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Riverbank Slope Erosion Monitoring using Unmanned Aerial Vehicle (UAV)

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Abstract:
River slope erosion is one of the major and unpredictable dangers worldwide including in Malaysia. Slope erosion is an important geomorphology in influencing changes in the river channels and the development of floodplains. It is a natural process and it could lead to a serious problem if not monitor and maintain properly by the authority. This paper aims to identify and detects factors that contributed to the riverbank slopes erosion. Site surveying was conducted to find a suitable study area and an interview was carried out to gain information regarding the study area. The study area is located at Sungai Kesang, Tangkak Johor with a study area approximately around 90m x 45m with a coordinate of 2'06'21" N and 102'29'17" E. Pilot testing method was applied to create the flight route and to identify the suitable configuration before collecting the data. Based on the results obtained, several types of erosion had been identified such as rainsplash erosion, rill erosion and gully erosion occurred at the riverbank. These types of erosion had been detected in both 3D model: Model 1 and Model 2. The significant factors for each slope erosion were also determined. The findings approved that by using UAV, the images of the slope can be captured and 3D modeling can be developed. Through this method, erosion can be identified from the beginning and the step of the controller can be done immediately.

Keywords: Riversplash erosion, Sheet erosion, Gully erosion, Rill erosion & Unmaned Aerial Vehicle (UAV)

1. Introduction

On the continent, except in the driest areas, precipitation exceeds evaporation. The river is the main pathway through which this excess water flows into the sea. Across the continent of Malaysia, the average annual rainfall is around 250 centimeters. Of this amount, about 213 centimeters return to the atmosphere by evaporation and transpiration. The remaining 120 centimeters feed streams and rivers, either directly (by landing in a channel or flowing across the surface) or indirectly, by passing through the shallow part of the Earth as groundwater first. This 120 centimeter represents a very large volume of water: 92.0 x 108 cubic meters per day. However, it can be a problem such as flooding, which is one

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of the most destructive natural hazards that cause damage to lives and property each year, and therefore the development of flood models to determine the puddle area in the river flow area is crucial to the decision - maker. Therefore, to avoid the slope erosion at the riverbank, slope monitoring was being done properly. The purpose of this method was to obtain visual images of the slope by using Unmanned Aerial Vehicle (UAV). Three-dimensional modeling was developed using the application of Pix4D to analyses the slopes profile changes. This study will help the process for monitoring the study area become easier, more efficient and better quality of the images. In addition, it can save the workforce and time.

1.1 Riverbank slope erosion

The slope is the prone ground that forms the angle to the horizontal plane. A detachment of soil on riverbanks is caused by two processes: 1) hydraulic erosion caused by channel flow and 2) sub aerial erosion due to weakness and weathering of bank material [1]. The slopes that not monitored will experience slope failure. Usually, the slope failure in the river is associated with many factors that may cause soil structure in the area to be eroded and the deposition of sediments of the soil. While erosion is the process of carving or sliding surface slopes and the transport of materials by erosion agents such as flowing air, wind, droplets. This process will make the depth of the river be shallow and bring disadvantages in the end.

Types of erosion at the river divided into slope erosion along the riverbanks and river erosion that can change the condition of the river. These two types of erosion can be confusing sometimes. The erosion that can change the condition of the river such as: 1) headward erosion, 2) vertical erosion and 3) lateral erosion. While types of erosion that causing the slope to collapse: 1) rain splash erosion, 2) sheet erosion, 3) rills erosion and 4) gully erosion as in Figure 1.

