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DESIGNING A LANDSLIDE SIMULATION SOFTWARE

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Abstract. *Statistics have indicated that, among natural disasters in Taiwan, typhoons have caused the most serious causalities and losses resulting from subsequent compound hazards. To assist local residents in disaster prevention and reduce the hazards and damage caused by landslides, this study collected data on the causes of landslides, deployed a camera-equipped drone to capture photos of mountain slopes prone to landslides, uploaded these photos to cloud storage, generated a 3D mountain slope model on ReCap, imported the model to Unity, composed scripts for simulating landslides (on the basis of the geological data and causes, scale, flow direction, speed, and possible hazards of landslides), and published the simulated results on websites and mobile platforms for those who require the information.*
Keywords: Mountain slope, Landslide, ReCap, Unity

1. **Introduction.** For most rivers in Taiwan, the drainage areas are small, the flow paths of the main streams are short, the water flow is fast, and the slopes are steep. For instance, for the Zhuoshui River, the longest river in Taiwan, the drainage area is roughly 3,157 km^2, the main stream length is approximately 186.6 km, and the average gradient reaches 1/190 [1]. In Taiwan, because of the effects of climate conditions [2], extreme rainfall is most likely to occur every year between summer and autumn, when typhoons frequent Taiwan. According to the rainfall records released by the Central Weather Bureau from 1902 to 2016 [3], the average 24-hour accumulated precipitation has increased, which means that the likelihood of natural disasters, such as slope collapses, landslides, and floods caused by heavy rainfall occurring in a short amount of time is likely to increase.

Statistics conducted from 1959-2016 on the top 10 natural disasters that have led to causalities in Taiwan [4] indicate that, by the number of occurrences, typhoons have caused the most serious casualties and losses in Taiwan by triggering compound hazards and damages. In recent years, the public's awareness of disaster prevention and evacuation procedures has increased because of government advocacies. However, even today officials are unable to predict what kind of disaster may be caused by what climate conditions. Therefore, to assist local residents in preventive measures and reduce the occurrence of landslides, this study utilized mountain slope data, set predetermined parameters in a simulation software, visualized through simulated landslides regarding what may happen when natural disasters occur, and published the simulated results on websites and mobile platforms for those who require the information. The research group has investigated on using computer software to construct 3D model of the hillside [5]. Some preliminary results have been obtained but further study is still needed to be performed. The objectives of this study were as follows.

A. Compile the causes of landslides and review studies on the simulation of landslides through a literature review and data retrieval.

B. Use a drone to take photos of mountain areas prone to landslides, upload these photos to the ReCap website developed by Autodesk, build 3D models of the mountain areas through cloud computing, and optimize these 3D models (or meshes) generated by ReCap.

C. Import the 3D models of the mountain areas into a software program called Unity (or Unity 3D), use the mountain slope data and geographical statistics to identify the possible causes, scale, flow direction, speed, and hazards of landslides, compose a script for simulating the disasters through these 3D models, and publish the simulation results on websites and mobile platforms.

The definition and characteristics of landslides will be discussed in Section 2. The methods used in this study and results of the article will be discoursed in Section 3. The conclusion of the essay is dissertated in Section 4.

2. Definition and Characteristics of Landslides.

2.1. Definition of landslides.

A natural disaster that affects geological conditions is called a sediment-related disaster, and includes surface soil erosion, slope collapse, landslip, landslide, river scouring, and river deposition. The density and scale of these disaster events are related to the intensity and amount of rainfall. In addition, these disaster events are more likely to occur at steep mountain slopes or geologically unstable areas. A landslide is a fluid mixture (of mud, sand, stones, rocks, and water) generated by gravity. In other words, a landslide is a mixture of water and these solid substances. The fast flow, eruptive nature, huge impact force, and devastating power of landslides have oftentimes led to catastrophes and hazards. Although defined differently by scholars in Taiwan and abroad, landslides are mostly described by conditions such as water flow, substances, and sediment gravity flows.

