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MODELLING OF GEOMETRIC CORRECTION AND RELATIVE RADIOMETRIC NORMALIZATION FOR NEAR EQUATORIAL EARTH OBSERVATION SATELLITE IMAGES

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By

HAYDER ABD AL-RAZZAQ ABD

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The near-equatorial earth observation satellite is a new-generation optical satellite that is expected to cater to the needs of many countries located in or near the equator. It does not move in a fixed row and path during capturing time. Therefore, in each visit, the images exhibit differences depending on the viewing angle, time, illumination, sun zenith and azimuth angles, sensor zenith and azimuth angles, altitude, and attitude (roll, yaw, and pitch) of the satellite. These factors result in near-equatorial imagery having: (a) mis-registration bands, (b) no geometric matching between features located in the sequences of two images even though they are captured from the same strip, and (c) no reflectance (radiometric) matching between features located in two images captured in the same area at different times. Conventional modeling does not able to process the near equatorial satellite images. The research aims is study the near equatorial satellite images and develop models that can overcome the difficulties that facing processing of near equatorial satellite imagery as follow:

(1) To develop band to band registration model for near equatorial image, to overcome the highly nonlinear band shifting of the near equatorial image bands.

(2) To develop geometric correction model for near equatorial images, to reduce the highly geometric correction between the near equatorial imagery.

(3) To design and implement remote sensing goniometer to simulate NEqO system images, to simulate the near equatorial satellite image.

(4) To develop relative radiometric normalization model for NEqO images, to normalize the near equatorial images that have been captured at different time.

A new technique to overcome band-to-band registration through the automatic generation of control points from satellite images via scale-invariant feature transform (SIFT) is proposed in this study. The SIFT generated control points are utilized to perform registration with first- and second-order polynomials and spline

transformations to correct the misregistration between near-equatorial orbit (NEqO) image bands. The image employed in this study is provided by Malaysian National Space Agency (ANGKASA) it was captured by the RazakSAT satellite. An accuracy assessment is performed by comparing the result of the proposed method with the result of both automatic and manual transformations using polynomial transformation. The root mean square errors of the first- and second-order polynomial transformations are 4 and 3 m, respectively. Moreover, the spline transformation produces RMSE 1.1×10^{-6} m.

A new technique is developed to improve the automatic extraction of control points. The technique is then utilized to perform geometric correction of near-equatorial images. The method, which is called refine and, improves scale-invariant feature transform (RI-SIFT). RazakSAT and SPOT-5 images are used. The proposed approach begins by selecting the reference and sensed images. Then, grayscale and image compression are performed. Automatic control point extraction is then performed to generate control points automatically. The generated control points are refined by using the sum of absolute difference algorithm (SAD), with the help of an empirical threshold and control point locations to avoid obtaining inaccurate control points. The refined control points are applied in spline transformation to overcome the geometric errors of near-equatorial orbit (NEqO) images. Validation is then performed by comparing the result of the proposed approach with that of direct geometric correction through the use of polynomial transformation. Results show that the accuracy values obtained from using the refine transformation (RI-SIFT with spline) and polynomial transformation are $7.08 \times 10-^{9}$ m and 104 m, respectively. The proposed model exhibits accuracy and precision.

A relative radiometric normalization model is implemented in three stages. First, a goniometer is designed and built to simulate near-equatorial images and perform relative radiometric normalization. Second, the goniometer is used to collect images with different illumination to conduct radiometric normalization. In the third stage, the refine and improve scale-invariant feature transform method is developed to extract automatically radiometric control points over the image bands. The method aims to acquire the intensity values of the control points to use as pseudo invariant features (PIFs) between the reference and sensed image bands. The next step is to perform statistical linear regression on the control points of the reference and sensed image bands to generate regression transformation functions for use in normalizing the sensed image bands to reference image bands. The proposed model is validated by determining the correlation between the normalized and reference image bands. The correlation range is 0.69–0.85 over the bands of the slave image.

