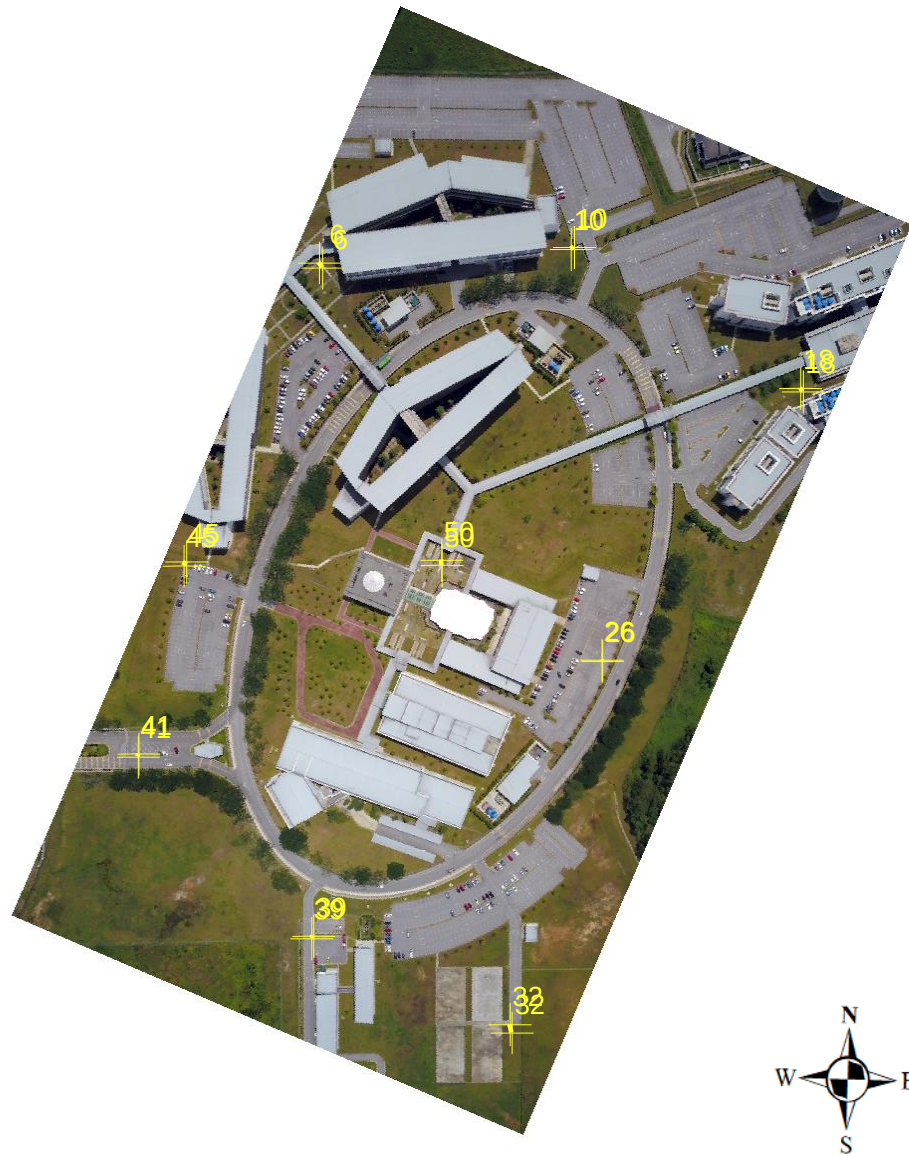


Figure 5.24: The distribution of expert selection size 9 for similarity transformation

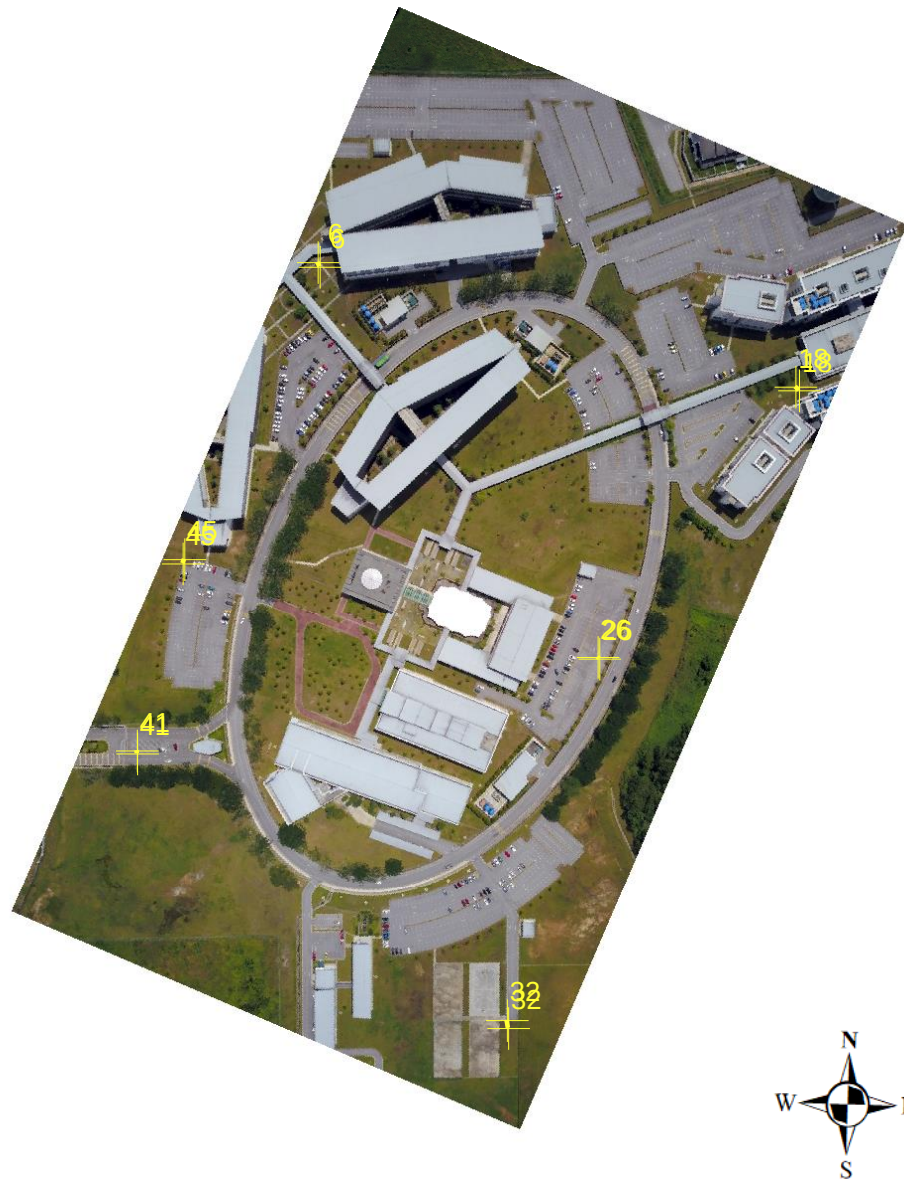


Figure 5.25: The distribution of expert selection size 6 for similarity transformation

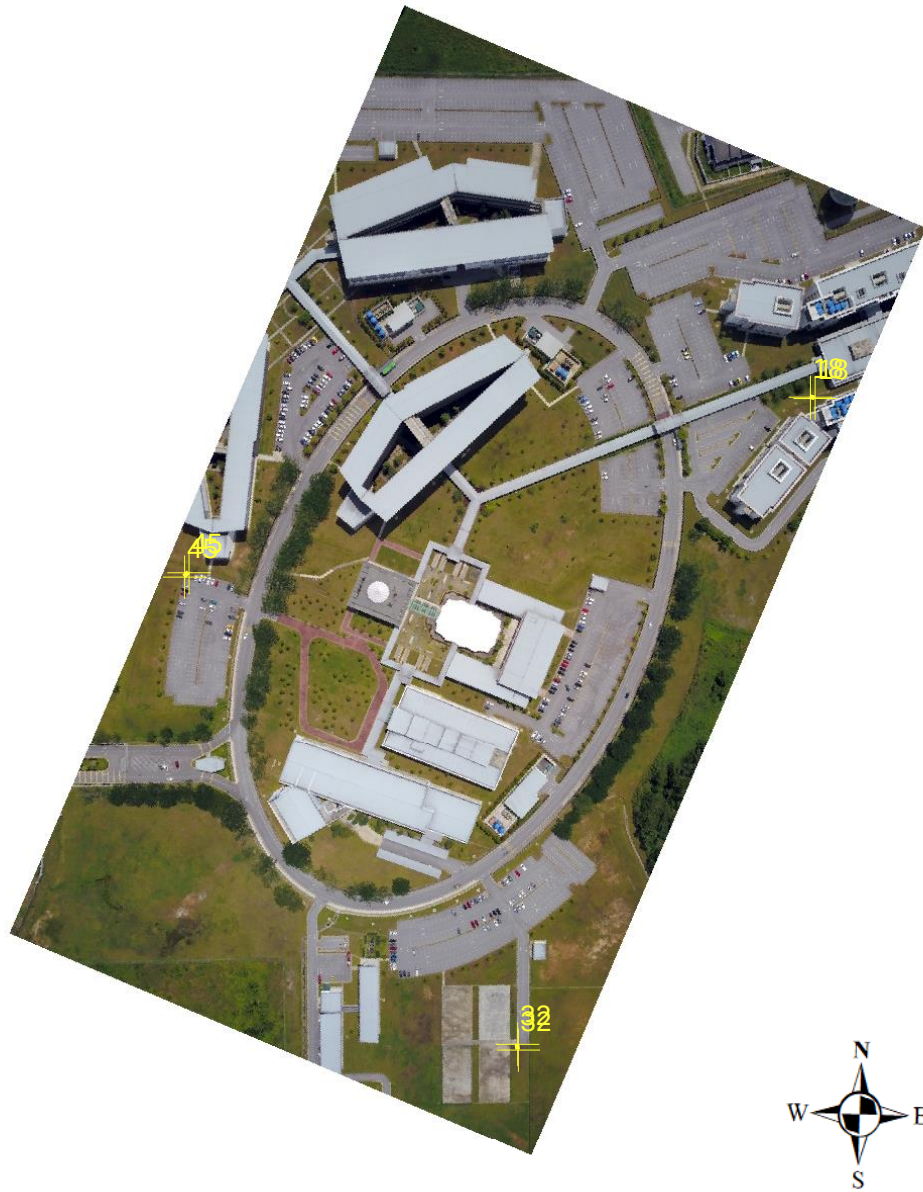


Figure 5.26: The distribution of expert selection size 3 for similarity transformation

As discussed in Section 3.4.3, a set of twelve fixed checkpoints, which is also listed in Table 5.3, is used to compare the results achieved. The total RMSE at the GCPs and checkpoints achieved for the different selection size when using similarity, affine, second order polynomial and third order polynomial transformations are shown in Table 5.5, Table 5.6, Table 5.7 and Table 5.8, respectively. Based on the selection done by expert, it is found that the lowest total RMSE at the checkpoints achieved is 0.88 meters when using nine GCPs transformed with second order polynomial transformation as shown in Table 5.7. The highest total RMSE at the checkpoints acquired is 2.94 meters when using three GCPs transformed with affine transformation as shown in Table 5.6. The comparison of the total RMSE at checkpoints achieved is shown in Figure 5.27. It is noticed that the achievement of the total RMSE at checkpoints when using similarity and affine transformations are more than one meter in all the selection size. The total RMSE at checkpoints achieves less than one meter when the selection size is more than six with second order polynomial transformation and selection size is more than eighteen with third order polynomial transformation.

Table 5.5: The total RMSE at the GCPs and checkpoints achieved using similarity transformation based on expert selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	2.48	2.29
24	2.44	2.33
21	2.54	2.36
18	2.69	2.34
15	2.65	2.26
12	2.85	2.36
9	2.98	2.53
6	3.09	2.82
3	3.41	2.59

Table 5.6: The total RMSE at the GCPs and checkpoints achieved using affine transformation based on expert selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	2.34	2.09
24	2.34	2.13
21	2.40	2.17
18	2.52	2.14
15	2.54	2.13
12	2.72	2.21
9	2.78	2.38
6	2.80	2.58
3	0.000	2.94

Table 5.7: The total RMSE at the GCPs and checkpoints achieved using second order polynomial transformation based on expert selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	0.52	0.91
24	0.49	0.92
21	0.55	0.89
18	0.55	0.90
15	0.59	0.90
12	0.60	0.89
9	0.60	0.88
6	0.000	2.76

Table 5.8: The total RMSE at the GCPs and checkpoints achieved using third order polynomial transformation based on expert selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	0.49	0.93
24	0.53	0.95
21	0.51	0.94
18	0.47	1.05
15	0.51	1.07
12	0.43	1.07

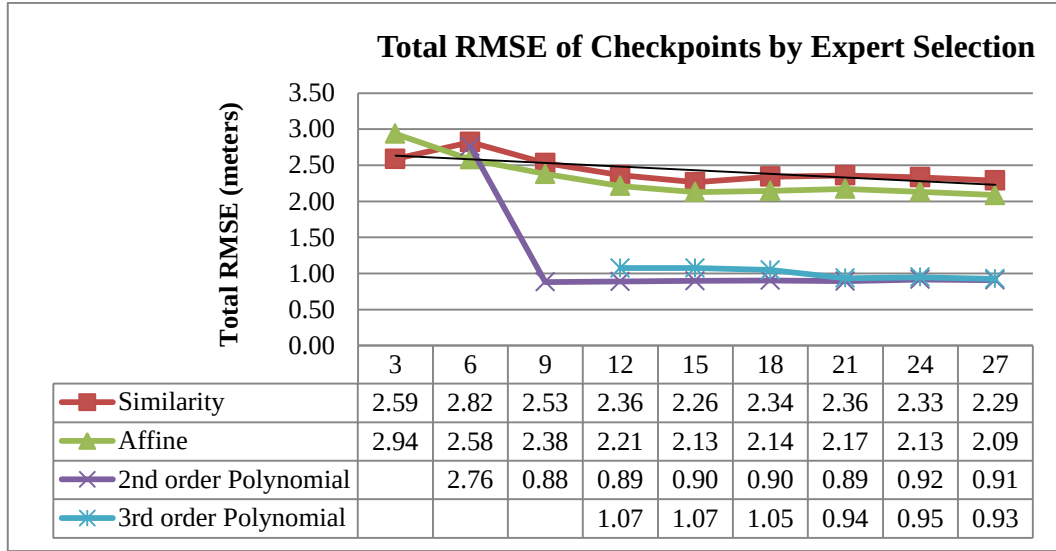


Figure 5.27: Comparison of the total RMSE of checkpoints by expert selection

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

The set of 28 control points as given to expert is used in the proposed multi-agent system (MAS) to perform selection of control points for the selection size of 3, 6, 9, 12, 15, 18, 21, 24 and 27 number of control points as explained in Section 3.4.4. The Corner agent computed the corner score of the GCPs after received the request from Rectifier agent. The Corner agent started to search and compute corner score with initial neighbourhood size of two pixels. However, the corner scores of the GCPs are unable to be calculated by the Corner agent using such small size of pixel neighbourhood, null values are returned. Hence, the corner score calculation is iterated by the Corner agent with neighbourhood pixel size of four. The iteration is continued each time with an increment of neighbourhood pixel size of two until the corner score is successful calculated. The neighbourhood pixel size used for corner score calculation of each GCP by Corner agent is shown in Table 5.9.

