UNIVERSITI PUTRA MALAYSIA

FOUR TIER FRAMEWORK FOR ONLINE APPLICATIONS OF 3D GIS VISUALIZATION

RUZINOOR CHE MAT

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By

RUZINOOR BIN CHE MAT

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

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DEDICATION

I dedicate this thesis to my wife Norani Nordin, my kids Naufal, Nazihah, Nabil and to my mum Romlah Hamzah.

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

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October 2012

Chairman: Associate Professor Abdul Rashid Mohammed Shariff, PhD

Faculty: Institute of Advanced Technology

The aim of this study is to discuss on the issues related to the use of a new proposed four-tier architecture for online applications of 3D GIS visualization. Conventional design of the system is generated from client/server based architecture. This architecture is the main platform for designing online system architecture, which works based on the distributing concept, which is a tier. The tier is normally set by the developers to separate the works/tasks between the system architecture. Currently, three tiers architecture is the most well-known architecture used in GIS applications and also other application. However, this architecture has some drawback on scalability, maintainability, and also its need more processing power in the middle tier to process the request from multiple of users. Based on the literature study, GIS applications, especially systems, which involve 3D visualization generate a massive amount of data. Due to this situation, the current three-tier architecture used for online application of 3D GIS visualization decrease the performance of the system in terms of time for processing the request from the users.

This research explores the use of the four-tier framework to overcome current impediments in the use of the three-tier framework for online applications of 3D GIS visualization. The new framework is designed based on client/server architecture with the tasks distributed using the tier's concept. It is formalized into four tiers framework by advancing one more tier into the existing three tiers framework for handling the visualization process. The four tiers framework is divided into the client, logic, visualization process, and database tiers respectively. The unique part of this new architecture is the middle tier which is divided into two other tier's, which handle the visualization process and logical process separately and make the framework more flexible and increase its performance. The framework has been successfully implemented in oil palm plantations application using a prototype developed to prove that the framework functions well based on the requirements. Several experiment related to terrain visualization application conducted to give an operational guidelines for developer. The results of experiments helps developer on utilising the best data and technique for developing the required system. The prototype shows that it can aid the oil palm plantation management to visualize their plantation easily in 3D. The oil palm trees can be visualized with 3D terrain in an online environment with GIS capabilities. The characteristic of the oil palm tree data is stored in the database tier, and the data can be modified based on users need. The 3D terrain is generated from the topographic data (LiDAR Data) and overlaid with the high- resolution satellite image (QUICK BIRD). The validation of the framework was performed by comparing the results from the existing three-tier framework with the new four tier framework. The new framework shows superiority in its performance based on loading time, response time, frames per second, CPU usage and memory usage. These results show that the approach in this research helps solve the processing power problem. The framework can be applied by

users to visualize a multitude of applications with GIS capabilities in an online 3D environment.

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

KERANGKA EMPAT TAHAP UNTUK APLIKASI DALAM TALIAN BAGI VISUALISASI 3D GIS

Oleh

RUZINOOR CHE MAT

Oktober 2012

Pengerusi: Profesor Madya Abdul Rashid Mohammed Shariff, PhD

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Applikasi talian visualasi 3D untuk data GIS bukan sahaja menjadi tarikan bagi banyak bidang seperti kartografi, geografi, geologi dan psikologi tetapi ia juga popular dikalangan orang awam. Rekabentuk konvensional bagi sistem ini dihasilkan berasaskan kepada arkitektur pelayan/pelanggan. Arkitektur ini merupakan tapak utama bagi merekabentuk arkitektur sistem talian yang berfungsi berdasarkan kepada konsep sebaran iaitu *'tahap'*. Biasanya konsep *'tahap'* digunakan oleh pemaju perisian bagi mengasingkan tugas-tugas antara sistem arkitektur. Ketika ini, arkitektur 3 *'tahap'* adalah yang paling terkenal digunakan di dalam aplikasi GIS dan juga lain-lain aplikasi. Namun aplikasi ini mempunyai kekurangan dalam penskalaan, penyelengaraan, dan juga memerlukan pemprosesan yang lebih pada *'tahap pertengahan'* bagi memproses permintaan dari pelbagai pengguna. Berdasarkan kajian literatur, aplikasi GIS terutama sistem yang melibatkan visualisasi 3D menghasilkan jumlah data yang besar. Oleh kerana situasi ini, penggunaan arkitektur tiga *'tahap'* yang biasa digunakan untuk aplikasi dalam talian untuk visualisasi 3D bagi data GIS akan menurunkan prestasi sistem ini dari segi masa untuk memproses permintaan dari pengguna. Penyelidikan ini