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

PEMODELAN PEMBETULAN GEOMETRIK DAN PEMULIHAN RADIOMETRIK RELATIF UNTUK GAMBAR SATELIT PEMERHATIAN BERDEKATAN KHATULISTIWA BUMI

Oleh

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Pemantauan satelit berdekatan khatulistiwa bumi merupakan satelit optikal generasi baru yang dijangka akan memenuhi keperluan negara-negara yang terletak berdekatan atau di kawasan khatulistiwa. Satelit ini tidak bergerak dalam baris dan laluan yang tetap semasa waktu cerapan. Oleh itu, dalam setiap lawatan, imej-imej yang dipamerkan adalah berbeza bergantung kepada sudut penglihatan, masa, pencahayaan, nadir matahari dan sudut azimuth, nadir sensor dan sudut azimuth, ketinggian dan ciri-ciri (*roll, yaw* dan *pitch*) satelit tersebut. Faktor-faktor ini menyebabkan imej berhampiran khatulistiwa mempunyai: (a) pendaftaran jalur yang salah, (b) tiada geometri yang sepadan antara ciri-ciri yang terletak diantara urutan kedua-dua imej walaupun ianya diambil pada jalur yang sama, dan (c) tiada pantulan (radiometrik) yang sepadan antara ciri-ciri yang terletak di kawasan yang sama pada waktu yang berbeza. Model konvensional tidak mampu untuk memproses imej satelit berdekatan khatulistiwa ini. Kajian ini bertujuan untuk mengkaji imej satelit berdekatan khatulistiwa dan membangunkan model yang dapat mengatasi kesukaran yang dihadapai semasa memproses imej satelit berhampiran khatulistiwa seperti yang berikut:

(1) Untuk membangunkan model pendaftaran jalur ke jalur untuk imej berhampiran khatulistiwa, untuk mengatasi peralihan jalur yang sangat tidak linear pada jalur imej berhampiran khatulistiwa.
(2) Untuk membangunkan model pembetulan geometri untuk imej berhampiran khatulistiwa, untuk mengurangkan pembetulan geometri antara imej berhampiran khatulistiwa.
(3) Untuk merekabentuk dan melaksanakan goniometer penderia jarak jauh untuk mensimulasi sistem imej NEqO , untuk mensimulasi imej satelit berhampiran khatulistiwa.
(4) Untuk membangunkan model radiometrik relatif normal untuk imej NEqO, untuk menormalkn kembali imej berhampiran khatulistiwa yang diambil pada masa yang berbeza.

Kajian ini mencadangkan satu teknik baru bagi mengatasi pendaftaran jalur ke jalur menerusi penjanaan automatiokautomatik titik kawalan dari imej satelit melalui ciri perubahan skala-tak berubah (SIFT). Titik kawalan yang dijana SIFT digunakan untuk melaksanakan pendaftaran dengan polynomial tertib pertama dan kedua dan perubahan Spline untuk membetulkan kesalahan pendaftaran antara jalur imej berdekatan orbit khatulistiwa. Imej yang digunakan dalam kajian ini adalah imej satelit RazakSAT yang diperoleh daripada Agensi Angkasa Negara Malaysia (ANGKASA). Penilaian ketepatan dilakukan dengan membandingkan hasil daripada kaedah yang dicadangkan dengan keputusan yang diperoleh daripada perubahan manual dan automatic menggunakan transformasi polynomial. Punca min ralat kuasa dua pertama dan kedua untuk transformasi polynomial masing-masing adalah 4 dan 3 m. Selain itu, transformasi spline menghasilkan RMSE 1.1×10^{-6} m.