Table 5.9: The neighbourhood pixel size used for corner score calculation of each GCP by Corner agent

GCP	Neighbourhood pixel size				
	2	4	6	8	10
CP01	null	null	0.000001		
CP03	null	null	null	0.000669	
CP05	null	null	0.001790		
CP06	null	null	null	0.000175	
CP10	null	null	0.010118		
CP12	null	null	0.001632		
CP18	null	null	null	0.000565	
CP20	null	null	null	0.000010	
CP21	null	null	null	0.001243	
CP23	null	null	0.001718		
CP24	null	null	0.000087		
CP26	null	null	0.000015		
CP27	null	0.000019			
CP28	null	null	null	0.000419	
CP30	null	null	null	0.000365	
CP32	null	null	null	0.000440	
CP33	null	null	null	0.000093	
CP34	null	null	null	0.000055	
CP35	null	null	null	0.000024	
CP37	null	null	0.000559		
CP39	null	null	0.000038		
CP40	null	null	null	0.001288	
CP41	null	null	0.000044		
CP43	null	null	null	null	0.001052
CP45	null	null	null	null	0.000458
CP46	null	null	0.000065		
CP48	null	null	null	0.000097	
CP50	null	null	0.000538		

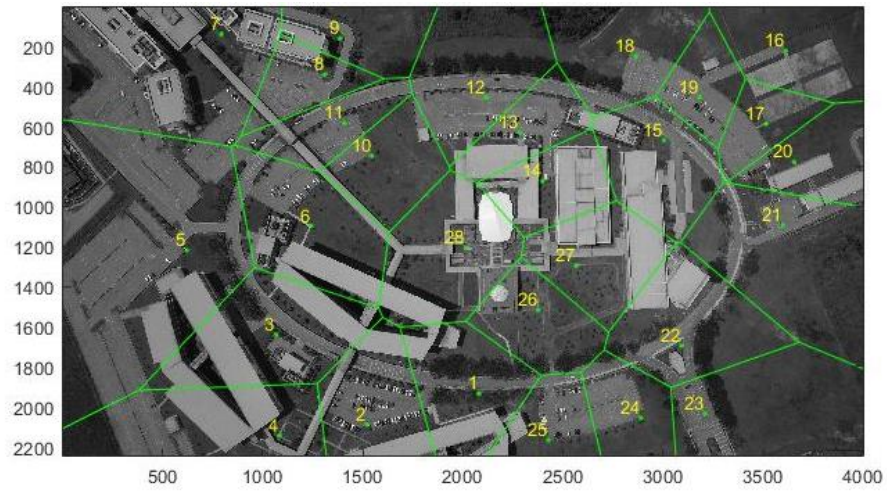
In Table 5.9, the null value means that the corner score for the GCP is unable to be calculated with that neighbourhood pixel size, while the shaded cell means the iteration for corner score calculation of the GCP has been stopped. The corner score describes the strength of the detected corner. A GCP with higher corner score denotes that it has a

sharper cornerness measure. The calculated corner score of each GCP is then ranked in ascending order. The rank (r^c) of the corner score for each GCP is shown in Table 5.10.

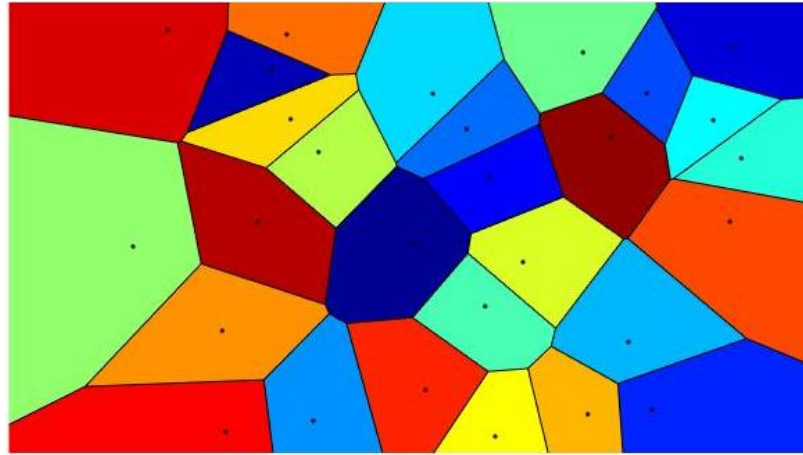
Table 5.10: The rank of the corner score for each GCP

GCP	Corner score	Rank, r^c
CP01	0.000001	1
CP03	0.000669	21
CP05	0.001790	27
CP06	0.000175	13
CP10	0.010118	28
CP12	0.001632	25
CP18	0.000565	20
CP20	0.000010	2
CP21	0.001243	23
CP23	0.001718	26
CP24	0.000087	10
CP26	0.000015	3
CP27	0.000019	4
CP28	0.000419	15
CP30	0.000365	14
CP32	0.000440	16
CP33	0.000093	11
CP34	0.000055	8
CP35	0.000024	5
CP37	0.000559	19
CP39	0.000038	6
CP40	0.001288	24
CP41	0.000044	7
CP43	0.001052	22
CP45	0.000458	17
CP46	0.000065	9
CP48	0.000097	12
CP50	0.000538	18

The task of distribution impact index calculation is performed by Distributor agent after received the request from Rectifier agent. The Voronoi diagram is constructed by Distributor agent using the 28 GCPs as shown in Figure 5.28. Figure 5.28 (a) shows the Voronoi diagram of the aerial image with the distribution of the 28 GCPs. Different colour patches are used to highlight the polygons constructed as presented in Figure 5.28 (b).



(a) Aerial image with Voronoi diagram



(b) Output image with Voronoi diagram

Figure 5.28: Voronoi diagram constructed using 28 GCPs

Each Voronoi polygon area in total pixels is calculated. The Voronoi polygon area, the distribution impact index, the rank of distribution impact index (r^d), the rank of corner

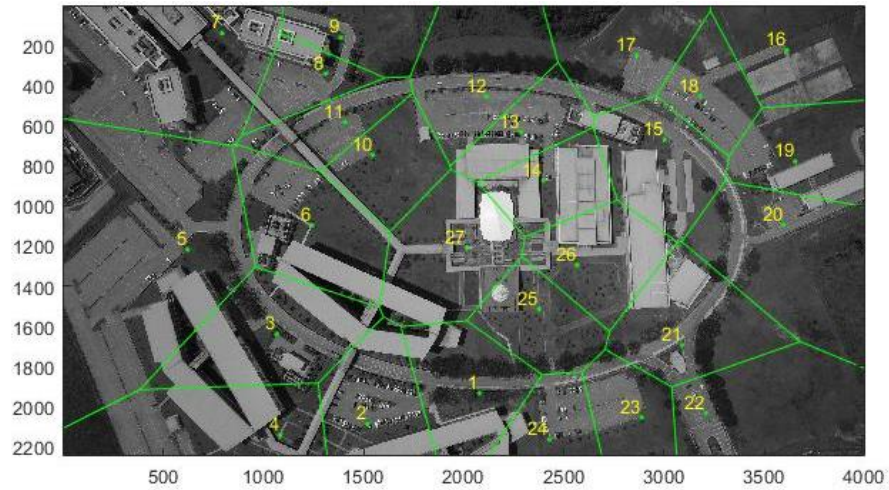
score (r^c) and the selection value (S) of each control point is shown in Table 5.11. The point retention is based on its selection value as discussed in Section 3.4.4.

Table 5.11: Selection values of 28 GCPs

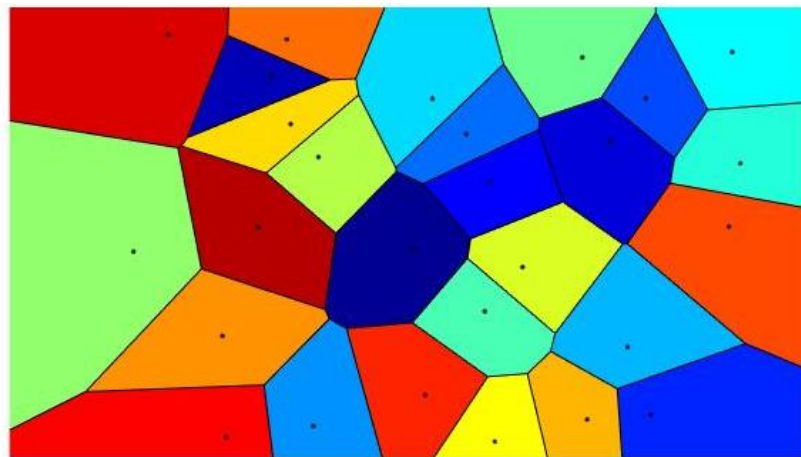
GCPs	Point No.	Voronoi polygon area (total pixels)	Dist. impact index	r^d	r^c	Selection value, S
CP01	1	307381	0.0341534	18	1	19
CP03	2	280012	0.0311124	14	21	35
CP05	3	420391	0.0467101	24	27	51
CP06	4	408574	0.0453971	23	13	36
CP10	5	1046637	0.1162930	28	28	56
CP12	6	382115	0.0424572	21	25	46
CP18	7	644032	0.0715591	27	20	47
CP20	8	152952	0.0169947	2	2	4
CP21	9	199289	0.0221432	8	23	31
CP23	10	224552	0.0249502	11	26	37
CP24	11	179676	0.0199640	5	10	15
CP26	12	375329	0.0417032	20	3	23
CP27	13	179809	0.0199788	6	4	10
CP28	14	205216	0.0228018	9	15	24
CP30	15	298705	0.0331894	16	14	30
CP32	16	293022	0.0325580	15	16	31
CP33	17	139999	0.0155554	1	11	12
CP34	18	306677	0.0340752	17	8	25
CP35	19	155133	0.0172370	3	5	8
CP37	20	206766	0.0229740	10	19	29
CP39	21	526137	0.0584597	26	6	32
CP40	22	365952	0.0406613	19	24	43
CP41	23	451455	0.0501617	25	7	32
CP43	24	184283	0.0204759	7	22	29
CP45	25	158237	0.0175819	4	17	21
CP46	26	230063	0.0255626	12	9	21
CP48	27	273344	0.0303716	13	12	25
CP50	28	404262	0.0449180	22	18	40

Based on the Table 5.11, it shows that CP20 has the lowest selection value. The proposed MAS selection for selection size of 27 is completed by excluding this GCP. The Voronoi

diagrams are reconstructed using the 27 GCPs, and the Voronoi polygon areas and the rank of distribution impact index are recalculated each time to produce the selection values. The Voronoi diagram for the selection size of 27 is shown in Figure 5.29.



(a) Aerial image with Voronoi diagram



(b) Output image with Voronoi diagram

Figure 5.29: Voronoi diagram constructed using 27 GCPs

Figure 5.29 (a) shows the Voronoi diagram of the aerial image with the distribution of the 27 GCPs. Different colour patches are used to highlight the polygons constructed as presented in Figure 5.29 (b). The Voronoi polygon area, the distribution impact index, the ranks of distribution impact index and corner score and the selection values of the 27 GCPs are shown in Table 5.12.

Table 5.12: Selection values of 27 GCPs

GCPs	Point No.	Voronoi polygon area (total pixels)	Dist. impact index	r^d	r^c	Selection value, S
CP01	1	307381	0.0341534	17	1	18
CP03	2	280012	0.0311124	13	21	34
CP05	3	420391	0.0467101	23	27	50
CP06	4	408574	0.0453971	22	13	35
CP10	5	1046637	0.1162930	27	28	55
CP12	6	382115	0.0424572	20	25	45
CP18	7	666420	0.0740467	26	20	46
CP21	8	263547	0.0292830	11	23	34
CP23	9	224552	0.0249502	8	26	34
CP24	10	246858	0.0274287	10	10	20
CP26	11	375329	0.0417032	19	3	22
CP27	12	179809	0.0199788	4	4	8
CP28	13	205216	0.0228018	6	15	21
CP30	14	298705	0.0331894	15	14	29
CP32	15	293022	0.0325580	14	16	30
CP33	16	139999	0.0155554	1	11	12
CP34	17	306677	0.0340752	16	8	24
CP35	18	155133	0.0172370	2	5	7
CP37	19	206766	0.0229740	7	19	26
CP39	20	526137	0.0584597	25	6	31
CP40	21	365952	0.0406613	18	24	42
CP41	22	451455	0.0501617	24	7	31
CP43	23	184283	0.0204759	5	22	27
CP45	24	158237	0.0175819	3	17	20
CP46	25	230063	0.0255626	9	9	18
CP48	26	273344	0.0303716	12	12	24
CP50	27	403386	0.0448207	21	18	39

Based on the Table 5.12, it shows that CP35 has the lowest selection value and this GCP is removed from the selection. After that, the Voronoi diagram is constructed again using the remaining 26 GCPs and the Voronoi polygon areas are recalculated. The Voronoi polygon area, the distribution impact index, the ranks of distribution impact index and corner score and the selection value for the 26 GCPs and 25 GCPs are shown in Table 5.13 and Table 5.14, respectively as examples of the selection process by proposed MAS.

