FEATURE-BASED REAL-TIME AERIAL IMAGE STITCHING AND QUALITY ASSESSMENT FOR POST-DISASTER APPLICATION

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ABSTRACT

In the past, digital maps were created using a photogrammetry framework where the Unmanned Aerial Vehicle (UAV) would collect the aerial images; then, images would be post-processed through commercial software using the Structure From Motion (SFM) method. Creating digital maps has been helpful for remote sensing, especially for studying and observing the terrain. However, one disadvantage of this method of creating digital maps is that it consumes more computational time. Although commercial solutions are widely used, they are not suitable in disaster-affected areas because of the long computational time. Disasters such as earthquakes, floods, and landslides would happen without prior notice, and areas affected by such a disaster would suffer heavy damage. In such a situation, the authorities need an instant digital map to observe the affected areas and decide. Hence, this study focuses on accelerating the creation of a digital map using the real-time image stitching method. Image stitching itself can be divided into feature-based and region-based methods. This study uses a feature-based image stitching method to accelerate the map creation process. This research formulated an image stitching algorithm to stitch aerial images in real-time. A processing speed of 37 frames per second was achieved. The image stitching algorithm was optimized to stitch large areas captured using the multi-grid flight path; a processing speed of 2 frames per second was achieved. Finally, an image selection algorithm was introduced to improve the stitch image quality by 14% and the computational time by 2-fold for a multi-grid flight path. In conclusion, the developed image stitching algorithm can reduce the computational time needed to produce a digital map at the disaster site. Although the developed image stitching algorithm can stitch faster with improved quality, more testing needs to be conducted using aerial images from disaster sites.

ABSTRAK

Pada masa lalu, peta digital dihasilkan menggunakan kerangka fotogrametri dengan menggunakan *Unmanned Aerial Vehicle* (UAV) untuk mengumpul gambar aerial; kemudian, gambar tersebut akan diproses melalui perisian komersial menggunakan kaedah *Structure From Motion* (SFM). Penghasilan peta digital membantu remote sensing terutama untuk kajian dan pemerhatian kawasan. Bagaimanapun salah satu kelemahan dengan kaedah ini dalam menghasilkan peta digital adalah ianya mengambil masa pemprosesan yang lebih. Walaupun penyelesaian komersial digunakan secara meluas, ia tidak sesuai digunakan untuk kawasan yang dilanda bencana kerana masa pemprosesan yang lama. Bencana seperti gempa bumi, banjir, dan tanah runtuh berlaku tanpa amaran awal, dan kawasan yang terkesan dari bencana tersebut akan mengalami kerosakan yang besar. Dalam keadaan seperti itu, pihak berkuasa memerlukan peta digital segera untuk memeliti kawasan terkesan dan membuat keputusan. Oleh itu, kajian ini menumpu kearah penghasilan peta digital pantas menggunakan kaedah berasaskan pencantuman imej masa-nyata. Kaedah pencantuman imej itu sendiri dapat dibahagikan kepada kaedah berasaskan ciri dan berasaskan wilayah. Kajian ini menggunakan kaedah pencantuman imej berasakan ciri untuk mempercepatkan proses penghasilan peta. Kajian ini merumus algoritma pencantuman imej untuk mencantum imej aerial dalam masa-nyata. Masa pemprosesan 37 bingkai sesaat telah dicapai. Algoritma pencantuman imej telah dioptimumkan untuk mencantum kawasan luas yang diperolehi menggunakan laluan penerbangan pelbagai grid; kelajuan pemprosesan 2 bingkai sesaat telah dicapai. Akhirnya, algoritma pemilihan imej telah diperkenalkan untuk meningkatkan kualiti imej cantuman sebanyak 14% dan meningkatkan masa pemprosesan sebanyak 2 kali ganda untuk laluan penerbangan pelbagai grid. Kesimpulannya, algoritma pencantuman imej yang dibangunkan dapat mengurangkan masa pemprosesan untuk menghasilkan peta digital di tapak bencana. Walaupun algoritma pencantuman imej yang dibangunkan dapat mencantum imej pada kadar yang lebih pantas dengan kualiti yang dipertingkatkan, lebih banyak ujian perlu dijalankan mengunakan imej aerial dari tapak bencana.