2.2. Characteristics of landslides.

Landslides occur primarily because of the following three factors.

A. Substantial water amount

The main source of momentum for landslides is water flow, which in this case comes from rainfall. After falling to the ground, rain water scours and erodes the surface geological materials. Because of this scouring and erosion, the surface soil layer is washed down to lower areas. When the rainfall is heavy, the rain water infiltrates into the ground surface, reduces the strength of mountain rocks, and generates side water pressure and increases water pressure along the nonuniform surfaces. Consequently, these two types of water pressure cause mountain slopes to slump and become hazardous.

B. Substantial earth volume

A substantial earth volume refers to a substantial amount of soil, stones, or rocks accumulated in an upstream river valley. Upstream sediment comes from the surface soil layer washed down to a valley. In addition, the main source of upstream sediment is soil, stones, or rocks washed down from upstream banks to a valley because of slope land collapses or landslips.

C. Effective gradient of stream bed

Gradient refers to the slope of the ground surface. A high gradient indicates a steep slope, which provides momentum for landslides to move down slope. A high gradient also suggests a powerful force of erosion. If calculated in degrees, the slope gradient of a landslide generally exceeds 15°.

2.3. **Gradient for the occurrence of landslides.** By considering statics, Takahashi derived the possible range of slope angles θ (gradient = $\tan\theta$) of a sediment deposition formed by water washing over sediments and turning into a landslide [6]:

$$\theta_1 < \theta < \theta_2 \tag{1}$$

where θ_1 denotes the smallest slope angle, whereas θ_2 denotes the largest angle. When $\theta > \theta_1$, the sediment deposition collapses and is washed down to downstream areas that are less steep. Conversely, $\theta < \theta_1$ suggests an immature debris flow or immobile mud. For instance, the slope angle of a granular flow roughly ranges between 14.5° and 22.9° ($14.5° < \theta < 22.9°$) [7]. However, using slope angle (θ) alone to determine the likelihood of a landslide is inadequate, because vegetation and sediment deposition are also crucial factors influencing the occurrence of landslides.

2.4. **Rainfall conditions for the occurrence of landslides or debris flows.** In 1978, by analyzing the relationship between landslide occurrences and rainfall, Katsumi and Yukihiro [8] generated a critical relation curve illustrating the relationship between rainfall intensity (I) and accumulated rainfall (R) as below:

$$R = \frac{a}{b + I} \tag{2}$$

where a and b denote empirical coefficients that vary with location. After analyzing the rainfall data from regions where landslides had occurred, Caine proposed a rainfall threshold for the occurrence of debris flows using rainfall intensity (I; mm/hr) and rainfall duration (T; hr) [9]:

$$I = 14.82 \times T^{-0.39} \tag{3}$$

Believing that the occurrence of landslides is closely related to the pore pressure in the soil, Keefer et al. [10] derived, by considering statics, the relationship between the rainfall intensity (I) and rainfall duration (T), and the occurrence of landslides:

$$(I - I_0) \times T \geq Q_c \tag{4}$$

where I denotes the rainfall intensity (mm/hr), I_0 denotes the rate of drainage (mm/hr), T denotes the rainfall duration (hr), $(I \times T)$ represents the total rainfall, and Q_c represents the water volume threshold (the amount of rainfall stored within the soil column).

By using a regression analysis, Keefer et al. applied the data on landslides (or debris flows) and rainfall (during landslide periods) [9,11,12] to Equation (4) to obtain the rainfall conditions required for triggering landslides. Table 1 shows the required rainfall conditions differed across regions according to the sedimentation characteristics, topography of the drainage basin, and stream bed gradient, as well as geological and climatic conditions of the regions. Generally, regions with sediments containing large particles and smaller stream bed gradient required greater amounts of rainfall for triggering landslides, and vice versa.