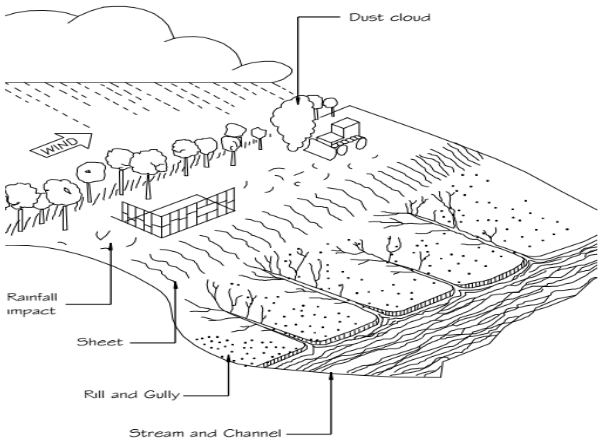

Figure 1: Types of slope erosion (Source: CDM, 1993)

Rainsplash erosion is the force from raindrops can weaken the strength of the soil structure, which will cause soil slippage on slope runoff as illustrated in Figure 2. Furthermore, Malaysia is one of the countries that receive rain throughout the year and this is the main cause of increased erosion especially on the bare soil surface.

Figure 2: Rainsplash erosion

Sheet erosion is the most common and less damaging erosion. It occurs quickly during heavy rains but is easily interrupted by vegetation. Details of land that have been affected by rainwater splashes will be eroded and transported by surface water runoff. As a result, small pieces of soil on the surface of the slope are eroded. A serious consequence of sheet erosion is a very noticeable layer of soil that is exposed on the surface after the top layer of soil is removed. Vegetation is very difficult to replant in such layers.

Rill erosion is the type of erosion can be classified as a moderate type of erosion and range between sheet and gully. Rills are shallow channels usually not more than 30 cm deep but can be meters long [2]. Soil-material is eroded and transport by water from the top of the slope to down of the slope through the small grooves. These small grooves are temporary and will disappear within a short period as illustrated in Figure 3.

Figure 3: Rill erosion

Gully erosion are incised channels, which often began as rills. Gullies are highly effective conveyors of sediment to rivers and their density and depth are indicators of the severity of erosion. Soil-material is eroded and transport with water from the top of the slope to down of the slope through the wide grooves as illustrated in Figure 4. The grooves are permanent and form the basis for river formation.

Figure 4: Gully erosion

When erosion occurs, the river becomes shallow. This is due to the process of hydraulic action, where water pressure breaks down rock particles from the bottom of riverbed and banks. Besides, the air becomes compressed; the pressure increases and the riverbank may collapse. Where high velocity such as miner outer bends, hydraulic action can remove material from the bank which can cause undercutting and collapse of riverbanks. Sediment carried by river scours, river bases and river banks is called abrasion. The eroded rocks collide and break into smaller fragments through the attrition process. The sediments become smaller, more rounded move downstream and become deposition. These processes can be understood clearly in Figure 5.

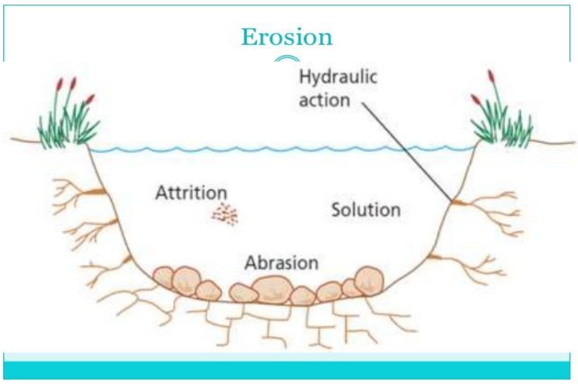

Figure 5: The processes of river erosion (Source: DID, 2012)

In Malaysia, the river, drainage and anything related to irrigation has its own authorities that responsible to monitor, preserve and conserve it and its called Department of Irrigation and Drainage (DID). Slope erosion and slope monitoring are included in their job scope which is they will take action if the public makes a complaint. If the complaint is not in their job scope, they will inform the appropriate authorities.

1.2 Unmanned Aerial Vehicle (UAV)

Unmanned aerial vehicles (UAVs) have been the subject of concerted research over the past few years [3], due to their autonomy, flexibility, and various application domains. Indeed, UAVs have been regarded as providers of a wide range of applications covering military operations, surveillance and monitoring, telecommunications, medical supply delivery, and rescue operations. The unprecedented advances in drone technology have allowed the widespread deployment of UAVs, such as drones, small aircraft, balloons, and aircraft for wireless communication purposes [4]. In particular, if deployed and operated properly, UAVs can provide reliable wireless communication solutions and save costs for a variety of real-world scenarios.