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LIST OF ABBREVIATIONS

BF Matcher	-	Brute Force Matcher
BLINDS	-	Blind Image Notator Using DCT Statistics
BOW	-	Bag Of Words
BRIEF	-	Binary Robust Independent Elementary Features
BRISK	-	Binary Robust Invariant Scalable Keypoints
BRISQUE	-	Blind/Referenceless Image Quality Assessment
CAAM	-	Civil Aviation Authority of Malaysia
CCD	-	Charge-Coupled Device
CMOS	-	Complementary Metal Oxide Semiconductor
CPU	-	Computational Processing Unit
FAST	-	Features from Accelerated Segment Test
GCP	-	Ground Control Point
GNSS	-	Global Navigation Satellite System
GPS	-	Global Position System
GPU	-	Graphics Processing Unit
GSD	-	Ground Sample Distance
INS	-	Inertial Navigation Sensors
ISO	-	International Organisation for Standarization
KD TREE	-	K-Decision Tree
KNN	-	K- Nearest Neighbour
LIDAR	-	Light Detection and Ranging
MSE	-	Mean Square Error
MCMC	-	Malaysian Communication and Multimedia Commission
ORB	-	Oriented fast and Rotated Brief
PPK	-	Post-Processing Kinematics
PSNR	-	Peak Signal to Noise Ratio
RAM	-	Random Access Memory
RANSAC	-	RANdom SAmple Consensus
RC	-	Remote Controlled
RMSE	-	Root Mean Square Error

ROA	-	Remotely Operated Aircraft
RPV	-	Remotely Piloted Vehicle
RTK	-	Real-time Kinematics
UAV	-	Unmanned Aerial Vehicle
UVS	-	Unmanned Vehicle System

CHAPTER 1

INTRODUCTION

1.1 Problem Background

A disaster is an unpredicted event that causes significant damage in terms of loss of life, destruction, and drastic environmental changes; this event can be divided into natural or man-made (Restas, 2015; Sathish Kumar et al., 2020). Natural disasters include earthquakes, floods, hurricanes, and landslides; man-made disasters are construction accidents, nuclear leaks, and explosions (Sathish Kumar et al., 2020). A disaster can be scaled into different scales depending on the affected area, affected population, and spreading time (see Figure 1.1 and Figure 1.2) (Restas, 2015). Between 2002 to 2011, about 107,000 people were killed, and 268 million people were victims of natural disasters worldwide annually (Tanzi et al., 2014). Hence, when a natural disaster occurs, it is necessary to quickly and effectively organize a disaster management operation to reduce life and economic losses; without such management, the disaster victims will undergo drastic losses (Sathish Kumar et al., 2020; Tanzi et al., 2014).