cuba mengenengahkan penggunaan kerangka empat *'tahap'* untuk mengatasi kelemahan yang ada dalam sistem arkitektur tiga *'tahap'* bagi penggunaan aplikasi dalam talian untuk visualisasi 3D GIS. Objektif kajian ini adalah (i) untuk memperkenalkan kerangka baru bagi aplikasi talian visualasi 3D GIS. (ii) untuk melaksanakan kerangka baru ini dalam aplikasi talian visualasi 3D GIS. (iii) untuk menganalisis dan mengesahkan kerangka baru ini dalam aplikasi talian visualasi 3D GIS. Kerangka baru ini direka bentuk berdasarkan arkitektur pelayan/pelanggan yang mengagihkan tugas kepada konsep *'tahap'*. Ia telah diformalisasikan kepada kerangka empat *'tahap'* dengan cara menambahkan satu lagi *'tahap'* ke dalam kerangka tiga *'tahap'* yang sedia ada bagi mengendalikan proses visualisasi. Kerangka kerja empat *'tahap'* dibahagikan kepada *'tahap'* pelanggan, *'tahap'* logik, *'tahap'* proses visualisasi, dan *'tahap'* pangkalan data. Bahagian yang unik dalam arkitektur baru ini adalah dimana 'tahap' pertengahan dibahagikan kepada dua lagi 'tahap' yang mengendalikan proses visualisasi dan proses logic secara berasingan yang membuatkan kerangka kerja ini lebih fleksibel dan meningkatkan prestasinya. Kerangka ini telah berjaya dilaksanakan dengan jayanya dalam perladangan kelapa sawit dan satu prototaip juga telah dibina untuk menunjukkan bahawa kerangka ini boleh digunakan dengan baik. Beberapa eksperimen berkaitan aplikasi visualisasi permukaan tanah telah dijalankan untuk memberi garis panduan operasi kepada pemaju sistem. Keputusan dari eksperimen ini membantu pemaju sistem dalam menggunakan data dan teknik terbaik untuk membangunkan sistem yang dikehendaki. Prototaip ini menunjukkan bahawa ia boleh membantu pengurusan ladang kelapa sawit untuk menggambarkan ladang mereka dengan mudah dalam 3 dimensi. Pokok kelapa sawit dan permukaan tanah juga boleh di visualisasi dalam bentuk 3D dalam persekitaran dalam talian dengan kemudahan GIS. Data mengenai ciri-ciri yang dimiliki oleh pokok kelapa sawit disimpan dalam *'tahap'* pangakalan data dan data ini

boleh diubahsuai mengikut keperluan peengguna. Permukaan tanah 3D dihasilkan daripada data topografi (data 'LiDAR') dan diselaputi dengan imej satelit resolusi tinggi (QUICK BIRD). Pengesahan kerangka kerja baru ini dilakukan dengan cara membandingkan hasil daripada kerangka tiga *'tahap'* yang sedia ada dengan kerangka empat *'tahap'*. Kerangka terbaru menunjukkan kelebihan yang banyak dari segi prestasinya berdasarkan 'masa muat turun', 'masa tindak balas', 'rangka sesaat', 'penggunaan CPU' dan penggunaan memori'. Prestasi ini menunjukkan bahawa ia boleh menyelesaikan masalah keperluan kuasa pemprosesan. Kerangka ini boleh diaplikasikan oleh pengguna untuk menggambarkan bermacam-macam jenis aplikasi dengan kemampuan GIS dalam talian persekitaran 3D.