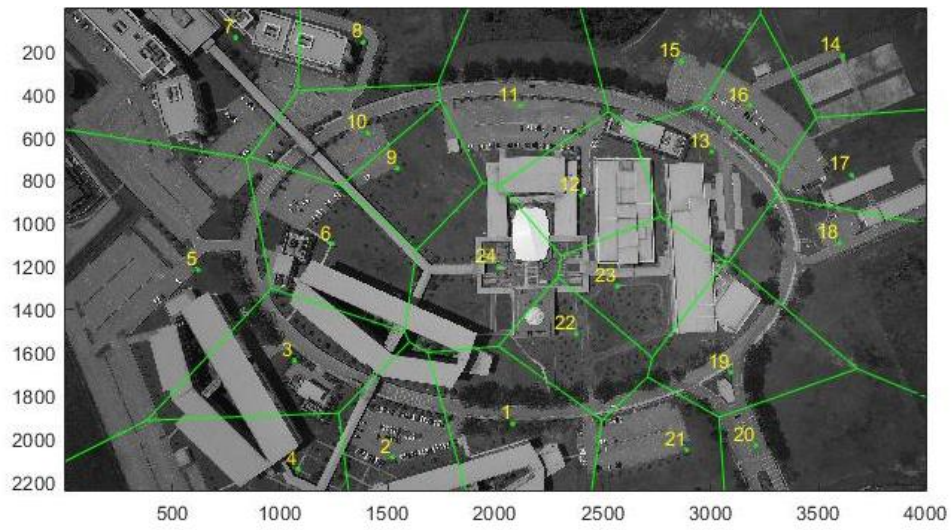
Table 5.13: Selection values of 26 GCPs

GCPs	Point No.	Voronoi polygon area (total pixels)	Dist. impact index	r^d	r^c	Selection value, S
CP01	1	307381	0.0341534	13	1	14
CP03	2	280012	0.0311124	12	21	33
CP05	3	420391	0.0467101	22	27	49
CP06	4	408574	0.0453971	21	13	34
CP10	5	1046637	0.1162930	26	28	54
CP12	6	382115	0.0424572	19	25	44
CP18	7	666420	0.0740467	25	20	45
CP21	8	263547	0.0292830	10	23	33
CP23	9	224552	0.0249502	7	26	33
CP24	10	246858	0.0274287	9	10	19
CP26	11	375329	0.0417032	18	3	21
CP27	12	179809	0.0199788	3	4	7
CP28	13	205216	0.0228018	5	15	20
CP30	14	345417	0.0383797	15	14	29
CP32	15	317438	0.0352709	14	16	30
CP33	16	177942	0.0197713	2	11	13
CP34	17	353353	0.0392614	16	8	24
CP37	18	206766	0.0229740	6	19	25
CP39	19	526137	0.0584597	24	6	30
CP40	20	365952	0.0406613	17	24	41
CP41	21	451455	0.0501617	23	7	30
CP43	22	184283	0.0204759	4	22	26
CP45	23	158237	0.0175819	1	17	18
CP46	24	230063	0.0255626	8	9	17
CP48	25	273344	0.0303716	11	12	23
CP50	26	402772	0.0447524	20	18	38

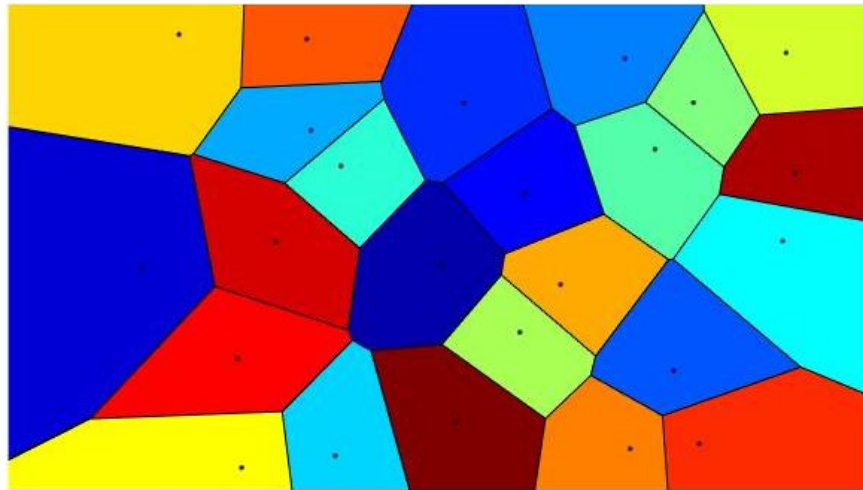
Table 5.14: Selection value of 25 GCPs

GCPs	Point No.	Voronoi polygon area (total pixels)	Dist. impact index	r^d	r^c	Selection value, S
CP01	1	307381	0.0341534	12	1	13
CP03	2	280012	0.0311124	10	21	31
CP05	3	420391	0.0467101	20	27	47
CP06	4	408574	0.0453971	19	13	32
CP10	5	1046637	0.1162930	25	28	53
CP12	6	382115	0.0424572	17	25	42
CP18	7	666420	0.0740467	24	20	44
CP21	8	263547	0.0292830	8	23	31
CP23	9	224593	0.0249548	5	26	31
CP24	10	246858	0.0274287	7	10	17
CP26	11	464335	0.0515928	22	3	25
CP28	12	282524	0.0313916	11	15	26
CP30	13	345911	0.0384346	14	14	28
CP32	14	317438	0.0352709	13	16	29
CP33	15	177942	0.0197713	2	11	13
CP34	16	364761	0.0405290	15	8	23
CP37	17	206766	0.0229740	4	19	23
CP39	18	526137	0.0584597	23	6	29
CP40	19	365952	0.0406613	16	24	40
CP41	20	451455	0.0501617	21	7	28
CP43	21	184283	0.0204759	3	22	25
CP45	22	158237	0.0175819	1	17	18
CP46	23	230063	0.0255626	6	9	15
CP48	24	273344	0.0303716	9	12	21
CP50	25	404324	0.0449249	18	18	36

The selection process is repeated to remove one GCP each time until the selection reached the size of 24, 21, 18, 15, 12, 9, 6 and 3. Example of Voronoi diagram for the selection size of 24 is shown in and Figure 5.30. Figure 5.30 (a) shows the Voronoi diagram of the aerial image with the distribution of the 24 GCPs and Figure 5.30 (b) shows the polygons constructed with different colour patches.



(a) Aerial image with Voronoi diagram



(b) Output image with Voronoi diagram

Figure 5.30: Voronoi diagram constructed using 24 GCPs

The selection of GCPs given by the proposed MAS according to selection size is shown in Table 5.15. It is noticed that the first three GCPs selected by the proposed MAS are CP10, CP23 and CP40. The locations of these three GCPs are surrounding the centre of the image. The next three GCPs added are CP05, CP12 and CP37 to form the selection size of six. Then, another three GCPs (CP18, CP30 and CP50) are selected for selection size of nine. CP20 is not being selected in all the selection size. The distribution of selection size

27, 24, 21, 18, 15, 12, 9, 6 and 3 used for similarity transformation is shown in Figure 5.31, Figure 5.32, Figure 5.33, Figure 5.34, Figure 5.35, Figure 5.36, Figure 5.37, Figure 5.38 and Figure 5.39, respectively.

Table 5.15: GCPs selection by the proposed multi-agent system according to selection size

Size	28	27	24	21	18	15	12	9	6	3
CP01	✓	✓	✓							
CP03	✓	✓	✓	✓	✓	✓	✓			
CP05	✓	✓	✓	✓	✓	✓	✓	✓	✓	
CP06	✓	✓	✓	✓						
CP10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP12	✓	✓	✓	✓	✓	✓	✓	✓	✓	
CP18	✓	✓	✓	✓	✓	✓	✓	✓		
CP20	✓									
CP21	✓	✓	✓	✓	✓	✓	✓			
CP23	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP24	✓	✓	✓							
CP26	✓	✓	✓	✓	✓					
CP27	✓	✓								
CP28	✓	✓	✓	✓	✓	✓				
CP30	✓	✓	✓	✓	✓	✓	✓	✓		
CP32	✓	✓	✓	✓	✓	✓				
CP33	✓	✓								
CP34	✓	✓	✓	✓						
CP35	✓	✓								
CP37	✓	✓	✓	✓	✓	✓	✓	✓	✓	
CP39	✓	✓	✓	✓	✓					
CP40	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP41	✓	✓	✓	✓	✓					
CP43	✓	✓	✓	✓	✓	✓	✓			
CP45	✓	✓	✓	✓						
CP46	✓	✓	✓	✓	✓	✓				
CP48	✓	✓	✓							
CP50	✓	✓	✓	✓	✓	✓	✓	✓		

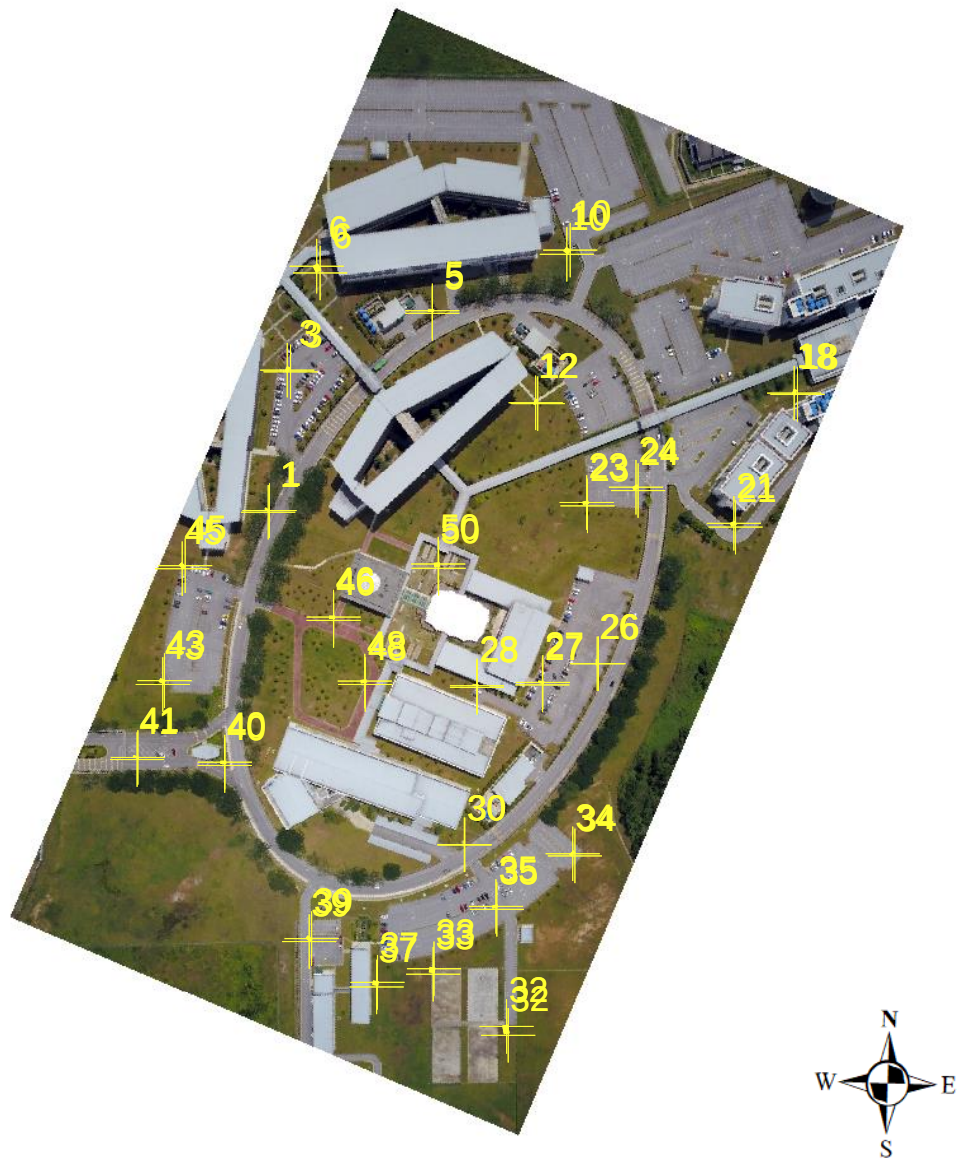


Figure 5.31: The distribution of proposed MAS selection size 27 for similarity transformation

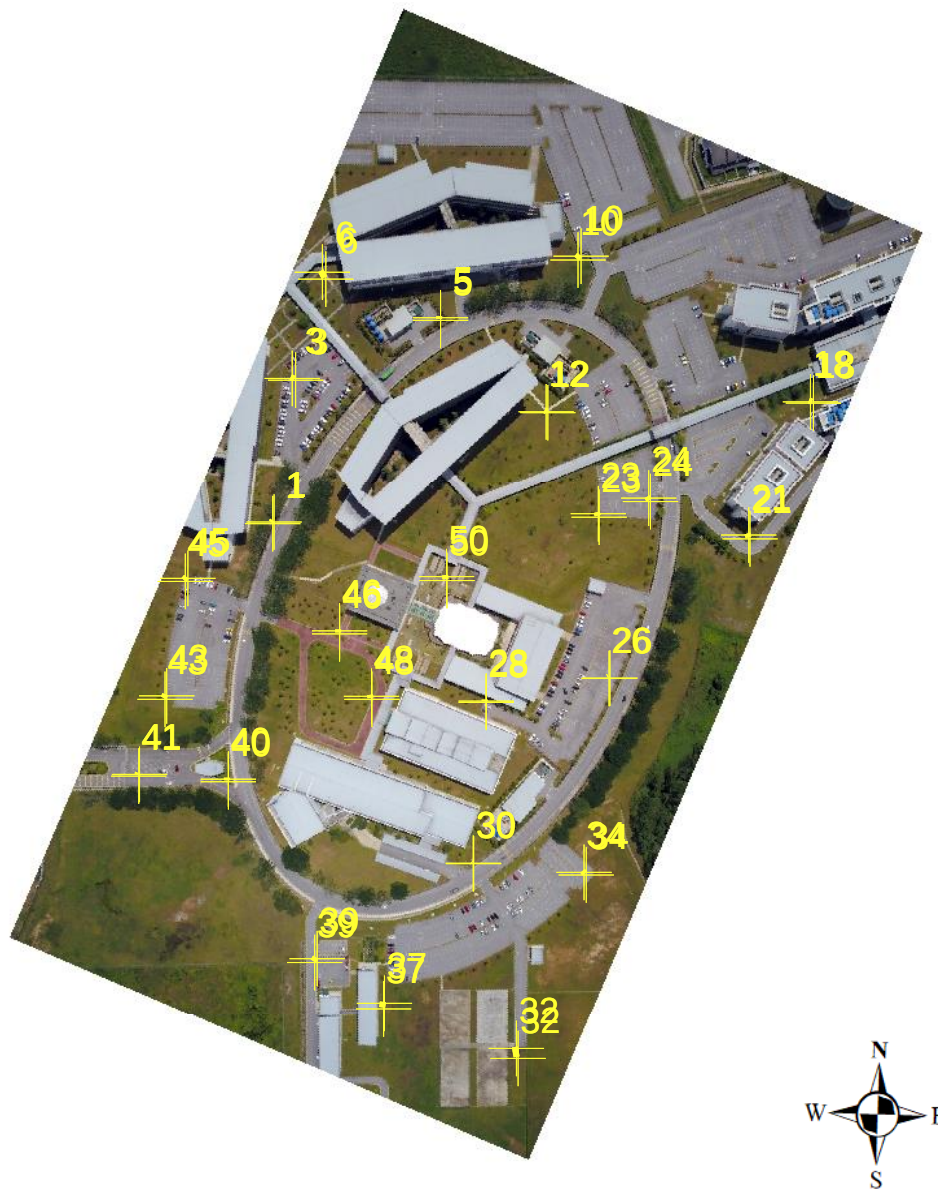


Figure 5.32: The distribution of proposed MAS selection size 24 for similarity transformation