Teknik baru telah dibangunkan untuk meningkatkan pengeluatan titik kawalan secara automatik. Teknik ini kemudiannya digunakan untuk melakukan pembetulan geometri bagi imej berhampiran khatulistiwa. Kaedah ini yang dipanggil penghalusan dan peningkatan ciri perubahan skala-tak berubah (RI-SIFT). Imej Razaksat dan SPOT-5 telah digunakan. Pendekatan yang dicadangkan bermula dengan memilih rujukan dan imej yang dideria. Kemudian, skala kelabu dan pemampatan imej dilaksanakan. Pengekstrakan titik kawalan secara automatik kemudiannya dilakukan untuk menjana titik kawalan automatik. Titik kawalan yang dihasilkan ditapis dengan menggunakan sejumlah algoritma perbezaan mutlak (SAD), dengan bantuan ambang empirikal dan titik kawalan lokasi untuk mengelakkan daripada mendapat titik kawalan yang tidak tepat. Titik kawalan yang diperhalusi digunakan dalam transformasi *Spline* untuk mengatasi kesilapan geometri imej berhampiran orbit khatulistiwa. Pengesahan kemudiannya dilakukan dengan membandingkan hasil daripada pendekatan yang dicadangkan dengan pembetulan geometri secara langsung melalui penggunaan transformasi polynomial. Keputusan menunjukkan bahawa nilai-nilai ketepatan diperolehi daripada menggunakan transformasi yang telah diperhalusi itu (RI-SIFT) dan transformasi polynomial adalah 7.08×10^{-9} m dan 104 m masing-masing. Model yang dicadangkan menunjukkan ketepatan dan kejituan.

Model normalisasi relatif radiometrik ini dilaksanakan dalam tiga peringkat. Pertama, goniometer yang direka dan dibina untuk mensimulasi imej hampir khatulistiwa dan melaksanakan relatif radiometrik pemulihan.Kedua, goniometer yang digunakan untuk mengumpul imej dengan pencahayaan yang berbeza untuk menjalankan pemulihan radiometrik. Pada peringkat ketiga, penghalusan dan peningkatan ciri skala-tak berubah dibangunkan untuk mengekstrak titik kawalan radiometrik secara automatik antara jalur imej. Kaedah ini bertujuan untuk memperoleh nilai-nilai keamatan titik kawalan untuk digunakan sebagai pseudo ciri tak berubah (PIFs) antara rujukan dan jalur imej yang dikesan. Langkah seterusnya adalah untuk melaksanakan regresi linear statistik mengenai titik kawalan rujukan dan mengesan jalur gambar untuk menjana fungsi transformasi regresi untuk digunakan dalam menormalkan jalur imej yang dikesan untuk rujukan jalur imej. Model yang dicadangkan disahkan dengan menentukan korelasi antara jalur imej normal dan rujukan. Rangkaian korelasi adalah 0.69-0,85 pada imej slave.

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

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LIST OF ABBREVIATIONS

ACE	Adaptive coherence estimator
ASD	Adaptive subspaced
BRDF	Bidirectional reflectance distribution function
CCD	Charge Coupled Devices
CLabSpeG	Compact Laboratory Spectro-Goniometer
CPs	Control points
CPU	Central processing unit
DN	Digital numbers
DTL	Direct linear transformation
ER	Equatorial Region
FIGOS	Field Goniometer System
FFT	Fast Fourier Transform
GCPs	Ground control points
GIS	Geographic information system
GPS	Global positioning system
GIS	Geographic information system
GUI	Graphical user interface
HPF	High pass filter
IGF	Israeli Goniometric Facility
IFOV	Instantaneous field of view
JPEG	Joint photographic experts group
LWIR	Long wavelength near-infrared
MAC	Medium-sized electro-optical push broom camera

MSE	Mean squared error
NC	No-change pixels
NEqO	Near equatorial satellite
NIR	Near infrared wavelength
OPENMP	Open Multi-Processing
PHD	Phase de-correlation
PIFs	Pseudo invariant features
QTH	Quartz tungsten halogen
RRN	Relative radiometric normalization
RFM	Rational function model
RSM	Rigorous sensor model
RI-SIFT	The Refining and improving of SIFT CPs
RMSE	Root mean square error
SIFT	Scale invariant feature transform
SAD	Sum of absolute difference
SAR	Synthetic aperture radar
SMWIR	Short and middle wavelength
SAM	Spectral angle mapper
SFG	Field Goniometer
ULGS	University of Lethbridge Goniometer System
VIS	Visible wavelength