In general, UAVs can be categorized, based on their altitudes into High Altitude Platform (HAPs) and Low Altitude Platform (LAPs). HAPs has a altitude of more than 17 km and is usually quasistationary [5]. LAPs, on the other hand, could fly at altitudes of tens of meters to several kilometers, can move quickly, and flexible. According to US Federal aviation regulations, the maximum altitude of an LAPs drone that can fly freely without ant permission is 400 feet [6].

In this study, the UAV that used to monitor the slope is DJI Phantom 3 Advanced as shown in Figure 6. The advantages of using this model in terms of: 1) design and features, 2) flying and 3) video and photo quality. Meanwhile, in design and features, this UAV has a three-axis gimbal on its belly that stabilizes the camera towards roll, pitch and yawning so that the video stays smooth even with the movement of a cane or a sudden gust of wind. In terms of flying, with GPS, the drone will just sit and hover wherever the user leaves it. Users can also fly without GPS, but if the sticks are released, the Phantom will not stop but instead continues to drift in the direction it last headed. It also has a good quality of video and photo because it comes with features a Sony-made 12-megapixel 1/2.3-inch CMOS sensor behind a new f2.8 20mm lens (35mm equivalent), which gives a 94-degree field of view.

Figure 6: DJI Phantom 3 Advanced

1.3 Pix4D application

Pix4D is a group of software products that use computer photogrammetry and vision algorithms to convert RGB and multispectral images into maps and 3D models. Its software solution line operates on desktop, cloud, and mobile platforms. It has been used to map the Matterhorn in Switzerland and the statue of Christ the Redeemer in Brazil [7]. Pix4D is commercial software that automatically converts hand-taken, drone, or aircraft images, and provides highly accurate 2D maps and 3D models and references. They can be customized, timely, and compliment a variety of applications and software. This software has proven useful for a variety of industries. With drones help calculate the danger of landslides after landslides, inspect buildings and assist in large-scale industrial surveys, among other uses.

Pix4D is suitable for processing photos derived from drones, aerial photographs for DSM and DEM generations [8]. The way software tends to work is quite simple: drones fly over target areas, capture images and record data to allow us to gather a comprehensive overview of land, or buildings, from above [9]. There is a range of Pix4D applications such as Pix4Dmapper, Pix4Dbim etc. The application that used in this research is Pix4Dcapture and Pix4Dmapper. Pix4Dcapture is used to capture the images and can be download in smartphones, while Pix4Dmapper is used to develop 3-dimensional modeling of slope and can be run in a computer only.

2. Methods

This study was conducted at riverbank slope located at Sungai Kesang Tangkak Johor as shown in Figure 7. This area was chosen due to location that is strategic as the height of the tree is not disrupted the flight routes and the distance to monitor the study area are not far and harmless. The study area is approximately 90m x 45m with a coordinate of 2’06’21” N and 102’29’17” E. Based on preliminary study, this area has experienced floods in 2010 and has been categorized as a high-risk area by Department of Irrigation and Drainage (DID). The high-risk river banks will be given more observations in terms of slope monitoring and maintenance. Thus, by using UAV’s, monitoring will be more effective as well as saving time and workforce. The DID Tangkak, used to monitor the river slope or irrigation when there is a complaint made by the public. The method used is by visiting the area and capture images by using a camera. Meanwhile, for the high-risk slopes or high-risk rivers, there is a special unit that handles the cases and the unit called Department of Drainage and Flood Mitigation. This unit is responsible to monitor, preserve, conserve and settle the flood mitigation project.

