Roof detection on 3D Mesh Building Model Generate from High-Resolution Oblique Image

THANABORDEE SAKUNARUNPHET

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR MASTER OF SCIENCE
IN GEOINFORMATICS
FACULTY OF GEOINFORMATICS
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2020

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ธนบดี สกุลอรุณเพชร

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2563

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2020

The Thesis of Thanabordee Sakunarunphet has been approved by the examining committee to be partial fulfillment of the requirements for the Master of Science in Geoinformatics of Burapha University

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Nowadays, the trend of using small aerial equipment such as, Unmanned Aerial Vehicle (UAV) mounting the oblique cameras is high efficiency to collect the 3D data, because it's can fly close to the object and has better accessibility to narrow space to capture the detailed information to ensure that all of the building in the area were captured from every single side of the whole building. Especially for the rooftops of the building, which is the main object of our study. The advantage of UAV is cheap for the operation in each time, more flexible, and short production cycle, when compared with the traditional acquisition method, and especially, to generate the high-resolution 3D models. Three-dimensional virtual building models with the high-level detailed information is an important description of the city areas, are wildly used in various fields, such as city plan, design, and solar energy area, helping in their decision process, and building information model (BIM), etc.

However, many applications require a building model with a topologic surface structure rather than mesh data, for the mesh data cannot provide semantic information about the roof and façade. These rooftops surface information can be extracted by using the digital geometry processing algorithm and most of the automatic segmentation methods, especially for the architecturally sophisticated building.

In order to segment rooftops and surface automatically from 3D mesh data generated from oblique images, This dissertation introduces an efficient segmentation method base on the Region Growing algorithm, which is an innovative, robust, and efficient method for three-dimensional building rooftops segmentation. Demonstrated a segmentation method aimed at breaking down the rooftops from the building structure by using the efficiency of triangle mesh derived from UAV. The materials as aerial images were generated to 3D mesh models by using Get3D software. Basically,

curvature estimation calculated for all vertices on the surface mesh and classified into several clusters. Then, the use of discrete curvature is calculated for each vertex on the triangle surface. Then vertices are classified into the clusters according to the principal curvature based on values of K-mean clustering. Afterward, the Region Growing algorithm is aimed at breaking down the structure in the meaningful of sub-component. We proposed it can detect opening boundary even on rooftop of the Building, by the mechanism of region growth used to extract the connected regions, starting with a seed region on surface data and grow up to the neighbor when neighbors seed are satisfied in some condition. The growing process is continuing until the vertices are met. Lastly, the used region merging approach is aimed to reduce the over-segmentation result from the growing clusters.

The result illustrated a structure of the roof plane with topology in each step of detection, the efficiency and precision of the proposed algorithm in terms of computation time, extraction accuracy. The rooftops were segmenting from Region Growing algorithm base curvature estimation, it can display the shape and structure that segmented from the mesh models. The integration of both techniques is significantly and advantageous from the detection and segmentation of triangle mesh data. However, the rooftops with topologic surface structure can provide the semantic information can be applied to various fields such as solar roof energy or city plan.

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Thanabordee Sakunarunphet

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER I
INTRODUCTION

This research investigates to realize the rooftop detection on 3D mesh models by using the novel of Region growing algorithm, that is apart from several segment algorithms. This chapter would be describing the statement of the problem to the reason for this research, the scope of the study, research question, objective, the definition of the term, and thesis structure.

1.1 Statement and Problem descriptions

Three-dimensional building models with a high level of detailed information is the role important of a Building Information Model (BIM), city design for solar rooftops areas, support decision making, and comprehensive social management. As the trend of using small equipment such as Unmanned Aerial Vehicle (UAV), instead, the traditional approach such as LiDAR to generate the 3D object is popularly used. Previously, the used of LiDAR can provide a point cloud; actually, we can using point clouds to generate a 3D model, but for the accuracy is not suitable for a virtual 3D model, the operation process is very expansive and long-time processing. Recently, a trend of surveying by using the small aerial vehicle is instead the traditional method, the use of UAV mounted the oblique camera sensor give the significantly to acquisition and processing operation, example, the UAV can fly close to the object, obtaining the single side of the Building (e.g. façade, balcony), and has better to accessibility to narrow space for captured the detail of building such as, rooftops, chimney, balcony, and façade, which will be a beneficially for our studying especially for 3D building model. In particular, the elements of the Building, as mention above, can be done by using photogrammetry techniques and image processing techniques. However, our research leads to analyses and conduct by using the methods of photogrammetry technique to detect the target as a building roof from the 3D mesh model.

In recent years, the oblique camera has been applying with a 3D building model. The main motivation of our study is applying the UAV to detect the building rooftops. The UAV mounted the oblique camera sensor is an efficient method for generating a real 3D building model for the demonstration of the geometry information.

The advantage of using UAV is cheap, short cycle process, and breaking through the limitations when compared to the traditional photogrammetry technique such as LiDAR, aerial photo imagery, and satellite imagery, because the UAV was obtained the abundant image from various perspective and have various software supported to process automatically. In terms of build-up the 3D model, to reduce the processing time for generating the model from the 2D image to 3D model mostly has been using the Multi-View Stereo algorithm. MVS algorithm is a part of photogrammetric computer vision that can provide efficiency modeling and automatic generation.

Previously, to generate the 3D model was use the traditional stereo image pair, and feature extraction, it is a time-consuming approach to create a large-scale. Therefore, recently to generate the 3D virtual city model, mostly, it has been processed by using Multi-View Stereo (MVS) algorithm. The MVS algorithm is a part of photogrammetric computer vision, known as a technique, to acquire a 3D virtual model object from the redundant images. The potential of these applications, Multi-View Stereo from the construction of realistic object models is an advantage for various fields, e.g., GIS application, urban planning, and design engineer. With the development of a number of different open-source software and low-cost systems, the multi-view stereo method is becoming a popular subject in computer vision.

In this research, demonstrated a detection method, which aims to detection and precise building roof plane by using the efficient of triangle mesh that derived and generated from the high-resolution oblique imagery. For the existing input data set of this research were generated the 3D mesh models via software, the use of Get3D software provided the opportunity generated the virtual 3D model from Multi-view image. Through the method, the building object can be quickly and robustly detected from the triangle mesh. To conduct the research, that was proposed to detect the rooftops from the mesh model. The curvature first of all, the algorithm calculated for all vertices on the surface mesh and classified into multiple clusters. Then a region growing algorithm extracts the connected a set of regions (associated with a similar curvature), starting from the initial seed facets. The Curvature estimation is applied to surface decomposed the existing structure. Firstly, discrete curvature is calculated from each vertex on the triangle mesh surface. Then vertices are classified into the clusters according to the principal curvature based on values of $K - mean$ clustering. The Region growing method is aimed at breaking out the existing structure into the meaningful of sub-component. (Landes & Grussenmeyer, 2016). The region growing is widely used to segmentation the range image data by selecting the vertex element on the surface and then growing the realized by adding the satisfy given criteria between vertex neighbors. This research leads to creating a segmentation. The growing algorithm process is always repeated a new vertex element in each time the previous growth is interrupted. The growing algorithm stops when all the vertex elements are visited or the values of vertex reach to the threshold of segmentation (Plataniotis & Zervakis, 2017).

The drawbacks of region growing algorithm is a dependency on the initial vertex (seeds). Indeed, a bad choice of initial vertex elements could be led to a bad segmentation. Another drawback is the over and under segmentation (small patches) induced by an important number of vertex elements.

1.2 Research Questions

1. Which algorithm has an efficient to segment and precise of building rooftops?
2. How does it increase the effective detection of building complement (e.g., Rooftops) obtain by Unmanned Aerial Vehicle (UAV)?

1.3 Objective

The research is focusing on the feature segmentation of region growing algorithm in the open dataset access and the image processing software. During the investigation of feature segmentation on triangle mesh focus on rooftops detection, the capability and limitations will become increasingly evident. The research aims to segment the building rooftop using a 3D mesh model generate from High-Resolution Oblique Imagery obtained from UAV.

1.4 Thesis structure

This research divides into five chapters, the first chapter is an introduction part, with content about the statement of the problem described by a short discussion about the topic, research question, objective of the research. The second chapter is the literature reviews that will describe what was previous research focuses on, review the efficiency of the proposed algorithm, and data acquisition by UAV. The third chapter will describe deep in detail the proposed technique in this research. The fourth chapter is a description of the results and discussions using the methods in this research. The fifth chapter gives a conclusion that will explain the capability and limitation that find out in this technique, a summary of the research and suggestions for future work.

CHAPTER II
REVIEW OF RELATE LITERATURE

This chapter given the definitions, approaches, results, and the limitations of the previous research. The photogrammetric applications have been present the three-dimensional information to represent the virtual 3D of the city model or even the interesting human-made objects. The proposed methods used for investigating detection and segmentation the feature of 3D modeling, as we were strongly focusing on the rooftops that will be discussed deep in detail in this chapter.

2.1 Overview

In the literature of using Unmanned Aerial Vehicle (UAV) with a high-resolution sensor, e.g., oblique camera system to generate the 3D virtual model. Moreover, several techniques have been using for detecting, extracting, and counting the difference of characteristic individual buildings such as the roof plane. Thus, we will discuss the methodology were employ for automatic detection.

2.2 Photogrammetry Technology

Photogrammetry technology is defined by the ASPRS (American Society for Photogrammetry and Remote Sensing) as the art science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena (Wolf & Ph, n.d.). The first oblique airborne photography was taken by James Wallace Black in 1860, Boston US. Oblique photogrammetry performed by the small aircraft carrying many oblique cameras with an oblique rotation angle to obtain the images by taking the photos from the air to the ground with different views. Oblique images are an indispensable tool for the following general uses, which will be subsequently described the examples in more detail.

Urban and infrastructural planning

- Design compare and measurement of city planning, Building, and structure.
- In field of telecommunication planning, it can be applied to do a line of sight calculations.

Critical infrastructural protection

- A multi-vision is an efficiency tools for the other facilities, such as Government buildings, Airport, Shopping malls, hospital, event for industrial areas.

The traditional approach to generating 3D information in remote sensing has always been the photogrammetric method. Traditionally, it requires delicate human effort and a time-consuming process. However, several innovations help to develops help to develop new automatic photogrammetry. Firstly, digital imagery collection by Unmanned Aerial Vehicle (UAV) is enables large overlap between images with low price when compared to the aerial images. The high overlap is increasing a chance to completely detect the control points matching and decreasing the undetected errors. A typical 60 percent front-lab and 30 percent side-lab place a higher reliance on ground control points (GCP) matches than imagery with higher piecewise overlap do. Secondary, the automatic features detection and image matching applied with computr vision provides a significant and opportunities to automate photogrammetry with ground truth. In the traditional method of photogrammetry, and human stereo operators can be create the matching between two images with less accuracy of few pixel at best. (Leberl et al., 2010). The automatic dense image matching technique can be achieving a level of accuracy as small as a pixel, which makes the high-density point cloud generation process possible.

2.3 Oblique Imagery Smart Image Acquisition Strategies

There are different 3D data acquisition and representation methods, which could be a continuum between more and less explicit geometry information. 3D data could be a set of the 3D point cloud that could be constructed by several techniques. In additional properties of the data set of points may be available, such as the connectivity between point by edge called mesh. Otherwise, 3D data could be referred to as a set of 2D observations of a 3D scene from multi-view angles since the image geometry is implicitly embedded in 2D observations. Recently, many researchers employed the small aerial equipment, and cheaper camera sensors developed from the nadir sensors that were developed to the oblique camera sensor and then mounted on the unmanned aerial vehicle (UAV). By the scientific community, geomatic professional, and software developer, has led to use more and more widely, in several fields of architecture, surveying, and engineering (Vacca, 2017). The traditional optical sensor used to capture the human-made objects has the different conditions compared to the oblique imagery sensor. Nowadays, multi-sensors aerial platforms combining between oblique cameras and nadir are experiencing a revival, and several researchers have to propose the new image acquisition system. The stereo images or multiple view systems are reached to a relatively mature state in this time. Images can be produced at 80 percent front lap and side lap, increasing the number of images per object interest from two to six or more, and absolutely no additional cost of acquisition. The present, at 90 percent forward overlap, the number of images per object is increased. Moreover, by an increase of the side-lap from the traditional 20 percent to now 60 percent, the cost will increase only for the additional flight time, but not for the increase in the number of images. The strategy increases the number of images per object point; there is much more beneficial to reduced occlusions, a higher level of automation, reduced occurrence of blunders/gross errors and therefore less manual editing, and finally, an increase of geometric accuracy (Leberl et al., 2010). Please see the example of the camera axis in Figure 1-2.

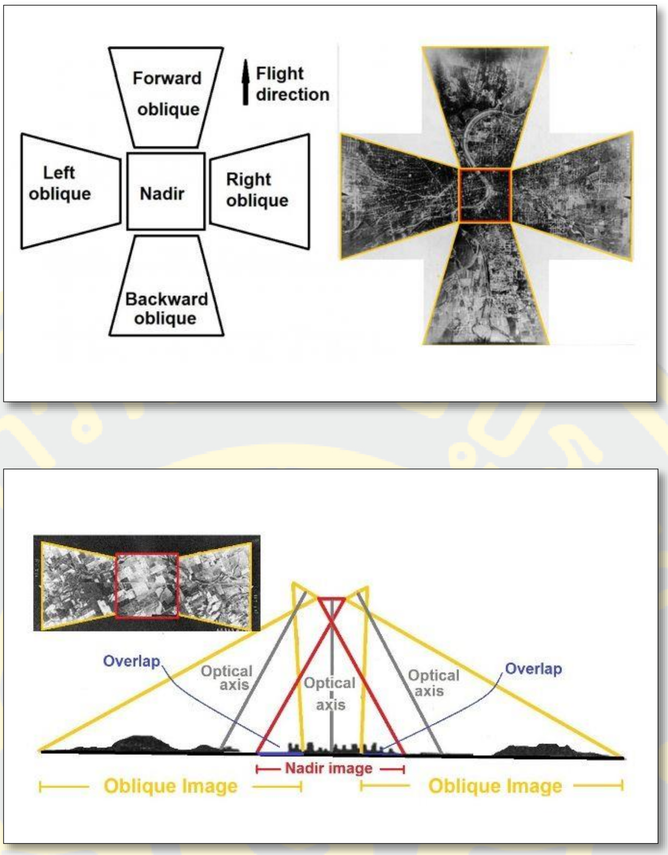


Figure 1 The axis of the sensor of the oblique camera in primary type.