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I certify that a Thesis Examination Committee has met on 12 December 2012 to conduct the final examination of Ruzinoor Che Mat on his thesis entitled "Four Tier Framework for Online Applications of 3D GIS Visualization" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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

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DECLARATION

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

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RUZINOOR CHE MAT

Date: 4 October 2012

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LIST OF ABBREVIATIONS

AJAX	Asynchronous JavaScript Technology and XML
CPU	Central Processing Unit
CVIS	Computerized Visitor Information System
DTM	Digital Terrain Model
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
fps	frames per second
Gb	Gigabytes
GIF	Graphics Interchange Format
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
IIS	Internet Information Server
JDBC	Java Database Connectivity
JNI	Java Native Interface
JNLP	Java Network Launching Protocol
JSP	JavaServer Page
JUPEM	Jabatan Ukur dan Pemetaan Malaysia
LKIM	Lembaga Kemajuan Ikan Malaysia
LiDAR	Light Detection and Ranging
LOD	Level of detail
MBNMS	Monterey Bay National Marine Sanctuary
MyGDI	Malaysian Geospatial Data Infrastructure
MySQL	My Structured Query Language

ms	Milliseconds
NPR	Non-photorealistic Rendering
NSDI	National Geospatial Data Infrastructure
ODBC	Open Database Connectivity
OGC	Open Geospatial Consortium
OpenGL	Open Graphic Library
PHP	PHP: Hypertext Preprocessor
RDBMS	Relational Database Management System
ROAM	Real-time Optimally Adapting Meshes
RS	Remote Sensing
sec	Seconds
SHP	Shapefile
SOA	Service Oriented Architecture
SQL	Structured Query Language
SRG	Spatial Research Group
TIFF	Tagged Image File Format
UPM	Universiti Putra Malaysia
UUM	Universiti Utara Malaysia
WebGL	Web-based Graphics Library
WFS	Web Feature Service
XML	Extensible Markup Language
X3D	Extensible 3D
2D	Two dimension
3D	Three dimension

CHAPTER 1

INTRODUCTION

1.1 Introduction

Visualization is the process of exploring, transforming, and viewing data as images (or other sensory forms) to gain understanding and insight into the data (Schroeder, *et al.*, 1998). Generally, visualization can be divided into 2D visualization, 3D visualization, and currently 4D visualizations are also being explored (Ding, *et al.*, 2012). The 2D visualization has the capability on rendering the objects in two dimensions (2D) while 3D visualization rendered the objects in three dimensions (3D). Nowadays, most of the systems still maintain 2D visualizations while lacking on 3D visualizations, especially in GIS communities (Zlanatova and Stoter, 2003). The trend currently is moving towards using the internet to visualize the information. This platform enables people to interact and share information more efficiently (Huang, *et al.*, 2001). It received most intention in the early 1990s because of the development of standard visual tools for information exchange, Web browsers (Mosaic, Netscape Navigator and Microsoft Explorer). Due to this aspect, the number of internet users and its technology also increased dramatically. In 2009, the numbers of internet users grew in the rural areas, accumulating to about 4 million users in Malaysia (Sulaiman, 2009). Concurrent with these, the new generation of geo-browsers such as Google Earth, Microsoft Virtual Earth and NASA's World Wind (Sipes, 2007) emerged since in 2005. Many people currently depend on these geo-browsers for their daily work and also for decision making purpose. This technology creates an opportunity to perform mix client/server visualization. Most

the system architecture for WWW is developed based upon client/server architecture (Nations, 2010). This architecture is the main platform for designing online system architecture, which works based on the distributing concept which is the tier.