Figure 7: Study area at Sungai Kesang

Meanwhile, in the preliminary study, all information about the location such as the history of slope erosion and history of the flood are gathered. Flight planning was prepared before image data were collected. In capturing the images, several methods were provided in this application and the suitable method for developing 3D modeling of the slope is by using a double grid method as illustrated in Figure 8. Double grid method captured images in two ways: 1) vertically and 2) horizontally, so the number of images captured is more than one way. The more image captured gives the better quality of the 3D model. In flight planning, the pilot test will be done to check either the configuration of the application and UAV either it is suitable or not. In this study, the overlaps used is 65 for front overlap and 70 for side overlap while the angle and altitude used is 70 degree and 15 meters respectively.

Figure 8: Double grid method

Before the flight, planning had been done to facilitate the work of data collection and information to ensure that research can be carried out as planned. A cloudy sky or a very hot blazing sun certainly will affect image quality. To capture this, in addition to ensuring air camera work properly, it must be ascertained at the time the weather circumstances also capture the image [12]. Driver UAV's also shall have efficient and adequate skills in controlling the drone for quality results. To ensure the safety of the drones, the area surrounding the river slope should be identified for suitable flight and landing. The selected area must be free from any obstacles that interfere with flight routes to fly drone and landed.

The flight route used in this research is shown in Figure 9. In this application, it has several methods provided to capture the images. As the objective of this study is to develop 3D modeling of slope, so the most suitable method for the route is by using double grid method. Double grid method captured images vertically and horizontally, so when it is compiled, the modeling that produced is flawless. The more images captured, the better the 3D modeling produced.

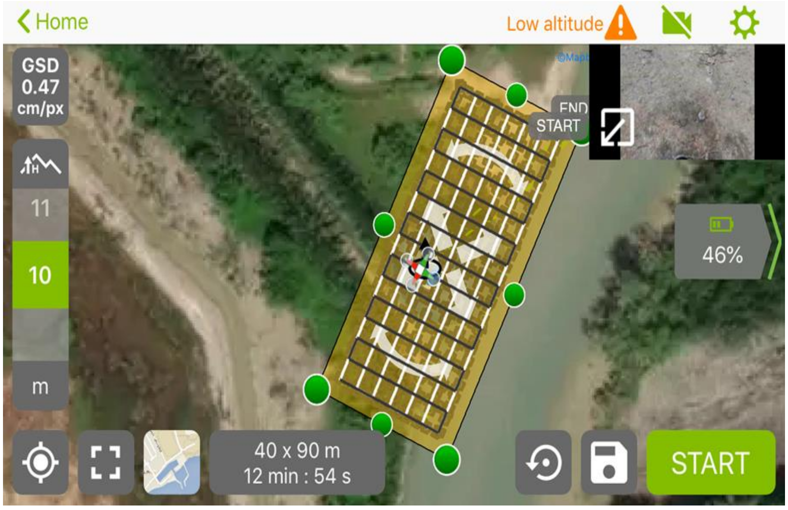

Figure 9: Flight route

This study was conducted by developing the 3D modeling of riverbank slopes erosion. After collecting the data by capturing the images, all the images are transferred to Pix4Dmapper application in computer. The images were captured two times within a month. By using this application, it can develop a 3D modeling slope that can show the surface, condition and contour of the slope clearly. All the 3D modeling slope will be analyses to compare the changes of the slope whether there has erosion or not.

3. Result and discussions

3.1 Photogrammetric Data Processing

After the data completely processed, it produced a quality report. The quality report contains details for three main information: 1) Initial Processing, 2) Point Cloud and Mesh and 3) Digital Surface Model (DSM), Orthomosaic and Index. For the first model, images that calibrated are 292 out of 345 which is 86%. While the second model is 88% calibrated 8with 295 shots. The preview of the point cloud in Figure 10, Orthophoto in Figure 11 and DSM in Figure 12 also shown in the quality report.