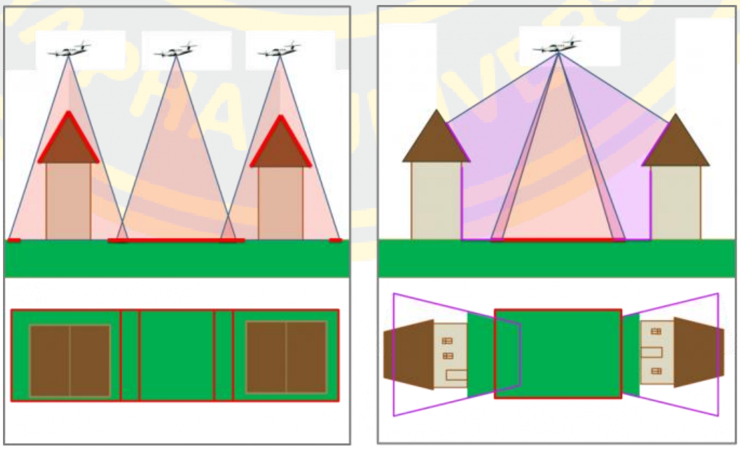


Figure 2Data collection By UVA mounted oblique sensor and generated the point cloud data from the multi-view image.
(https://www.gim-international.com/content/article/growing-use-of-oblique-imagery-by-municipalities)

Previously, the used of oblique images were generally taken for visualization and interpretation purposes, rather than for measurement applications. The Unmanned Aerial Vehicle (UAV) that mounted the oblique multi-camera sensors are becoming a standard sensor technology across a growing geospatial market, with multiple applications. The field of photogrammetry can apply with several applications, but in this research, using the oblique imagery and photogrammetric to create the semantic element of the building model. The efficiency of The Hight- Resolution Oblique Imagery obtained from a UAV breaks through the limitations of the primitive aerial imagery because it obtains abundant oblique images from various perspectives that have been widely applied to 3D Modeling Figure 3. Furthermore, the special one is this type of sensor can provide the collector to capture the side of the building when compared to traditional nadir image that was important because oblique imagery allows us to see on each side of a building structure, e.g., exposing blind spots, balcony, façade plane entrance and exit previously impossible to located from vertical photography with the virtual 3D building model, see in **Figure 4.** Technically, we focus on the methods for building, roof plane, and façade detection from the 3D geometry (Oblique Imagery, Mesh model).

Figure 3 Multi-Oblique Camera Sensors employed in this research, thanks to DASPATIAL for support.

Figure 4. General of Aerial Image, the nadir axis can snap only the top of the building (left). The oblique imagery provided to snap the side of the building (right). (https://geozoneblog.wordpress.com/2016/03/28/oblique-images-a-tool-you-need/)

2.4 Image Matching

The use of data collection by using UAV. The photogrammetry techniques are the main idea of creating the virtual 3D model. (Lingua, Noardo, Spanò, Sanna, & Matrone, 2017) employing oblique images to detect and observation of vertical structures, some further problems more than for acquiring nadir image must be considered. To cover the whole area and give more stability to the photogrammetric block were performed using standard overlapping criteria for SFM processing: 80% front lap each image and 60% side lap each image. Matching defined as the establishment of the correspondence between the images datasets. Image matching is a part of computer vision, and the approach focuses on finding similarities in an image and matches them together and estimate the corresponding 3D coordinate by linearity or projective model (Remondino et al., 2013). (Lingua et al., 2017) describes the Structure From Motion (SFM) algorithm as a simple technique of image matching by estimating the 3D structure and camera alignment.

To describe how it works, SFM can extract the corresponding images feature of stereo pairs by moving the camera around the scene; the algorithm will detects and describes the similar feature for each image, then matches them out the multiple-image as a 2D point. After that, the matched point used to entire input and using SFM to computes the position of those points and 3D point clouds produced to representing the 3D geometry by triangulation using the interior and exterior parameters of the taking camera (Lai et al., 2018). Dense Image matching, Multiple View Stereo (MVS), and

Structure From Motion (SFM), as previous mention SFM can estimate camera pose and orientation automatically, making capability of processing multiple-view image simultaneously, while dense image matching and MVS algorithms provide the potentiality to generate the large scale of point clouds. Recently, 3D dense point clouds can be acquired in the full of city-scale easily through an oblique photography techniques based on MVS and SFM (Xie, Tian, & Zhu, 2019). **See Figure 5**

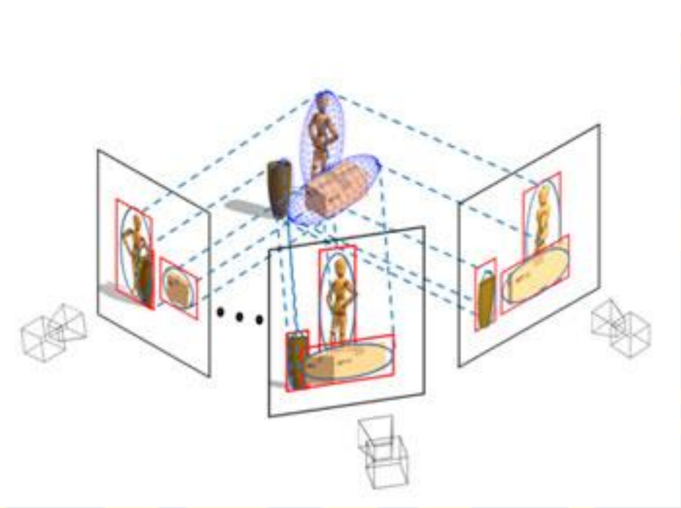


Figure 5. the demonstration of the Multi-View camera posed.
(https://vgm.iit.it/code/structure-from-motion-with-objects)

2.5 Segmentation Type

Mesh segmentation requisite and criterion function and definition for optimization are affected by the segmentation objective. Although various objectives, we found there is a distinction between two types of segmentations. (Shamir, 2015) According to recent state-of-the-art, mesh segmentation techniques can divide into categories: surface type (or geometric) methods and part-type (or semantic) methods. See Figure 6.

Figure 6. The example of part-type segmentation (left), surface mesh segmentation (right)

In the first type, surface-segmentation uses generally geometric surface properties of the surface mesh models, such as curvature or planarity, to creates patches. There are also times when the semantic model used by surface-segmentation, such as CAD segmentations, where is an the algorithm can be decomposed the semantic model into geometric primitives, e.g., planes, patches, spherical part, etc. (Hoffman & Singh, 1997).

2.6 Texture Mapping

Texture mapping allows users to stick the reality surface image to a polygonal mesh to enrich realistic photo rendering and to reduce its complexity in terms of size, see Figure 7. (Rau & Chu, 2010) have been propose a texture mapping approach for the more detail of mesh. Given an arbitrary, they have been constructed a progressive mesh, such that all meshes in the progressive mesh sequence shared a common parameter. The method was starting by separating the mesh into surface patches using the planar and compactness heuristics. Then, it simplifies the mesh model while concerning the chart boundaries. Finally, the charts are packed into a texture atlas. (Sander, Snyder, Gortler, & Hoppe, 2001) proposed the algorithm which partitions a mesh into rectangular while preserving a Texel correspondence across chart boundaries. This mapping permits any computation on the mesh, which is carried out on a regular grid and prevents seams by ensuring the resolution along the boundary.

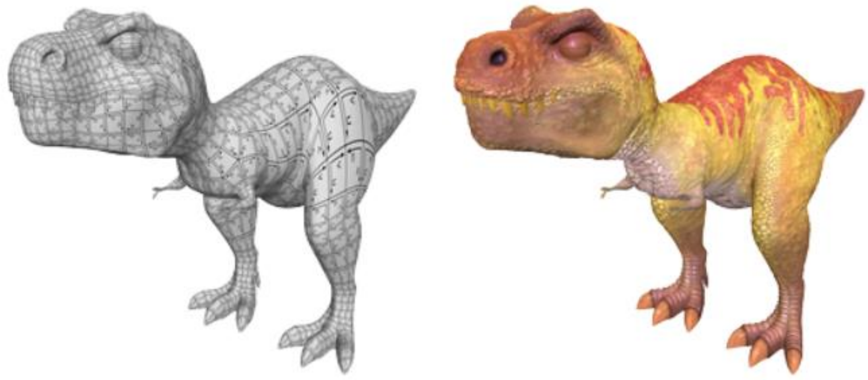


Figure 7. Example of texture mapping for a 3-D mesh.
(http://ptex.us/ptexpaper.html)

2.7 Segmentation Technique

2.7.1 Curvature estimation

Meshes support wide variation in complexity and resolution for the local region in the object. They use a relative to represent the consisting of vertices (point sample on the surface), and polygonal faces are defining connectivity between vertices. The visualization tools are compatible with the mesh structure. However, the tools for observing the surface properties, such as smoothness from mesh, is not yet progressed to match with Computer-Aided Design (CAD) (Grimm, 2014). The curvature is an intrinsic property of the surface. It can be used to identify the feature on mesh such as ridges, valleys, and planar, convex, and saddle shapes. Analytic methods are also applied for the curvature estimation by fitting the surface to the mesh in the neighborhoods of the point of interest and evaluate it curvature (Asi-nagy, 2006). Principal curvature and principal direction of a triangular surface estimation at each vertex lie on the surface by the least-square fitting of an osculating paraboloid to the vertex and its neighbor (Magid, Soldea, & Rivlin, n.d.).

The assumptions are represents an each vertex of mesh the sampling of piecewise mesh surface the curvature of the vertex is a generally used to segmentation on the surface mesh algorithm, the curvature information used to considerate it does not contain the situations which may lead failure when they can detect the concave vertexes on a mesh. The calculation of concave vertices extends the work remarkably, especially for the model has been generated in the very high resolution that has to enlarge the normal 1-

ring neighborhood the extend the multi-ring based on the neighborhood (Fei, Fan, Ruo-mei, & Li, 2014). The model often to represent the complex triangle mesh, which a thousand or much more of vertices and polygons. The segmentation is an approach to breaking down an existing structure into meaningful connected the component of the model structure. A curvature estimation is a common tool for describing and analyzing the triangle surface; we can see the difference of region surface by using the Gaussian curvature. 3D mesh composed of the different components and the point of an individual component has a specific characteristic such as hyperbolic. Therefore, we can divide the surface of the model by considering the disjunctive region and detect the boundaries with the hyperbolic (Chen & Georganas, 2006). In the use of Gaussian curvature, we can extract the boundary between the polygon, which is useful for future segmentation. The Use of methods for normal surface estimation, quadric fitting, and curvature estimation used to analyzing dense unconstructed triangular mesh. The curvature estimation is used to detect the sharp edge and separate the mesh into the similar shape characteristic regions. The use of noise estimation is worked during the region growing to determine the geometric capability when they adding the vertices to regions (Martin, 2000).

2.7.2 Region Growing Algorithm

Region growing is well known as simple to segmentation on mesh data. Region growing algorithms work well in a range of images. The principal of region growing is to start with a seed region on surface data and grow up the neighborhood pixel when the neighbor's pixel is satisfied in some condition (Deschaud, 2010). The performance of this algorithm depends heavily on the choice of the initial seeds. In addition, the segmentation processes are performed within the extracted region of interest in the aerial image based on grayscale values. The growing process is continuing until the condition is met. For the description of the region growing method, see in Figure 8.

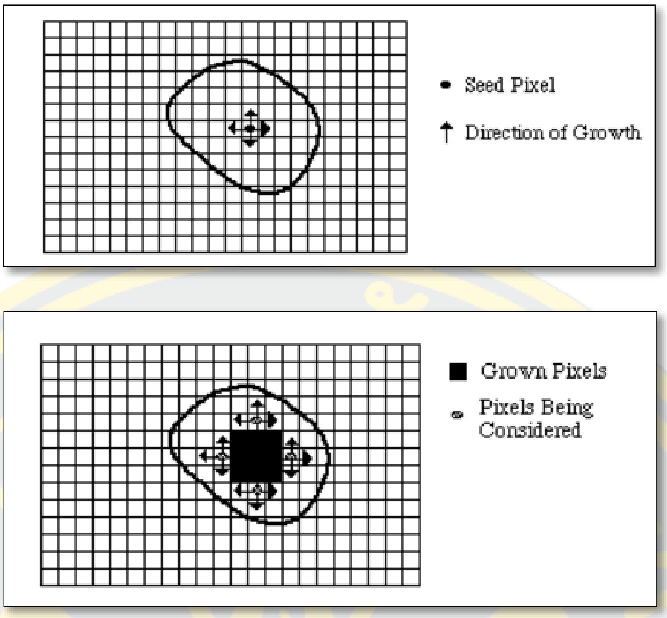


Figure 8. Start of growing a region process (Top), a growing process after iteration (Bottom)

The major difference between the region growing algorithm lies in the choice of the condition of a region, which decides as an element can be added to a given region. (Yan, Jiang, & Shan, 2012) The several types of segmentation methods, one of them is based on region growing algorithm. The algorithm starts by computing the graph of the input mesh. Each node of the graph represents the adjacency seed or pixel relation between facets. Then, the algorithm is randomly selecting a seed element and grow the graph while collecting the facet, which from a convex patch is launched each time the previous one is interrupted because of the violation of the convexity.

Algorithm 1: Region Growing

1: *Innitialize a queue Q*
2: *Select seed elements s and insert them into Q*
3: ***While*** *Q is not empty* ***Do***
4: *Get the next seed element si from Q*
5: *Define a new region Ri*
6: *Add si to Ri*
7: *Add all compatible elements with si to Ri*
8: ***end while***

(Lavoué, Dupont, & Baskurt, 2005) The purposed segmentation method is based on a region growing algorithm. The curvature estimation is a first calculated for whole of vertices on mesh surface, and it can classify the vertices into several clusters. A region growing algorithm then extracts a region, starting from the initial seeds facet. One of the difficulties of region growing techniques depends on the initial seeds. Indeed, not the right choice of seed element can lead to a bad segmentation. Another problematic thing is over-segmentation (Multi-small patches) induced by an important number of seed elements. Seed region creation, the use of a region growing process is the most effective when the vertices are along the boundary of growing regions are geometic corresponding with the existing region. According to the connected of each region into a minimum and maximum interior group of the vertices surrounding by the vertices with similar characteristics such as the geometric properties. Each seed regions are lies within the group of vertices with the identical Gaussian estimation and mean curvature sign. Because a seed region that was lies on the surrounding mesh has a similar geometric property, that meaningful to the surface approximately and a neighbor seed region should also similar characteristics quite well. As the region will set of topological connected vertices, each vertex was defined as the number of values of the region to which it belongs.