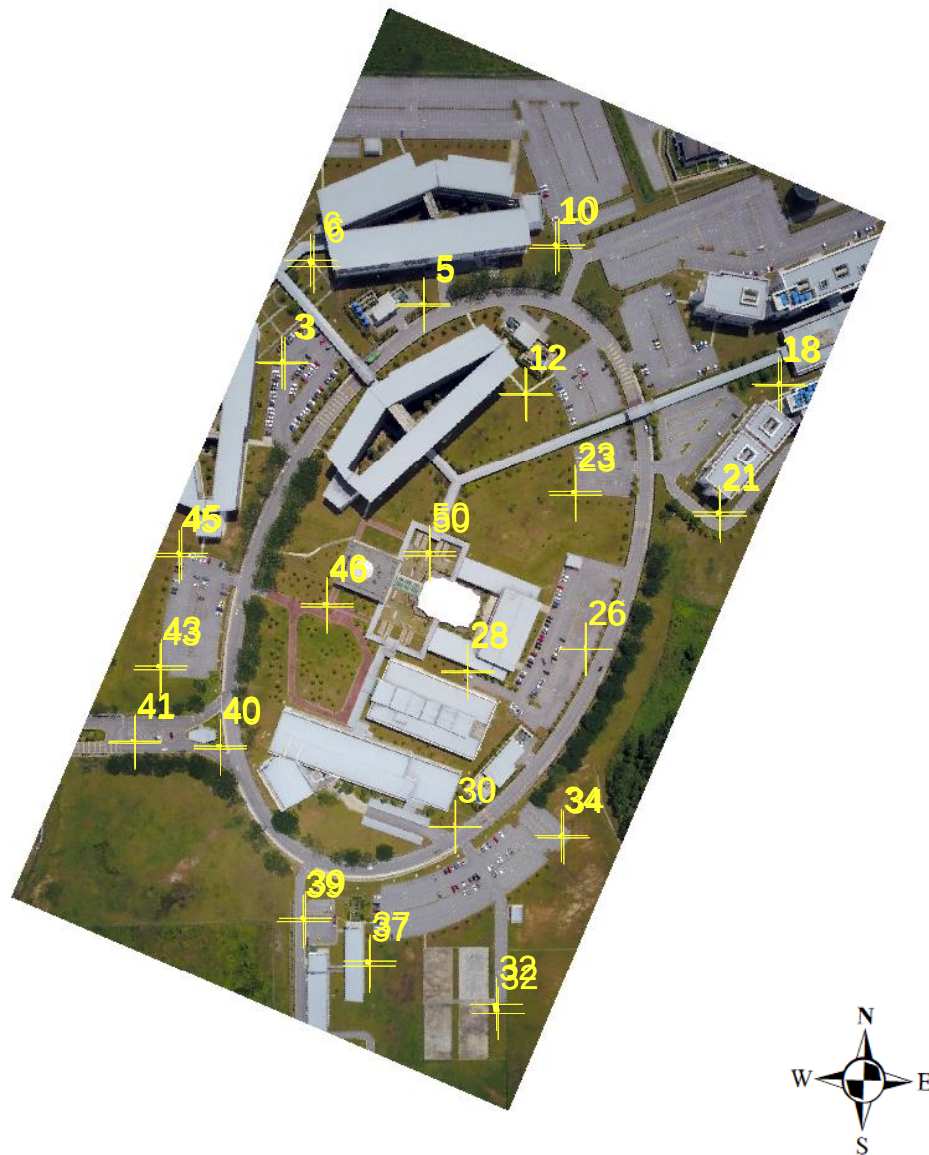


Figure 5.33: The distribution of proposed MAS selection size 21 for similarity transformation

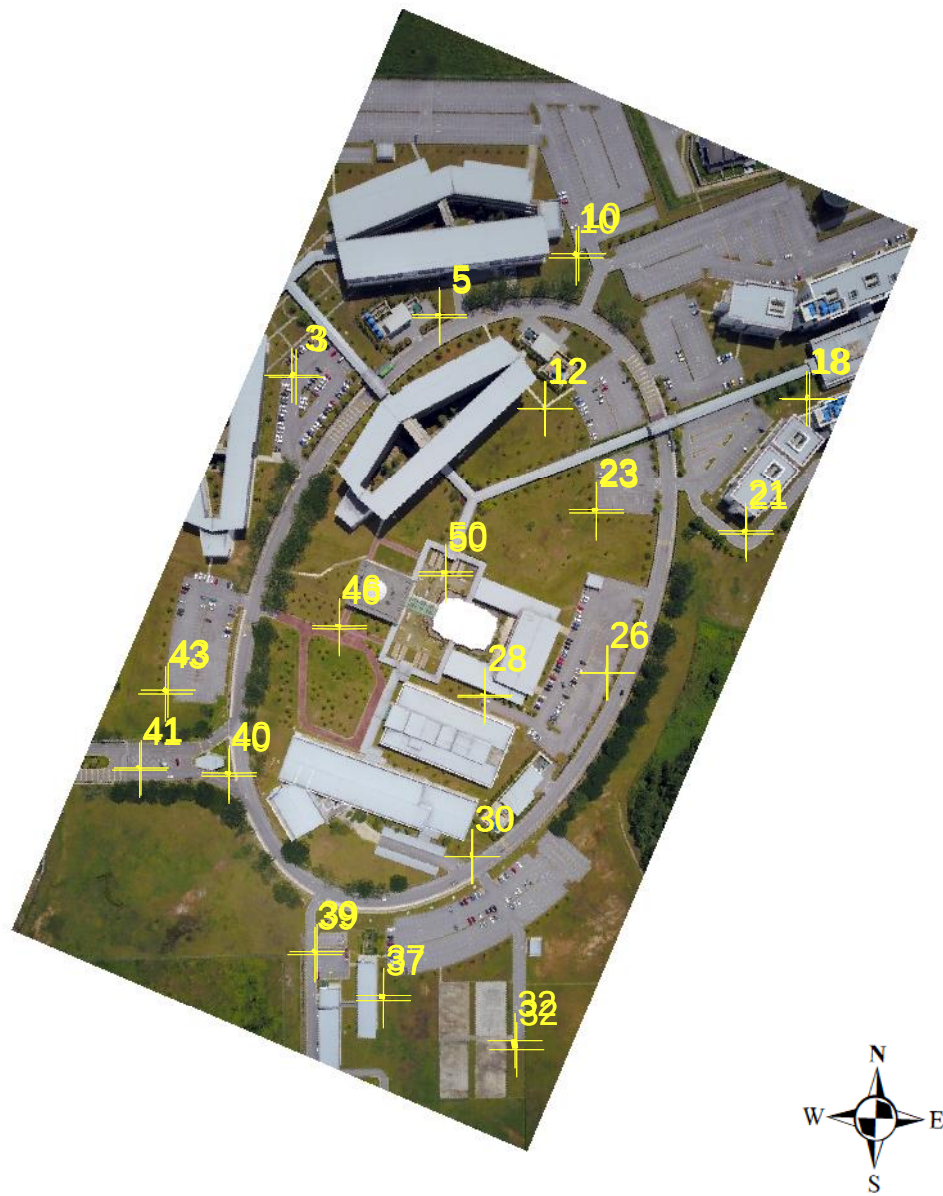


Figure 5.34: The distribution of proposed MAS selection size 18 for similarity transformation

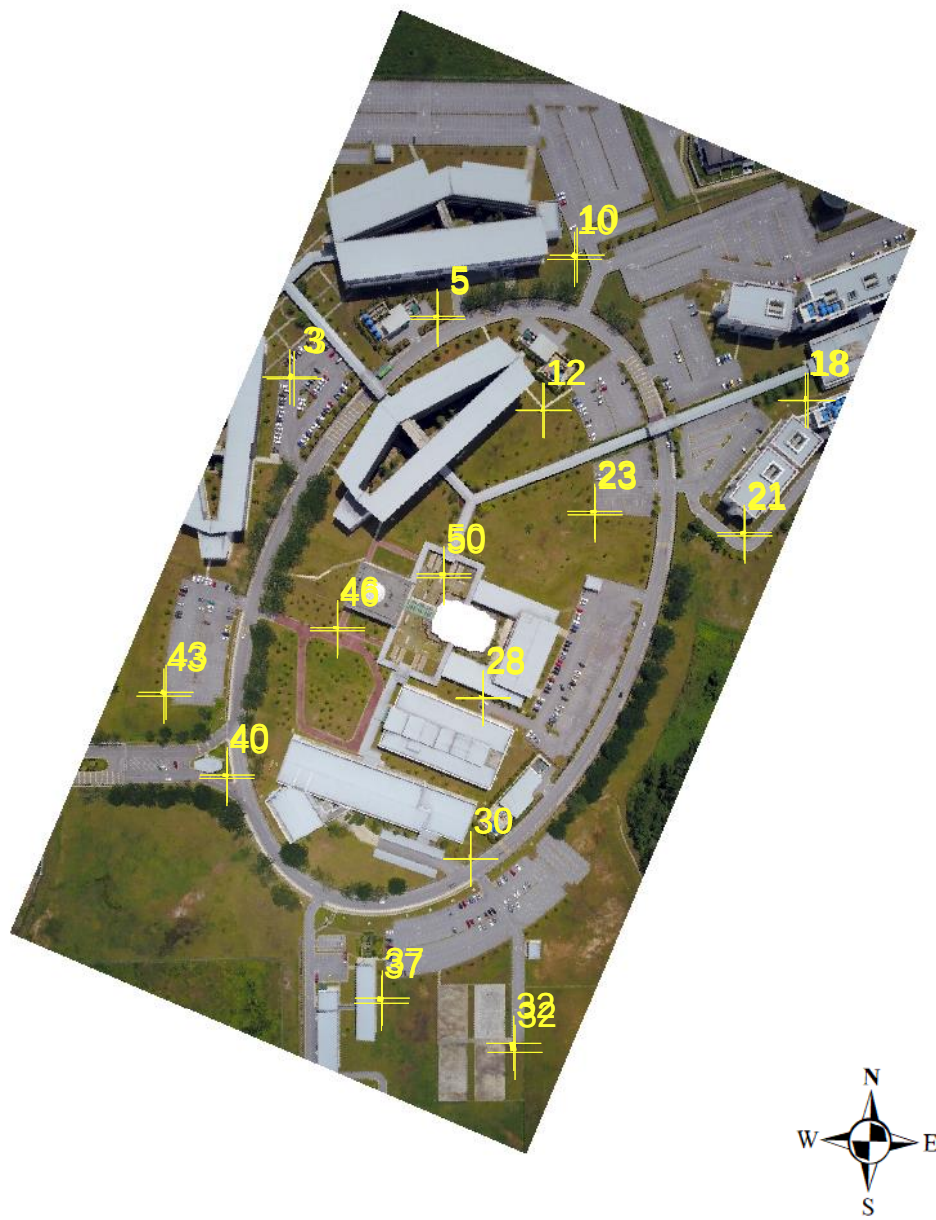


Figure 5.35: The distribution of proposed MAS selection size 15 for similarity transformation