Table 1. Rainfall conditions required for triggering landslides (derived from $(I - I_0) \times T \geq Q_c$) [10]

Source of data	I_0 (mm/hr)	Q_c (mm)	Notes
Caine [9]	4.49	13.65	Data on multiple landslides from various areas
Cannon and Ellen [11]	6.86	38.10	Data on multiple landslides from one area
Wieczorek [12]	1.52	9.00	Data on one landslide from one area

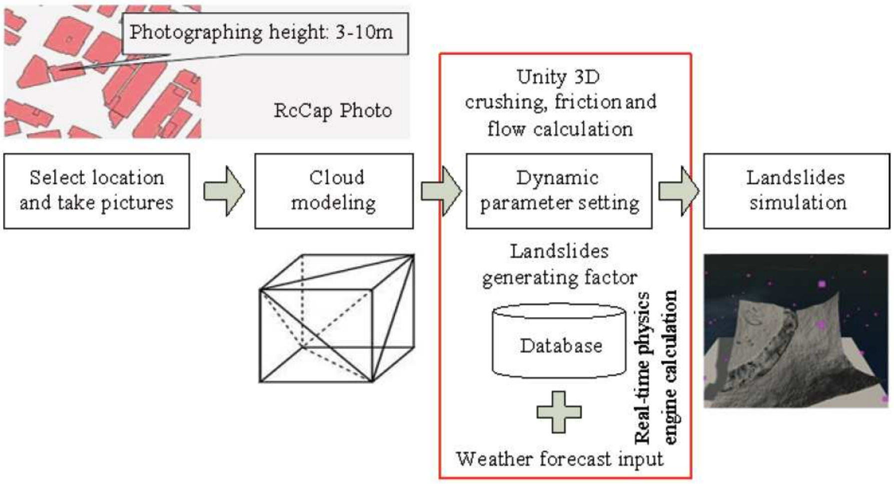

Figure 1. Research procedures

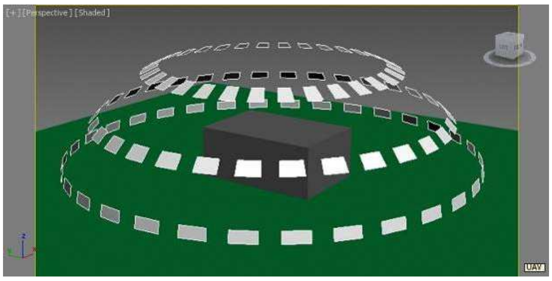

Figure 2. Aerial photo shooting from three levels of height

3. **Method and Results.** A drone was deployed in this study to photograph the target mountain slope from various angles and heights. These photos were uploaded to a cloud database to generate a 3D model, which was then imported to Unity to simulate landslides. The research procedures are demonstrated in Figure 1.

3.1. **Photographing with a camera-equipped drone.** Typically, mountain areas where landslides tend to occur are not easily accessible. However, to build an accurate 3D model for a mountain slope, photos taken from various angles and heights (as shown in Figure 2) are required. The drone employed in this study was a DJI Phantom Go Pro, which operated at a height of 3-10 m above ground. Before the photos were taken, the mountain slope was divided into multiple areas. The size of each area was approximately 50×50 m. If each area was too large, the amount of photos required would be too high and thus cause difficulties in cloud computing. The drone was equipped with functions such as automatic balancing, fixed-point hovering, and automatic landing during system failures. In addition, the drone was able to transmit a signal to cell phones, enabling users to view, zoom in, and zoom out of photos remotely. Using the Ci-Hui Temple, Zhu-Dong in Hsinchu County as an example, this study collected photos of this temple taken from three levels of height.

3.2. **Constructing a 3D model by using ReCap.** Developed by Autodesk, ReCap 360 [13] offers a web-based environment for work and creativity. To implement reality capture technology, ReCap operates through cloud computing to generate high resolution 3D models. A user is only required to apply for an account to use ReCap. The 3D models generated using ReCap can be viewed on the Google Chrome browser or other WebGL-supported browsers (such as Firefox and Safari).