CHAPTER III
MATERIAL AND METHODOLOGY

In order to accomplish this research, describe the characteristics of a study area, the existing dataset, and the trend of methodology. The study area selected in Wuhan, CHINA. The existing dataset as 3d building models were used to analyze the proposed method of segmentation. Thus, for more understanding, the conceptual framework was divided into three sections: pre-processing, preliminary data analysis, generation of the semantic model.

3.1 Study area

The study area located in Wuhan, Hubei, China. The area surveyed by Unmanned Aerial Vehicle (UAV) with an oblique camera that can demonstrate the true 3D model. The choice for this area was to realize five objects of this research. The object had five different characteristics with complex rooftops. This was done to ensure that all the buildings in the area were captured from the 360-degree view covered the whole of the Building to experimented in this research. See Figure 9.

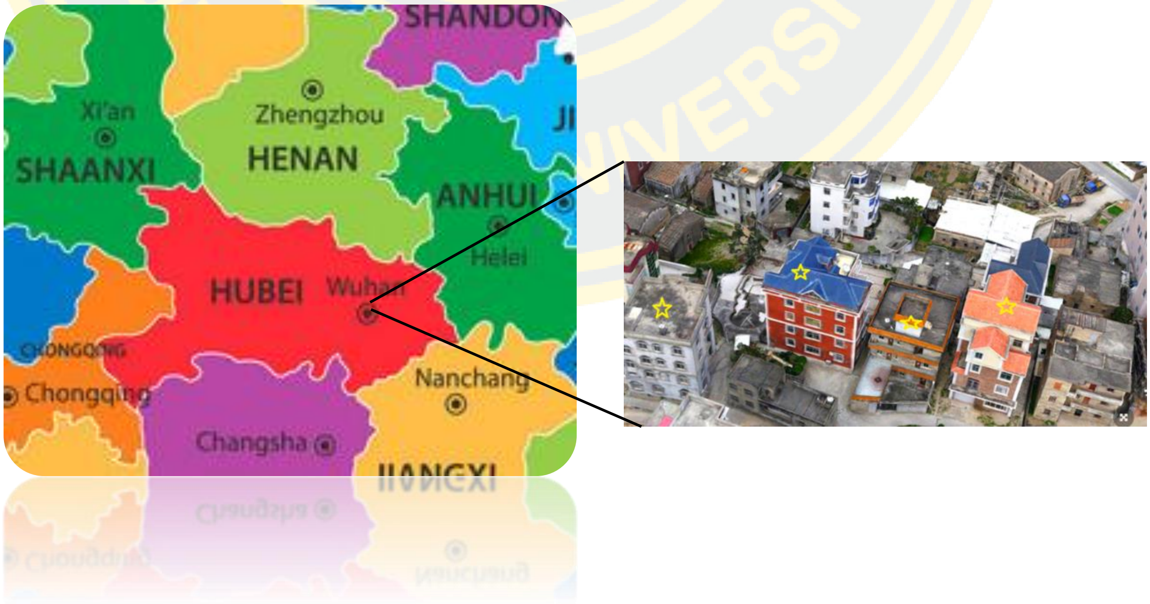


Figure 9. Study area used for method Implement and Evaluation.

3.2 Data Acquisition

The use of Unmanned Aerial Vehicle (UAV) in this research, presented the oblique camera sensors mounted on a movable axis, equipped with gimbal joints that enable the position of the lens orthogonal to the ground for the acquisition of oblique images, see Figure 10 and 11. The angle of camera sensors must be determined considering the height of the building objects, height of the flight, eventual obstructions, the position of detail to be acquired on objects.

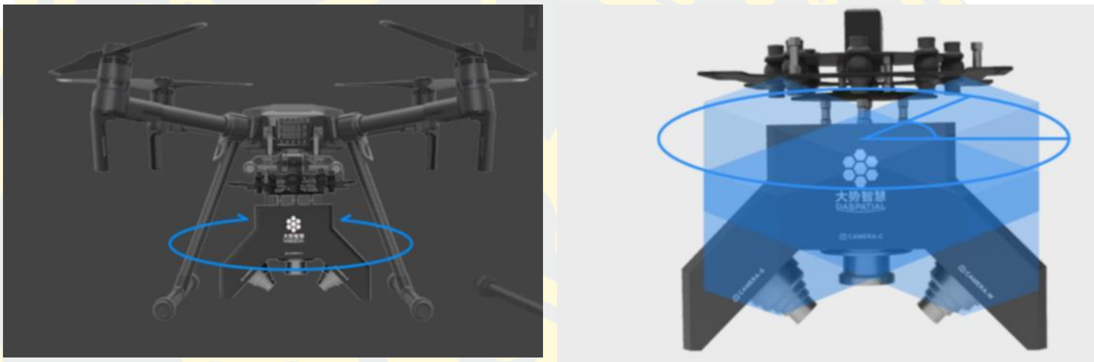
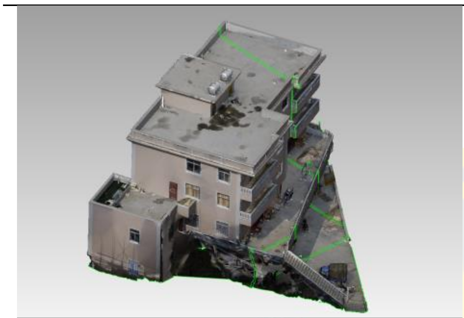
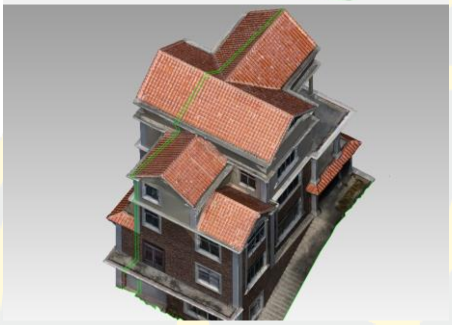
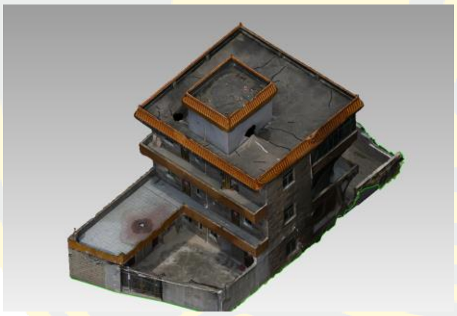
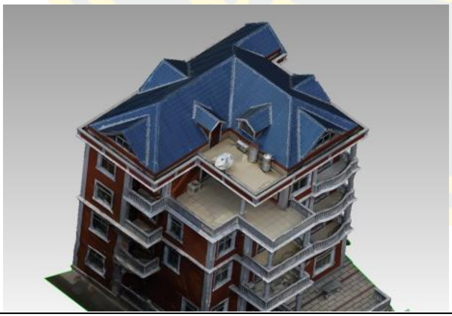


Figure 10. The UAV with payload oblique camera sensors.

Figure 11. Example of two nearest images in the same flying direction, with underline an approximated overlapping area.

Table 1 The detail information of 3D mesh models for the region growing approach.

Data used	Details
	Building model with flat roofs. Composition of current triangles: 70,847
	Building model with complex Gable and Valler roof. Composition of current triangles: 48,647
	Building model with Mansard roof. Composition of current triangles: 690,552
	Building model with complex Gable Roof with Dormer Window. Composition of current triangles: 84,119

3.3 Method

As we already know, a 3D triangular mesh can be described as a set of vertices that are connected to the other vertices by edges. This dataset represented is one of the general data structures are used for showing the complex 3D objects due to the latest advances in 3D scanning and acquisition technology. Many cases, such as meshes, are not explicit high-resolution structures. Generally, the high-resolution structure is useful for computer vision tasks such as feature modeling, object improvement, model fitting etc. one issue to determine such a high-resolution description is through mesh segmentation. The means of segmentation is breaking down an innitail structure into the meaningfully connected sub-components. It is a common approach in 2D image processing; recently, the segmentation approach has been introduced into the 3D mesh model. As mentions in chapter 2, we have reviewed various algorithms of 3D mesh segmentation. The region growing algorithm becomes more interesting. The algorithm, described in (Hojjatoleslami & Kittler, n.d.) generalized the region growing method to arbitrary meshes by using discrete curvature at each vertex of the mesh. The curvature estimation for 3D meshes is not a trivial operation, as a mathematically defined for a smooth surface meshes only. The most of region growing algorithms are computationally expensive simple segmentation method using the curvature analysis. It is efficient for 3D models. However, many existing methods, this algorithm has a drawback that comes in most cases, it is not possible to process high-resolution 3D models as well as the geometrical characteristics of the polygon. In such models, such as normal values, curvature, so close that these algorithms will not be able to detect. Found some features section, Therefore, being effective and A strong algorithm is needed for 3D mesh segmentation. This research proposed to segment the rooftops from meshes models. This is the challenge of our research because of data represent the complex of building. In this paper, we present a region growing technique segmentation see Figure 12.

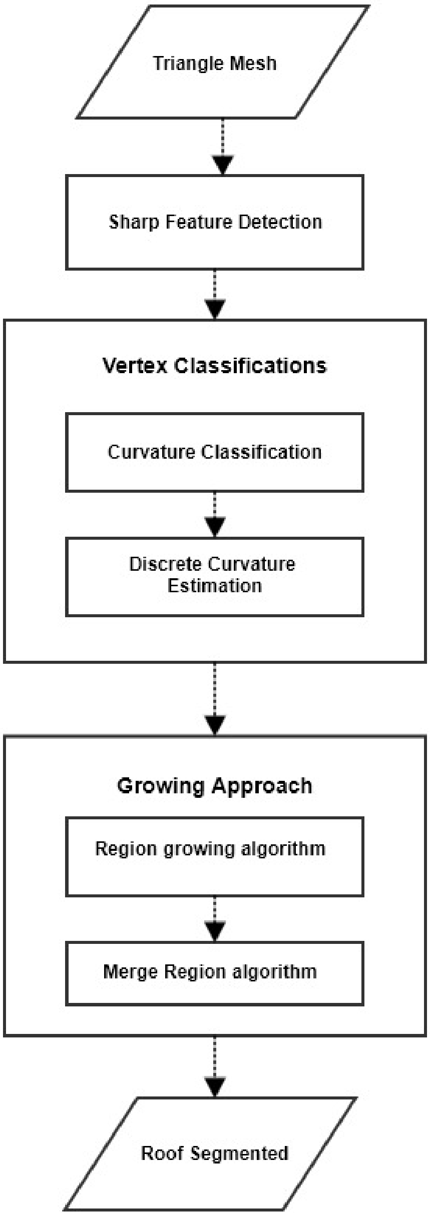


Figure 12. Conceptual framework of proposed 3D mesh segmentation.

This step, the entire dataset as 3D mesh building models are using to analyze in the proposed methods. In this dissertation, we presented an efficient 3D mesh region growing segmentation algorithm using curvature estimation, and it can detect whether the vertex and edge. Thus, we proposed a curvature tensor to complement the principal curvature. After feature extraction using curvature estimation, we have to completed segmentation by using region growing algorithm with an efficient merging scheme. The processing method in this research describes below.

3.3.1 UAV images and Automatic generated 3D building models.

This section, the materials as aerial imagery, was generated by the efficiency of Get3D software. However, we would like to brief the approach to achieve an object in the field of photogrammetry technology has various application to generate the virtual 3D model from 2D images. The use of Get3D software, which allowed a further reduction in the cost of time and operation. So, in this research, the software was used for image alignment, then, Dense Image Matching is based on computer vision algorithms it is can be defining the unknow of the interior and exterior of camera parameters by matching the features in the overlap of two images pared. Consequence allowed to generate the accuracy of the 3D model see Figure 13.

Figure 13. A photogrammetric survey of the urban area displayed overlapping of two images. It used for the Dense Image Matching algorithm process.

3.3.2 Triangular Mesh Representation

From raw data as the aerial images, we generate a point cloud from the image matching technique that gives an opportunity to generated point cloud (vertices). Then, (Tiendee, Sinthanayothin, & Electronics, 2015) the method of 3D mesh reconstruction from point cloud data see Figure 14. A rectangular solid is constructed to cover the whole point cloud. It is divided into smaller cubes. Each cube will be contained some part of the point cloud. In each, the points are connected. So, that is the component of mesh. A mesh was made from a connected of edge and vertices. The input data is a given as an Object File Format (OBJ) belonging to the wavefront, namely the position of each vertices f = {v1, v2,.vn}, where n is the number of vertices. Each individuals' vertices are often represented merely by its Cartesian coordinates (x, y, z).

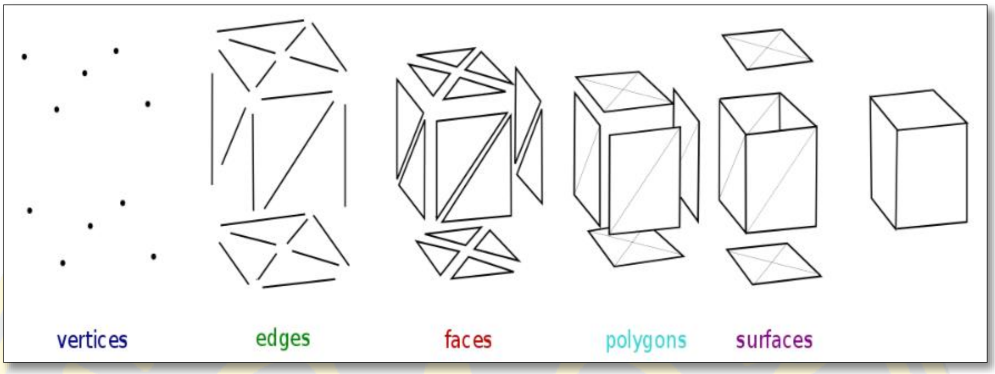


Figure 14. Elements of Objects created with polygon meshes must store different types.

3.3.3 Sharp feature detection

This segmentation algorithm is based on the analysis of the curvature of each vertex on the surface. In the first step, we must take it into account a sharp edge, especially for CAD objects. According to the differential geometry preliminaries, for a smooth oriented surface, feature line can be defined, and followed by the curvature derivative. Even if, in practice, curvature values are associate with sharp edges, the curvature is not theoretically to defined on their features. This means that we cannot consider a sharp edge like any other curvature edge, because in this step on defines only the target edge length (boundary) and not in a region. That is a reason why we considered to process a sharp feature detection. A sharp edge is defined as follows; an edge shared by to triangles whose normal vectors make an angle higher than a given threshold. Vertices are belonging to a sharp edge are considered as sharp vertices (nevertheless and edge shared by two sharp vertices is not necessary a sharp edge). This step of sharp feature detection is beneficial within the region growing algorithm. As a preprocessing step to the process, a mesh enrichment on bad tessellated objects particularly optimized triangulate a polygon mesh to produce a more uniform tessellation. (Lavoué et al., 2005). Each triangle is associate with three sharp vertices, in case we cannot evaluate curvature associate with a region, it ties up without boundary problem risen. Thus, we can do subdivide these sharp triangles by adding a new vertex at the center. see figure 15. The region segmentation is applied to this modified mesh and added vertices are removed when the end of the process.