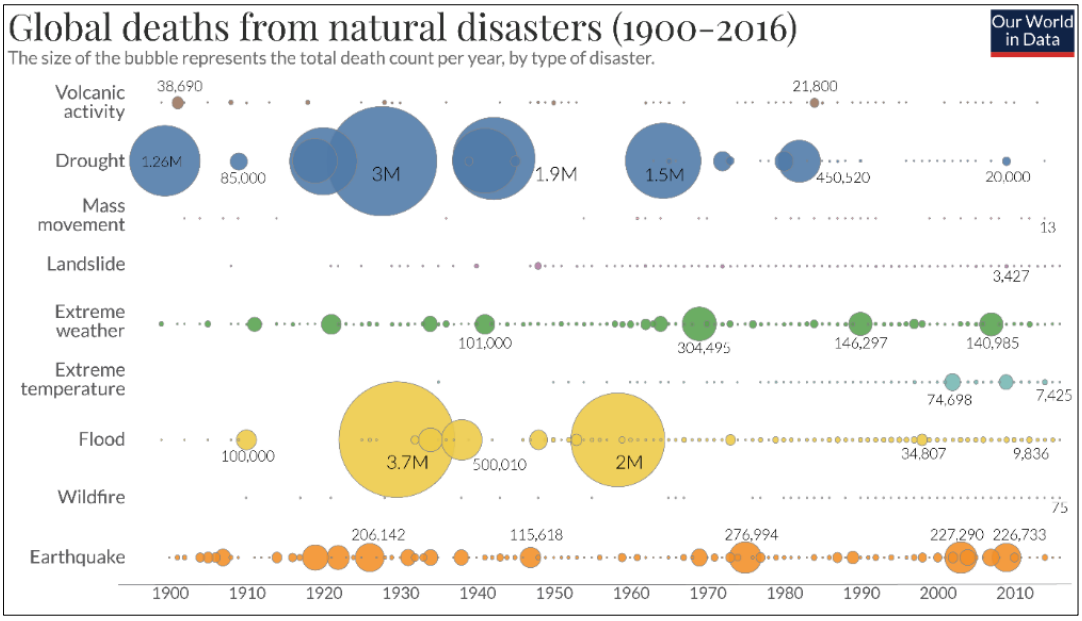

Figure 1.1 From the year 1900 to the year 2010, people died due to natural disasters. Source: Our World in Data https://ourworldindata.org/natural-disaster.

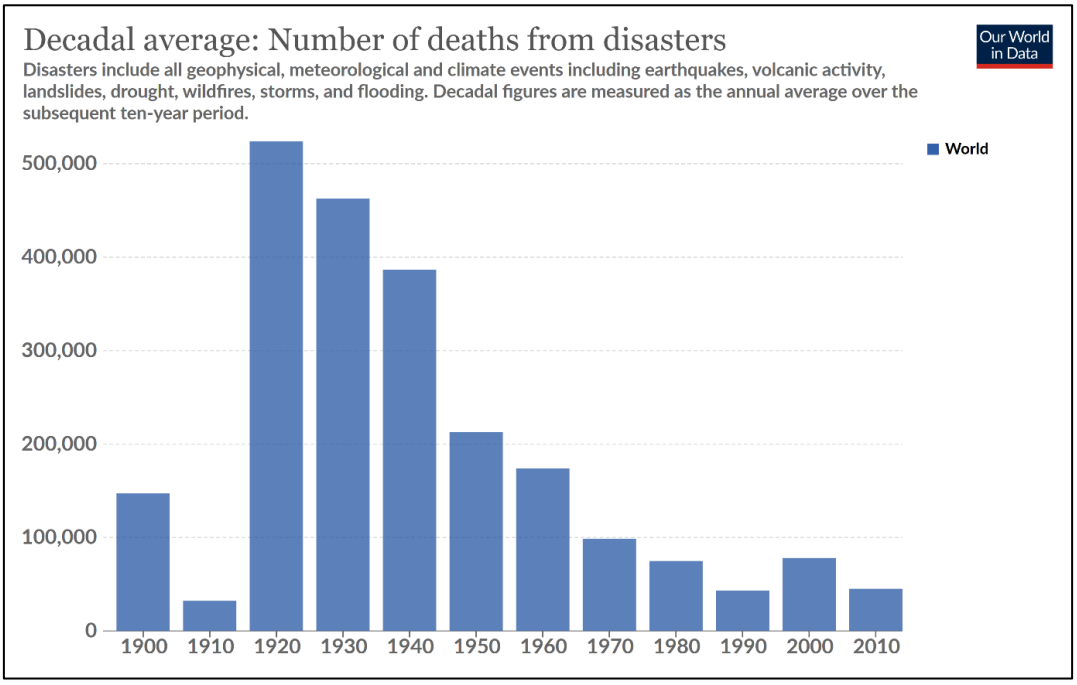

Figure 1.2 Death people annually due to natural disasters. Source: Our World in Data https://ourworldindata.org/natural-disasters.