CHAPTER 1

INTRODUCTION

1.1 Background

Accurate geometric and radiometric corrections are very important to extract and provide accurate information and minimize errors in different types of remote sensing applications. Geometric transformation is an image processing procedure to redefine the spatial relationship among all image points. This procedure involves the PDQLSXODWLRQ RI WKH LPDJH¶V VSDWLDO OD\RXW H J correction for images has elicited much attention from researchers because of the practical limitations in remote sensing and geographic information systems (GISs), computer vision, medical imaging, and computer graphics. The typical application of geometric correction includes imaging sensor distortion (error) compensation, image registration de-calibration, texture mapping of image synthesis, and map projection. The first geometric transformation was performed on analog imagery using an optical system. One of those who worked early in this scientific area was Cutrona et al. (1960). Since then, many researches advances have been made in this area (Escobal, 1965; CNES, 1980; Light et al., 1980; Toutin, 1995a; Jensen 1996, Mather, 1999; Toutin, 2003). In fact, the digital computer system has resolved geometric errors and offers a high level of accuracy.

Geometric correction methods can be classified as systematic, non-systematic, or a combination of both (Rees, 2001; Montenbruck and Gill, 2001; Wu et al., 2003). Systematic geometric correction is applied when the reference data or the sensor geometry is measured. The non-systematic type is employed when calculation is required for the transformation from a geographic coordinate system to an image coordinate system and/or vice versa. The combination method begins by applying systematic correction and then reducing the residual errors by employing a non-systematic method (Haydan et al., 1982; Moigne et al., 2002; Robertson, 2003; Dial and Grodecki, 2004; Richard and Jia, 2006). Most of all satellite systems that provide high resolution imagery have fixed path and row during its orbital journey such as polar, geostationary and multi-sensor, so their geometric distortion will be linear distortion, and there are considerable algorithms can overcome the linear geometric distortion such polynomial , affine, and spline (Jensen, 1996). However, for this research the used satellite system does not have fixed bath and row and it will produce imagery with highly non-linear distortion, and there very few researches have been studied this issue (Ahmad, 2013).

The acquisition of spectral data from remote sensing sensors is affected by numerous parameters, such as atmospheric scattering and absorption, geometry of illumination-target-sensor, sensor calibrations, and imagery processing procedures; these parameters tend to change constantly over time (Teillet, 1986; Scott et al. 1988; Hall, 1991; Yuan and Elvidge 1996). In temporal imagery, features are impossible to compare because they are extremely variable (Kim and Elman, 1990). To detect any change in object reflec WDQFH RQ WKH (DUWK¶V VXUIDFH IURP WHPSRUDO correction must be performed Yuan and Elvidge (1996). Radiometric correction involves two approaches, namely, absolute and relative radiometric approaches (Lo and Yang, 1998). In the absolute radiometric approach, ground data must be measured during data acquisition for sensor calibration and atmospheric correction. This procedure is costly and impractical when archival satellite imagery is employed for change analysis (Hall et al., 1991). The relative radiometric correction approach is the process of relative radiometric normalization (RRN). It is the preferred approach when in situ measurement is not needed. RRN includes normalizing the brightness value (intensity) or digital numbers (DN) of temporal imagery band by band in the image selected as a reference image by analysts. The normalized imagery should appear as similar as possible to the reference image (particularly if they are acquired by the same sensor) and should exhibit similar illumination and atmospheric conditions as those in the reference image. The satellite that have fixed path and row do not show a highly differences in pixels reflectance such as the NEqO imagery due to the NEqO satellite visit the same area many times per a day with different illumination (RazakSAT, 2011).