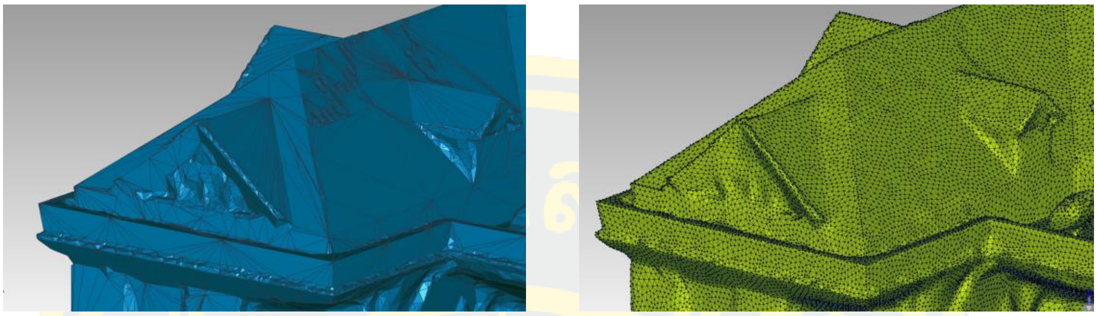


Figure 15. The initial mesh (left) and the optimized mesh by sharp feature detection (right)

3.3.4 Vertex Classification

Vertices of the triangular mesh are classified according to the principal $Kmin$ and $Kmax$. Furthermore, as the boundary rectification step needs a principal curvature direction, so, we must calculate the curvature tensor for each vertex of the input mesh see Figure 16.

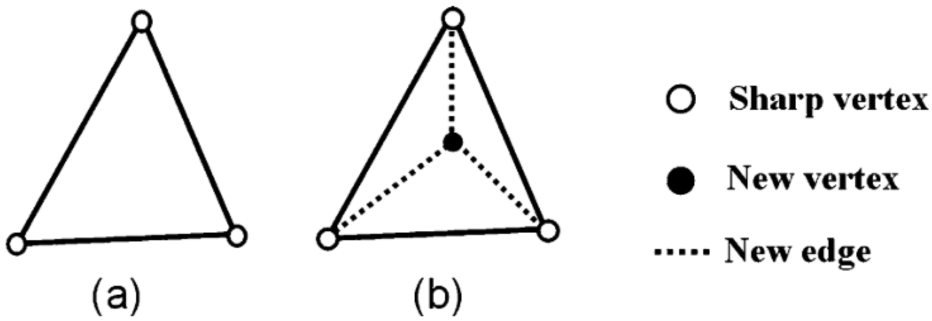


Figure 16. Mesh surface enrichment. (a) Triangle with sharp vertices, (b) associate subdivides triangle.

1. Discrete Curvature Estimation

Discrete curvature is a triangular mesh piecewise on a linear surface. Therefore, its curvature is invalid values everywhere except on edge where it is not defined. Although, it could be attractive to considerate such as a surface as a discrete approximation of the continuous surface. Otherwise, it could be defined as discrete curvature indicators. Ideally, one discrete indicator should converge to the continuous ones as a mesh density increases. Many definitions have been proposed for such a discrete indicator, and we chose to use the definition by (Guillaume n.d.). The triangular mesh is the most frequently used to surface representation in many surface-orientation applications. The surface curvature property has been employed for the solution of difference manifolds very important invariants in a different geometry object, and critical role in the task such as registration, smoothing, simplified mesh in several models, also surface classification, and 3D object recognition. By the way, almost the method for the surface derivative and curvature estimation on the mesh is based on the connectivity of vertex (Dassi, Mola, & Si, 2014). In this approach to specify a neighborhood of vertex was formed by adjacent vertices, edge, and face used to approximate (Cohen-steiner, 2003). This estimation procedure provides efficient and stable among the other and gives a satisfying result even for bad tessellated objects. It is depended on solid convergence properties (Lavoué et al., 2005). For each vertex, the curvature tensor used to calculate, and the principal curvature value $Kmin$ and $Kmax$ and direction $Dmin$ and $Dmax$ are extracted. They correspond, respectively, to the eigenvector and eigenvalues of the curvature tensor.

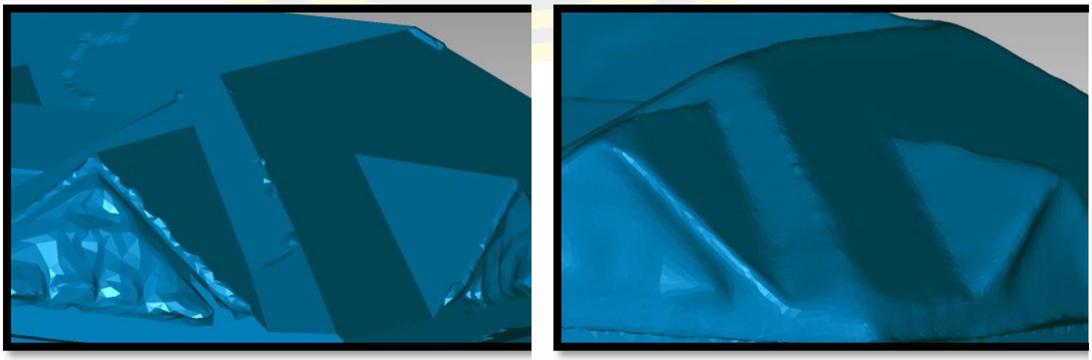


Figure 17. Smooth surface using Discrete curvature, an initial object with sharp feature detection (left), object smoothly by deleted the spike point on the curvature surface (right).

2. Curvature classification

Vertices classified according to the values of principal curvatures $Kmin$ and $Kmax$. Associated with Euclidian distance in the curvature surface. This classification is independent of the spatial disposition on the vertices. In this research, we proposed to consider basic curvature information. Besides, $Kmin, Kmax$ carry the complementary information. Usually, $Kmin$ could be negative; we consider it is an absolute value, and not necessary to separate the negative and positive values.

The clustering is done by the K-mean algorithm (This approach is unsupervised classification) (Guillaume, n.d.), the approach completed by a cluster regularization (merging similar clusters). Thus, the end of the algorithm processed each vertex on the surface is associated with a Cluster Ci (Ci is a two scalars vector which contains classified values), which the center of the associated with the cluster. The clustering starting from the initial seeds, and randomly to choose, the methods iterate in two simple steps:

- Assign value each vertex to the nearest vertex
- Compute the cluster and use them as a cluster seed.

Particularly, the number of clusters in K-mean clustering in the curvature area can set by the user. However, it is not serious because the curvature is not a final segmentation result. (Chen & Georganas, 2006) The use of K-mean classification applied to the vertex principle, which allows a fine region segmentation by detecting smooth Gaussian curvature (Lavoué et al., 2005). This algorithm has the efficiency to classify a similar level of the plane on a building like if there are lie at the same level, it can be easy to classify in the same type and provide the preside of the feature see Figure 18.

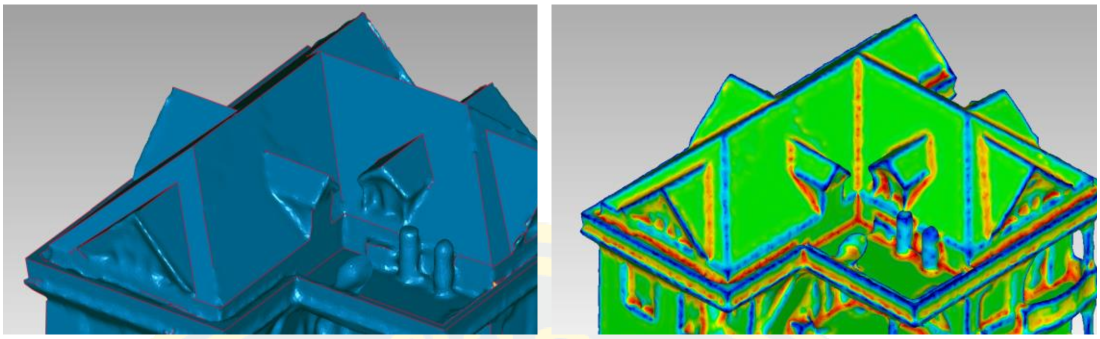


Figure 18. Vertex classification of rooftop mesh in similar curvature clusters.

3.3.5 The Region Growing Process

This section explains the methodology to achieve an objective, To assess an algorithm that can automatically detect whether roof segmentations are complete, and the question of the best algorithm to reconstruct a correct, and true reality 3D building model that can be applied with many application is that individual buildings can be reconstructed from a composition of segmented planar faces.

Segmentation is very important in the detection of the roof outlines and for the reconstruction approach of the buildings, and a set of the planar face can properly model individual buildings. The segmentation is mean to cluster the edges and vertices with similar characteristics into homogenous regions, and a variety of algorithms is available for the segmentation of triangular mesh.

To segmentation the surface of the rooftop, the proposed method as a region growing algorithm is the most popular 3D mesh segmentation method. The main idea of segmentation in this research is the approach to partition and group the similar face to region. The process starts with the initial vertex elements in the 3D mesh surface. The vertex element could be vertices or face was lies in the curvature surface. Then, the number of vertex elements is equal to the number of regions to be detected. According to the K nearest neighbors are evaluated by (i) the similar normal vector and (ii) 3D distance between vertices and neighbor. If a neighbor reaches to the criteria from the threshold, there are continue to grow up to the next vertices (Besl & Jain, 1988). The step of region segmentation, the algorithm described, each vertex on the curvature surface is given a label based on value itself and the neighborhood values. The label can only take on eight possible values based on two surface-curvature indicates the qualitative sharp approximating surface that best-fits the data surrounding point. The surface label can be analyzed for the connected region using standard connected component analysis (Dubois, 1984). This process is repeated for every other seed triangle still unlabeled.

There are three situations where a triangle is considered as a seed:

- Its three vertices belong to the same cluster c_i; thus, the curvature value c_i of this cluster is assigned to the corresponding created region **see Figure 19-a**
- It contains two sharp vertices; thus, the curvature value c_i of the third vertex is assigned to the created region **see Figure 19-b**
- It is composed of two vertices from the same cluster c_i and a sharp one. Hence, c_i is assigned to the created region **see Figure 19-c**

In every other case, **see Figure 19-d**, it cannot assign a curvature value to the triangle; thus, it cannot consider it as a seed to a region.

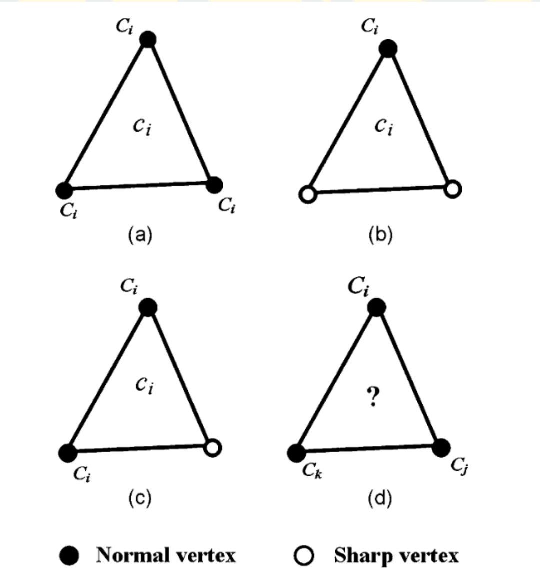


Figure 19. Three seed triangle situation (a)-(c) and undetermined triangle (d).

In case, the growing mechanism, when a face is encountered, a new region is created, and contain this triangle associated with the label L and a curvature value c_L. Then a recursive process extends this region see Figure 20. For each triangle t_L belonging to the region, for each non-sharp edge e_i of this triangle, consider the associated neighboring triangles t_i and their opposite vertex v_i. If vi is a sharp vertex or if it has the c_L curvature value, then the considered triangle is integrated into the region (the curvature associated with the region remains the same).

The region growing is repeated for every other triangle side and labeled as a seed that still unlabeled. The processed, it has remained, sometimes, not labeled triangles at the end of the algorithm (e.g., triangle with three vertices from difference curvature clusters). In the experiment, these holes appear only for a few triangles and often near to the boundary between regions. Finally, the growing algorithm depends on the number of curvature clusters. Furthermore, a fixed value of K for the K-Means classification algorithm can generate a different set of clusters because of the random point of the K initial seeds. Thus, for the given of K, the growing step can give different results in terms of number and localization of extracted regions. In order to reduce the number of curvature clusters and on the K initial seeds, a method of region merging process was developed in order to merge results,

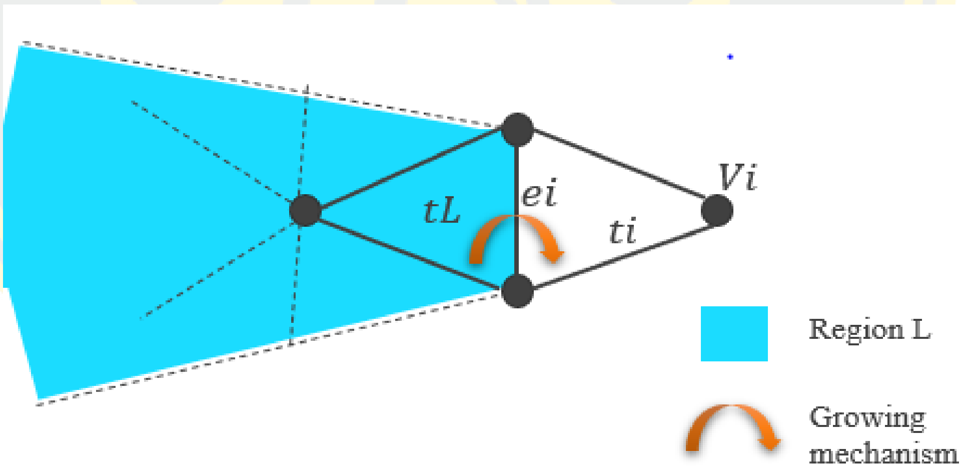


Figure 20. considered feature of region growth on curvature surface.