In the past, digital maps for remote sensing and surveillance are created using photogrammetric workflow (a process of developing a three-dimensional (3D) model using two-dimensional (2D) images), which uses the structure from motion (SFM) method (a technique of estimating the camera poses based on the 2D image) (Fanta-Jende et al., 2020; Hein et al., 2019). The aerial images are acquired using an Unmanned Aerial Vehicle (UAV) in the photogrammetry workflow. Then the aerial images undergo post-processing using the commercial software after the UAV lands (Hein et al., 2019). Much commercial software (Pix4d, Agisoft Metashape, and 3D Survey) was developed using the SFM method for creating a digital map (Fanta-Jende et al., 2020); the disadvantage of the SFM method is that it has a prolonged computational time (see Table 1.1) (Bu et al., 2016; Hein et al., 2019). Besides, the commercial software is imposed with charges once the free trial period has ended (see Table 1.2) (Alidoost and Arefi, 2017).

Since the authorities require an instant digital map to decide, the traditional method is unsuitable for the response stage. As a solution, image stitching has been used to provide a faster digital map (see Figure 1.4) (Fanta-Jende et al., 2020; Hein et al., 2019). Image stitching combines overlapping images with similar features into one large image (see Figure 1.4) (Abdelkrim et al., 2018; Nocerino et al., 2020; Vaidya and Gandhe, 2018; Wang and Yang, 2020). An instant observation image is needed for the authorities to decide and calculate the risk in the response stage. However, the commercial software cannot meet the computational requirement. Hence, in this research, the image stitching method will be deployed to produce a fast observation image for disaster management authorities.

Table 1.1 Comparison between commercial software and image stitching proposed by (Bu et al., 2016) .Note: The computational time is in minutes.

Sequence Id	Frames	Keyframes	Bu & Co-workers	Pix4D	Photoscan
1	28493	337	15.84	107.05	153.62
2	18869	395	10.49	52.62	334.73
3	19371	482	16.44	83.75	683.98
4	13983	457	9.32	140.08	532.38
5	12744	471	8.49	127.73	563.57
6	4585	648	2.39	154.77	999.67
7	16969	406	11.31	132.07	360.70
8	16292	221	10.86	72.13	145.52
9	14776	393	10.36	102.83	462.32

Table 1.2 Comparison between trial duration between commercial software (Alidoost and Arefi, 2017)

Software	Trial License Validation (day)
3D Survey	15
Agisoft	30
Pix4Dmapper	7
SURE	4

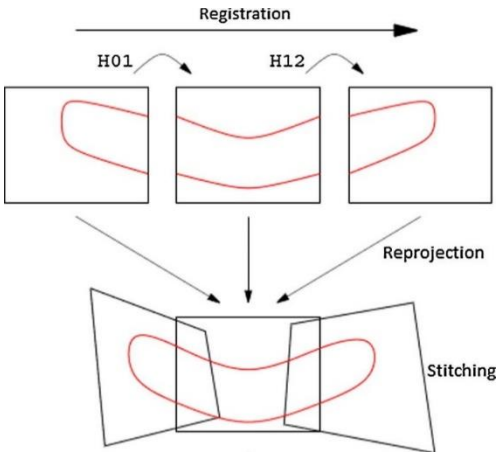

Figure 1.4 Process of Image stitching (registration, reprojection, and stitching). ‘H01’ and ‘H12’ refer to homography estimation (Ghosh and Kaabouch, 2016).

1.2 Problem Statement

Currently, digital maps are generated using commercial software such as Pix4D and Agisoft(Fanta-Jende et al., 2020). This commercial software generates a digital map using the photogrammetry framework; one drawback of using the commercial software is that it consumes prolonged computational time depending on the area size and resolution of aerial images (Bu et al., 2016; Hein et al., 2019). Since the commercial software needs a prolonged time to generate a digital map, it is not suitable to be deployed in disaster areas because at the disaster site; the disaster management authorities require a real-time digital map or observatory image to plan the intervention during the response stage (Bu et al., 2016; de Lima et al., 2020; Fanta-Jende et al., 2020). Hence, to solve this problem, Bu and co-workers suggested deploying the image stitching algorithm to generate the digital map faster (see Table 1.1) (Bu et al., 2016).