The term tier refers to the physical distribution of components of a system on separate servers, computers, or networks (processing nodes). It can be defined as "one of two or more rows, levels, or ranks arranged one above another" (Encyclopedia Britannica Company, 2011). However, Chartier (2001) has defined tier as any number of levels arranged above another, each serving distinct and separate task. It means that each tier has its own function, which is connecting each other in separate level of the physical layer for processing the request from the client. Besides that, Microsoft Library (2011) defined the tier whereby the tier is composed of one or more computers that share one or more of this system characteristic such as resource consumption profile, operational requirement, and design constraints. Moreover, the concept of tier is actually generated from distributed architecture, which means that systems are collected from multiple hosts running the programs. This host can be a web server and a database server which can be virtually distributed on a single host whereby the tier may be a logical or physical layer of the system (Sun, 2005). The tier is normally set by the developers to separate the works/tasks between the system architecture.

Three-tiers is the most well-known architecture used in GIS applications, but it has disadvantages on scalability, maintainability, and needs more processing power on the web server. This research explores the use of the four-tier framework to overcome current impediments in the use of the three-tier framework for online

applications of 3D visualization for GIS data, focusing specifically on the needs of processing power.

1.2 Problem Background

Google Earth was released to the public on June 2005 and followed by Google Maps, which was released on February 2007 (Hollinger, 2011). This geo-browsers has the capability of displaying the world in 3D, although due to the data availability, the accuracy of the height value is low, where there only hilly areas are shown while low areas are not. There is a limitation in this software where the interaction of 3D visualization is only possible in fly through and not walk through mode.

Zlatanova et al. (2002) mentioned that "the increasing number of applications needs more advanced tools for representing and analyzing the 3D world". That is why the research on online 3D visualization has been interest to many researchers, until now.

Yu et al. (2010) has stated that ″at present, there are still some difficulties in researching and implementing 3D visualization and spatial analysis based on the internet because of the network bandwidth constraints' and the immature 3D graphics display technology″. Other than that, most of the three-tier framework developed by researchers is for 2D visualization (Chen, *et al.*, 2003; Man, *et al.*, 2006; Varun, *et al.*, 2004; Zhou, *et al.*, 2009) which is not appropriate to be used for 3D visualization.

Xu & Lee (2002) mentioned that ″although there have been some serious studies into specific issues, we still lack a framework to consider the problem as a whole and to coordinate the various studies. In our opinion, fully networking GIS, although desirable, is extremely difficult″. They stated that ″layering GIS has not been studied extensively″ and that ″while truly distributed GIS system involving highly autonomous component is still a long way to go″. Based on the above statement, there is a need to introduce a new framework for solving the problem in distributed GIS, especially for online applications of 3D visualization for 3D GIS data.

A web 2.0 concept has the capability on handling the data accessibility, data interoperability, and data information sharing over the internet and the World Wide Web. Nevertheless, in terms of information visualization, the representation of the data is still limited to 2 or 2.5 dimensions such as text, pictures, or videos (Settapat, *et al.*, 2010). That is why there is a need for implementing 3D visualization over the internet.

1.3 Problem Statement

Based on the literature survey, the use of four tiers architecture for design of GIS application is only for visualization in 2D and not for 3D (Luqun, *et al.*, 2002; Luqun and Minglu, 2004). The current use of this framework, mainly for 2D visualization and not related to GIS application. For example, in health geographic, four-tier frameworks are designed for mapping and sharing the disease information. The product of this framework is only for 2D maps, which can monitor the information of the disease without any GIS capabilities. The advantage of this system is that it can

collaborate interactively between the partners such as public health officials, researchers, policy makers and the public (Gao, *et al.*, 2008). Mahmoudi *et al*. (2010) introduced the interactive web based 2D and 3D medical image processing and visualization based on the four layer architecture. Their architecture consists of an algorithm, manage code, server communication and user-interface layer respectively. They also mentioned that they have a wrapper layer inside the manage code layer. Their architecture, with consideration of wrapper layer therefore contains five layers. As mentioned by Simmons (Simmons, 2009) the term layer and tier has different meaning, whereby each layer could sit on a single tier or multiple tiers. It means that, the layer is just the organizational concept in an application but tier implies physical separation, if needed. Mahmoudi system applied the layer concept and is different with our approach which proposed four-tier frameworks. Mahmoudi does not mention which layers sit on a particular tier. VRML is used for visualizing their images. However, Mahmoudi system is specifically for medical image with raster image processing and does not address GIS vector data. Our approach is specifically of visualization of GIS data and in particular this thesis research address vector based coordinate information. ″The development of efficient and reliable systems with more than three-tiers is still an imprecise science, but research in distributed computing continues to increase the availability and usefulness of such systems″ (Lewandowski, 1998).