1.2 Near equatorial satellite

NEqO satellites operate at an altitude of hundreds of kilometers up to approximately 1,000 km. NEqO satellites have orbital periods of roughly 90 min (Ng et al., 2009, Lawal and Radic, 2013). The desire to acquire near real-time and high-resolution images to monitor a region, such as the equatorial region (ER), has always been appealing to scientific and commercial industries. A few NEqO satellites, such as RADAR synthetic aperture radar constellation, LAPAN-A2, LAPAN-A1, and a new generation of optical satellite systems (e.g., RazakSAT), have been launched into space in the last decade (RazakSAT, 2011; Mazlan et al., 2013). Typical synthetic aperture radar (SAR) satellites are evidence that developing nations can immensely benefit from the availability of data provided by a multi-static SAR system potentially serving as a ³VSULQJ ERDUG´ IRU (5 GHYHORSPHQW 6RHZDUWR HW D -A2 microsatellite is the successor of the LAPAN-TUBSAT (LAPAN-A1) microsatellite family and is the first indigenous satellite designed and developed by Lembaga Penerbangan dan Antariksa Nasional (LAPAN) or the National Institute of Aeronautics and Space in Jakarta. It is funded by the government of Indonesia. LAPAN was launched in November 1964. This space agency is responsible for carrying out civil and military aerospace and space research. One of the important tasks of LAPAN is to interconnect the more than 6000 islands of Indonesia. For this reason, LAPAN has launched several satellites to provide telecommunication coverage for the islands of Indonesia. LAPAN communication satellites include the Palapa satellites, which were launched on August 7, 1976, and Palapa-A2, which was launched on October 3, 1977. LAPAN-TUBSAT (A1) was launched on January 10, 2007, and became operational in 2012. The LAPAN-A2 spacecraft was then designed and developed indigenously, followed by the design of the LAPAN-A3 satellite, which are all based on LAPAN-A1.

The primary mission of LAPAN-A2 is to support disaster management by earth observation and for land use, environment monitoring, natural resource, and moon observation. Satellite design, integration, and testing have been performed in

Indonesia. The NEqO satellites have used to conduct frequent daily satellite orbit overpass over Indonesia. Near-equatorial earth orbit, at an inclination of between 6° to 10° and altitude of 650 km (RazakSAT, 2011, Mazlan et al., 2013). LAPAN-ORARI Satellite supports disaster management by amateur radio communication as well as earth observation for natural resource, land use, and environment monitoring.

RazakSAT satellite is an optical NEqO satellite system; it had a nominal altitude of 685 km and 9° inclination after its launch. It is a Malaysian satellite with a high-resolution camera. This NEqO satellite provides Malaysia and ER the highest imaging opportunity among all satellites. NEqO, unlike other sun-synchronous orbit satellites, does not have a fixed path and row during imaging, and the requirement of correcting RazakSAT images with varying illumination is vital for constant reflectance (Mazlan et al., 2013). RazakSAT was launched into orbit by a Falcon 1 rocket on July 14, 2009. It was placed into a near equatorial orbit that presents many imaging opportunities for the equatorial region. It weighs over three times as much as TiungSAT-1 and carries a high-resolution Earth observation camera (RazakSAT, 2011). It was intended to provide greatly increased coverage of Malaysia compared with other earth observation satellites. Its capability of highly frequent passing (14 times per day) over Malaysia makes earth observation easier than ever (RazakSAT, 2011).

The medium-sized electro-optical push broom camera (MAC) is a system that utilizes linear charge coupled devices (CCD) to produce images. The MAC system produces high-resolution images in one panchromatic and four multi-spectral bands with ground sampling distance of 2.5 and 5.0 m, respectively. Normally the ratio of PAN and multi-spectral bands is (1:4) in term of spatial resolution of high spatial resolution satellite imagery. Howevere, for RazakSAT imagery the ratio is (1:2) (RazakSAT, 2011; Ahmad, 2013). Its MAC has a swath width of 20 km. The MAC system is designed for a three-axis stabilized platform, with tilting capability in the across- and along-track directions to support stereoscopic and target-specific imaging (Mazlan et al., 2013; Ng et al., 2009).

1.3 Problem Statement

A NEqO satellite is a new generation of optical satellite, it does not have fixed path and row in his journey around the equator such as the polar and geostationary satellite systems. So, will visit each equatorial region 14 times a day (Ahmad, 2013). Each visit exhibit differences depending on viewing point, solar zenith and azimuth angles, satellite zenith and azimuth angles, capture time, illumination, and attitude (roll, yaw, and pitch) of the satellite during imaging, for these reasons NEqO images are unusable and cannot be processed many errors encountered in NEqO Images. All these problems together make the NEqO satellite imagery unusable because it can not perform any analysis and processing with these imagery. Conventional modeling is insufficient and lacks the capability to process images. All these factors will constantly change over the time and make the NEqO imagery unusable and there is no ability to process this imagery with conventional models (RazakSAT, 2011; Ahmad, 2013).