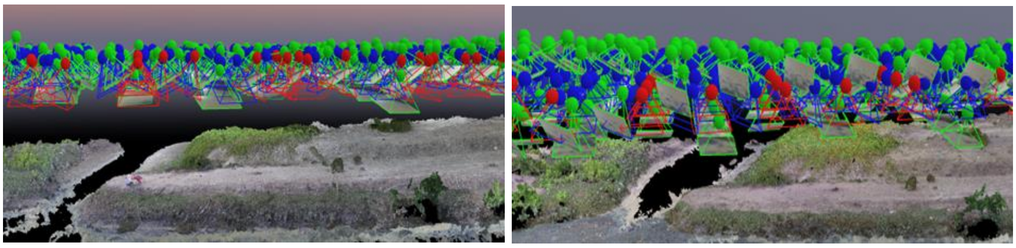

Figure 10: Point Cloud Generation of Model 1 (left) and Model 2 (right)

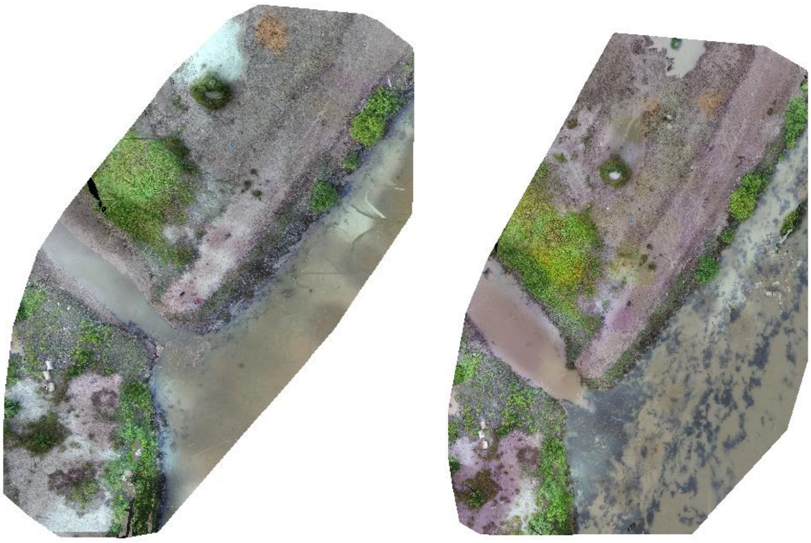

Figure 11: Orthophoto Generation of Model 1 (left) and Model 2 (right)

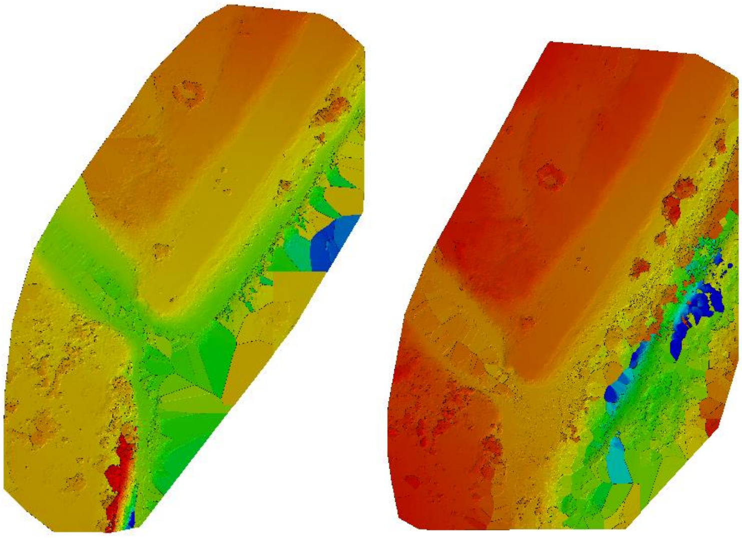

Figure 12: DSM of Model 1 (left) and Model 2 (right)

From the compilation of these data, it develops a 3D modeling of slopes as the outcome. The models can be view in any axis by rotating the model. One of the views is shown in Figure 13 and Figure 14.