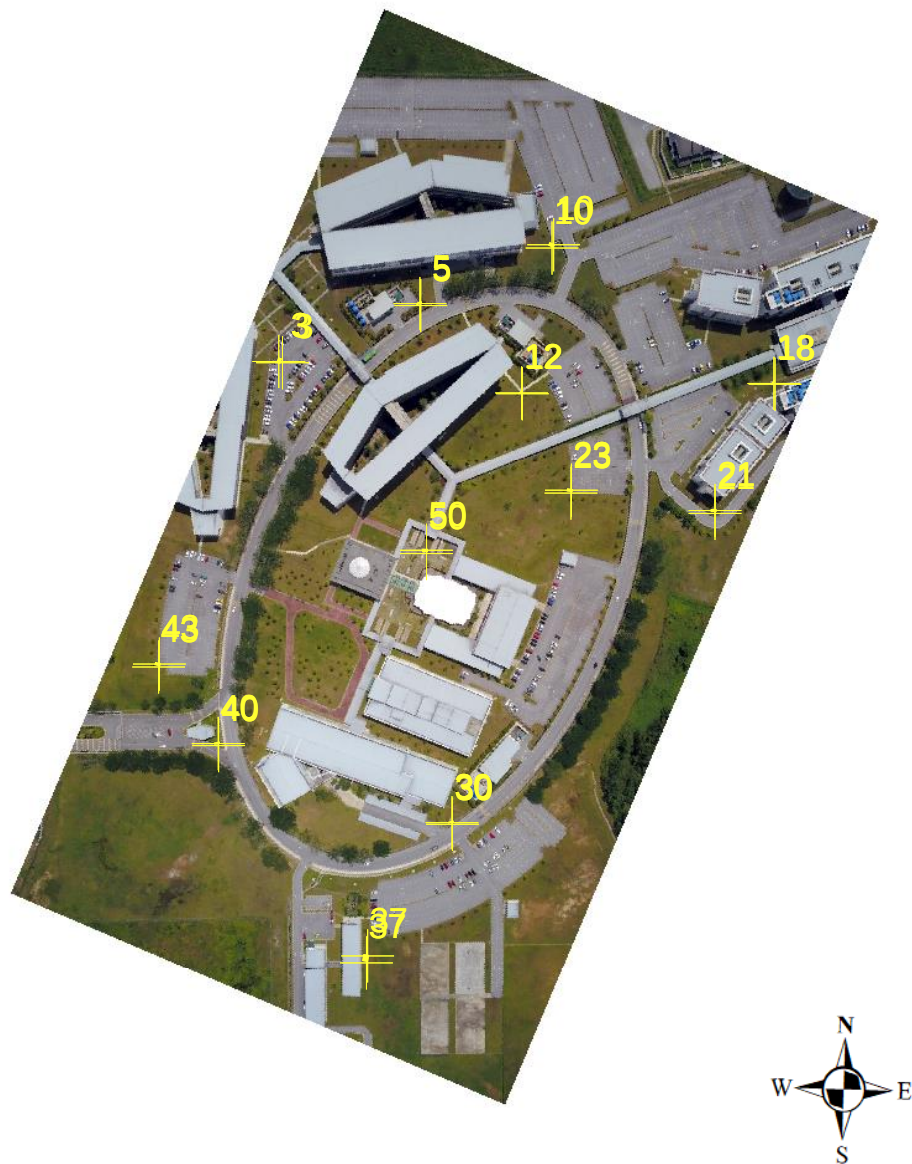


Figure 5.36: The distribution of proposed MAS selection size 12 for similarity transformation

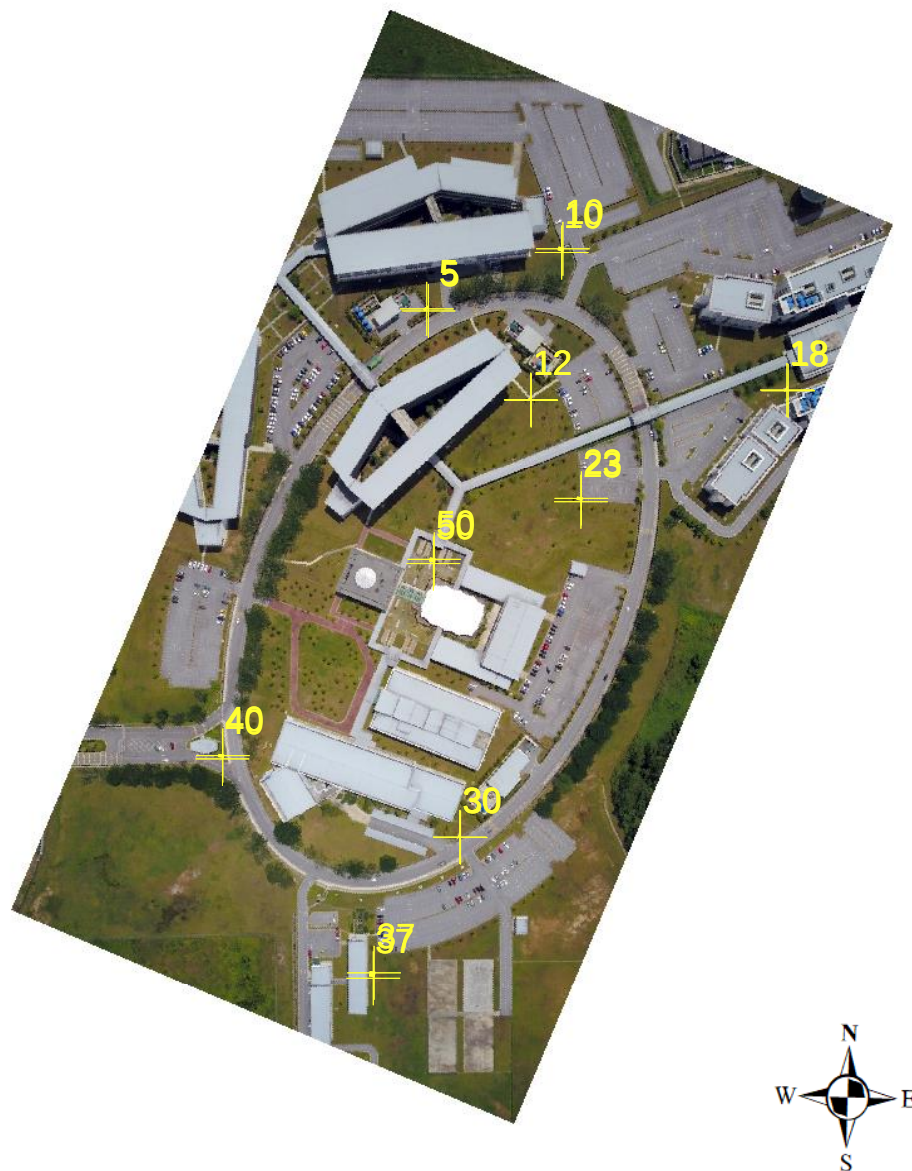


Figure 5.37: The distribution of proposed MAS selection size 9 for similarity transformation

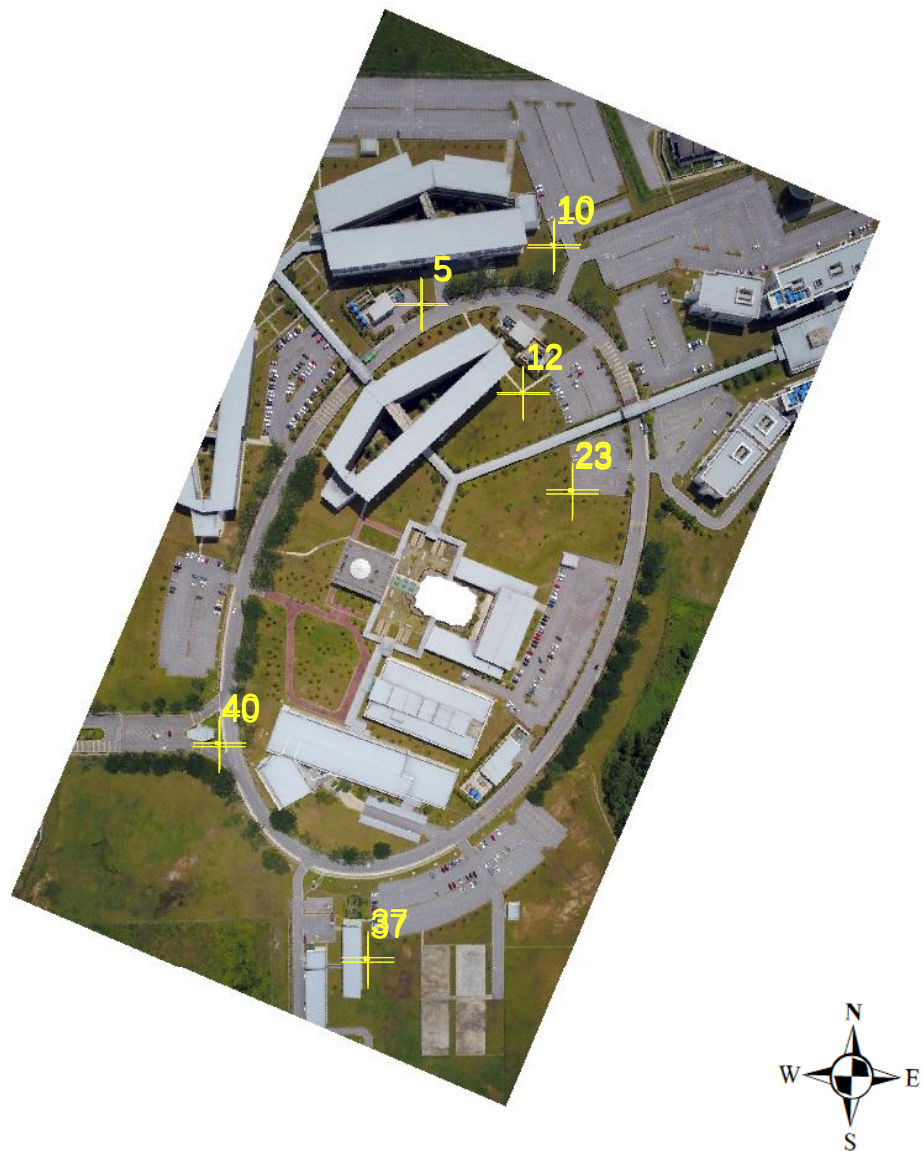


Figure 5.38: The distribution of proposed MAS selection size 6 for similarity transformation

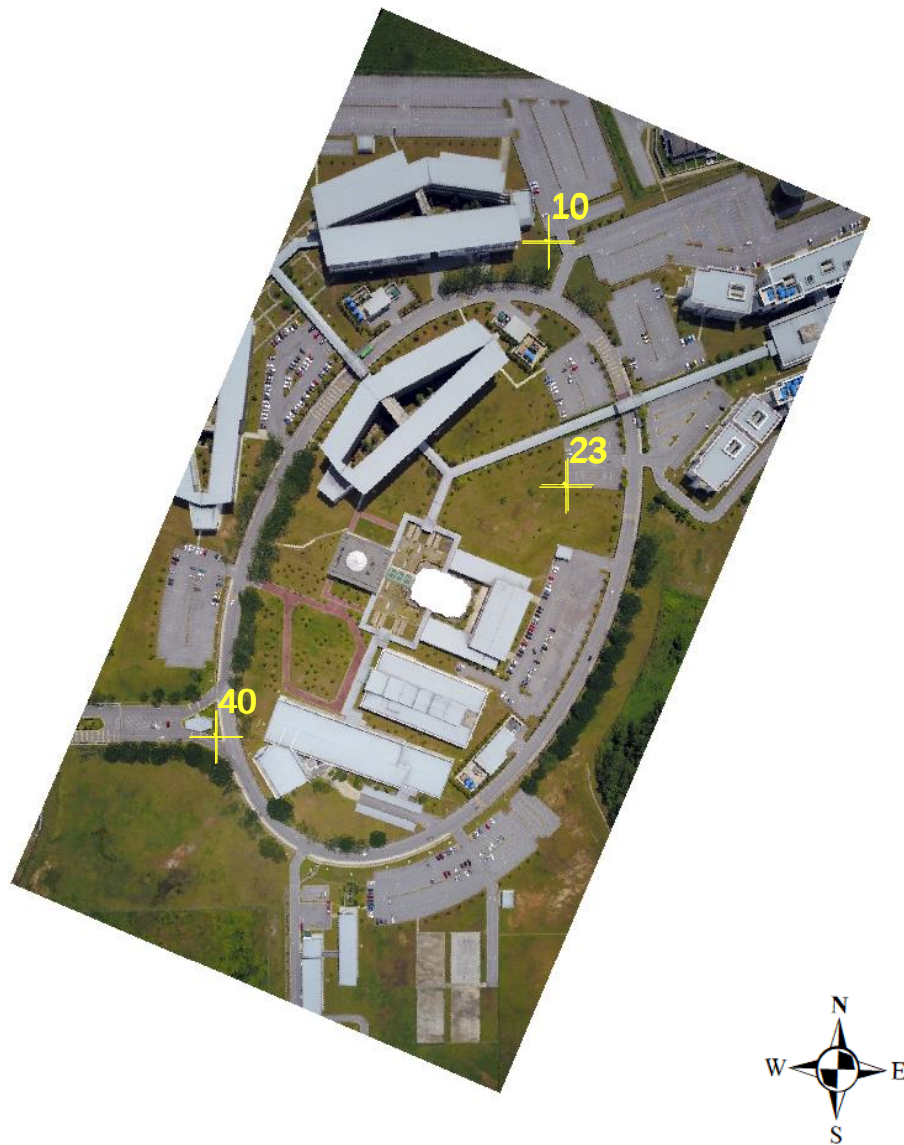


Figure 5.39: The distribution of proposed MAS selection size 3 for similarity transformation

The total RMSE of the GCPs and checkpoints achieved for the different selection size when using similarity transformation, affine transformation, second order polynomial and third order polynomial transformation is shown in Table 5.16, Table 5.17, Table 5.18 and Table 5.19, respectively. When using the proposed MAS selection, the lowest total RMSE of the checkpoints achieved is 0.91 meters when using eighteen GCPs transformed with second order polynomial transformation as shown in Table 5.18. The highest total RMSE of the checkpoints achieved is 4.99 meters when using three GCPs transformed with affine transformation as shown in Table 5.17.

The comparison of the total RMSE at checkpoints achieved is shown in Figure 5.40. It is noticed that the achievement of the total RMSE at checkpoints when using similarity and affine transformations are more than one meter in all the selection size. The total RMSE at checkpoints achieves less than one meter when the selection size is more than twelve with second order polynomial transformation and third order polynomial transformation.