Using cloud computing, ReCap is a web service that converts photos into high resolution 3D models and mesh models (in the format of OBJ, RCM, FBX, and IPM). Subsequently, modeling software (such as 3ds Max, MAYA, and Mudbox) can be used to process the photos through mesh optimization, which converts these photos to a point cloud format. Therefore, without downloading any software, this study fully utilized the computing power of cloud computing, and thereby constructed 3D models without requiring a high-end computer. A camera-equipped drone was employed to capture photos of the temple. Figure 3 displays several photos taken in this study. These photos were later uploaded to ReCap to generate a 3D model as illustrated in Figure 4.

The photos of the temple were uploaded to http://recap.autodesk.com. A cloud-based modeling technology called Reality Capture was then applied to comparing the pixels of the photos, perform algorithms, and convert the 2D pixel coordinates into 3D coordinates, construct 3D mesh surfaces, generate textures, and finally export a model, as illustrated in Figures 5 and 6.

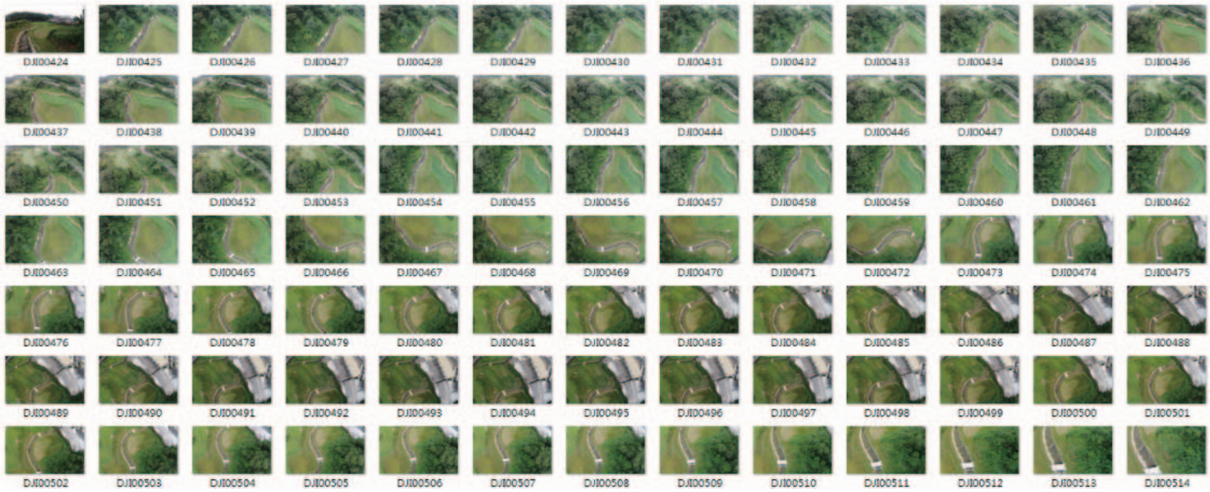

FIGURE 3. Aerial photos of the Ci-Hui Temple, Zhu-Dong

FIGURE 4. 3D model converted from the photos shown in Figure 3

FIGURE 5. A 3D-RGB terrain model generated from the cloud-based ReCap website

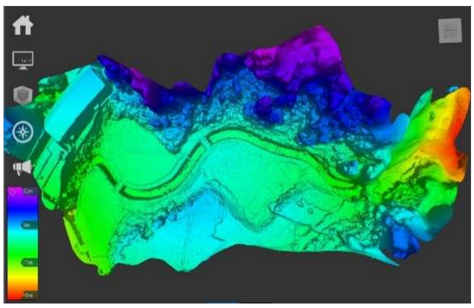

FIGURE 6. A 3D elevation terrain model generated form the ReCap website

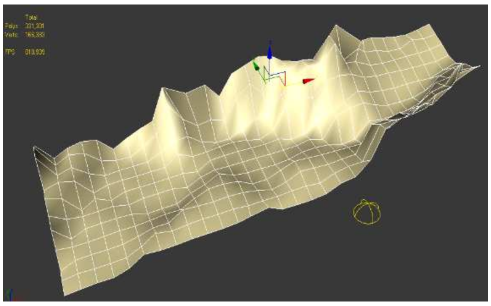

Figure 7. 3D model divided into 30 × 10 meshes

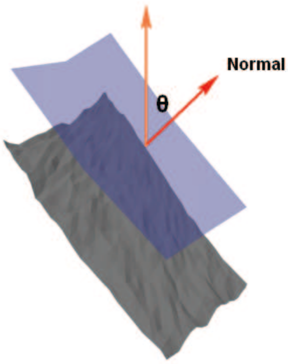

Figure 8. Calculating the slope gradient of a 3D model

3.3. **Slicing and adjusting meshes.** The model generated using ReCap contained redundant meshes and was thus massive in size. Therefore, the 3ds Max software was used to slice, readjust, and calibrate the content, which was later processed by Autodesk Mudbox [14] for mesh optimization (which, in this case, was conducted through retopology tools) to obtain a concise model. The file size of the model required being reduced to 1/20 of the original size to be efficiently applied to Unity 3D. Furthermore, Rayfire [15], a plugin of the 3ds Max software, was used to fragment the terrain surface of the model into various pieces (Figure 7).