Although many studies have been conducted on the photogrammetry workflow, scant attention has been given to producing a faster digital map using the image stitching method. A few works have been conducted to create digital maps using the image stitching method.

Since aerial image stitching is still an emerging research niche, previous work has identified a few gaps. Fanta and co-workers established a near real-time image stitching algorithm, but the authors found that stitch quality and processing time need improvement (Fanta-Jende et al., 2020). A similar problem was faced by Hein and co-workers, where the quality of the stitch map needs to be improved by improving the stitch quality and positional accuracy by geo-referencing (Hein et al., 2019). De Lima and co-workers created a real-time image stitching algorithm; however, the algorithm consumes more time with the high-resolution image (4MP) in real-time (De Lima and Martinez-Carranza, 2017). Besides, the authors also suggested that real-time image stitching can be improved by incorporating GPS coordinates in image registration to avoid drift error(change of flight trajectory due to crosswind) (de Lima et al., 2020).

By reviewing the gaps in the literature, this research will focus on developing an algorithm to stitch aerial images in real-time and improve the visual quality of stitched images to aid the disaster management authorities. Real-time image processing is the image processing speed equivalent to the source (video) speed. For example, if the video has 25 fps, each frame must be processed within 0.04s to achieve real-time speed (Burgos-Artizzu et al., 2011). Disaster management authorities can plan the intervention route faster by deploying a real-time image stitching algorithm.

1.3 Purpose Statement

This research aims to formulate an algorithm to stitch aerial images faster and improve the stitch quality. A faster image stitching algorithm will be developed to reduce computational time. The quality of the stitched image will be assessed and improved to optimize the quality.

1.4 Objectives

This research aims to reduce the computational time of creating an observatory image for disaster-affected areas.

1. To formulate an algorithm for real-time aerial image stitching.
2. To optimize the algorithm to stitch aerial images in a multi-grid flight path.
3. To quantify the visual quality of the stitched image and optimize the quality of the stitched image.

1.5 Scope and Limitation

The research focuses on feature-based image stitching. Hence image stitching requires areas rich with features (a feature is a distinct pattern in an image, such as corners, blobs, and edges)(Szeliski, 2007; Wang and Yang, 2020). The maximum distance covered in this research is 150m only from the UAV lab at UTM due to the limitation of the communicational link between the UAV and the ground station. In addition, the mobility of the ground station is limited; hence the research is conducted at a 150m distance radius from the UAV lab. Besides rules from the Civil Aviation Authorities of Malaysia (CAAM), rules limit that UAVs should not fly beyond the visual line of sight (CAAM: UAS 02/2019 (https://www.caam.gov.my/wp-content/uploads/2021/03/CAAM-Drone_Requirement_2020.pdf)).

On the other hand, a maximum altitude of 120m will only be tested in this research because CAAM does not allow the flight of UAVs more than 400 feet (121.92m) from the earth's surface. A commercial UAV (DJI mini 2) was utilized in this research because the custom-made drone requires a special permit to fly. In addition, UTM is located in a no-fly zone due to the presence of Senai International Airport.

Besides, this research focuses on capturing aerial images by facing the camera at the nadir line to maintain a constant Ground Sample Distance (GSD) (not including terrain relief). In the research, only one camera is used for real-time image stitching. This research does not include multi-camera image stitching because of increased payload and cost. Latency by communicational link is not covered in this research because the speed and strength of the communicational link depend on the distance from the cellular tower. Besides, this research intends to speed up the image processing time. Since this research intends to create an observation image for the authorities, geo-referencing and geo-rectification are omitted.

In addition, the OpenCV library in a python environment was deployed to formulate the algorithm in this research. The OpenCV library was deployed because it was equipped with tools for image processing. Besides, the python environment was able to import the OpenCV library.