1- The detectors of the optical system of NEqO satellite systems are not aligned. Hence, band shifting occurs despite of the existence of band-to-band registration algorithms. No algorithm, approach and technique has addressed the band shifting of a NEqO satellite image.
2- No geometric matching exists between similar features from two images even if they are obtained from the same strip.
3- The NEqO satellite system lacks a simulation device to simulate NEqO images. There are many remote sensing goniometer to simulate different type of satellite system (RazakSAT, 2011). However, there is not device able to simulate the NEqO satellite system images.
4- The difference in reflectance (intensity values) of similar features located in two or more images obtained at different times and illumination causes no radiometric matching between the images even if are related to the same area.

1.4 Research Objectives

The primary aim of this research is to study of NEqO satellite images and the development of algorithms that can overcome the difficulties in processing NEqO satellite images.

The specific objectives of this study are indicated below.

1- To develop an approach to operational band ±to-band registration model for improving registration NEqO satellite image bands.
2- To develop an algorithm to perform geometric correction model to overcome the highly nonlinear distortion of NEqO imagery.
3- To design and build a simulation device (goniometer) to simulate NEqO satellite images. Then to use the goniometer to collect images have different illumination to investigate and study the RRN.
4- To develop an algorithm to overcome relative radiometric normalization model of NEqO satellite images resulting of different in capturing time and illumination.

1.5 Scope of the Study

This study investigates, analyzes, and processes NEqO satellite images. It aims to provide insights into the development of methodologies to overcome band ±to-band registration, geometric correction, and relative radiometric normalization of such images. The near-equatorial satellite is a new-generation optical satellite system. The methodologies tested in this study are implemented in the study area, Pekan that located in south of Pahang state, Malaysia. A satellite images obtained from the Malaysian RazakSAT satellite and simulated imagery are investigated. The devices utilized in fieldwork are differential digital global positioning system (DGPS) hemisphere MD A30 device and an invented goniometer (simulation device). The algorithms used include scale-invariant feature transform (SIFT) and sum of absolute difference (SAD) algorithms, nearest neighbor (Euclidean distance) for the matching process, spline transformation, and polynomial transformation. Assessment is conducted by using the root mean square error and by comparing the result of the proposed methods with that of ground reference data locations collected from fieldwork. Result validation is limited to three techniques: automatic registration, manual registration, and the root mean square error (RMSE). Correlation calculation is also performed. The developed algorithms (RI-SIFT and PIFs-SIFT) are successfully applied to the data, and the verification result is promising.

1.6 Thesis Organization

The thesis is organized into six chapters. Chapter One presents a general overview of geometric correction and relative radiometric normalization. The focus is on the problems, objectives, and scope of the study.

Chapter Two presents a detailed literature review of the NEqO satellite, band-to-band registration, geometric correction, relative radiometric normalization models, and feature extraction while focusing on the techniques and algorithms (e.g., SIFT, SAD, spline transformation, and polynomial transformation) applied in previous studies. The accuracy of these techniques is also assessed.

Chapter Three presents the methodology of and the algorithms developed for this thesis. It presents and discusses the data utilized to perform a study of NEqO satellite images. The chapter includes the following. A band-to-band registration technique is proposed to overcome band shifting between NEqO satellite image bands. Then, an automatic algorithm is developed to refine the extracted control points (reference points extract from imagery to use in registration transformation) automatically for use in conducting geometric correction for NEqO images. Afterward, a goniometer is designed and built to simulate NEqO satellite images and NEqO satellite system movement and orientation with respect to the sun. The goniometer is also used to collect data to address the next objective. Relative radiometric normalization is conducted as follows:

1- Laboratory data are collected.
2- An automatic algorithm is developed to extract the intensities of pseudo invariant features that remain constant despite any change in rotation, skewing, shifting, and viewpoints. Illumination is employed as radiometric reference data, and regression is conducted to determine the regression functions to perform relative radiometric normalization.

The proposed and developed models and algorithms are assessed and validated for accuracy assessment. Chapter Four presents the design and implementation of the developed goniometer for NEqO satellite images in detail. Chapter Five presents the results and a discussion of band registration, geometric correction, and relative radiometric normalization models. Chapter Six provides a summary and presents the research findings, limitations, and suggestions for future work.

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