3.4. **Importing the model into Unity 3D.** Equipped with an excellent physics engine system, Unity 3D is able to instantly compute the kinetic friction, static friction, and fluid mechanics of a model. In addition, vegetation can be generated to reflect changes in the vegetation on the real life terrain surface. These features can be performed in Unity 3D by programming. In this case, Unity 3D can be used to divide a digital model into multiple sections and adjust attributes settings, depending on the actual geological conditions. By calculating the angle between a normal vector and a vertical axis perpendicular to the ground, Unity 3D is able to measure the average gradient (θ; Figure 8) of each section. Thus, through incorporating the data on the accumulated rainfall in different areas, this study identified the areas where landslides are likely to occur and measured the scale of the landslides through computing and simulation.

3.5. **Composing scripts to simulate disasters using the 3D model.** Based on the data collected through onsite measurement and previous landslide studies, a script was composed to consider the triggering factors of landslides (such as rainfall, slope gradient, and earthquakes), scale, flow direction, flow speed, and hazard factors, as illustrated in Figure 9. Two types of simulation methods were applied to the model examined in this study.

(a) Beginning of the rain event

(b) When rainfall accumulated to certain level, warning sign regarding possible landslides appears

(c) The landslide slumps, blocks the river path, creating a barrier lake

FIGURE 9. Simulated scenes from the model (before and after a landslide)

FIGURE 10. Publishing the simulated results of the model on a mobile platform

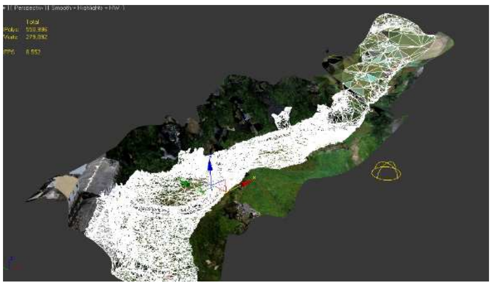

FIGURE 11. Simulating the areas where landslides may occur

A. Simulation Method 1 first compared the data on the geographical and weather conditions before and after landslides (collected from previous studies) with the simulated results of this model, and then conducted further simulations for readjustments.

B. Simulation Method 2 first imported photos into ReCap and the model designed in this study, compared the model with those created by other modeling software, and adjusted the parameters to increase the applicability of this study.