1.6 Research Contribution

A real-time image stitching algorithm for observing the disaster-affected areas was developed to solve the computational complexity in commercial software. The significance and contribution of this research are listed :

1. Developed an image stitching algorithm for disaster-affected areas.
2. Proposed an image selection algorithm to optimize the visual quality of stitch images.
3. Stitched aerial images with a multi-grid flight path at a processing speed.

1.7 Significance of Research

This research developed a faster observation image through the image stitching method; this would help the authorities, such as NADMA, to make the decision easier and faster. Since the visual quality of the observatory image was improved, it helped the authority's decision-making process more manageable. The outcome of this research can also be applied in other fields, such as forest monitoring and surveillance, by easing the forest inventory update process. In addition, the proposed method will be helpful for a country like Malaysia (especially the Kelantan river basin) since frequent flooding occurs due to monsoon winds and heavy rains (Chan et al., 2016). In addition, this research is multidisciplinary by consisting of many fields together (computer vision, drone technology, and remote sensing)

1.8 Research Flowchart

The following is the workflow of the research to achieve the respective objective.

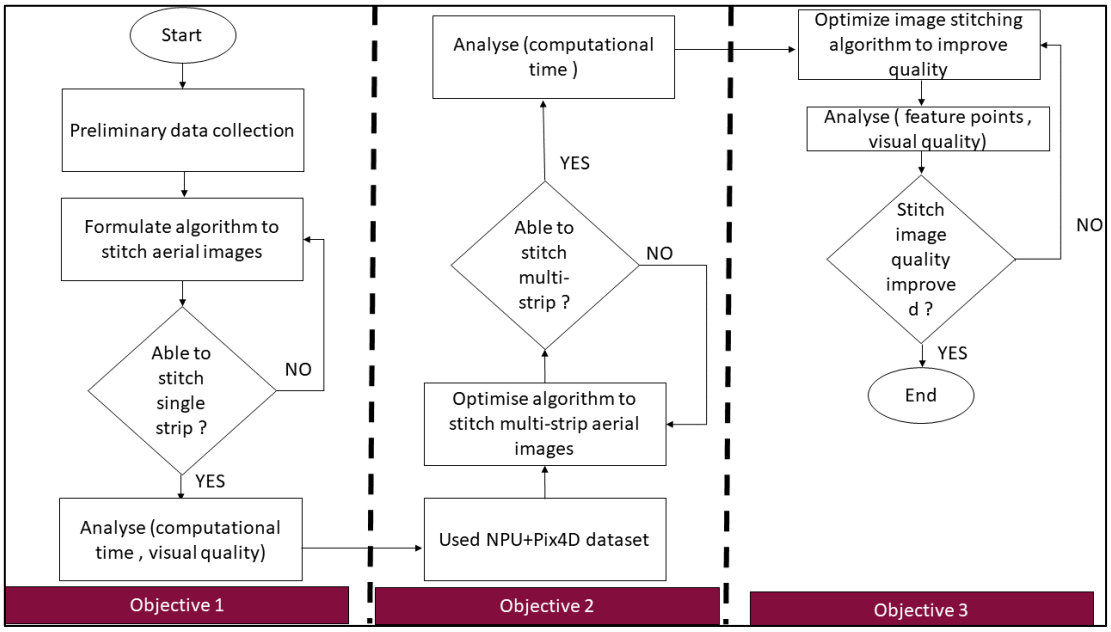

Figure 1.5 Flowchart representing the workflow to achieve the respective objective.

1.9 Organization of Thesis

The organization of the thesis are as follows:

(a) Chapter 2: The material for image stitching, algorithm, and quality assessment of stitched images will be discussed in detail using prior work from other authors as a reference in this chapter.

(b) Chapter 3: A detailed discussion of the image stitching methodology will be discussed in this chapter. This section will be subdivided into a research procedure flowchart, experimental setup, and research timeline.

(c) Chapter 4: In this chapter, a discussion on the results from the image stitching algorithm for a straight-line trajectory are discussed in depth. Then, the results from the image stitching algorithm for the multi-grid flight path are discussed in this chapter.

(d) Chapter 5: The conclusion and future works for the research are discussed in this chapter.

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