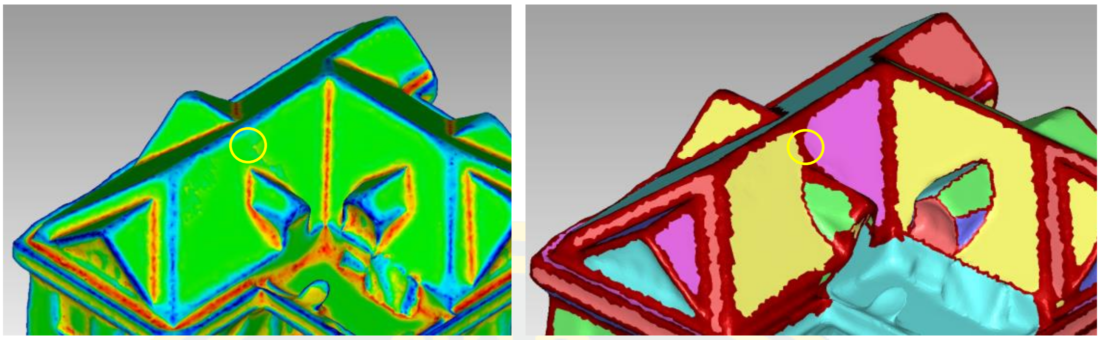


Figure 21. (left) a cluster of curvature classification. (right) Connected labeled regions grow (Region colors are randomly chosen)

The result from curvature classification is represented in Figure 21. left the vertices are classified according to the value of principal curvature $Kmin$ and $Kmax$ the absolute value demonstrated in similar region extraction in a similar color. As a result, is represented, there is a yellow remark on the curvature surface, it's a small crack on a surface in a similar region. Thus, Figure 21. right represented the labeled of region growing algorithm, the algorithm starting from a vertex and compute the neighbor of a vertex to grow up in a similar region with the satisfied condition.

Nevertheless, an example in the yellow remark Figure 21. right, there is an effected from the cluster operation, vertices have lied on a similar plane, but the different threshold values, the growing approach stops, and separated the region patch, even there are lied on a similar location, the smalls patches are merged in the next procedures.

3.3.6 Region Merging process

The region merging process is aimed at (i) reduce the over-segmentation result from the growing clusters, (ii) reduce the algorithm dependence to the number of curvature clusters issued from the K-Means vertex classification. The data strongly contribute to the efficiency of an algorithm. The purpose of the region merging algorithm is to merge the similar adjacent region on the surface curvature. A good represent result is a region adjacent graph (RAG), a data scheme used for their face clustering algorithm. The analysis structure contained the set of vertices and edges. Each vertex represents a connected region, and the edge represents the adjacency between two regions. Edge was evaluated by a similar distance between two corresponding regions.

The once connected region has been extracted by the region growing algorithm, the region adjacency graph RAG is processed, and the distance between them is calculated. Then, at each iteration, the smallest edge of the graph is eliminated. Hence the corresponding region is merged. Therefore, two regions are merged, their curvatures are merged into their areas to give the curvature of the resulting region. This graph reduction ends when the number of regions reaches a quired value chosen by the user, or when the weight of the smallest edge is larger than a given threshold.

The approach of Region distance measurement is the region distance D_{ij} used in our method is equal to the curvature distance DC_{ij}, between two corresponding regions R_i and R_j weighted by two coefficients: N_{ij}, which measures the nesting between the two corresponding regions and S_{ij} the aim of which is to eliminate the smallest regions:

$$D_{ij} = DC_{ij} \times N_{ij} \times S_{ij} \quad (1)$$

Each coefficient is detailed in the following paragraphs. The curvature distance D_{ij} is processed by using the curvature values c_i and c_j of the two corresponding regions and the curvature value c_{ij} of their boundary

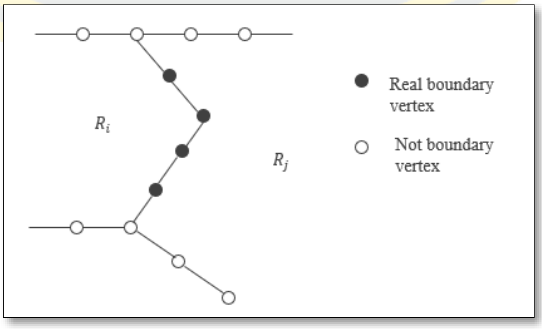


Figure 22. Demonstration of the vertices taken into account for the calculation of the mean curvature c_{ij} of the boundary between two regions.

$$DC_{ij} = ||c_i - c_{ij}|| + ||c_j - c_{ij}|| \quad (2)$$

c_i and c_j come from the region growing step. c_{ij} is an average of the vertices on curvature surface belong to the boundary between two regions. Only vertices within the incident edge separating these regions (real boundary vertices) are considered in Figure 22. in order to consider only the real boundary between them.

This is important for the calculation of the curvature distance between the two regions to consider not only their respective curvature c_i and c_j but also their boundary one c_{ij}, because two situations may happen between these region. Either region has some different curvatures, and no precise boundary or regions have almost the same curvature and a very different boundary curvature.

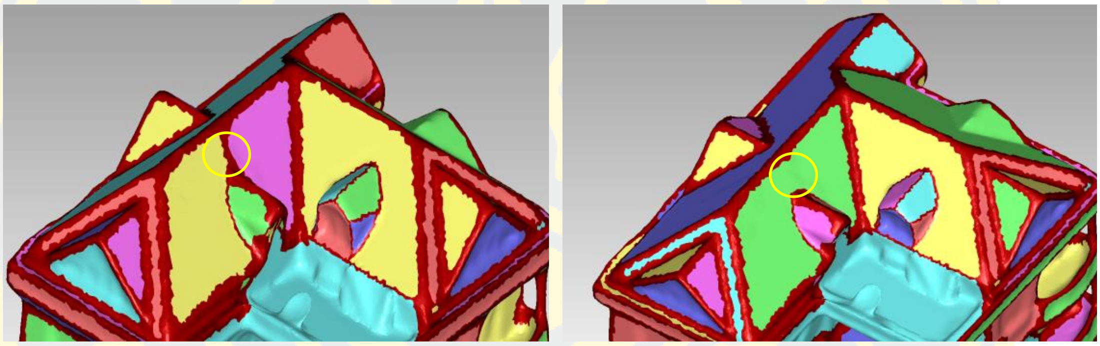


Figure 23. (left) Finished region growth (Multi small patches) (right) Merge small patches are similar regions together.

We can compare see Fig 23. left growing process, in a similar plane, have a small patch and separate patch. Thus, to solve that problem, the merging algorithm see Fig 23. right used to merge the smalls patches, and the final result should be a similar plane. As a result, represented the merging process, a small patch on a similar plane is connected to a single plane. The coefficient measures between the two corresponding regions were introduced in image processing for the color image segmentation. The approach is to consider the spatial disposition of the regions in the merging decision. Regions with a large common border are more likely to belong to the same characteristic part. Thus, their similar distance is reduced. Then some of region area is smaller than each other, and it is considered a region will be more easily merged with another region.

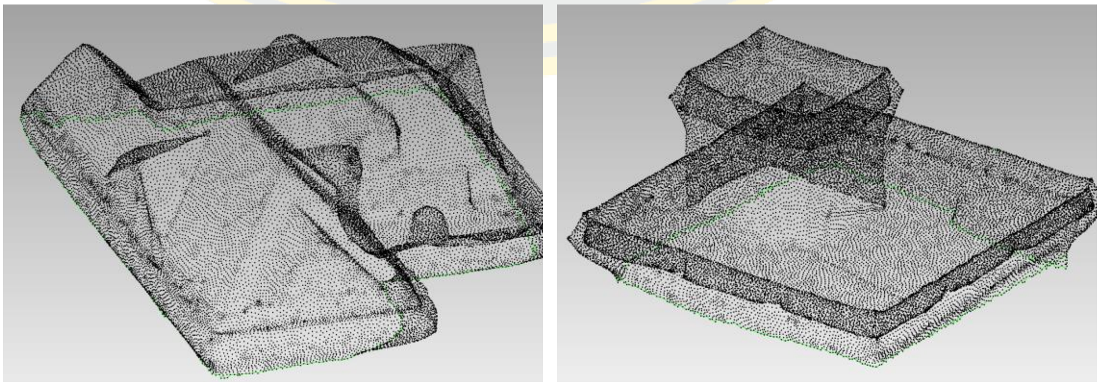
CHAPTER IV

RESULT AND DISCUSSION

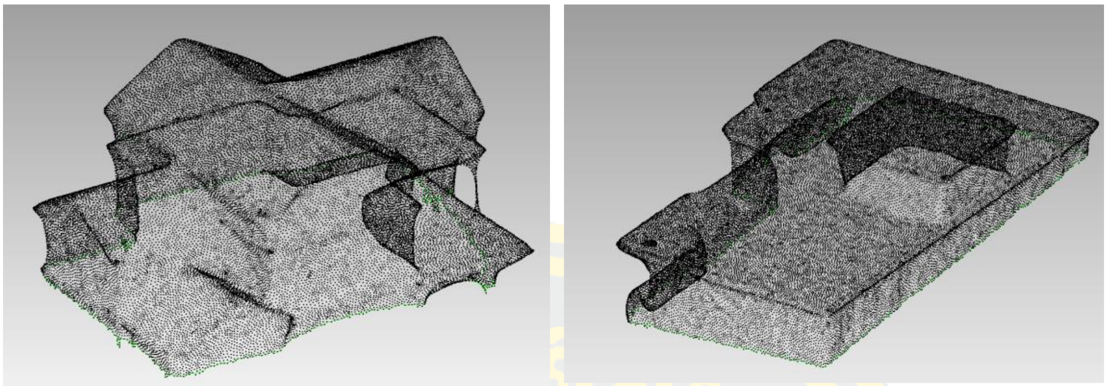
This chapter demonstrated the results of the Region Growing technique based on curvature analysis observed the triangle mesh and provide the opportunity to segmentation the rooftops. The results are represented the Rooftops structure derived from the proposed method, give a discussion in each step and comparison with other methods.

4.1 Results of UAV Images of the dataset

As the material is oblique images derived from UAV, in order to reduce the execution time, proposed to use the Get3D software to generate the point clouds from 2D image to 3D geometry points. The following results were achieved in see Figure 24. The algorithm of photogrammetry allows using the Multi-View Stereo image and redundancy image to be generated point cloud based on dense image matching. According to the matching results of the feature points and the orientation parameters, point clouds are covered in the study area were generated, it is the dense point clouds reflect the high of building. The noise filtering is done by the least squares for the best plane fit algorithms. Then, result from Multi-View Stereo, all pixels were re-projected to obtain the dense point cloud model.



(a) (b)



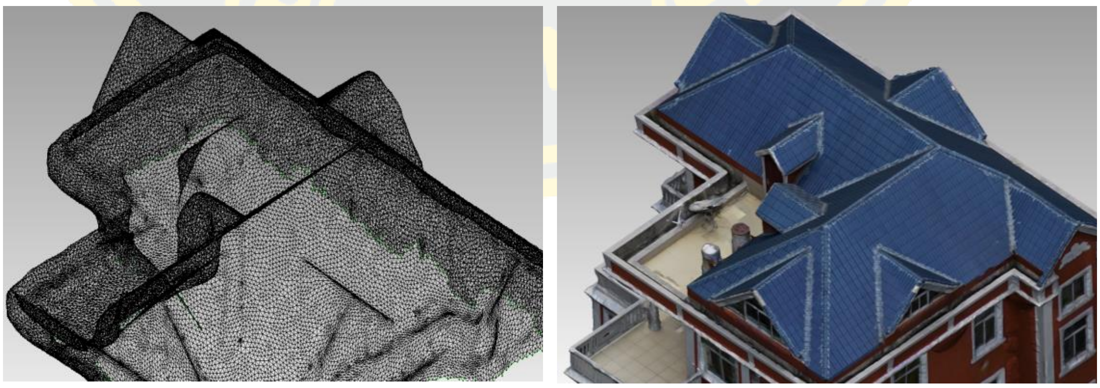
(c) (d)

Figure 24 Generated point clouds of 3D building model from the approach of dese image matching

Finding: Describe the specific equipment and method useful for exploiting the significant advantages given by the use of oblique images derived from UAV for obtaining the complete 3D building models of very complex architecture. The use of the Dense Image Matching technique allows achieving a very accurate and dense point cloud. In particular, in the use of commercial software, in this research, we used Get3D software, realizes the feature matching and exterior orientation image very rapidly. However, the technique allows a collection of complex and complete information in a short time, which an excellent advantage for generated the high-detailed 3D building proposed for roof detection. Previously, we have tried to generate the 3D dataset from the manual algorithm and opensource software, but it cannot provide the realistic models in our study in a large area. It is not easy to generate the dataset on a large scale, however, depended on the performance of hardware and powerfully software. So, if other user would like to use the 3D building model, we suggest to using the commercial software and focus on the small area.

4.2 Results for mesh models with realistic texture representation.

The surfaces of the 3D model are often represented by approximating triangular meshes. Their triangles are the simple form of surface samples, which may be acquired from the small aerial equipment that was generated by the photogrammetric methods. This measurement performed with automatic procedures. The dense image matching algorithm produced a very dense point cloud. A triangulation converts the given set of point clouds into the consistency polygon model (called mesh model). The operation partitions the input data into simplices and usually generated vertices, edges, and faces (representing the analyzed surface) that meet only at shared edges. Then, for the textured surface, it is used for photorealistic visualization of 3D building models. Texture mapping, in its simplest form, involves a single texture (Image orthophoto) being mapped on to the surface composed to one or more polygons. When mapping an image onto the objects, the color of the object of each pixel is modified by the corresponding color derived from the texture. This part demonstrated the triangular mesh building finished by the photogrammetry software, and they furnish the complete building model on a precise scale on the study area. This research was focused only on the rooftops of data set, see Figure 25. The data set of our experiment has a different characteristic for the implemented region growing algorithm.