3.6. **Publishing the simulated results on websites and mobile platforms.** The simulated results from Unity 3D can be published on up to 11 types of platforms or device, including computers, websites, mobile devices, Wii, Xbox 360, and PS3. In this study, the results were published on websites and mobile platforms (Figure 10) for the convenience of relevant authorities and the public. The results of the simulated model, as shown in Figure 11, can be used to predict the possible areas where landslides may occur, and can be used by relevant organizations for disaster control, rescue affairs, and the evacuation operations.

4. **Conclusion.** By capturing and using photos of mountain areas to simulate the areas where landslides may occur, this study generated simulated results through 3D modeling and published them on various platforms for the public to download, especially for those

living in areas prone to landslides. Thus, the goal of providing an early warning for natural disasters can be achieved. Furthermore, the results of this study can be used to generate disaster prevention models covering smaller areas with more precise details, keep abreast of the conditions of these mountain areas through collecting and compiling data, and create visualizations of these landslide-prone areas to help with rescue and evacuation efforts as well as reduce loss of lives and properties. Furthermore, this study contributed to the following aspects.

A. The results of this study can be used for planning disaster prevention programs that deploy a camera-equipped drone to capture photos and convert these 2D photos and data to advanced 3D models.

B. The published simulated results (generated from the data on geological conditions and rainfall distribution) can alert local residents and help them implement preventative measures at an earlier stage.

C. The simulation results generated from the software used in this study can serve as a reference for evacuating local residents when landslides occur.

This study examined a few causes of landslides, such as geological conditions and rainfall. Thus, to generate more comprehensive models for disaster prevention, further studies should focus on other causes of landslides, including earthquakes, vegetation, manmade hazards, and the removal of miscellaneous structures. In addition, future studies should focus on measures to enhance geological conditions.

REFERENCES

[1] Water Resources Agency, *Disaster Prevention Information Service Network*, http://fhy.wra.gov.tw/Pub_Web_2011/.

[2] P. J. Chiang, Book on the climate of Taiwan, *Journal of Taiwan Studies*, p.220, 1954.

[3] Central Weather Bureau of R.O.C., *Central Weather Bureau Information Website*, http://www.cwb.gov.tw/V7/index.htm.

[4] National Fire Agency of R.O.C., *National Fire Agency Information Website*, http://www.nfa.gov.tw/main/index.aspx.

[5] Y.-P. Chiu, Y.-C. Shiau and S.-J. Song, A study on simulating landslides using Unity software, *Applied Mechanics and Materials*, vols.764-765, pp.806-811, 2015.

[6] T. Takahashi, Debris flow, *Netherlands: IAHR Monograph*, 1991.

[7] C. D. Jan, Assessment and prediction of debris flow hazards, *Journal of Chinese Soil and Water Conservation*, vol.25, no.2, pp.95-102, 1994.

[8] Katsumi and Saiwaiyoku, Study on landslide disaster and rainfall, *New Landslide Prevention*, vol.108, pp.14-18, 1978.

[9] N. Caine, The rainfall intensity-duration control of shallow landslides and debris flows, *Geografiska Annaler*, vol.62, pp.23-27, 1980.

[10] D. K. Keefer et al., Real-time landslide warning during heavy rainfall, *Science*, vol.238, pp.921-925, 1987.

[11] S. H. Cannon and S. D. Ellen, Rainfall conditions for abundant debris avalanches in the San Francisco Bay Region, California, *California Geology*, vol.38, no.12, pp.267-272, 1985.

[12] G. F. Wieczorek, Effect of rainfall intensity and duration on debris flows in central Santa Cruz Mountains, California, *Reviews in Engineering Geology*, vol.7, pp.93-104, 1987.

[13] *Autodesk Recap 360 Website*, https://recap360.autodesk.com/signin.aspx.

[14] *Autodesk Mudbox Website*, http://www.autodesk.com/products/mudbox/overview.

[15] *RayFire Website*, http://www.51render.com/post/RayFiretool.php.