Table 5.16: The total RMSE of the GCPs and checkpoints achieved using similarity transformation based on the proposed MAS selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	2.48	2.29
24	2.46	2.30
21	2.53	2.34
18	2.38	2.18
15	2.50	2.20
12	2.08	2.37
9	1.99	2.19
6	2.13	2.24
3	1.44	3.07

Table 5.17: The total RMSE of the GCPs and checkpoints achieved using affine transformation based on the proposed MAS selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	2.33	2.09
24	2.35	2.09
21	2.42	2.15
18	2.19	2.00
15	2.31	2.07
12	2.01	2.19
9	1.97	2.11
6	2.09	2.20
3	0.00	4.99

Table 5.18: The total RMSE of the GCPs and checkpoints achieved using 2nd order polynomial transformation based on the proposed MAS selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	0.51	0.91
24	0.53	0.91
21	0.54	0.92
18	0.55	0.91
15	0.32	0.97
12	0.19	1.05
9	0.11	1.06
6	0.00	1.15

Table 5.19: The total RMSE of the GCPs and checkpoints achieved using 3rd order polynomial transformation based on the proposed MAS selection

Selection size	Total RMSE of GCPs	Total RMSE of 12 checkpoints
27	0.48	0.93
24	0.49	0.93
21	0.48	0.99
18	0.49	0.99
15	0.27	0.98
12	0.11	1.06

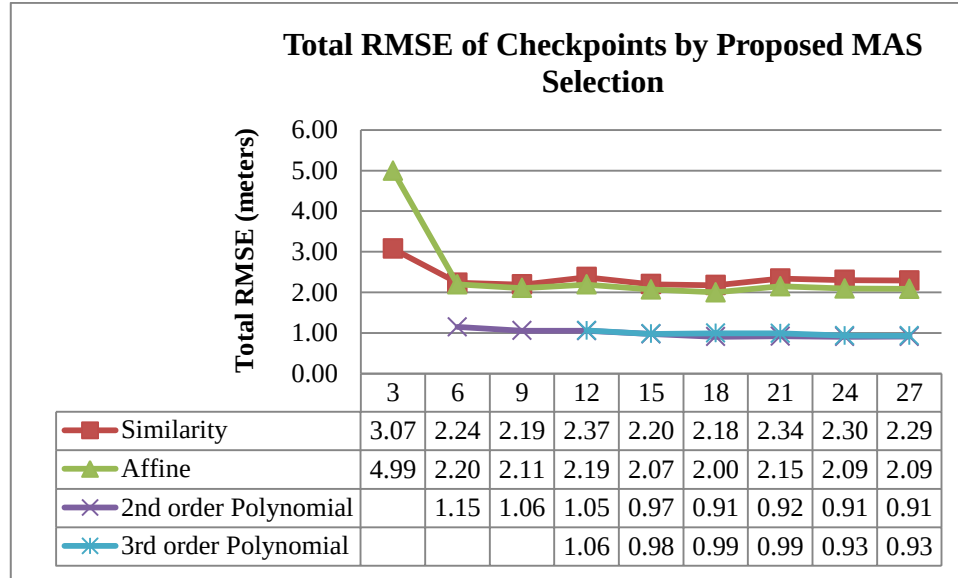


Figure 5.40: Comparison of the total RMSE of checkpoints by proposed MAS selection

5.6 Results analyses and comparisons

The evaluation of expert selection and the proposed MAS selection have been discussed separately in Section 5.4 and Section 5.5. In this section, the comparisons between the results obtained by expert selection and the proposed MAS selection are discussed. After that, the discussion continued with the comparison between the achievement of the proposed MAS and the conventional selection method based on the residual of the GCPs.

The comparison of the total RMSE of the checkpoints selected by expert and proposed MAS when using similarity transformation, affine transformation, second order polynomial transformation and third order polynomial transformation are shown in Figure 5.41, Figure 5.42, Figure 5.43 and Figure 5.44, respectively. It is noticed that the differences between the total RMSE of checkpoints among the selection of expert and proposed MAS are more obvious when using the smaller size of selection and the achievement of the total RMSE of checkpoints are approaching to similar result when

increasing in selection size. The details of the comparisons according to different transformations used are discussed separately as follows.

According to Figure 5.41, the proposed MAS selection achieved a lower RMSE of checkpoints compared to expert selection when the selection size is six, nine, fifteen, eighteen, twenty-one and twenty-four while using similarity transformation. Among these six selection sizes, the proposed MAS selection achieved the highest percentage of reduction in the total RMSE of checkpoints with selection size of six. The total RMSE of checkpoints achieved by the proposed MAS selection has reduced 20.71% when compared to the achievement by expert selection.

Based on Figure 5.42, the proposed MAS selection acquired a lower RMSE of checkpoints compared to expert selection with selection size of six, nine, twelve, fifteen, eighteen, twenty-one and twenty-four while using affine transformation. Among these seven selection sizes, the proposed MAS selection acquired the highest percentage of decrement in the total RMSE of checkpoints with selection size of six. The total RMSE of checkpoints acquired by the proposed MAS selection has decreased by 14.83% when compared to expert selection.

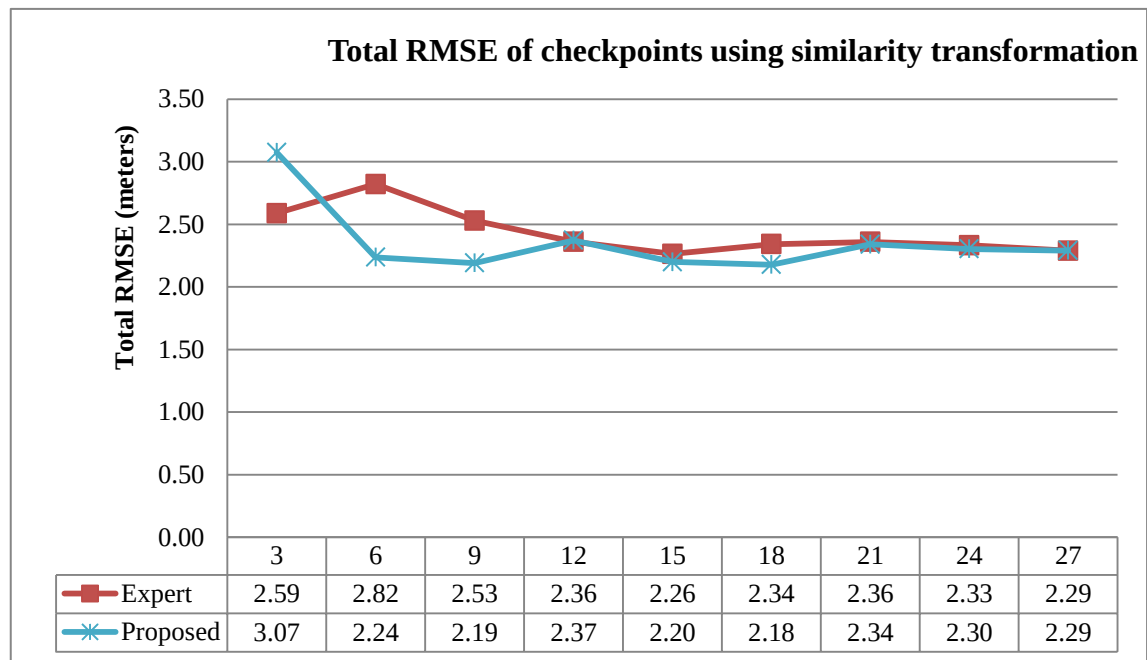


Figure 5.41: Total RMSE of checkpoints achieved using similarity transformation on selection done by expert and proposed system

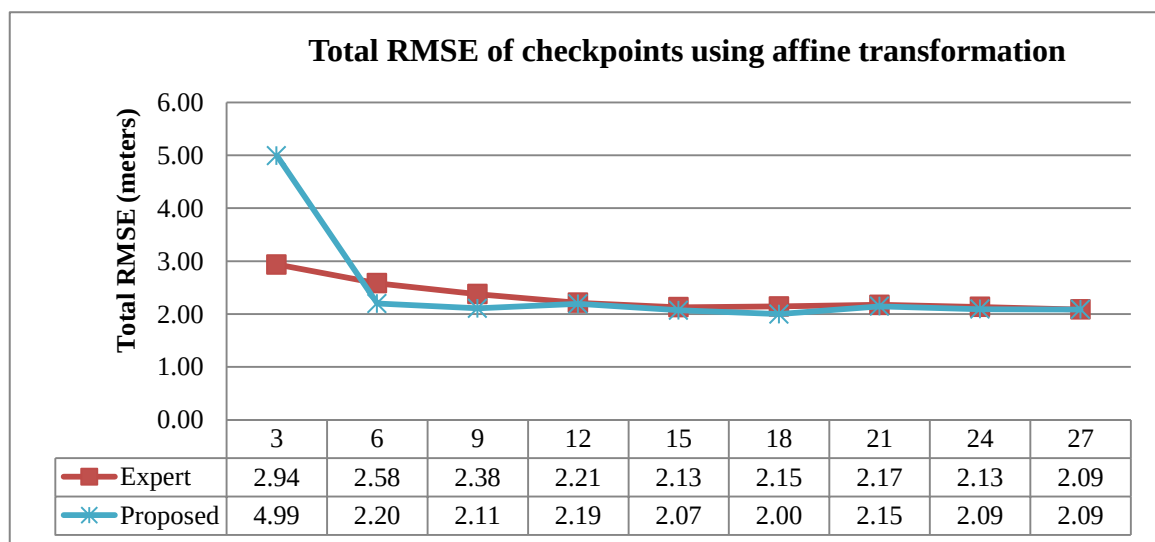


Figure 5.42: Total RMSE of checkpoints using affine transformation on selection done by expert and proposed system

When using second order polynomial transformation, the proposed MAS selection achieved a lower RMSE of checkpoints compared to expert selection with selection size of six and twenty-four as shown in Figure 5.43. Among these two selection sizes, the proposed MAS selection achieved the highest percentage of reduction in the total RMSE of checkpoints with selection size of six. The total RMSE of checkpoints achieved by the proposed MAS selection has reduced 58.31% when compared to the achievement by expert selection.

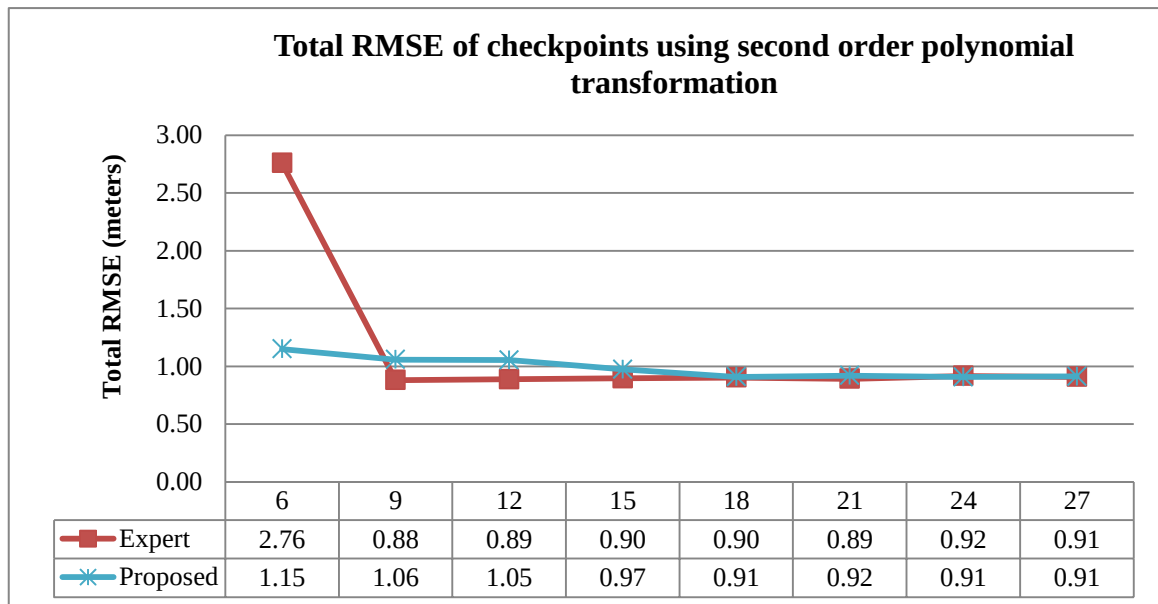


Figure 5.43: Total RMSE of checkpoints using second order polynomial transformation on selection done by expert and proposed system

As shown in Figure 5.44, the proposed MAS selection acquired a lower RMSE of checkpoints compared to expert selection with selection size of twelve, fifteen, eighteen and twenty-four. Among these four selection sizes, the proposed MAS selection acquired the highest percentage of reduction in the total RMSE of checkpoints with selection size of

fifteen. The total RMSE of checkpoints achieved by the proposed MAS selection has reduced 8.91% when compared to the achievement by expert selection. Although the decrement is less than 9%, it is found that that the achievements of the proposed MAS selection have the smallest range compared to the achievements of expert when using third order polynomial transformation.

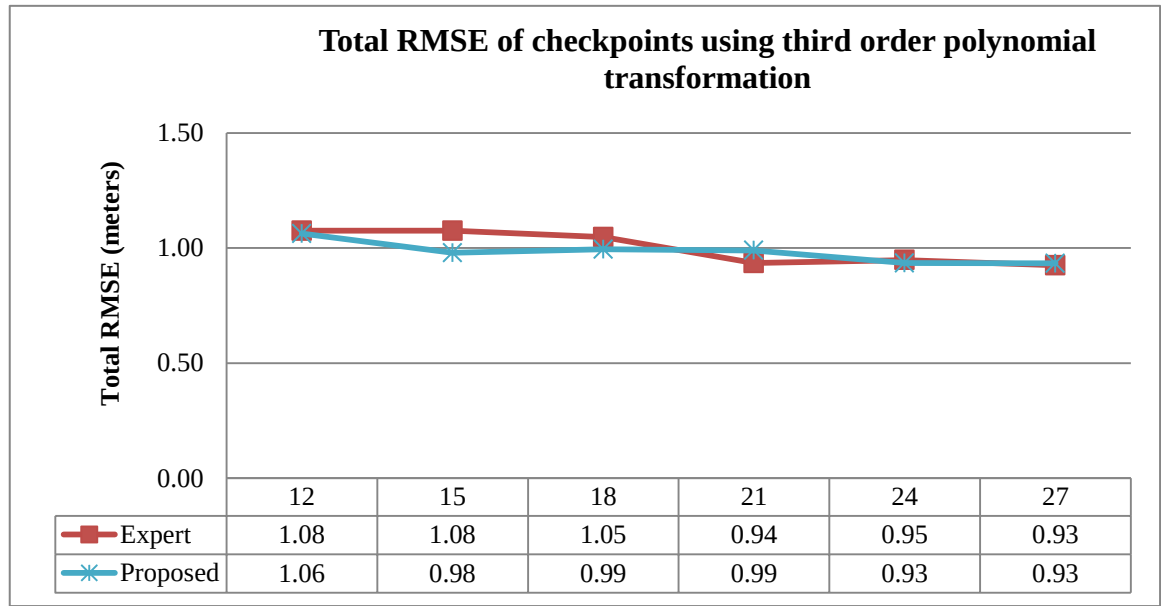


Figure 5.44: Total RMSE of checkpoints using third order polynomial transformation on selection done by expert and proposed system

The range is the difference between the maximum and minimum of the total RMSE of checkpoints achieved by each selection. The shorter the range describes the smaller the fluctuate limit of the total RMSE achieved, which indicates that the achievement is more consistent and stable within the tested selection sizes. The illustrations of the maximum and minimum of the total RMSE of checkpoints when using similarity, affine, second order polynomial and third order polynomial transformations are depicted in Figure 5.45, Figure 5.46, Figure 5.47 and Figure 5.48, respectively.