The design of online applications which involve 3D visualization of GIS data normally involves a great amount of spatial data, especially for terrain information (Xu and Lee, 2002). By combining terrain data with other objects on its surface, a massive amount of data will be generated. The existing three-tier framework has

some drawbacks on scalability, maintainability, and it needs more processing power in the middle tier to process the request from multiple of users. Due to this situation, the use of the current three-tier framework for online application of 3D visualization for GIS data is not capable of processing the huge amount of data from the users. Hence, this research explores how to develop a new four tier framework which can solve the existing problem of processing power. The following specific research questions are addressed:

1. How to develop a new four-tier framework of online applications of 3D visualization for GIS data by enhancing the existing three-tier framework?
2. How to implement a new four-tier framework of online applications of 3D visualization for GIS data?
3. How to analyse the performance and validate the accuracy of a new four-tier framework of online applications of 3D visualization for GIS data?

1.4 Motivations

By creating 3D visualizations that look as photorealistic as current technology allows, it becomes possible to see, explore, and spatially understand parts of the Earth as if we were actually there (Patterson, 2003).

In Malaysia, the need for 3D visualization is crucial whereby Malaysian Geospatial Data Infrastructure (MaCGDI) is responsible to providing the services of National Geospatial Data Infrastructure (NSDI). The service provided by this agency is the system which can view the spatial data and also map (MaCGDI, 2011). This system

restricts the user to view the data in 2D (Figure 1.1) and require further commands to see further information. Furthermore, the user cannot view the data in 3D where more realistic information can be viewed. That is why 3D visualization is important for organizations, which provide services to its users. The required service of 3D visualization is not in place yet in Malaysia.

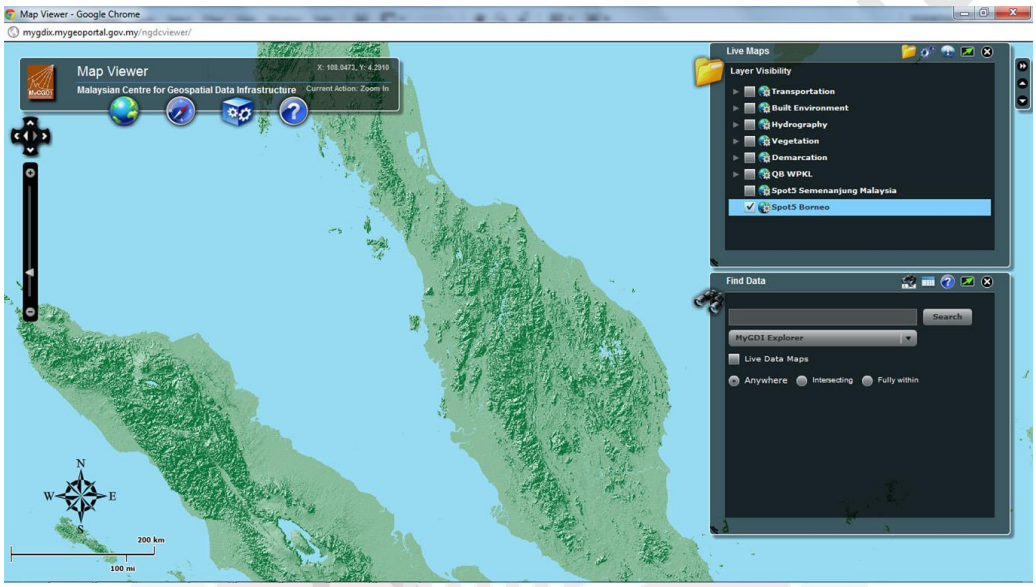

Figure 1.1 Image of Malaysia geospatial data in 2D Image source MaCGDI (2011))