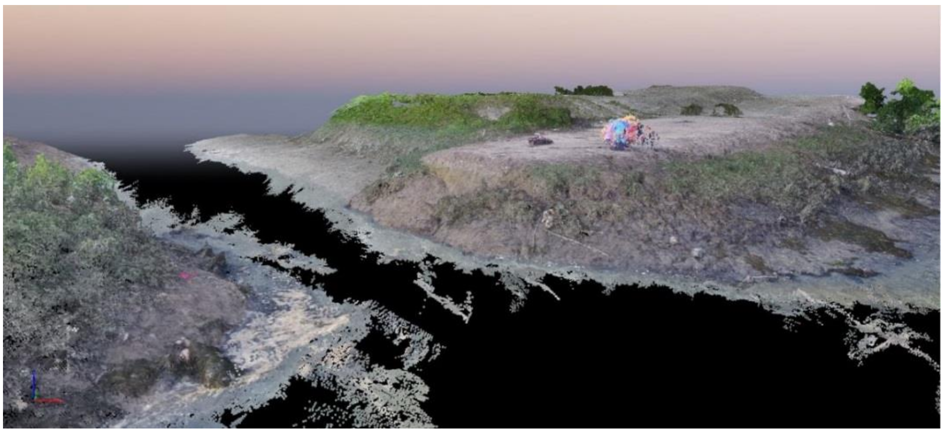

Figure 13: The first 3D model

Figure 14: The second 3D model

3.2 Erosion of the slope

Soil erosion is the detachment, absorption and transport of soil particles from their place of origin by erosion agents, such as water, wind and gravity. This is a form of soil degradation and can be categorized as geological surface erosion or accelerated soil [10]. By comparing two models of slopes, there are a few types of erosion that occurred that had been detected. The comparison between both models are intangible and the erosion occurred at the same location in both model was stated in Table 1 until Table 3.

Table 1: Comparison between models for Rainsplash Erosion

Model 1	Model 2
	
The rainsplash erosion still occurred but the difference between Model 1 and Model 2 cannot be seen clearly. The changes are very intangible so rainsplash erosion was considered as not critical erosion	The rainsplash erosion still occurred but the difference between Model 1 and Model 2 cannot be seen clearly. The changes are very intangible so rainsplash erosion was considered as not critical erosion

Table 2: Comparison between models for Rill Erosion

Model 1	Model 2
	
The rills erosion had been detected at several locations of the riverbank. The rills are about 2-3 centimeter from the soil surface.	The rills erosion still occurred in the same location. Erosion became more noticeable compare to model 1. This is because of the severe weather conditions caused by the monsoon season.

Table 3: Comparison between models for Gully Erosion

Model 1	Model 2
	
At first, the gully erosion was not very noticeable and it started to occur when the rills erosion became worst and forming a deep channel compare to rill erosion.	Within a month, the gully erosion at the same location became worst and caused the soil at the slope to collapse. This caused by the heavy rainstorm that occurred in that area.

The overall of erosion of the two models was occurred in the same area. The location of the erosion was shown in Figure 15.

Figure 15: Location of the erosion occurred

Slope erosion or soil erosion is a natural change in the surface of the earth. The main factor that causes the earth's surface to erode is rainfall. During rainfall, the impact of the striking force on the soil surface results in the splash of soil particles. When striking and splashing soil particles, some parts of the rainfall will infiltrate to reach saturation levels after the process ceases. The rainfall with soil particles goes through to surface runoff. During the process, the soil surface becomes weak and the particles become loose. The surface surface washes the soil particles to the slope until the end of the process by deposition.

4. Conclusion

The captured images by UAV is vital to build 3D modeling of a slope. With 3D model, it helps to identify the erosion that occurred from the beginning and the controller can be done before the erosion becomes critical. This study has identified significant types of erosion at the slope. The erosion still can be detected even though the difference between both 3D models is intangible. Factors for the intangible difference were identified which is: 1) the duration for first data taken and the second data taken is too short due to the time constraint and 2) different lighting during the data taken process. By identifying the types of erosion in the study area, the authority is able to notice the best ways to apply new practices for monitoring and prevention can be done earlier before it becomes worst.

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