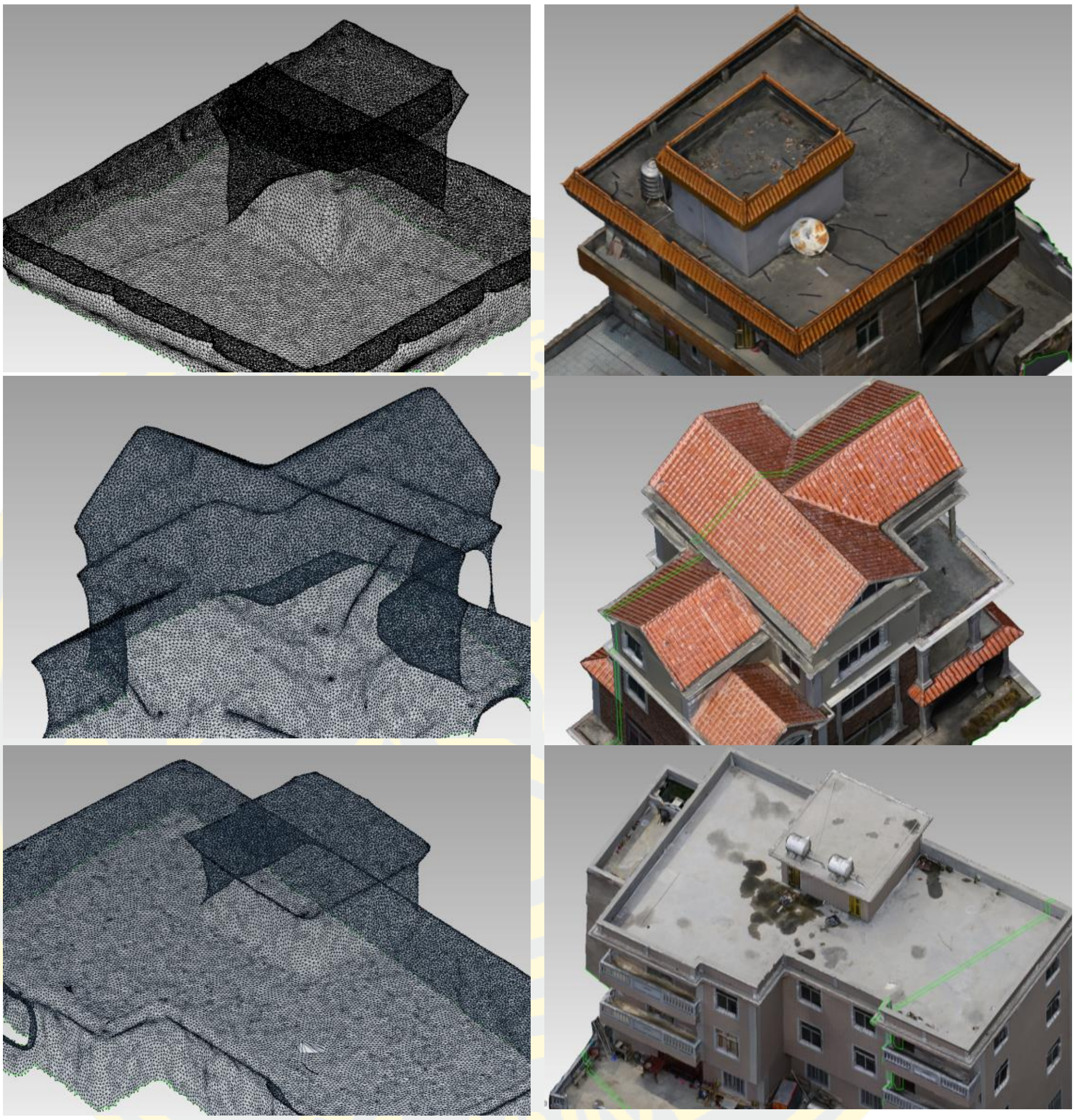
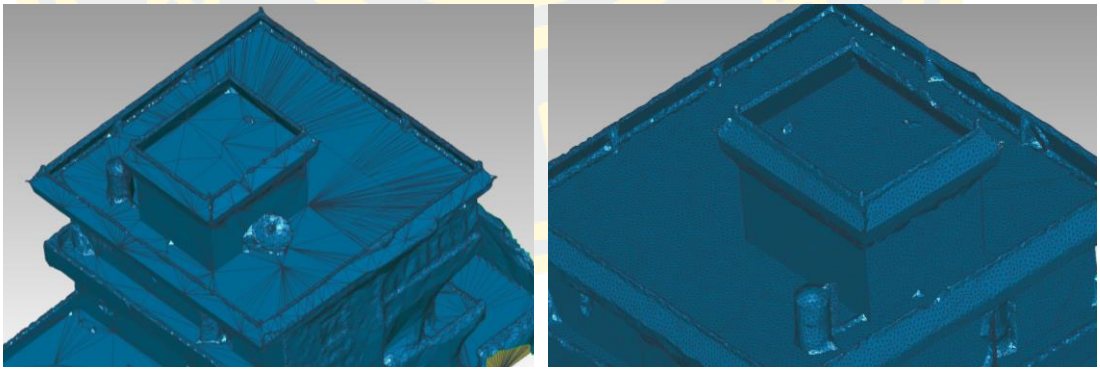


Figure 25 Triangle mesh models represent vertex and edge (left), the triangle mesh triangular mesh with mapping texture represented building rooftops (right)

Finding: The greatest limitation was founded in the step is the system required a lot of memory for generating the dense cloud, mesh surface, and realistic 3D texturized models. The approach to generate the 3D virtual model is very time-consuming for the large scale, we have tried to use many applications such as visualSFM, Agisoft Metashape, and photoscan software. Finally, we used the existing 3D mesh model's data were generated by Get3D software that given the completely high-resolution model. The advantage of the 3D model is possible to capture all of the building rooftops from the 360-degree view of a building. Even the software can process the automatic build-up of the model. However, the models still have some problems at the boundary and a little bit on the surface mesh but not too much. We can solve the problem of this problem by using the image processing algorithms are described in a later section.

4.3 Result of sharp edge detection

This section presented the strategy of generated the new vertices on sharp edges on CAD models that implemented. Following the result were achieved by sharp feature detection to preserve the geometrical features of the specified objects. In order to reduce the number of bits to vertex locations, our algorithm performs a remeshing of an original mesh, constraining the position of the vertices to follow a prescribed scheme. Particularly, the method is created and grows the new mesh by attaching the new triangle at that time following the order of method Figure 26, b, d, f, h. When the new triangle has a new vertex, the location of the new vertex is computed as the intersection of a cycle orthogonal to the gate with the original surface, forcing a new edge to a prescribed length. In our case, we have observed that sharp features significantly reduce the error between the original shape.



(a) (b)

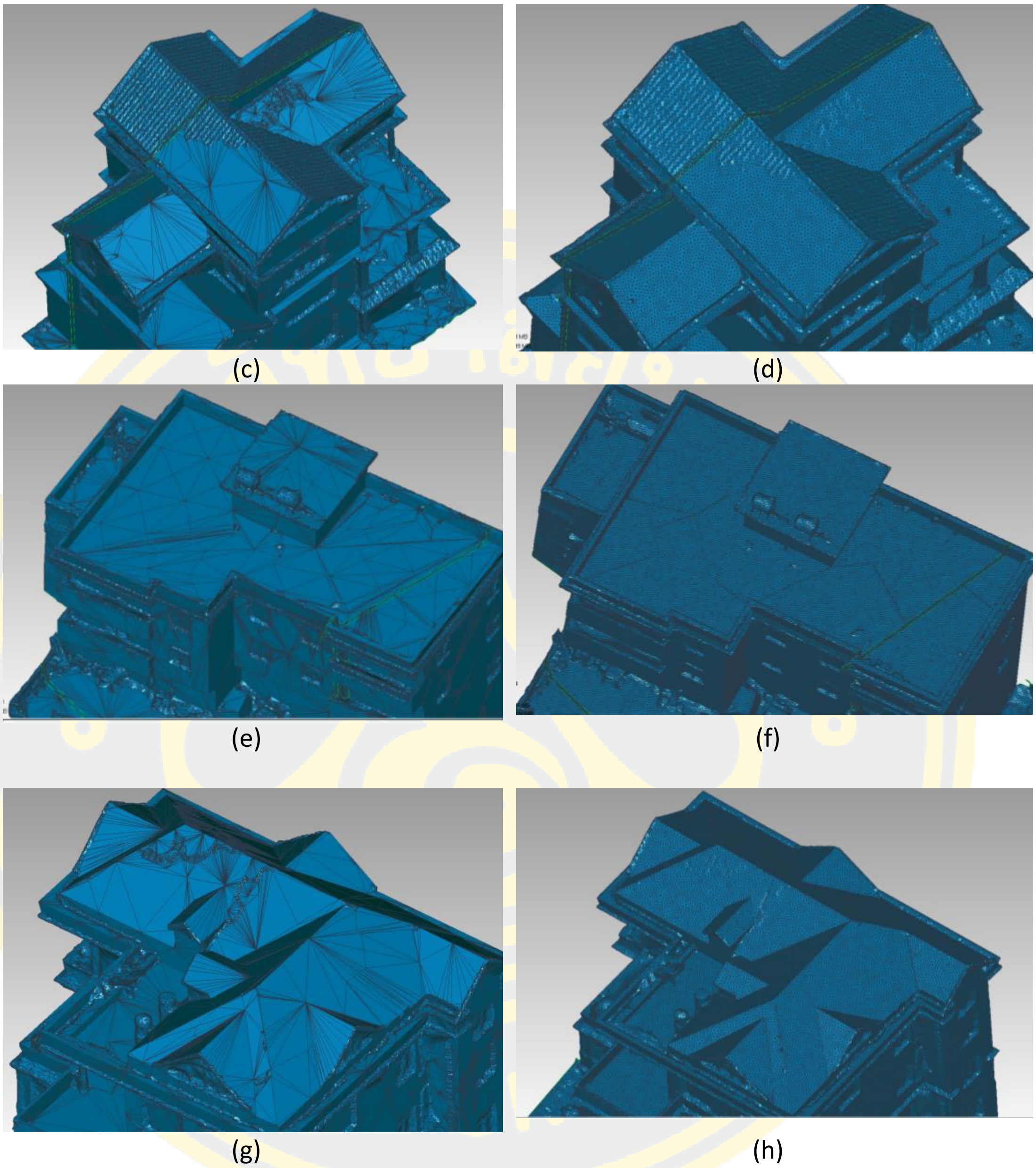


Figure 26. the initial edge and vertices column left (a, c, e, g), the optimized mesh extending to smooth surface column right (b, d, f, h)

We have tested our algorithm on an existing of meshes generated through the sharp feature detection method remeshing strategy. We had found that, when the original model was sampled with a sufficiently high density, most of the sharp features can be completely recovered, while the parts of the mesh that correspond to the regions of the original model without sharp features are not modified by our algorithm. Moreover, while a remeshing on the whole model can represent an additional error on the regions without sharp features, the local modification we propose only affects the aliased zone. Moreover, the effectiveness of the proposed method is not restricted to uniformly sampled meshes. For example, Sharp feature detection method correctly restores the sharp features of typical

Finding: This approach presented a surface remeshing method for CAD surface. The advantage of the method is beneficial to optimize geometry approximation and mesh quality. As the input data representation, the vertex align on the surface is not surrounding, so, from the approach of sharp edge detection, they can calculate to generate the new vertices on the original surface mesh by reducing the encoding of each vertex. After sharp edge detection restored by the sharp feature algorithms, the error between triangle mesh and the original one is distributed more uniform and accounts for the difference between the original curved surface; it is a piecewise-linear approximation. When the original surface is smooth, the error may be further reduced by subdividing the approximate triangle mesh.

4.4 Results of Discrete Curvature Estimation

This section represented the smooth surface objects that were achieved from the discrete curvature method. Following the results were achieved to smooth the mesh surface in order to reduce the vertex by calculated the neighbors of a vertex in a similar region. From the previous procedure, the objects are closely to smooth. Due to the surface of models, they have an error geometric (spike point), that vertex is high curvature rather than each other. The principal curvature used to evaluate the normal surface at a particular vertex and spin that intersecting plane around according K_{min} and K_{max}. They represent on the surface of discrete curvature of the same surface after the parameter has been smoothed by using the mean of curvature are explored to observe in the whole model. To clearly, identifies the blending the area of a surface. Using several threshold values specified by the user, the surface decomposition illustrated in the figure see Figure 27. has been obtained. Though this result cannot be produced by fully automatic because some constant value of the threshold cannot be suited for the whole of the building process.