Many researchers utilized Virtual Reality Markup Language (VRML) as their file format for implementing online 3D visualization (Basic and Nuantawee, 2004; Beard, 2006; Honjo and Lim, 2001; Huirong, *et al.*, 2009). VRML is fundamentally a 3D interchange format designed for visualizing 3D objects in web-based environments (Carey and Bell, 1997). Basic and Nuantawee (2004) quoted that ″VRML has proven to be a useful tool for modeling reality, producing 3D animations, and interactive mapping″.

By utilizing the VRML, the techniques such as level of details, tile's technique, progressive technique, and selective visualization was introduced by researchers to achieved real time visualization (Araya, *et al.*, 2002; Beard, 2006; Huirong, *et al.*, 2009; Zhu, *et al.*, 2003). VRML format can be used as an effective stimulus for landscape assessment (included terrain data) (Lim, *et al.*, 2006). In terms of terrain visualization, Martinez (2010) stated that ″the use of VRML for the creation of terrain visualization is viable″. VRML is a high-performance language, and the VRML technology is still a valid environment for implementing 3D visualization, especially terrain visualization. For this reasons much research still use VRML as their tools for 3D visualization. This is the reason why VRML is still being used in this research for the output format. The 3D information can be easily transferred through the internet by using this technology (Honjo and Lim, 2001).

As quoted by Huang & Lin (2000) ″3D visualization and analysis become more powerful when combined with internet based technologies. Through the network, data, analysis, and interaction can be distributed to the desktops of decision makers who are able to act upon the most recent information″.

1.5 Objectives

The goal of this research is to develop a new method of online 3D visualization for GIS data. In order to achieve this goal, three objectives have been formulated:

- develop a new four-tier framework for online application of 3D visualization for GIS data.

- implement a new four-tier framework for online application of 3D visualization for GIS data.
- analyze the performance and validate the accuracy of a new four-tier framework for online application of 3D visualization for GIS data.

1.6 Scope of Research

The scope of this research is meant for a client/server architecture. The new four tier frameworks is develop based on tier concept for online applications of 3D visualization for GIS data focusing specifically on the processing power problem. For application development, this research focused only on the oil palm plantation application. The visualization of 3D for oil palm plantation generates 3D objects like the oil palm tree together with pseudo of 3D terrain visualization.

1.7 Thesis Structure

The thesis is organized into six chapters. This is the introductory chapter. It provides the problem background, problem statement, goal, objectives, motivation, and the scope of the research.

In Chapter 2, detailed descriptions of the study background are discussed. It explains the background of 3D visualization, 3D terrain visualization, the concept of tier, and on-line visualization framework. All the topics are discussed in details which distributed into other sub topics. The discussion guide the author to find the research gaps on why the new framework needs to be introduced. This chapter ends with the

conclusion on the research gap being attempted that trying to be solved in this research.

Methodology of the research is discussed in chapter 3. It includes the framework of the study and other contributing factors in this research study. This chapter discusses the formalization of the framework, its design and the interaction between each tier.

Chapter 4 discusses an example implementation of the research in oil palm plantation. The details of the implementation of each tier are explained in this chapter. The explanation on how to develop 3D terrain is described in detail in this chapter. It describes the prototype developed to suit an oil palm plantation.

Chapter 5 continues the discussion on the operational guideline's experiments for on-line 3D terrain visualization, which is divided into five experiments. The results give the visualization developer an idea on the best way of implementing on-line 3D terrain visualization in terms of topographic data, rendering technique, GIS software, satellite data, and web server. In order to analyse and validate the new framework, the comparison between the new four-tier framework and three-tier frameworks is made. The measurement of the comparison is based on response time, loading time, frames per second (fps), Central Processing unit (CPU) usage, and memory usage. The result of the comparison is presented and analysed.

Chapter 6 concludes the thesis. This chapter describes the research contributions of the study. Suggestions on future research are also discussed.

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