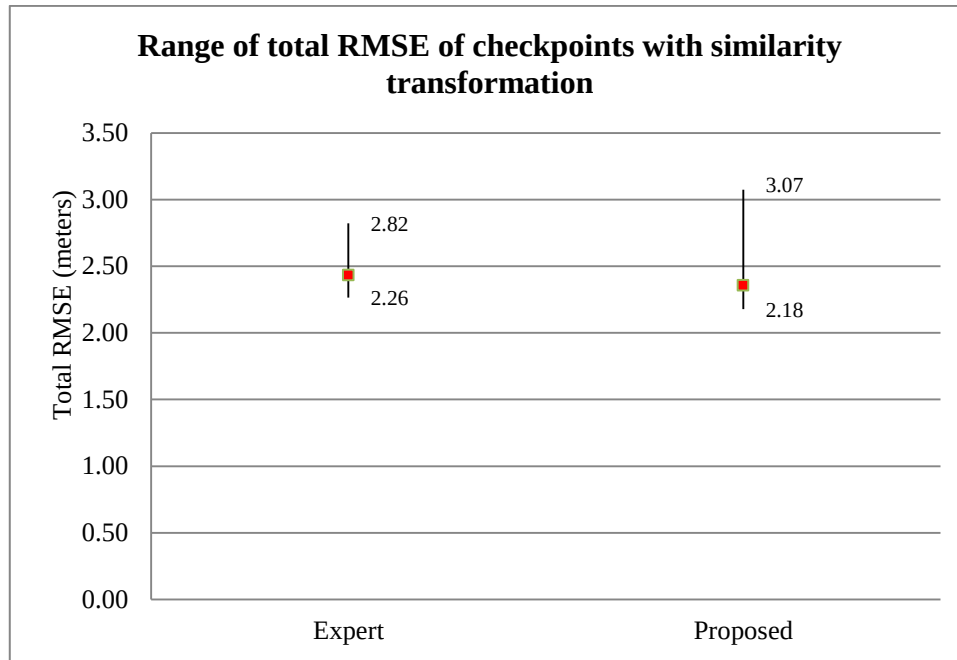


Figure 5.45: The range of total RMSE of checkpoints when using similarity transformation

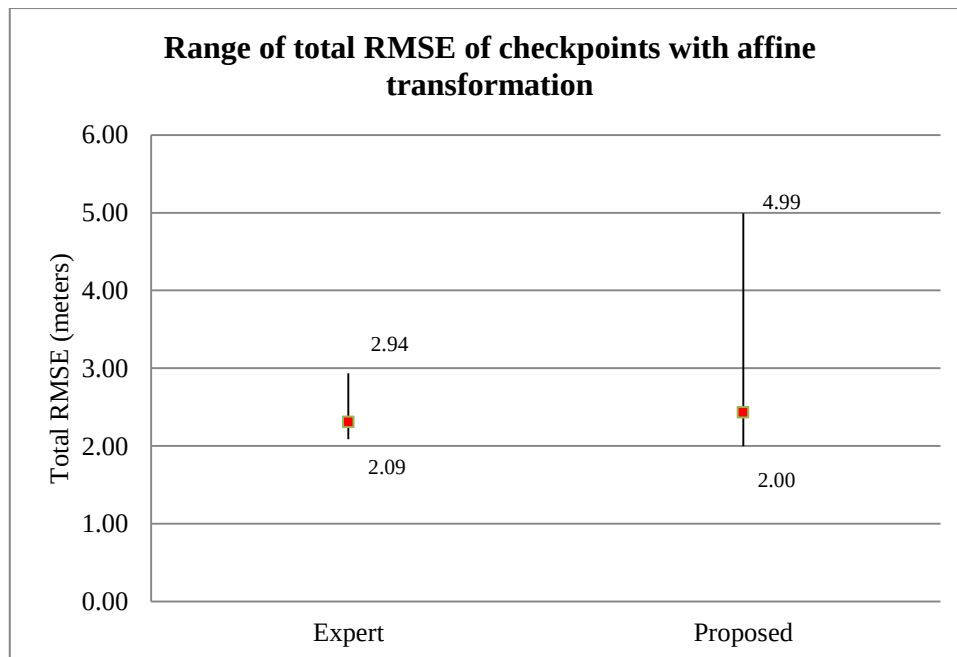


Figure 5.46: The range of total RMSE of checkpoints when using affine transformation

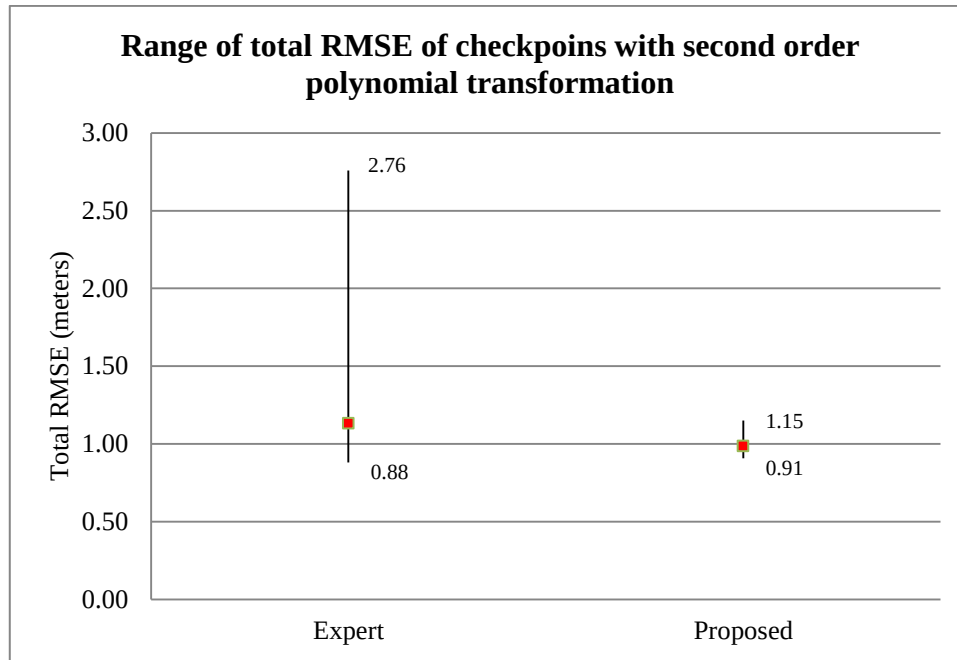


Figure 5.47: The range of total RMSE of checkpoints when using second order polynomial transformation

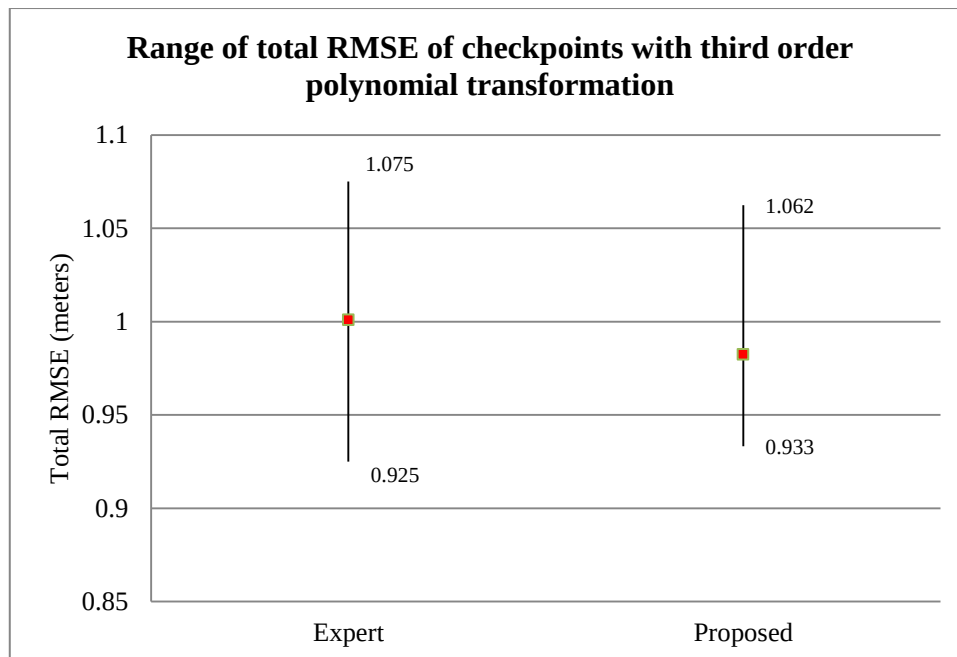


Figure 5.48: The range of total RMSE of checkpoints when using third order polynomial transformation

The range values for each selection when using similarity, affine second order polynomial and third order polynomial transformations are shown in Table 5.20. The proposed MAS selection has the smallest range compared to the achievements by expert selections when using second order polynomial and third order polynomial transformation.

Table 5.20: The range between maximum and minimum of total RMSE of checkpoints

Selection	Similarity	Affine	Second order polynomial	Third order polynomial
Expert	0.56	0.85	1.88	0.15
Proposed MAS	0.9	3.00	0.24	0.13

When using different transformations and different selection sizes with different GCPs selected, the total RMSE at the same checkpoints achieved are different. Based on the achievement of each transformation tested, it is found that both the expert and the proposed MAS selections produced a higher total RMSE of checkpoints, which are more than one meter in all the selection size when using similarity and affine transformations. This implied that selections by expert and the proposed MAS produce less error when using the second and third order polynomial transformation.

In addition, both selections achieved the lowest total RMSE of checkpoints individually when using the second order polynomial transformation. However, the proposed MAS selection has a smaller range of the total RMSE of checkpoints when using the second order polynomial transformation compared to the expert selection. This means that the results obtained from the proposed MAS selection are more stable when using the second order polynomial transformation.

Besides that, the achievement of the proposed MAS is also compared with the conventional selection method based on the residual of the GCPs. The comparison only focused on the transformation of second order polynomial since the performance of selections done by expert and the proposed MAS achieved the lowest total RMSE of checkpoints when using the second order polynomial transformation.

The selection based on the residual of GCPs started from the set of 28 control points as given to the proposed MAS. The highest residual is removed one by one to have its achievement for different selection size. The selection of GCPs based on residual according to selection size is shown in Table 5.21. The total RMSE of ground control points and checkpoints are measured as shown in Table 5.22. When using the second order polynomial transformation, the lowest of the total RMSE of checkpoints achieved is 0.93 meters with the selection size of twenty-seven GCPs while the highest of the total RMSE of checkpoints achieved is 1.09 meters with the selection size of twelve GCPs.

The comparison of the total RMSE of checkpoints using the second order polynomial transformation between the selections by the residual method and the proposed MAS is shown in Figure 5.49. It is noticed that the proposed MAS is outperformed the conventional residual method in all the selection sizes except selection size of six. The total RMSE of checkpoints achieved by the proposed MAS selection has decreased 12.41% as the highest when compared to the achievement by the conventional residual method with selection size of eighteen.

Table 5.21: GCPs selection based on residual

Size	28	27	24	21	18	15	12	9	6
CP01	✓	✓							
CP03	✓	✓	✓	✓	✓				
CP05	✓	✓	✓	✓	✓	✓	✓	✓	
CP06	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP10	✓	✓	✓	✓	✓	✓	✓	✓	
CP12	✓	✓	✓	✓	✓	✓			
CP18	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP20	✓	✓	✓	✓					
CP21	✓	✓	✓						
CP23	✓	✓	✓	✓	✓	✓	✓		
CP24	✓	✓	✓	✓	✓				
CP26	✓								
CP27	✓	✓	✓	✓	✓	✓			
CP28	✓	✓							
CP30	✓	✓	✓	✓	✓	✓	✓	✓	
CP32	✓	✓	✓						
CP33	✓	✓	✓	✓	✓				
CP34	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP35	✓	✓	✓	✓	✓	✓	✓		
CP37	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP39	✓	✓	✓	✓					
CP40	✓	✓	✓	✓	✓	✓			
CP41	✓	✓							
CP43	✓	✓	✓	✓	✓	✓	✓	✓	✓
CP45	✓	✓	✓	✓	✓	✓	✓		
CP46	✓	✓	✓						
CP48	✓	✓	✓	✓					
CP50	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 5.22: The total RMSE of the GCPs and checkpoints achieved using second order polynomial transformation based on residual of GCPs

Selection size	Total RMSE of GCPs	Total RMSE of 12 Checkpoints
27	0.36	0.93
24	0.27	0.96
21	0.22	0.99
18	0.17	1.04
15	0.13	1.05
12	0.08	1.09
9	0.03	1.08
6	0.00	1.06

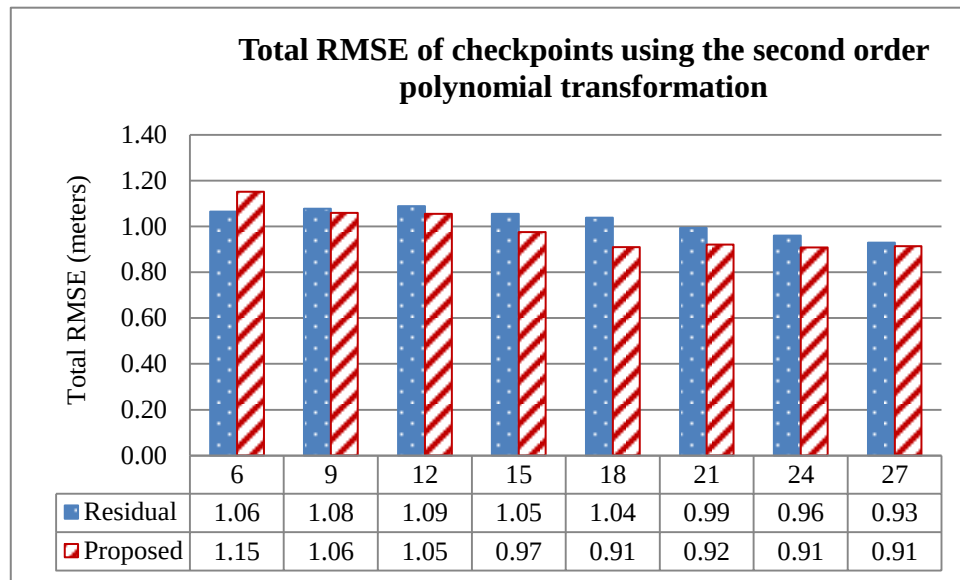


Figure 5.49: Total RMSE of checkpoints using the second order polynomial transformation on selection by residual method and the proposed MAS

As mentioned in Section 2.8, the corresponding control points from the reference and target image are used to determine the parameters of a transformation. The transformation function is typically derived with the aid of this set of GCPs. Hence, the normal aim is to achieve a close registration and the average distance between the GCPs used as the parameters for the second order polynomial transformation is analysed.