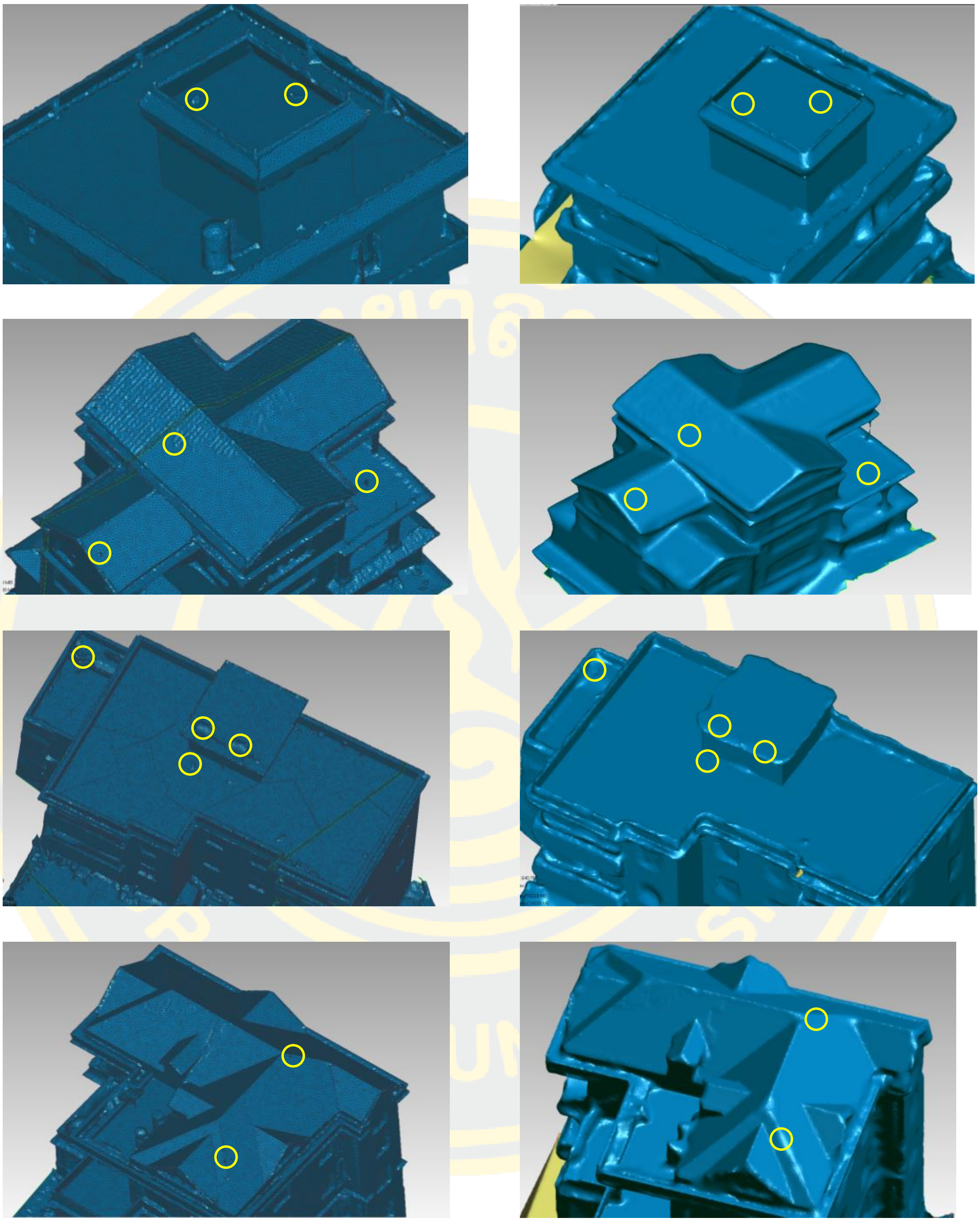
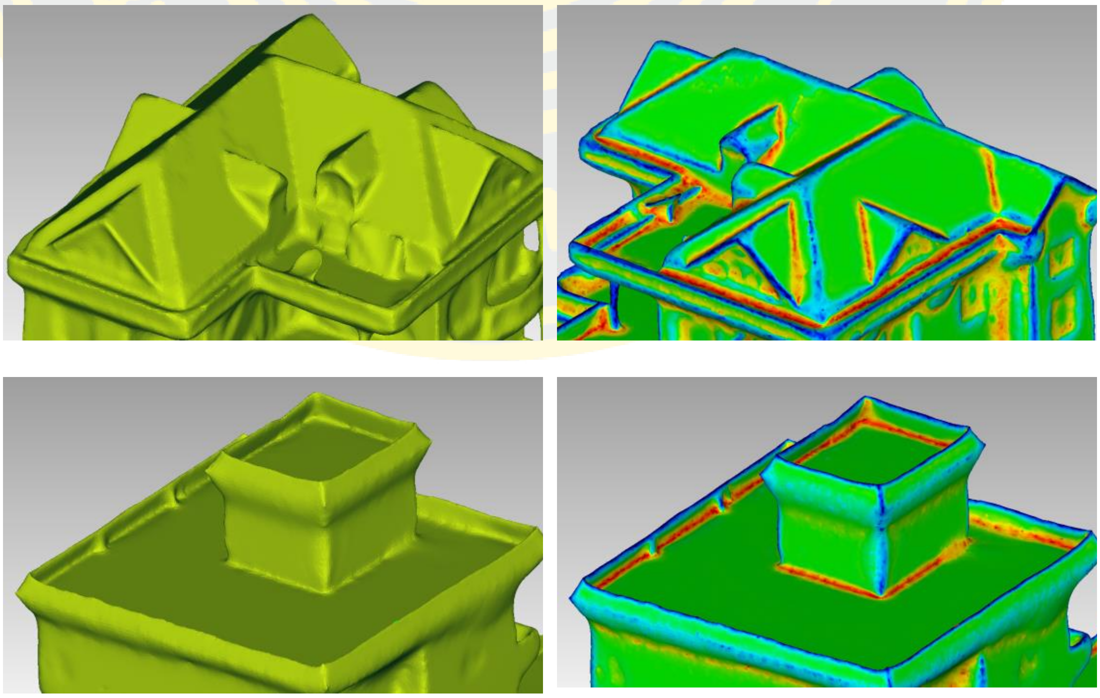


Figure 27. Spike point on the surface, example yellow remark(left) the surface already solved by remove the spike point and calculated based on principal curvature to estimate the edge and new vertices (right)

Finding: As a result of the building mesh surface models was smoothed by the parameter of discrete curvature based on the normal cycle, the surface objects are represented quite smooth on the whole surface, but when focusing on the yellow remark, we point it to describe as we mention above. This approach cannot produce by fully automatic, because even if the method can smooth closely complete, there still have some spike points lied on the surface. Though this result cannot be produced by fully automatic because some constant value of the threshold cannot be suited for the whole of the building process, we can solve this problem by manually.

4.5 Result of Curvature classification

After the processing of vertex classification base on curvature estimation, the following results were achieved in Figure 28. the initial building objects (left column) every vertex on the surface were calculated according to the values of their principal curvatures K_{min} and K_{max} (right column), associated with the Euclidian distance (in the curvature space). This classified is independent of the spatial disposition of the group of vertices. In this step, we just needed to consider basic curvature information and not a complex tensor feature like a shape or the orientation. Moreover, K_{min} and K_{max} can carry complementary information. In fact, the result represented K_{min} can be negative, but this procedure considers only its absolute value, as it's not necessary for us to differentiate positive values or negative values regions, which have a similar visible curve aspect.



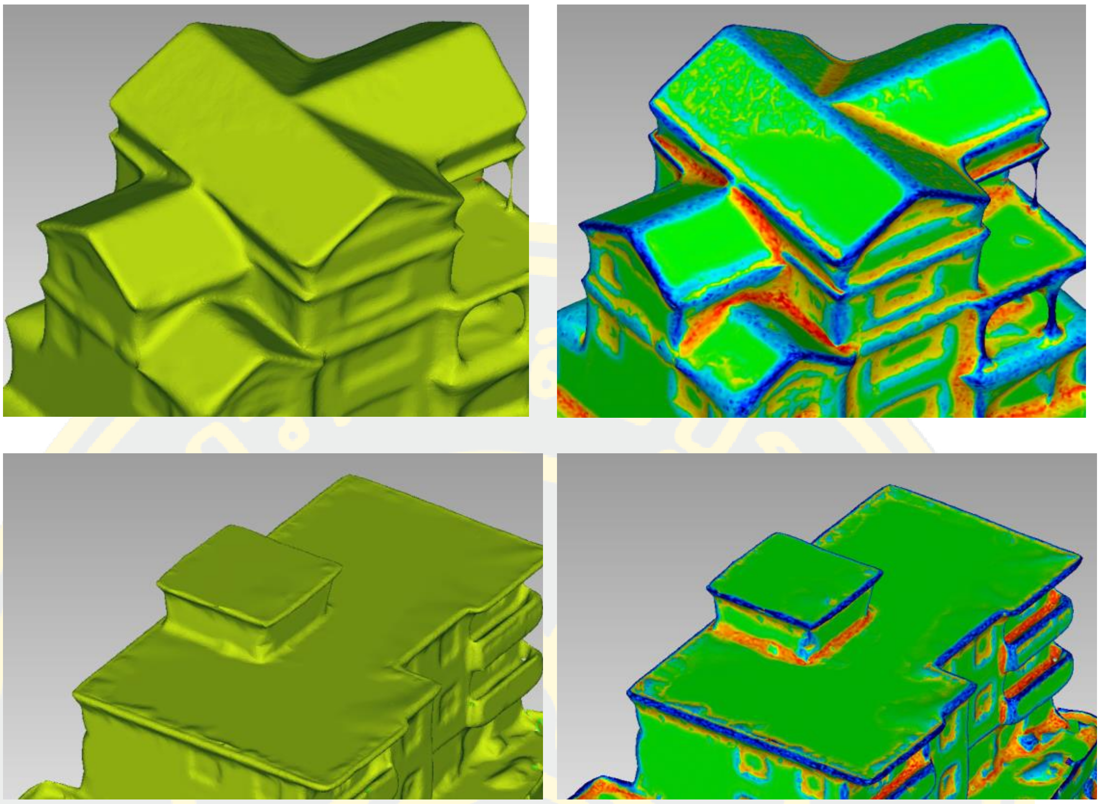


Figure 28. Vertex classification of the rooftop mesh in a similar cluster.

Finding. As a result, the color of classification meaningful the group of similar vertices on the surface, The number of clusters K, in the curvature space, is set by the user but is not critical for the final segmentation result, because of the region growing and merging in the next steps. The use of K – means algorithm is followed by a cluster regularization (merging of the similar small clusters), which gives K' final clusters.

4.6 Results of Region growing process

4.6.1 Growing and Merging method

This section was focus on our segmentation method; the proposed method was tested on several different objects. The examples are given for various complex 3D mesh elements see Figure 29. and for four objects, different characteristics see Figure 28. a complex Gable Roof with Dormer Window (a), a Mansard roof (b), a complex Gable and Valler roof (c), a common flat roof (d). Figure 28. demonstrated the segmentation results for the 3D object's elements. Their decompositions are correct and adapted to our constant curvature region extraction and surface fitting objective. Our method permits to detecting curvature transition or curve points and not only region separated by high curvature boundaries, or sharp boundaries, like traditional watershed methods. Even for a bad tessellated object, however, we can obtain a good result after the enrichment of detected sharp triangles. As a result of the region growing processed all vertices and edges are covering the roof planes, it can be detected and classified by the roughness and segmented into the homogeneous triangle mesh surface of similar normal vectors. Each segment at a similar region represents one roof plane. The vertices' K nearest neighbors are evaluated by first, similar to the normal vector, and the second is the 3D distance between vertices and neighbors. If a neighbor reaches the criteria, they accepted as belonging to the segment and used as a next vertex, as we see in Figure 29. In each initial vertex started to grow to the neighbor and they are reaching to criteria, on a similar roof plane represented a similar color, means to they are similar region surface. The number of triangles, the number of curvature clusters, and number classification algorithm iterations. Hence, complexities are the following: for the curvature computation and for the vertex classification. Considering the region growing algorithm and region merging steps, the processing time depends on a number of regions grown and region removal number.

We studied the dependency of the algorithm on the number of curvatures $K - clustreing$ which parameters the K-means algorithm within the vertex classification procedure. The vertex classification was processed with different values, and the threshold fixed to 75 was chosen for the region merging step. The results show that of course, K influences the number of regions created after the growing step, but the final region number is regularized by the region merging algorithm, and the result segmented regions are almost identical. It happened because the region merging process is strongly linked to the curvature values of the regions. Indeed, the different sets of region merge associated with different values of K for a similar object, keep the partially the same curvature distribution. Thus, the strongly reduced algorithm dependence considered a critical parameter method.

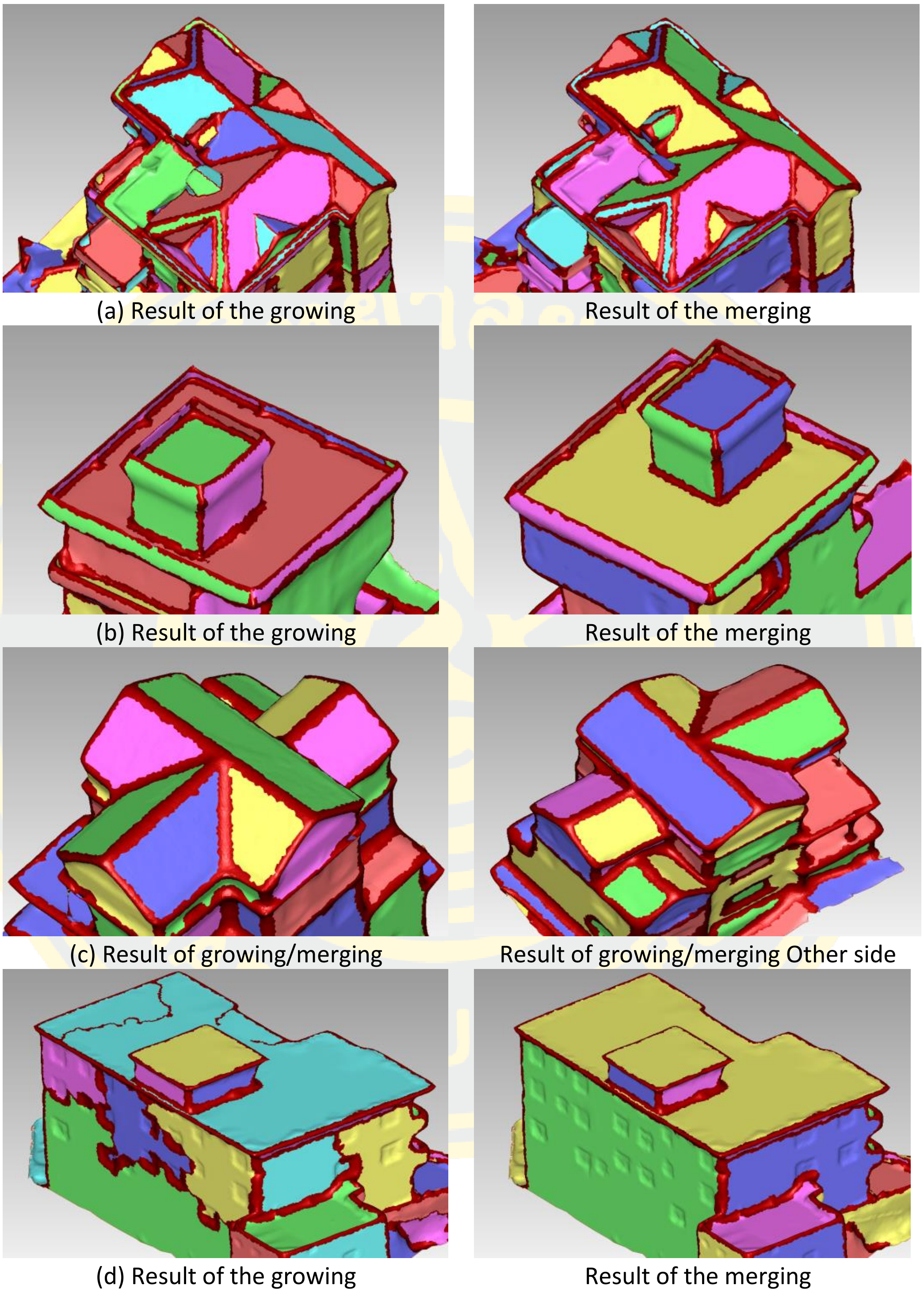


Figure 29. segmentation region from the growing method (left) merging region lies on a similar plane (right).