The average distance according to different selection sizes of GCPs for the reference and transformed locations among the selection done by expert, the proposed MAS and residual method when using the second order polynomial transformation is showed in Table 5.23. Based on the Table 5.23, the overall average distance of the all selection sizes for the selection of expert, the proposed MAS and the residual method is 0.38 meters, 0.27 meters and 0.14 meters, respectively.

Table 5.23: Average distance according to selection size among the selection done by expert, the proposed MAS and residual method

Selection size	Expert			Proposed MAS			Residual method		
	ΔX	ΔY	Distance	ΔX	ΔY	Distance	ΔX	ΔY	Distance
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.04	0.32	0.51	0.01	0.01	0.09	0.00	0.00	0.03
12	0.08	0.28	0.48	0.02	0.01	0.16	0.00	0.00	0.07
15	0.08	0.27	0.44	0.03	0.08	0.26	0.00	0.01	0.11
18	0.07	0.23	0.41	0.07	0.24	0.43	0.01	0.02	0.15
21	0.08	0.23	0.44	0.07	0.22	0.42	0.02	0.03	0.20
24	0.06	0.18	0.39	0.07	0.21	0.42	0.03	0.05	0.25
27	0.07	0.20	0.40	0.07	0.19	0.40	0.04	0.09	0.32

Based on the comparison of the overall results, the experiments show that the proposed MAS provide reliable results when the performance is compared with expert selection and the conventional residual method.

5.7 Agent communication in JADE

The objective of this research is to optimise the selection of control points based on the corner score and distribution impact index using a multi-agent system for aerial image rectification. This section discusses the communication of the proposed multi-agent system. It is important to show the interaction process among the agents in every multi-

agent system development to ensure that the system runs according to the design. The communication protocol in the multi-agent system can be monitored and verified using the Sniffer Agent in JADE to ensure the message flow is running properly. The interaction and message passing between the four agents are shown in Figure 5.50.

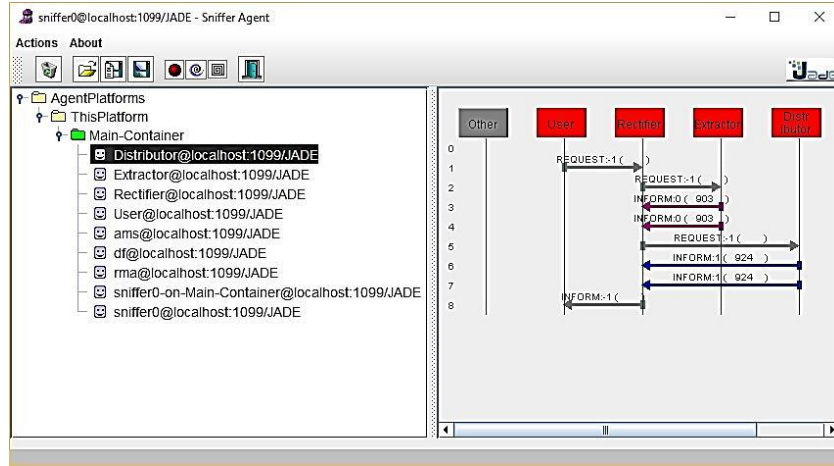


Figure 5.50: Interaction between agents monitored using JADE Sniffer Agent

From the sequence shown in Figure 5.50, the rectification processes start when User agent sends a rectification request message to Rectifier agent. When Rectifier agent receives the request message from the User agent, it sends extraction request to Corner agent. Corner agent carries out its duty on calculating corner score after receiving a request from Rectifier agent. A message would be replied to Rectifier agent by Corner agent to inform the completion of its duty. Then, Rectifier agent sends distribution request to Distributor agent. Distributor agent carries out its duty on compiling a set of points based on the distribution after receiving a request from Rectifier agent. A message would be replied to Rectifier agent by Distributor agent to inform the completion of its duty. After that, Rectifier agent continues with the processes of transformation and error rate measurement. It replies User agent the output obtained from the cooperation of agents at the end of the

processes. The example of messages sent and received between the various agents is shown in Figure 5.51.

```
Command Prompt - java -cp lib\jade.jar;myTestAgentClasses jade.Boot-gui
INFO: -----
Agent container Main-Container@localhost is ready.
-----
Distributor is ready.
Extractor is ready.
Rectifier is ready.
User is ready.
User sends request to Rectifier Agent.
Agent Rectifier received RECTIFY request from User
Agent Rectifier sends EXTRACT request to Extractor Agent.
Agent Extractor - Received EXTRACT Request from Rectifier
Extraction is in progress...
Agent Rectifier Received notification of DONE-EXTRACT from Extractor
Agent Rectifier sends DISTRIBUTE request to Distributor Agent.
Agent Distributor - Received DISTRIBUTE Request from Rectifier
Distribution is in progress...
Agent Rectifier Received notification of DONE-EXTRACT from Distributor
Thank you, Rectifier Agent.
```

Figure 5.51: Messages sent and receives by the various agents

The system emphasises the interaction between agents and the emergent effects from relatively simple individual behaviours of agents. One of the key promises of multi-agent systems is its capability to decompose a complex problem into manageable pieces. Agents communicate and interact with each other through an understanding of common ontology and communication languages.

5.8 Summary

Control points are important features and the selection of control points is an essential process for aerial image rectification. The preliminary study shows that the distribution of control points affects the rectification result. The selections of control points done by expert and proposed multi-agent system are evaluated by calculating the total RMSE of a set of twelve control points. The results are then compared among the different selection sizes.

The selections by expert and proposed multi-agent system have the lowest total RMSE when using second order polynomial transformation. The achievements of the total RMSE of checkpoints are approaching similar results when increasing in selection size. The proposed multi-agent selection achieved the highest percentage of reduction in the total RMSE of checkpoints with selection size of six. 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 has the smallest range of the total RMSE of checkpoints when using second order polynomial and third order polynomial transformation. Besides that, the achievement of the proposed multi-agent system is also compared with the conventional residual method. The selection by the proposed multi-agent system achieved a reduction of the total RMSE of checkpoints with 12.41% when compared to the achievement using the conventional residual method. This chapter also shows the interaction between agents designed during the implementation which is monitored by Sniffer agent. Multi-agent approach allows agents to interact with each other in the environment in a cooperative manner to achieve individual and group objectives.

The next chapter will present the findings and contributions of this research and outlines the directions for future works.

CHAPTER 6

CONCLUSION AND FUTURE WORKS

6.1 Introduction

This research focuses on enhancing current non-parametric aerial images rectification by introducing Harris corner score and Voronoi distribution impact index as control points' selection criteria. This research also integrates a cooperative multi-agent approach in designing non-parametric aerial image rectification. The rectification of the selection performed by the proposed multi-agent system is compared with the rectification of the selection performed by an expert using different sizes of selection number and with different transformations. The performance of the rectification is measured using the total root mean square error (RMSE) of a set of checkpoints. The achievement of proposed multi-agent system is also compared with the conventional residual method. This chapter summarises the findings and contributions, future works and overall conclusions of the research.

6.2 Research findings and contributions

Rectification is the essential pre-processing step to eliminate or reduce the effect of distortion before the image information could be extracted for further purpose. The research has undergone a comprehensive study of the state-of-art of non-parametric aerial images rectification to identify the strengths and weaknesses of the existing methods.

Selecting control points with consideration of distribution are the key factors that contribute to the accuracy of rectification. This research has found that the Voronoi area and corner score ranking is suitable as the criteria for selecting the GCPs for rectification.

The proposed multi-agent system models problems in terms of autonomous interacting component-agents. Each agent operates independently on each sub-problem. The cooperation of agents enables the cohabitation of different selection strategies. It operates with multiple simultaneous solutions held by agents who iteratively suggest their particular solutions. Finally, the proposed solution is determined by assembling of agents' individual results. While using a sequential approach with normal computer programs, it is difficult to simulate such independence with interactions to automate the procedure. Hence, the multi-agent system is more extensible, fault-tolerant and scalable than a conventional system. This is useful as it simplifies the tediousness procedure and therefore saves the time consumed by human task of removing or adding the GCPs which could take times from a few hours to 4-5 days for registering and rectifying a single image as (Krishnan & Varghese, 2015). Obviously, if involving a huge volume of data images, human selections are definitely more laborious and time consuming.

The research tests on the potential of integrating multi-agent system in aerial image rectification. Experiments show that the proposed multi-agent system provides reliable results and the performance is compared with human selections and a conventional method. It proves that multi-agent approach is a way of representing task allocation, team planning, user preferences and open environments which could support in providing a systematic way of structuring an aerial image rectification. It shows that multi-agent approach offers a new and an appropriate method to the design, development and implementation of aerial image rectification. Besides the contribution to the image rectification in the domain of remote sensing, the research has introduced a new case study specifically on the aerial image rectification to the multi-agent research community. It also helps to build the confidence among system designers, developers and industrial players to

integrate multi-agent approach which able to provide with a way of organising applications around autonomous and communicative components to manage complex systems compared with normal computer programs.

The proposed multi-agent system works on rectifying 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 $270,000 \text{ m}^2$. 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 proposed multi-agent system achieved its lowest total RMSE of checkpoints when the system is used to select 18 GCPs for the second order polynomial rectification transformation. The total RMSE of checkpoints achieved is 0.91 meters. The GCPs selected using the proposed multi-agent system produce a lower total RMSE of checkpoints compared to the GCPs selected manually when the selection size is small. For instance, when the selection size is six and with second order polynomial transformation, the proposed multi-agent system reduces the total RMSE of checkpoints up to 58.31% when compared with the achievement by the expert selection. However, when the selection size increased to 27, the difference between the total RMSE of checkpoints when using the selected GCPs by the proposed multi-agent system and expert are small. The highest difference of the achievement by the proposed multi-agent system selection compared to expert selection is less than 1% with selection size of 27. The research also shows that the total RMSE of checkpoints achieved by the proposed system is more consistent which has the smallest range in the total RMSE of checkpoints when using second and third order polynomial transformations.

The objectives of this research are achieved. The research has examined the selection of control points based on the distribution of points and studied how the selection number and distribution of control points affect the accuracy of the transformation result. This research designed a novel control point selection for aerial image rectification with the integration of cooperative multi-agent system to facilitate the selection task in image rectification.

6.3 Future works

GCP acquisition is now conveniently extracted by many automatic techniques which can provide a large number of GCPs. The automatically extracted GCPs will need to be filtered and selected for aiming the most accurate rectification model. Hence, the proposed approach could combine with an automatic GCP extraction method.

During the research, it was observed that many of the auto extracted points are rising above the ground, such as buildings corner that may appear to lean in the image when using corner detection to extract the potential GCPs from the image. However, this point collected from the top of the building may be displaced from the actual ground coordinate. Other than that, some of the points are extracted from shadows and cars that may be easily found in the image, but not permanent and can move from one image to another. Therefore, some future work on filtering these points is critical to ensure the potential GCPs extracted from the image can reflect the actual ground coordinate.

In this research, the GCPs are selected based on the ranking of the features of the points. The GCPs that have the ranking of the features that pass the threshold are selected for the transformation of the aerial image. The goal of the selection of the points is to identify the good GCPs that can produce an output image that has low RMSE on both GCPs and the checkpoints. In other word, the GCPs can be classified into two categories, i.e. the good

GCPs and the poor GCPs. In future, it is recommended to explore into the field of computer classification techniques such as Support Vector Machine, a supervised learning models that can be trained to analyse the large amount of data to identify patterns from them. The common concern on using SVM for classification is on getting a large amount of data and lengthy training time. Other classification techniques such as decision tree and fuzzy classifier are worth to explore too.

The proposed approach has only been evaluated on small datasets. The results obtained are based on the images used in the experiments. The areas of interest are mostly flat areas, there are no hilly or mountainous aerial images involved in the testing. In future, experiments could be extended by using aerial images taken at hilly or mountainous areas to study how well the proposed method works on rectifying the two dimensional (2D) aerial images taken at slope when topography data is added into the model. A shortcoming in the experimental results of this study is that the model is only applied to aerial image. It is likely worth to apply and verify the proposed approach with other type of images such as scanned paper maps.

Recently, the combination of the rapid development of low-cost multi-rotor unmanned aerial vehicle (UAV) and conventional optical sensors in terms of cost and dimensions, has led to new opportunities in environmental remote sensing and 3D surface modelling. Future works can be carried out to study on how to rectify the acquire images during the aerial surveys to obtain a continuous 3D surface model of the studied area using a photogrammetric approach.

The definition and implementation of new specialised agents such as matchAgent could be considered to improve current multi-agent framework. The inclusion of learning and

reasoning algorithm, for example, Q-learning and case-based reasoning in the multi-agent approach might enhance the multi-agent based rectification model. The use of different tools might change the current and general purpose of agent-oriented software engineering (AOSE) methodologies as assistants for actual programming and/or modelling. The tools could be integrated with Integrated Development Environments or standalone tools that are made specifically for a certain AOSE methodology. The proposed methodological framework could incorporate new ideas from these and use them if possible.

6.4 Conclusion

Control points selection is an important step to provide an optimised set from the existing collection of control points for rectification purpose. The research shows the assessment of the aerial image rectification by considering the selection of control points based on their distribution and local feature. The distribution of control points is organised by using Voronoi diagram and their local feature relevance is using corner score from the Harris corner detection algorithm. Different selection sizes have been carried out in the implementation. The cooperative multi-agent approach has been built to facilitate the selection based on the corner score and distribution of the control points. It handles the human task in selecting the control points during the rectification process.

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