Finding: After preprocessing, the algorithm of region growing started working by being the initial on some vertex on a plane and calculated the neighbor to find the way to grow around. As the picture result, similar color and planes mean there are some values in those criteria of a growing approach. The red line on the primitive result is a separator, the separator working on the partition of the different values on the surface it is on the threshold setup. After that, if they are the separate region on the same plane, then while the growing process, in a similar plane, has a small patch and separate patch. Thus, to solve that problem, the merging algorithm used to merge the smalls patches and the final result should be a similar plane. We can decide to be using a merge of the region to combine them.

4.7 Final segmentation results

The developed segmentation algorithm was tested with the 3D mesh models generated from the UAV images of a small urban area in Wuhan, Hubei, China. The images are captured in oblique combined with the nadir view. The buildings in this region are selected by different complex characteristics. The buildings selected are more identically and mainly made of planar surfaces. Among them, four buildings that show different structures were considered for testing the segmentation algorithm see Figure 30. The selected buildings have a gabled, flat, and different kind of roof styles.

The obtained results were high-quality when compared to the original models (Figure 28, b, d, f, h). Most of the roof plane elements were also segmented. However, a few places on the rooftops were deleted before started segmentation, such as a water tank, or some dirt things on the rooftops, because it’s can make the over-segmentation. Finally, our method can achieve the rooftops with geometrically recognized as single planar segmentation.

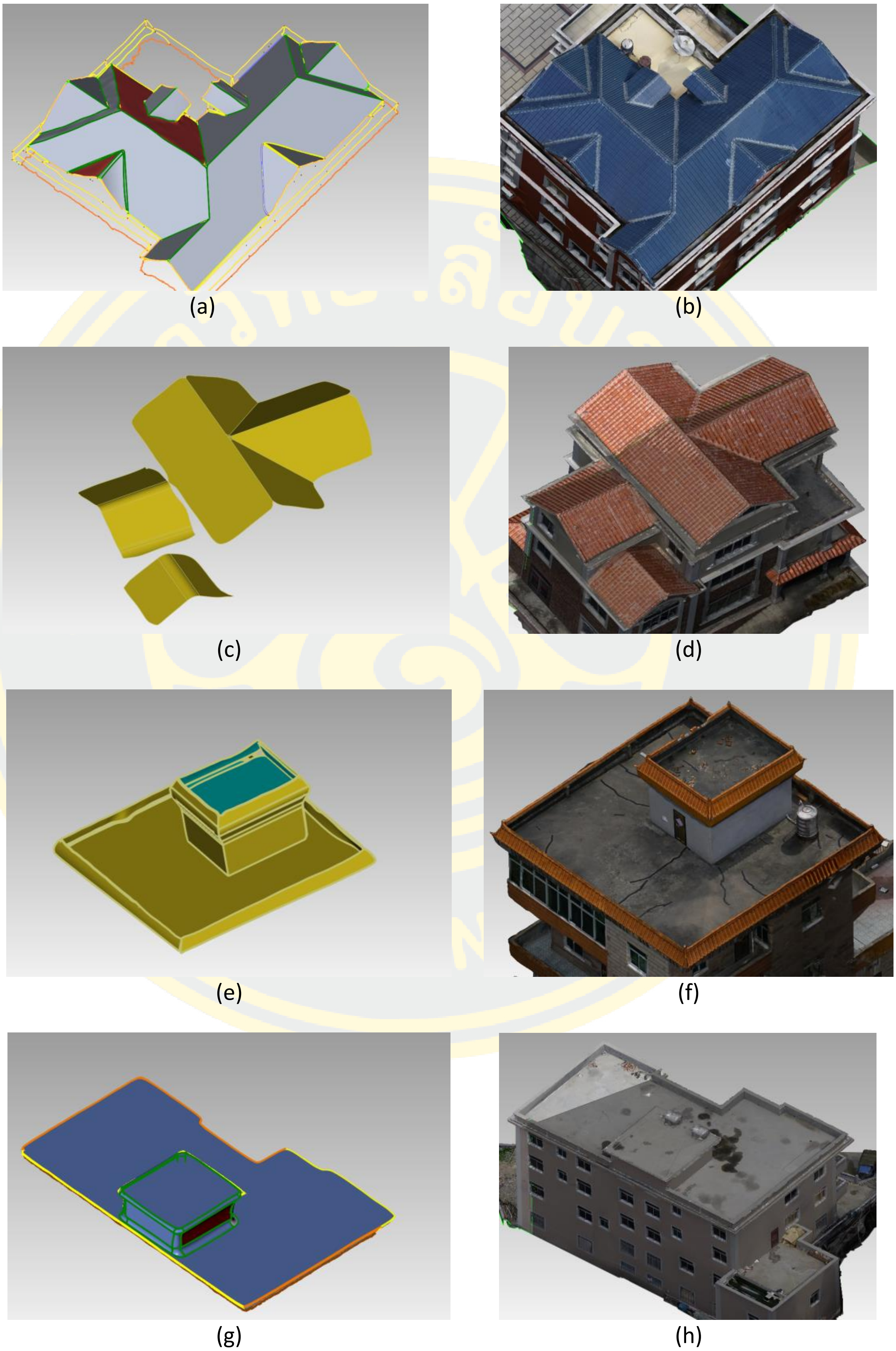


Figure 30. Segmentation results for several complex 3D elements, Finally, segmented image using our developed method, (a), (c), (e), (g). Building from UAV (b), (d), (f), (h)

Table 2Performance estimation of region growing algorithm.

3D mesh model	Composition of the current triangle	Automatic detected based on region growing method	Manual detected/number of roofs each model.
Building model with complex gable, and Dormer window (b)	70,847	19	19
Building model with complex gable with valler roof (d)	48,647	8	8
Building Model with mansard roof (f)	690,552	14	14
Building model with flat roof (h)	84,119	6	7

Finding. Table 2 above represents the quantity accuracies of automatic detection based on region growing algorithm and compared with the manual detection for 4 triangle meshes models. Automatic region growing detection were detect model (b) 19 plane, (d) 8 plane, (f) 14 plane, (h) 6 plane. The percentage of the overall accuracy of the detection roof plane is 97.92%. We have conducted tests with several objects; our method allows detecting curvature transitions or inflection points and not only regions separated by high curvature boundaries, or sharp boundaries, like traditional watershed methods. Even for the bad tessellated objects, we obtain good results after the enrichment of detected sharp triangles. This research studied the computational cost of the algorithm; examples are illustrated in table 2. All of the experiments were conducted on a laptop with a 2.2GHz Intel Core i7. In this context, the objective of the boundary rectification process is to suppress these artifacts in order to obtain clean and smooth boundaries corresponding to the real natural boundaries of the object.

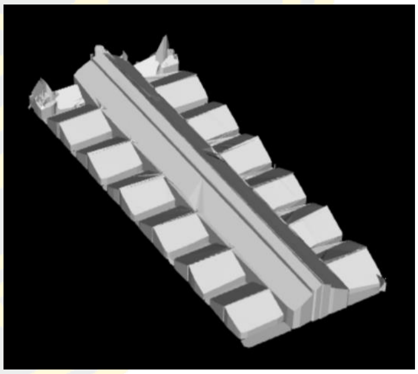
4.8 Comparison with other methods.

Our segmentation method was evaluated and compared quantitatively to the most recent algorithms from state of the art. (Vetrivel, Gerke, Kerle, & Vosselman, 2015) was develop the segmentation of delineation using a roof base approach algorithm tested with the 3D point cloud also generated from UAV. They also selected the Building have different characteristic to considerate the testing segmentation. (Jochem, Höfle, Rutzinger, & Pfeifer, 2009) developed the segmentation of point-based region growing method.

Table 3Comparison of previous studies with the detection method

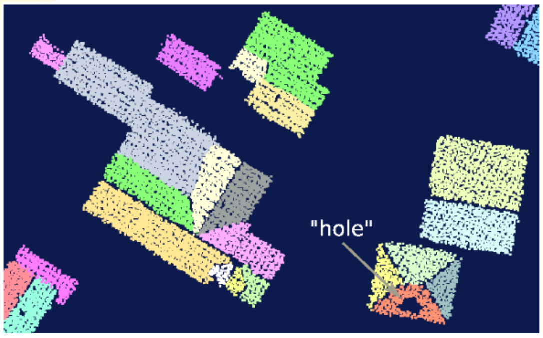
Data	Modeling	Reference
LiDAR Point cloud	Point based region growing	(Jochem, Höfle, Rutzinger, & Pfeifer, 2009)
3D mesh model	Moving Least Squares (MLS) algorithm	(Polcz & Benedek, 2014)
3D mesh model	Region Growing method	This study

(a)

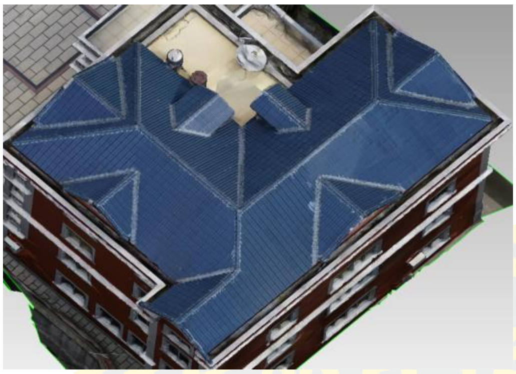


(b)

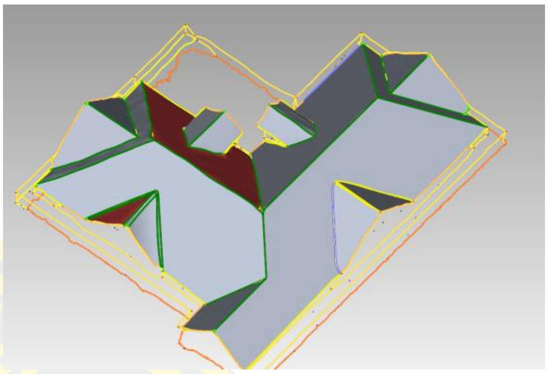
(c)



(d)



(e)



(f)

Figure 31. (a) (b): segmented 3D rooftop based on Moving Least Square (MLS) algorithm (Polcz & Benedek, 2014), (c) (d): LiDAR point cloud segmentation using point-based region growing (Jochem, Höfle, Rutzinger, & Pfeifer, 2009), (e) (f): roof segmented based on region growing using curvature estimation.

The results are shown from roof segmented based on Moving Least Square (MLS) algorithm (Polcz & Benedek, 2014), a surface roof plane of the segment resulted are illustrated the the algorithm can be applied for a wide range of building types even though it solely estimates the geometry of objects by several planar elements (polygons) see Figure 31 (a) (b). the Moving Least Square (MLS) algorithm can reconstruct the building with complex architectural roof models. The result from the proposed method gives a very good of roof detailed when compared to the reference aerial photo. Another author as (Jochem, Höfle, Rutzinger, & Pfeifer, 2009) using the point-based region growing process on LiDAR point cloud data. Consequently, roof ridges are not always detected by the segmentation algorithm. Points having a normal vector that differs beyond a defined angle threshold do not become part of the current segment. As represented in see Figure 31 (d), the normal vector of points on the roof ridges are more or less the vertical to the ground. Note that the number K of nearest neighbors strongly influences the resultant normal. Otherwise, the reason why missing the roof ridge is the values of each point. It is higher on the ridge than other parts of the roof. They using a robust plane fit for feature calculation would be to improve the results, and the segment could grow closer to the ridge. We have studied from many previous problems, so I tried to develop the approach of automatic roof detection using region growing algorithm based on curvature estimation, our results represented the geometry roof structure. We used 3D triangle mesh model to experiment this method, even the method works well and give the results closely to the natural object, however, at the boundary of roof structure still not completely as it is not sharp enough in the corner, and a bit roughness see in Figure 31 (f) and Figure 31 (c).

CHAPTER V

CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

The high-detailed 3D mesh models generated from the high-resolution oblique images taken from different view directions contain more building rooftops information than nadir image. The availability of oblique aerial images brings the possibility to extract dense point clouds, then used the dense cloud to generate the virtual 3D model with more detail of building automatically. The 3D object detection using the efficiency of the mesh model can be applied to several applications such as city planning design and solar roof areas but, it's cannot provide the semantic information about the roof structure. Thus, the need for mesh segmentation as a preprocessing step for various application.

This thesis investigated detection on a triangular mesh data structure based on the efficiency of region growing algorithm using curvature estimation to generate the roof structure. In this chapter, we summarize the work in this thesis and provide the suggestion for the direction of the future work in some of areas addressed in the previous chapter.

We first, presented to use the high detailed information of mesh derived from UAV, the reason that we chose the UAV data for our research because the advantage of UAV operation is cheap and provided the true 3D model. Many applications provided the Automatic generate from 2D aerial image to 3D models. We studied the mesh segmentation of the 3D mesh model; the existence of mesh still has a problem on the surface boundary. We modified by sharp feature detection in order to reduce the number of encoding the vertex location, the error between a curved smooth surface and its triangle mesh approximation can often be reduced through the subdivision. We have used the remeshing approach that preserves the sharpness of sharp edge while remeshing their piecewise linear approximations into a smooth curve surface. The sharp feature detection is useful within the region growing process.

The second, Vertices of the mesh are classified according to their discrete curvature. We estimated the curvature information of each vertex of the proposed triangular mesh we have implemented work using the average Voronoi cell and finite-element and volume of the method. The result presented the color scale depend on the considered curvature. Then, vertices classified according to principal curvatures $Kmin$ and $Kmax$. Then, completed by a cluster regularization, merge of similar small clusters. At the end of this procedure, each vertex is associated with a cluster and classified curvature value.

The third, we studied in the proposed is region growing algorithm, from the previous step once vertices have been classified, we used the triangle growing and labeling operation. In each triangle, they have three vertices belong to the same cluster is considered as a vertex. This region grows by starting from a vertex and go to the neighbor vertex in the satisfied condition. This process is repeated for every vertex and not yet labeled.

Lastly, our segmentation method was tested on the different complex of a roof structure; we have to present the boundaries of the final extraction patches. The decompose a 3D mesh results, as well as the boundary, are quite satisfying with regard to our further surface fitting application.

5.2 Future work

Our first contribution (Rooftop detection on 3D mesh models) has been thoroughly studied in this research. And for future work, we have the plan to extend our work to develop the criteria to identify the other features part of the building required to obtained an operation segmentation of the façade, balcony, and the outer boundary of the building area. However, learning mesh segmentation is a new research area and can benefit from further improvement. Moreover, this type of algorithm produces the automatically meaningful segmentation, sometimes look similar to create by humans, that several applications requiring such type of the segmentation can use this algorithm as a preprocessing step. In what follows, this research points out some research areas concerning possible improvements that can be brought to our method and the direct application of this latter one.

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